From: Skone, Timothy
Sent: Tue, 12 Sep 2023 16:00:59 +0000
To: Jamieson, Matthew B.; Matthews, Howard Scott (CONTR)
Cc: Curry, Thomas
Subject: LNG Reg Report LCA Section Interim Comments from Tim Skone
Attachments: DOE_FECM_LNG_Analysis_Report_FINAL_REVIEW_05Sep23_V2-NETL-LCA - Comments-Sent-12SEPT23.docx

DRAFT * DELIBERATIVE * PRE-DECISIONAL

Matt and Scott,

Please find attached a copy of my comments on the LCA section for discussion today at 3 pm. Additional reviews are on-going so this is not the final set of DOE comments.

Tom mentioned that the text in the report reflects a significant reduction from the original text (~60 pages) that you (LCA) generated for submission but were guided to reduce the text to better align with the GCAM and NEMS level of detail.

Could you please send Tom and I the longer version to determine what already exists if we choose to expand for additional transparency?

In general, most comments are formatting or minor editorial suggestions. However, there is a handful of technical questions to discuss today.

Overall – nice job in getting this text ready for internal review!

Thanks,

Tim Skone

ENERGY, ECONOMIC, AND ENVIRONMENTAL ASSESSMENT OF U.S. LNG EXPORTS

FINAL REVIEW DRAFT September 5, 2023

Prepared for:

Office of Resource Sustainability
U.S. DEPARTMENT OF ENERGY | Fossil Energy and Carbon Management

Prepared by:

OnLocation, Inc.
501 Church St NE, Suite 300
Vienna, VA 22180

Joint Global Change Research Institute
Pacific Northwest National Laboratory
5825 University Research Ct
College Park, MD 20740

National Energy Technology Laboratory
Department of Energy
3610 Collins Ferry Road
Morgantown, WV 26505

Table of Contents

I. Executive Summary 1
II. Background on LNG Export Studies Commissioned by Department of Energy 5
III. Introduction 7
A. Project Background 7
B. Purpose of Study 7
C. Organization of the Report 8
IV. Scenarios, Methodology, and Key Assumptions 10
A. GCAM Model and Global Scenarios Design 10
B. NEMS Models and Analysis Methodology 14
1. AEO2023-NEMS 14
2. FECM-NEMS 14
3. Harmonizing GCAM and NEMS 15
C. NETL Life Cycle Analysis Model Methodology 16
1. Past NETL Natural Gas Life Cycle Reports 17
2. Market Adjustment Factors 20
V. Results 21
A. U.S. LNG exports 21
B. Global Natural Gas Consumption, Production, and Trade Under Scenarios *S1* And *S2* 22
C. Global Primary Energy Consumption by Fuel and GHG Emissions by Sector Under *S6* And *S7* 25
D. Global Natural Gas Consumption, Production, and Trade Under Scenarios *S6* and *S7* 28
E. Global Primary Energy Consumption and GHG Emissions Across All Scenarios 32
F. NEMS Analysis: Implications for U.S. Energy Systems 33
1. Energy Impacts 33
2. Natural Gas Production and Consumption Impacts 34
3. Natural Gas Henry Hub Prices Impacts 36
4. U.S. Macroeconomic Outcomes 38
5. U.S. GHG Results 41
G. NETL Life Cycle Analysis 43
1. Assessment of NEMS Domestic Natural Gas Production by Region 44
2. Comparison of GCAM and NETL Estimates of GHG Emissions of the Natural Gas sector 44
3. Market Adjustment Factor Results 45
4. Interpretation of Market Adjustment Factor Results 46

VI. Conclusions 47
Appendix A: Global Analysis and Description of GCAM....50
A. Additional detail about GCAM's energy system 50
B. Additional detail about scenario design 51
C. Additional GCAM results....52
Appendix B: U.S. Analysis and Description of AEO2023-NEMS and FECM-NEMS 56
A. Modeling U.S. LNG exports....56
B. Additional detail on U.S. natural gas markets 57
1. Regional natural gas production....57
2. Natural gas consumption by economic sector....58
C. CO_2 removal technologies in FECM-NEMS 63
Appendix C: Supporting LCA Analysis 65
A. NEMS and NETL LCA model comparison 65
B. Global Change Assessment Model – data inputs to LCA 69
C. GCAM and NETL emissions intensity comparison 70
1. Market Adjustment Factors for other IPCC GWP Values....75

List of Figures

Figure ES-1. U.S. LNG exports across the scenarios explored in this study. 4
Figure 1. U.S. GHG emissions and removals in the net-zero scenarios 16
Figure 2. Life cycle GHG emissions from the 2020 U.S. average Natural Gas supply chain, HHV basis....19
Figure 3. U.S. LNG exports across the scenarios.....21
Figure 4 Natural gas consumption, production, and trade by region....23
Figure 5. Changes in natural gas consumption, production, and trade by region in S2 vs. S1 24
Figure 6. Global primary energy consumption by fuel and GHG emissions by sector under S2 and S1....25
Figure 7. Global primary energy consumption by fuel and GHG emissions by sector under S6 and S7....26
Figure 8. Changes in global primary energy consumption and GHG emissions under S6 and S7....27
Figure 9. CDR deployment by type and region in S6 and S7....28
Figure 10. Natural gas consumption, production, consumption, and trade by region under S6 and S7....29
Figure 11. Changes in natural gas consumption, production, and trade by region: S6 vs S1 and S7 vs S2 30
Figure 12. Changes in natural gas markets in S7 vs. S6 31
Figure 13. Primary energy consumption by fuel and GHG emissions by sector under all scenarios....32
Figure 14. U.S. primary energy consumption, S1 through S5....33
Figure 15. U.S. primary energy consumption S6 and S7....34
Figure 16. Total U.S. natural gas production, consumption, and export volumes over time, by scenario.35
Figure 17. Total U.S. natural gas production, consumption, and export volumes, net-zero scenarios....36

Figure 18. Total U.S. natural gas Henry Hub price by scenario ($2022) 37
Figure 19. U.S. real GDP changes....38
Figure 20. U.S. residential natural gas prices....39
Figure 21. U.S. value of industrial shipments and real consumption 40
Figure 22. U.S. LNG export revenues....41
Figure 23. Total U.S. CO_2 emissions from fossil fuel combustion 42
Figure 24. Total U.S. CO_2 emissions from fossil fuel combustion and removals, S6 and S7 43
Figure 25. Mapping of NETL natural gas stages to GCAM sectors....45

Appendix A Figures

Figure A-1. Global natural gas consumption by sector across all scenarios 52
Figure A-2. Global natural gas consumption by region across all scenarios....52
Figure A-3. Global natural gas production by region across all scenarios 53
Figure A-4. Global LNG exports by region across all scenarios....53
Figure A-5. Global LNG imports by region across all scenarios 54
Figure A-6. Global primary energy consumption by fuel across all scenarios 54
Figure A-7. Global GHG emissions by sector across all scenarios....55

Appendix B Figures

Figure B-1. U.S. Regional Natural gas production, S1 through S5 57
Figure B-2. U.S. regional natural gas production in S6 and S7....58
Figure B-3. U.S. natural gas consumption by sector, S1 through S5....59
Figure B-4. U.S. natural gas consumption by sector, net-zero scenarios 61
Figure B-5. Natural gas consumed for DAC, net-zero scenarios....62
Figure B-6. U.S. CO_2 emissions and removals, net-zero scenarios....63

Appendix C Figures

Figure C-1. Dry NG production percentage time-series for each region 68
Figure C-2. Estimated U.S. Average GHG Intensity (g CO_2e/MJ) (S1 through S7), ...69

List of Tables

Table 1. Previous Studies....5
Table 2. Scenario Descriptions....13
Table 3. Natural Gas and Liquefied Natural Gas Life Cycle Stages....17
Table 4. Market Adjustment Factors for S2 vs. S1....46
Table 5. Market Adjustment Factors for S7 vs. S6....46
Table 6. Key Results for U.S. and globe in 2050 across scenarios....49
Table A-1. Detailed assumptions in the S4: Regional Import Limits scenario....51
Table B-1. DAC technology assumptions in FECM-NEMS 64
Table C-1. Matching NEMS (OGMP States) to NETL states and subsequently regions....65

Table C-2 Regional dry production (trillion cubic feet) between 2020 and 2050, S1 67
Table C-3 Regional dry production ratio, S1 67
Table C-4. Regional GHG Intensities (gCO_2e/MJ) from 2020 NETL Natural Gas Report 68
Table C-5. Provided set of GCAM Data Documentation 69
Table C-6. LCA Stage Cross-Mapping 71
Table C-7. GCAM Emissions Intensities for Sectors (S1, 2020, USA region, AR6-100 basis) 72
Table C-8. GCAM Emissions Intensities for Sectors (S1, 2020, USA region, AR6-20 basis) 73
Table C-9. GCAM Emissions Intensities for Sectors (S1, 2020, USA region, AR5-100 basis) 74
Table C-10. GCAM Emissions Intensities for Sectors (S1, 2020, USA region, AR5-20 basis) 74
Table C-11. GWP Values used in this analysis....75
Table C-12. NETL-adjusted MAF results for S2 75
Table C-13 NETL-adjusted MAF results for S7 76
Table C-14. Annual Export Volumes of US LNG and Adjusted Global CO_2 Emissions (AR6-100 basis) 76

Acronyms and Abbreviations

AEO	Annual Energy Outlook
BECCS	Bioenergy with carbon capture and storage
Bcf	Billion cubic feet
BIL	Bipartisan Infrastructure Law
BP	British Petroleum
BTU	British Thermal Unit
CAFE	Corporate Average Fuel Economy
CCS	Carbon capture and storage
CCUS	Carbon capture, utilization, and storage
CDR	Carbon dioxide removal
CH_4	Methane
CO_2	Carbon dioxide
DAC	Direct air capture
DOE	Department of Energy
EIA	Energy Information Administration
EJ	Exajoule (10^{18} joules)
EPA	Environmental Protection Agency
FECM	Fossil Energy and Carbon Management
GHG	Greenhouse gas
GCAM	Global Change Analysis Model
GNGM	Global Natural Gas Model
Gt	Gigaton
GWP	Global warming potential
HMM	Hydrogen Market Module
ITC	Investment tax credit
IRA	Inflation Reduction Act
Kwhr	Kilowatt-hour

LHV	Lower heating value
LNG	Liquefied natural gas
LULUCF	Land use, land use change, and forestry
MAF	Market Adjustment Factor
Mcf	Million cubic feet
MMT	Million metric Tons
NERA	NERA Economic Consulting
NEMS	National Energy Modeling System
NETL	National Energy Technology Laboratory
NGA	Natural Gas Act
NGP	Natural gas processing
NHTSA	National Highway Traffic Safety Administration
NREL	National Renewable Energy Laboratory
N2O	Nitrous oxide
OPEX	Operating Expenses
PNNL	Pacific Northwest National Laboratory
PTC	Production tax credit
S&P	Standard & Poor's
Tcf	Trillion cubic feet
Tg	Teragram (10^{12} grams)

I. EXECUTIVE SUMMARY

The Department of Energy (DOE) is responsible for authorizing exports of U.S. natural gas, including liquefied natural gas (LNG), to foreign countries pursuant to section 3 of the Natural Gas Act (NGA), 15 U.S.C. 717b. Under the NGA provisions, applications requesting authority for the import or export of natural gas, including LNG, from and to a nation with which there is in effect a free trade agreement (FTA) requiring national treatment for trade in natural gas, and/or the import of LNG from other international sources, are deemed consistent with the public interest and granted without modification or delay. For Authorizations relating to those countries with which the United States does not have an FTA requiring national treatment trade in natural gas and with which trade is not prohibited by U.S. law or policy, then pursuant to Section 3(a) of the NGA DOE is required to grant a permit to export domestically produced natural gas unless it finds that such action is not consistent with the public interest.

To inform its Public Interest determination, since 2012, the Office of Fossil Energy and Carbon Management (DOE-FECM) and its predecessor, the Office of Fossil Energy, previously commissioned five studies to assess the effects of different levels of LNG exports on the U.S. economy and energy markets. This sixth updated study, like the previous ones, servesd as an input to be considered in the evaluation of applications to export LNG from the United States under Section 3 of the NGA.

The purpose of this latest study was is to examine the potential global and U.S. energy system and greenhouse gas (GHG) emissions implications of a wide range of economic levels of U.S. LNG exports. The study was comprised of three coordinated analyses: 1) **a Global Analysis** to explore a wide range of scenarios of U.S. LNG exports under alternative assumptions about future socioeconomic growth, regional preferences for domestically produced natural gas, pace of technological change in competing technologies (e.g. renewables), and countries' announced GHG emissions pledges and policies; 2) **a U.S. Domestic Analysis** of the implications of the various U.S. LNG export levels derived from the Global Analysis for the supply and demand of natural gas within the U.S. and the U.S. economy; and 3) **a Life Cycle Analysis** to examine the life cycle emissions implications of the various levels of U.S. LNG exports derived from the Domestic and Global analyses.

As part of the **Global Analysis**, we DOE-FECM explored seven scenarios spanning a range of plausible U.S. LNG export outcomes by 2050 using the Pacific Northwest National Laboratory's Global Change Analysis Model (GCAM). GCAM is a model of the global energy, economy, agriculture, land use, water, and climate systems with regional detail in 32 geopolitical regions. This includes major economies as single-country regions (e.g., U.S., Canada, China, India, Russia). The seven scenarios explored in this study are shown in Table ES-1.

Table ES-1. Scenario Descriptions

Scenario	Description	U.S. LNG Export Volumes (Bcf/d)
***S1*: Reference Exports**	Reference scenario in which U.S. LNG exports follow EIA's 2023 Annual Energy Outlook (AEO). Incorporates U.S. policy assumptions (including the 2022 Inflation Reduction Act). Assumes existing policies and measures, globally.	Grows to 27.34 Bcf/d by 2050
***S2*: Market Response**	Assumes policies consistent with *S1*, but U.S. LNG exports are determined by global market equilibrium.	GCAM Market Response
***S3*: High Global Demand**	Same assumptions as *S2*, U.S. LNG exports determined by global market equilibrium, but assumes higher population growth outside of the U.S.	
***S4*: Regional Import Limits**	Same assumptions as *S2*, U.S. LNG exports determined by global market equilibrium, but includes constraints on importing and exporting natural gas with a global focus to maximize use of domestic gas.	
***S5*: Low-cost Renewables**	Same assumptions as *S2*, U.S. LNG exports determined by global market equilibrium, but assumes lower capital costs for renewable energy technologies.	
***S6*: Energy Transition (Ref Exp)**	Assumes an emissions pathway consistent with a global temperature change of 1.5°C by end of century. Countries' emissions are constrained to announced GHG pledges, including the U.S. following a path to net-zero GHG emissions by 2050. NEMS follows CO_2 emissions constraint from GCAM. U.S. LNG exports are limited to the values from the AEO 2023 Reference scenario.	Grows to 27.34 Bcf/d by 2050
***S7*: Energy Transition**	Same emissions pathway assumptions as *S6*, but U.S. LNG exports are determined by global market equilibrium.	GCAM Market Response

Commented [UP1]: Is there a reason why S6 has a different background color than the other sections of the table? Also on the third column why is GCAM Market Response "white background" for S2-S5 but then "blue" for S7?

All of the scenarios include representations of the 2022 Inflation Reduction Act (IRA) in the U.S. and existing emission policies in the rest of the world. The scenarios also include a constraint on Russian exports. The modeling and analysis for this report was completed by August 2023.

The **U.S. D~~d~~omestic A~~a~~nalysis** was conducted using the National Energy Modeling System (NEMS). U.S. LNG exports (for all scenarios except *S1*) and CO_2 emissions (in scenarios *S6* and *S7*) used in NEMS were harmonized to values from GCAM. NEMS was then used to explore the implications of the seven global scenarios ~~for~~ on domestic gas prices, the energy system, and the macro-economy within the U.S.

Finally, the **Life Cycle Analysis** of natural gas used for export was enhanced by comparing the results provided from the domestic and global analyses to previously completed NETL studies of the natural gas life cycle. GCAM results were assessed against existing DOE life cycle studies of natural gas and aligned to have the same GHG intensity for the purposes of consistency. The main results of this analysis were a series of estimated market adjustment factors that supplement the previous life cycle analyses and better represent the total global change in emissions per unit of U.S. LNG exported.

A number of key insights emerged from this study:

1. Across all modeled scenarios, U.S. LNG exports and U.S. natural gas production increase beyond current levels through 2050 (Figure ES-1).
2. Global natural gas consumption increases only slightly (<1 percent) under a scenario with increased availability of U.S. natural gas in the global market that reflects economically driven LNG export levels (S2) compared to the reference scenario (S1). The majority of the additional U.S. natural gas substitutes for other global sources of natural gas.
3. U.S. natural gas prices as measured at the Henry Hub increase modestly when comparing a scenario that reflects global market demand for exports (S2) to the reference scenario (S1). Across those scenarios, 2050 Henry Hub prices ~~were~~ are projected to increase from $3.61/Mcf to $4.74/Mcf, both of which are less than the reference 2050 price expected in the most recent study[5] commissioned on the economic impacts from U.S. LNG exports in 2018.
4. U.S. residential prices ~~were~~ are projected to be 4% higher in 2050 when comparing a scenario that reflects global market demand for exports (S2) to the reference scenario (S1).
5. The value of industrial shipments remains essentially unchanged (increasing less than 0.1% by 2050) under a scenario that reflects global market demand for exports (S2) compared to the reference scenario (S1). The impact of increased LNG exports on GDP is essentially flat: positive by less than 0.1% across scenarios through 2045 while all changes are within 0.3% in 2050.
6. Global and U.S. GHG emissions do not change appreciably across the scenarios with current climate policy assumptions (S2 to S5) even though these scenarios vary widely in terms of U.S. LNG export outcomes. In these scenarios, global emissions range from 47.5-50.3 Gt CO_2e and U.S. emissions range from 4.3-4.6 Gt CO_2e while U.S. LNG exports range from 23 to 47 Bcf/day.
7. The induced global market effects per unit of increased LNG exports in a scenario that reflects global market demand for exports (S2) compared to the reference scenario (S1) are equivalent to an overall reduction in GHG emissions that is about 70% of the estimated upstream emissions associated with production through delivery of the natural gas through the transmission system in the U.S.
8. Relative to the other scenarios, the scenarios in which countries are assumed to achieve GHG emissions pledges and pursue ambitious GHG mitigation policies (S6 and S7) are characterized

by lower energy consumption; lower fossil fuel consumption without carbon capture, utilization, and storage (CCUS); higher deployment of renewables and fossil fuels and biomass with CCUS; and higher deployment of carbon dioxide removal strategies.

Commented [ST2]: Did we run a non-CCUS S6 and S7 case?

What supports this finding?

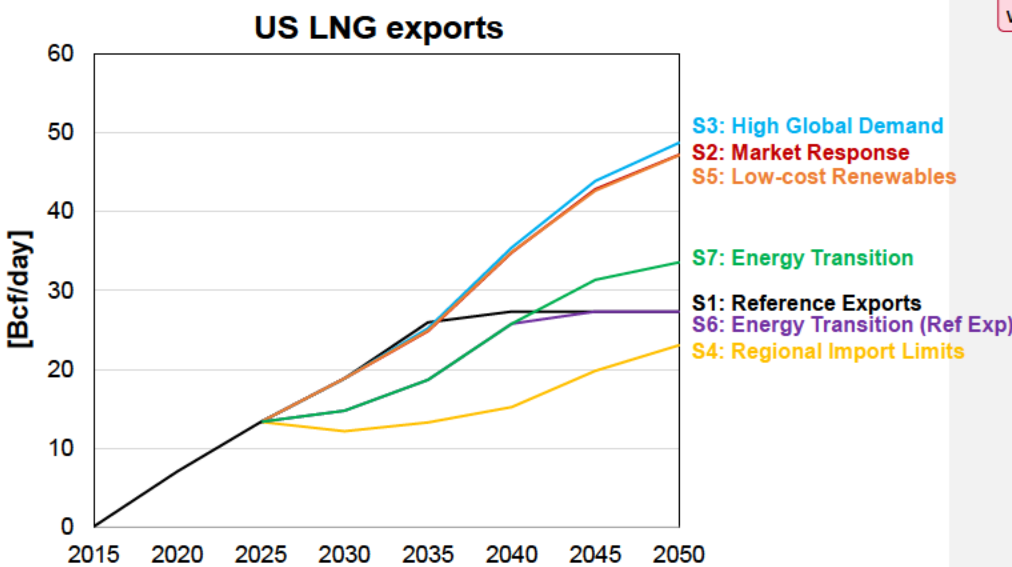


Figure ES-1. U.S. LNG exports across the scenarios explored in this study. Note that the U.S. LNG export outcomes for S2 and S5 were very close to each other.

II. Background on LNG Export Studies Commissioned by Department of Energy

Since 2012, the Office of Fossil Energy and Carbon Management (DOE-FECM) and its predecessor, the Office of Fossil Energy, previously commissioned five studies on the effects of increased LNG exports on the U.S. economy and energy markets. The previous studies of the impact of LNG exports are listed in Table 1.

Commented [UP3]: Table 1 should be moved back to below paragraph 1 where it is mentioned.

The EIA 2012 study examined four different levels of exports across four domestic natural gas supply scenarios for a total of 16 scenarios. Exports ranged from 6 to 12 Bcf/day with varying trajectories. The supply scenarios were: AEO2011 Reference, High Shale Estimated Ultimate Recovery (EUR), the Low Shale EUR, and High Economic Growth. Key results demonstrate that natural gas markets balanced the increased exports through increased supply and prices and a reduction in demand for power generation and in the other sectors.

The NERA 2012 report used NERA's Global Natural Gas Model (GNGM) and NewERA energy-economy model to look at the domestic economic effects of LNG exports. Building upon the EIA 2012 study, the NERA 2012 report examined sixteen scenarios from the earlier study using different assumptions on natural gas supply and demand. The report additionally included scenarios examining the global demand for U.S. LNG exports and the macroeconomic impact of increased LNG exports on the economy.

The EIA 2014 study included updated export scenarios from 12 to 20 Bcf/day and domestic natural gas supply scenarios from AEO2014: the Low and High Oil and Gas Resource scenarios, High Economic Growth, and Accelerated Coal and Nuclear Retirements. Increased exports led to increased natural gas production and prices relative to respective base scenarios, though also higher primary energy consumption and energy-related CO_2 emissions.

Table 1. Previous Studies

Report Name	Organization	Short Name
Effect of Increased Natural Gas Exports on Domestic Energy Markets[1]	EIA	EIA 2012
Effect of Increased Natural Gas Exports on Domestic Energy Markets[2]	NERA	NERA 2012
Effect of Increased Levels of Liquefied Natural Gas Exports on U.S. Energy Market[3]	EIA	EIA 2014

[1] U.S. EIA. (2012). Effects of Increased Natural Gas Exports on Domestic Energy Markets. Available at: https://energy.gov/sites/prod/files/2013/04/f0/fe_eia_lng.pdf
[2] NERA Economic Consulting. (2012). Macroeconomic Impacts of LNG Exports from the United States. Available at: https://energy.gov/sites/prod/files/2013/04/f0/nera_lng_report.pdf
[3] U.S. EIA. (2014). Effect of Increased Levels of Liquefied Natural Gas Exports on U.S. Energy Markets. Available at: https://www.eia.gov/analysis/requests/fe/pdf/lng.pdf

Report Name	Organization	Short Name
The Macroeconomic Impact of Increasing U.S. LNG Exports[4]	Baker Institute/ Oxford Economics	Baker 2018
Macroeconomic Outcomes of Market Determined Levels of U.S. LNG Exports[5]	NERA	NERA 2018

The Baker 2015 study examined U.S. LNG exports of 12 and 20 Bcf/day. Two models were used: an international natural gas model (from the Baker institute) and a global economic model from Oxford Economics. This study outlined the international conditions that could result in a market for over 20 Bcf/day of LNG exports and examined in the impact on the U.S. economy of scenarios with 12 and 20 Bcf/day of LNG exports and with low gas resource recovery, high gas resource recovery and high demand.

The NERA 2018 study again used NERA's Global Natural Gas Model and the NewERA energy-economy model to look at the domestic economic effects of LNG exports. LNG exports were determined by the model for each scenario. The study included 54 different scenarios capturing a broad range of domestic and international gas supply and demand conditions, and probabilities on the likelihood of each of the 54 export scenarios. In general, high levels of LNG exports corresponded to high oil and gas supply but higher prices. Since approximately 80% of the exports resulted from increased production rather than decreased demand, the general economic impact was positive across the scenarios. The report concluded that the impact on energy-intensive~~sensitive~~ industries was ~~very small~~minimal while increased investment attributed to LNG exports raised GDP.

[4] Cooper, A., Kleiman, M., Livermore, S., & Medlock III, K. B. (2015). The Macroeconomic Impact of Increasing US LNG Exports. Available at:
https://energy.gov/sites/prod/files/2015/12/f27/20151113_macro_impact_of_lng_exports_0.pdf
[5] NERA Economic Consulting. (2018). Macroeconomic Outcomes of Market Determined Levels of U.S. LNG Exports. Available at:
https://www.energy.gov/sites/prod/files/2018/06/f52/Macroeconomic%20LNG%20Export%20Study%202018.pdf

III. Introduction

A. Project Background

The Department of Energy (DOE) is responsible for authorizing exports of natural gas, including LNG, to foreign countries pursuant to Section 3 of the Natural Gas Act (NGA), 15 U.S.C. 717b. Under the NGA provisions, applications requesting authority for the import or export of natural gas, including LNG, from and to a nation with which there is in effect a free trade agreement (FTA) requiring national treatment for trade in natural gas, and/or the import of LNG from other international sources, are deemed consistent with the public interest and granted without modification or delay. For Authorizations relating to those countries with which the United States does not have an FTA ~~requiring national treatment trade in natural gas~~ and with which trade is not prohibited by the United States law or policy, pursuant to Section 3(a) of the NGA, requires DOE to grant a permit to export domestically produced natural gas unless it finds that such action is not consistent with the public interest.[6]

DOE has identified a range of factors that it evaluates when reviewing an application for LNG export authorization. Specifically, DOE's review of export applications has focused on: "(i) the domestic need for the natural gas proposed to be exported, (ii) whether the proposed exports pose a threat to the security of domestic natural gas supplies, (iii) whether the arrangement is consistent with DOE's policy of promoting market competition, and (iv) any other factors bearing on the public interest as determined by DOE, such as international and environmental impacts."[7]

To inform its Public Interest determination, since 2012, the Office of Fossil Energy and Carbon Management (DOE-FECM) and its predecessor, the Office of Fossil Energy, commissioned five studies on the effects of increased LNG exports on the U.S. economy and energy markets. The studies examined the impacts of increasing demand, including exports, on the domestic natural gas market.

This updated study, similar to the previous studies, ~~was~~ is intended to serve as an input to be considered in the evaluation of applications to export LNG from the United States under Section 3 of the Natural Gas Act. DOE-FECM commissioned OnLocation, Inc., Pacific Northwest National Laboratory (PNNL), and the National Energy Technology Laboratory (NETL) to assess the economic level of U.S. LNG exports across seven scenarios representing a broad range of economic, environmental, and political scenarios, along with changes to global greenhouse gas emissions at differing levels of U.S. LNG exports. U.S. LNG exports volumes(?) were found using a global equilibrium model and were then input~~ted~~ into the domestic model to examine the market effects of increased LNG exports, including natural gas price and consumption across sectors and changes in U.S. greenhouse gas emissions. Finally, the incumbent life cycle analysis of U.S. LNG exports was expanded to incorporate market effects from the results of this study.

[6] Natural Gas Act. 15 U.S.C. 717b.

[7] Order Amending Long-Term Authorization to Export Liquefied Natural Gas to Non-Free Trade Agreement Nations at 43, Magnolia LLC, Docket 13-132-LNG (April 2022).

B. Purpose of Study

Since the NERA 2018 report was published, several events altered the explicit and implicit assumptions underpinning the global and U.S. natural gas markets. These include: i) the issuance of additional DOE LNG export authorizations, ii) the Russia-Ukraine war, iii) global and U.S. greenhouse gas policy developments, iv) technological change in production, transmission, storage, and end-use of natural gas, iv) and the passage of significant energy-related legislation in the U.S. (Bipartisan Infrastructure Law (BIL) and Inflation Reduction Act (IRA)). This report updated previous analytical work in line with current laws and regulations, as well as economic and technology conditions using newly derived scenarios. The defined seven scenarios included:

***S1*: Reference Exports** (Reference scenario in which U.S. LNG exports follow the Reference case from the U.S. Energy Information Administration's 2023 Annual Energy Outlook (AEO))

***S2*: Market Response** (U.S. LNG exports determined by global market equilibrium)

***S3*: High Global Demand** (U.S. LNG exports determined by global market equilibrium, higher population growth outside of the U.S.)

***S4*: Regional Import Limits** (U.S. LNG exports determined by global market equilibrium, global focus on maximizing consumption of local energy sources)

***S5*: Low-cost Renewables** (U.S. LNG exports determined by global market equilibrium, lower costs for variable renewable energy technologies)

***S6*: Energy Transition (Ref Exp)** (U.S. LNG exports are limited to the values from the AEO 2023 Reference case, countries achieve emissions pledges and pursue ambitious GHG mitigation policies consistent with limiting global warming to 1.5°C, U.S. emissions to net-zero by 2050)

***S7*: Energy Transition** (U.S. LNG exports determined by global market equilibrium, countries achieve emissions pledges and pursue ambitious GHG mitigation policies consistent with limiting global warming to 1.5°C, U.S. emissions to net-zero by 2050)

These scenarios are described in more detail in Section 1.A.

Several considerations were required in interpreting this study and its results. Foremost, this study was not intended to serve as forecasts of U.S. LNG exports, rather, it was an exercise in exploring alternative conditional "what-if" scenarios of future U.S. LNG exports and examining their implications for the global and U.S. energy and economic systems, and GHG emissions. Such scenario analysis is a well-established analytical approach for exploring complex relationships across a range of variables. In addition, the scenarios explored in this study were meant to span a range of plausible U.S. LNG export outcomes by 2050. However, they hinged on many assumptions about a wide range of domestic and international, and economic and non-economic factors such as future socioeconomic development, technology and resource availability, technological advance, institutional change, etc. A full uncertainty analysis encompassing all of the above factors was beyond the scope of this study. This study did not attach probabilities to any of the scenarios and no inference about the likelihood of these scenarios occurring should be made.

C. Organization of the Report

Following the Background of LNG Export Studies and Introduction sections of the Report, Section IV presents a more detailed review of the study methodology, scenario design, and key assumptions. The section introduces the scenarios, the versions of GCAM and NEMS models used for the analysis, and the life cycle analysis methodology. Section V of the report includes key results by scenario:

- U.S. LNG exports
- Global gas and primary energy consumption
- Implications for U.S. energy systems
- Life cycle analysis

IV. SCENARIOS, METHODOLOGY, AND KEY ASSUMPTIONS

Three primary analytical frameworks were used for this analysis: i) the Global Change Analysis Model (GCAM) developed and maintained at the Pacific Northwest National Laboratory's (PNNL's) Joint Global Change Research Institute, ii) the National Energy Modeling System (NEMS) developed by EIA and modified for this study by OnLocation, and iii) the natural gas system life cycle analysis (LCA) model developed and maintained by NETL. These frameworks and key assumptions are described below.

A. GCAM Model and Global Scenarios Design

GCAM is a model of the global energy, economy, agriculture, land use, water, and climate systems.[8] These systems are represented in 32 geopolitical regions, 384 land subregions, and 235 water basins across the globe. GCAM operates in five-year time-steps from 2015 (calibration year) to 2100 by solving for equilibrium prices and quantities of various energy, agricultural, water, land use, and greenhouse gas (GHG) markets in each time period and in each region. Outcomes of GCAM are driven by exogenous assumptions about population growth, labor participation rates and labor productivity in the 32 geo-political regions, along with representations of resources, technologies, and policy.

GCAM tracks emissions of twenty-four gases, including GHGs, short-lived species, and ozone precursors, endogenously based on the resulting energy, agriculture, and land use systems. GCAM's energy system contains representations of fossil resources (coal, oil, and gas), uranium, and renewable sources (wind, solar, geothermal, hydro, biomass, and traditional biomass) along with processes that transform these resources to final energy carriers (electricity generation, refining, hydrogen production, natural gas processing, and district heat), which are ultimately used to deliver goods and services demanded by end use sectors (residential buildings, commercial buildings, transportation, and industry). Natural gas competes for share with other fuels in the electricity generation sector, and with other fuels and electricity in the buildings, industrial, and transportation sectors. Each of the sectors in GCAM includes technological detail. In every sector within GCAM, individual technologies compete for market share based on the levelized cost of a technology (see appendix for more details). The version of GCAM used in this study also included a representation of three carbon dioxide (CO_2) removal strategies that were deployed in scenarios with emissions policies, namely, direct air capture (DAC), bioenergy in combination with carbon capture, utilization, and storage (BECCS), and afforestation.

The version of GCAM used in this study includes a representation of natural gas trade that creates price-based competition between domestic and imported natural gas. This representation introduces realistic inertia in the evolution of trade from current patterns. Natural gas can be imported as liquefied natural gas (LNG) or through pipelines. Traded LNG is represented as a single global market. All producers of natural gas can export to a global LNG pool from which importers can import. While the price of domestic gas is based on extraction costs that are derived from long-term regional resource supply curves, the price of imported LNG includes costs for shipping, liquefaction, and regasification in addition to extraction costs. Traded pipeline gas is represented in six regional markets (North America, Latin America, Europe, Russia+, Africa and Middle East, and Asia-Pacific). Exporters of pipeline gas export to one of the six regional pipeline blocs from which importers can import. Inter-pipeline bloc trade can also occur. For example, GCAM's China region exports only to the "Asia-Pacific" pipeline bloc but can import

[8] The full documentation of the model is available at the GCAM documentation page (http://jgcri.github.io/gcam-doc/), and the description here and in the appendix is a summary of the online documentation.

from the "Russia+" pipeline bloc and the "Asia-Pacific" pipeline bloc. These pipeline trade relationships are based on existing relationships. The price of imported pipeline gas includes the costs of building and operating pipeline infrastructure in addition to resource extraction costs. Gross exports and imports of LNG and pipeline gas are calibrated to historical data in GCAM's historical calibration year (2015). In a future model period, trade volumes evolve from historical patterns depending on future demands and prices. For the purposes of this project, historical natural gas producer prices in the U.S. are calibrated to the Henry Hub prices from the Energy Information Administration (EIA)[9] and in Canada, they are calibrated to Alberta marker prices from the BP Statistical Review.[10] For the rest of the world, natural gas producer prices in each GCAM region are based on the cost, insurance, and freight (CIF) prices from S&P.[11] In a future model period, as demand changes, the change in regional producer prices from the historical calibrated values are calculated endogenously using regional supply curves that represent increasing cost of extraction as cumulative extraction increases. GCAM also tracks turnover of trade infrastructure (e.g., liquefaction and regasification units, and pipelines). Trade infrastructure can either retire naturally or in response to economic changes (e.g., those driven by an emissions policy).

Using GCAM, we explored seven scenarios spanning a range of plausible U.S. LNG export outcomes by 2050 (Table 2). All of our scenarios include the 2022 Inflation Reduction Act in the U.S. and current emission policies in the rest of the world. The scenarios also include a constraint on Russian exports such that Russian pipeline exports to EU declined to a level below current levels by 2035 and then remain flat, LNG exports from Russia remain flat beyond 2025, and Russian pipeline exports to the east (e.g., to China) continue to increase. Our scenarios include planned and existing LNG capacity additions in major economies including the U.S., Middle East, Australia, Canada, Southeast Asia, and Africa. Socioeconomic (population and economic growth) assumptions for the U.S. were harmonized to the AEO2023 Reference.

The seven scenarios include:

> ***S1: Reference Exports*.** This scenario assumes that the U.S. LNG exports follow the trajectory from the Reference case of the U.S. Energy Information Administration's (EIA's) 2023 Annual Energy Outlook (AEO2023) to grow to 27.34 Bcf/day in 2050. The AEO2023 Reference case incorporated U.S. LNG export projects that were either operating or under construction as of August 2022 and then added capacity based on the cost-competitiveness of exporting U.S. LNG to the international market including an annual capacity build-constraint. More specifically, in AEO2023, LNG export facilities had a combined operating capacity of 10.3 Bcf/d with an additional 4.5 Bcf/d of operating capacity under construction. AEO2023 projected an additional 12.6 Bcf/d of operating capacity that was assumed to be constructed in response to international demand for U.S. LNG.

---

[9] U.S. EIA (2023). Henry Hub Natural Gas Spot Price. Available at: https://www.eia.gov/dnav/ng/hist/rngwhhda.htm

[10] BP (2022). bp Statistical Review of World Energy. 71st edition. Available at: https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2022-full-report.pdf

[11] S&P Global (2023). S&P Global Commodity Insights. Historical and forecasted LNG prices data sheet.

S2: Market Response. This scenario has assumptions consistent with S1 and assumes economically driven, market-based outcomes for U.S. LNG exports.

S3: High Global Demand. This scenario includes the same assumptions as in *S2*, but assumes a higher population growth in regions outside of the U.S. consistent with the Shared Socioeconomic Pathways – 3.[12] This results in ~1 billion more people globally in *S3* by 2050 compared to *S1 and S2* and explores the effects of higher U.S. LNG exports driven by higher demand for all energy sources (including natural gas) compared to *S2*.

S4. Regional Import Limits. This scenario includes the same assumptions as in *S2*, but with constraints on natural gas imports globally to maximize the use of domestically produced natural gas across the world (Table A-1). This scenario explores the effects of lower U.S. and global LNG exports driven by global energy security concerns and trade limitations.

S5: Low-cost Renewables. *S5* includes the same assumptions as in *S2* but assumes lower capital costs for renewable energy technologies such as onshore and offshore wind, solar photovoltaic, concentrated solar power, and geothermal. This scenario explores the effects of faster technological improvements in competing technologies. While technology cost assumptions in other scenarios are consistent with NREL's Annual Technology Baseline (ATB) "Medium" assumptions, capital cost assumptions for onshore and offshore wind, solar photovoltaic, concentrated solar power, and geothermal technologies under *S5* are based on the "Low" assumptions.

S6: Energy Transition (Ref Cap)* and *S7: Energy Transition. Both scenarios assume an emission pathway that is consistent with a global temperature change of 1.5°C by 2100 derived from published peer-reviewed literature.[13,14,15] Both of these scenarios assume that countries achieve their emission pledges as made during the 26th Conference of Parties of the United Nations Framework on Climate Change held in Glasgow. The pledges include nationally-determined contributions that outline emission reduction plans through 2030, long-term strategies, and net-zero pledges through mid-century. The U.S. is assumed to reduce economy-wide greenhouse gas emissions by 51% in 2030 and 100% by 2050. Countries without pledges are assumed to follow an emissions pathway defined by a minimum decarbonization rate of 8% that is indicative of strong mitigation policies and significant departure from historically observed decarbonization rates. The scenarios assume that countries achieve their pledges within their geographic boundaries without trading emissions. Scenario *S6* differs from *S7* in that it also limits U.S. LNG exports to the values from the AEO2023 Reference case. A key distinction between scenarios *S1* and *S6* is that while the former assumes the U.S. LNG exports to follow the AEO2023 Reference case exactly, the latter assumes the values from the AEO2023

[12] Samir, K. C., & Lutz, W. (2017). The human core of the shared socioeconomic pathways: Population scenarios by age, sex and level of education for all countries to 2100. Global Environmental Change, 42, 181-192.
[13] Fawcett, A. A., et al. (2015). Can Paris pledges avert severe climate change? Science, 350(6265), 1168-1169.
[14] Ou, Y., Iyer, G., et al. (2021). Can updated climate pledges limit warming well below 2°C? Science, 374(6568), 693-695.
[15] Iyer, G., Ou, Y., et al. (2022). Ratcheting of climate pledges needed to limit peak global warming. Nature Climate Change, 12(12), 1129-1135.

Reference case to be an upper bound. Nevertheless, scenario *S6* enables comparisons with *S1*, and scenario *S7* enables comparisons with *S2*.

Table 2. Scenario Descriptions

Scenario	Description	U.S. LNG Export Volumes (Bcf/d)
***S1*: Reference Exports**	Reference scenario in which U.S. LNG exports follow EIA's 2023 Annual Energy Outlook (AEO). Incorporates U.S. policy assumptions (including the 2022 Inflation Reduction Act). Assumes existing policies and measures, globally.	Grow to 27.34 Bcf/d by 2050
***S2*: Market Response**	Assumes policies consistent with *S1*, but U.S. LNG exports are determined by global market equilibrium.	GCAM Market Response
***S3*: High Global Demand**	Same assumptions as *S2*, U.S. LNG exports determined by global market equilibrium, but assumes higher population growth outside of the U.S.	
***S4*: Regional Import Limits**	Same assumptions as *S2*, U.S. LNG exports determined by global market equilibrium, but includes constraints on importing and exporting natural gas with a global focus to maximize use of domestic gas.	
***S5*: Low-cost Renewables**	Same assumptions as *S2*, U.S. LNG exports determined by global market equilibrium, but assumes lower capital costs for renewable energy technologies.	
***S6*: Energy Transition (Ref Exp)**	Assumes an emissions pathway consistent with a global temperature change of 1.5°C by end of century. Countries' emissions are constrained to announced GHG pledges, including the U.S. following a path to net-zero GHG emissions by 2050. NEMS follows CO_2 emissions constraint from GCAM. U.S. LNG exports are limited to the values from the AEO 2023 Reference scenario.	Grow to 27.34 Bcf/d by 2050
***S7*: Energy Transition**	Same emissions pathway assumptions as *S6*, but U.S. LNG exports are determined by global market equilibrium.	GCAM Market Response

B. NEMS Models and Analysis Methodology

NEMS is an energy-economic model of the U.S. It projects supply, demand conversion, imports, and exports of major energy commodities, drivers such as macroeconomic conditions, world energy markets, technology choices and costs, resource availability, and demographics. The NEMS model includes both cost minimization representative of competitive markets and behavioral representations of the energy market.

NEMS is a modular energy system model. There are four supply modules covering oil, natural gas, coal, and renewables. There are two conversion modules: converting primary fuels into electricity and petroleum and other liquids into liquid fuel products, respectively. There are four demand modules covering the residential, commercial, industrial, and transportation sectors. Other modules include the macroeconomic module, emissions policy modules, and an integrating module that synthesizes the output across all other modules. NEMS solves iteratively to reach a general market equilibrium across the energy economy. The EIA provides an archive of the NEMS model with source code and input sufficient to reproduce the reference and side cases comprising the Annual Energy Outlook.

1. AEO2023-NEMS

AEO2023-NEMS is OnLocation's version of the NEMS model, modified to allow exogenous input of U.S. LNG exports. The AEO2023 reference scenario has a macroeconomic growth assumption of 1.9% average growth per year. The model has the EIA's interpretation of the IRA which includes most major provisions of the policy. The model does not include carbon capture at industrial sites (ethanol, hydrogen, NGP, and cement) or direct air capture (DAC). Therefore, the IRA 45Q credit for DAC is not included. Similarly, IRA 45V hydrogen credits are also not represented in the AEO2023 version of NEMS as it does not have the hydrogen module.

2. FECM-NEMS

FECM-NEMS is a version of NEMS that includes updates that allow for the modeling of deep decarbonization technologies and strategies. FECM-NEMS models the Inflation Reduction Act based on FECM's interpretation of the policy. It includes major IRA energy-related provisions including but not limited to the extension of 45Q CO_2 sequestration credits, clean vehicle tax credits, energy efficient home tax credits and rebate programs, clean energy PTC and ITC, zero emission nuclear credits, and hydrogen tax credits. Additional modeling updates include provisions from the Bipartisan Infrastructure Law (BIL) such as funding for carbon capture demos, CO_2 transportation and storage infrastructure, and updated EPA/NHTSA CAFE standards.

Given the carbon capture opportunities and the net negative carbon technologies such as DAC and BECCS, the FECM-NEMS model allows the economy to achieve a net-zero carbon emission scenario.

FECM-NEMS is based on OnLocation's version of the Annual Energy Outlook 2022 (AEO2022) NEMS model. For consistency with updated economic assumptions, FECM-NEMS uses the low economic growth assumption from AEO2022, assuming a real GDP average growth of 1.8% per year to 2050. Under the Office of Carbon Management Policy & Analysis, DOE-FECM, the standard NEMS has been enhanced to represent several CO_2 mitigation technologies including carbon capture and sequestration (CCS), DAC, bioenergy with CCS (BECCS), and the Hydrogen Market Module (HMM). Industrial carbon capture is found in the liquid fuels module which allows for the construction of new hydrogen and ethanol facilities with CCS. It also allows for existing hydrogen, ethanol, and natural gas processing plants to retrofit CCS capability. The cement industry has also been enhanced to include CCS opportunities. Industries have the option to send captured CO_2 to an enhanced oil recovery market or store it in saline aquifers.

The HMM is integrated into NEMS to produce hydrogen via conventional and low carbon processes. The hydrogen production technologies available in the HMM include steam methane reformation (SMR), SMR with CCS, biomass gasification with CCS, and electrolysis.

3. Harmonizing GCAM and NEMS

While GCAM and NEMS are distinct models, coordination between them was necessary to maintain consistency and tie the NEMS results back to the global LNG market forecast. Harmonization efforts ensured that LNG exports (for all scenarios) and CO_2 emissions (in the net-zero scenarios) were consistent between the two models.

The EIA's AEO2023 reference case was selected to define *S1*. In AEO2023-NEMS, the AEO2023 reference case solution file was adopted for all variables. LNG exports from the AEO2023 reference case were then used as exogenous inputs into the GCAM model in place of endogenous estimates. For *S2* through *S7*, the process was reversed: the scenarios were first run in the GCAM model, from which endogenously calculated LNG export curves were taken and input exogenously into AEO2023-NEMS. The endogenous algorithm used by NEMS to calculate LNG exports was turned off for these scenarios. Since a key driver of LNG exports is the differential between domestic and world natural gas prices, domestic natural gas prices from NEMS were then compared with North American prices in GCAM. In all scenarios except *S5*, technology and resource were aligned between GCAM and the AEO2023 reference scenario. In *S5*, both models adjusted power generation technology assumptions consistent with the AEO2023 Low Renewable Cost scenario from the AEO.

For *S6* and *S7*, the net-zero scenarios were first run in the GCAM model, which uses global interactions and feedback to model U.S. LNG under a criteria of net-zero GHG by 2050. As part of the modeling process, GCAM generates a set of emissions curves that list quantities of GHG emissions of various sectors and gases (CO_2, CH_4, N_2O, F), as well as emissions and removals from land use, land-use change, and forestry (LULUCF). These curves were outputs of the model, although the sum of individual emissions was defined in the model inputs such that they reached or exceeded a net-zero target in 2050. The output emissions curves from GCAM were used to specify how the net-zero scenario was implemented in FECM-NEMS.

The values of CO_2 emissions from the energy sector were taken from the GCAM output and used explicitly as the carbon cap in FECM-NEMS to model the net-zero scenarios. The carbon cap curve (used to define both *S6* and *S7*) is plotted in Figure 1.

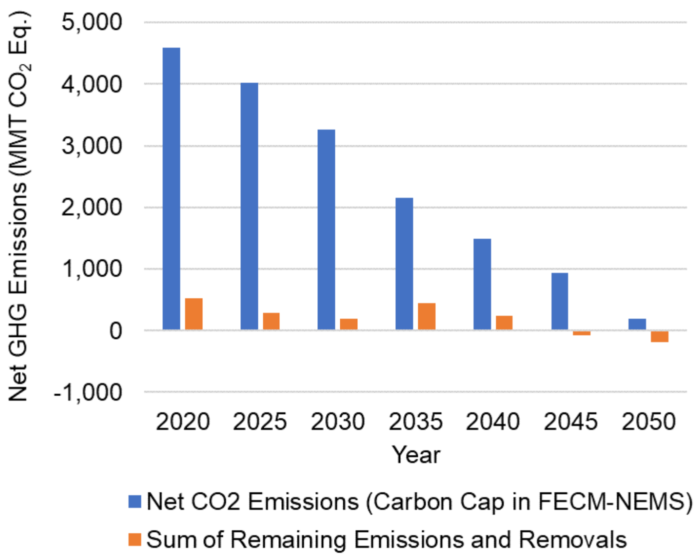


Figure 1. U.S. GHG emissions and removals in the net-zero scenarios

Referring to this carbon cap each model year, FECM-NEMS calculates emissions and removals throughout the model and adjusts a carbon price to equalize them with the carbon cap. With this method, FECM-NEMS ensures that the CO_2 emissions from the energy sector match the corresponding emissions from GCAM. Although FECM-NEMS calculates CH_4 emissions from natural gas systems, they were excluded from the carbon cap in favor of adopting the values calculated by GCAM.

The carbon cap used in FECM-NEMS for both net-zero scenarios ended with 187 MMT CO_2 in 2050. Although this value does not equal zero, it was balanced by the sum of non-energy CO_2, non-CO_2 GHGs, and LULUCF-sector emissions and removals calculated by the GCAM model which added together total -185 MMT CO_2 equivalent (the total was negative because of large quantities of LULUCF-sector removals). The remaining emissions and removals (non-energy CO_2, non-CO_2 GHGs, and LULUCF) were treated as exogenous to FECM-NEMS and could be added with the endogenous CO_2 emissions to calculate net total GHG emissions (which would equal near-zero in 2050). The sum of non-energy CO_2, non-CO_2 GHGs, and LULUCF-sector emissions and removals is also plotted in Figure 1.

C. NETL Life Cycle Analysis Model Methodology

Past life cycle studies conducted by NETL on natural gas and LNG have been attributional studies that estimate the emissions and other impacts associated with current units of natural gas/LNG delivered. These LCA studies have not, to date, considered the *consequences* of delivering LNG, such as how domestic or foreign energy markets may be affected by increasing the supply of natural gas (e.g., whether different sources of natural gas compete in the market, or whether, given additional supply, natural gas-fired power plants in Europe might take market share from other types of electric plants).

Such market-based effects could lead to consequential increases or decreases in GHG emissions. As part of this study, these consequential effects were estimated by tracking differences in global GHG emissions and quantities of LNG exported from the GCAM model results.

This section details the various existing representations of the natural gas supply chain within the context of the NETL natural gas model and the GCAM model. The purpose of documenting these representations is to subsequently apply the insights from the GCAM model to the NETL LCA framework.

1. Past NETL Natural Gas Life Cycle Reports

As shown in the top half of Table 3, the NETL Natural Gas model[16] is separated into five stages that generally align with categories used in other federal efforts such as the US EPA's Greenhouse Gas Reporting Program (GHGRP)[17] and Greenhouse Gas Inventory (GHGI)[18]. Results of this model are provided for two scopes: Production through Transmission (e.g., for large scale industrial users, like power plants and LNG facilities that are directly connected to a pipeline), and Production through Distribution (e.g., for residential or smaller industrial users where the natural gas is delivered through smaller distribution pipelines). Results are provided for various techno-basins of production, regions, and U.S. average production, using a variety of IPCC Assessment Report Global Warming Potential (GWP) values on 100-year or 20-year basis.

Commented [ST4]: The 2020 report and model are not public. The reference will need updated upon release of the 2020 report.

I checked the ISSST Presentation and it is marked "do not cite" and does not contain the production thru transmission result of 7.4 g. Not a good reference.

Evaluating U.S. Natural Gas Environmental Performance, ISSST 2023 Conference, June 14, 2023, Fort Collins, CO.

In addition, past work by NETL has modeled the additional processing stages to produce and deliver LNG, adding another four stages in the bottom half of Table 3.

Table 3. Natural Gas and Liquefied Natural Gas Life Cycle Stages

Stage Name	Description
Natural Gas Production Only Stages	
Production	Drilling and construction of conventional and unconventional wells (e.g., from hydraulic fracturing), and extraction of gas, including liquids unloading operations.
Gathering and Boosting	Movement of natural gas from wells via gathering pipelines and delivered to treatment and/or processing plants. Boosting systems may include compressors, dehydration, and pneumatic devices and pumps.
Treatment and Processing	Removal of impurities and compression of input gas to meet transmission pipeline standards. May include acid gas removal (AGR), dehydration), NGL recovery, etc.
Transmission and Storage	Construction of pipelines, and movement of bulk quantities of natural gas in large

[16] Khutal, H., et al. Life Cycle Analysis of Natural Gas Extraction and Power Generation: U.S. 2020 Emissions Profile. National Energy Technology Laboratory, Pittsburgh, July 7, 2023

[17] US EPA Greenhouse Gas Reporting Program, https://www.epa.gov/ghgreporting, last accessed Sept 1, 2023.

[18] US EPA , Inventory of U.S. Greenhouse Gas Emissions and Sinks, https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks, last accessed Sept 1, 2023.

	pipelines to large users or city gates for subsequent distribution. Typically includes compressor stations along pipelines. Storage includes insertion of gas into units such as underground storage facilities as well as additional gas processing and compression after removal from storage before injection into the transmission pipeline network.
Distribution*	Movement of gas from transmission or storage facilities to city gates for subsequent delivery to smaller consumers via small diameter pipelines. (*may or may not be included depending on scope)
Additional Stages to Produce and Deliver LNG	
Liquefaction	Pre-treatment of gas, liquefaction to low temperatures and storage.
Loading/Unloading	Process to load (and unload) LNG to and from tankers to facilities.
Ocean Transport	Shipment of LNG on ocean-going vessels of varying technology types to distant ports for subsequent regasification. Depending on technology, may use LNG as fuel.
Regasification	Regasification of LNG and injection into transmission pipelines.
Destination Transmission / Distribution	Similar processes as described above, and not functionally different than as described for the natural gas only part.

Quantitatively, the NETL natural gas model has estimated ranges of GHG emissions by species and by stage for the domestic natural gas supply chain as shown in Figure 2. Given the scope of domestic natural gas production through the transmission stage, the mean U.S. average total CO_2-equivalent emissions are about 7.44 g CO_2e/MJ (IPCC AR6, 100-year basis), with a confidence interval of the mean of 4.6-11.1 g CO_2e/MJ. This report also estimated GWP intensity of natural gas extraction in different geographic regions of the US, which have higher or lower intensity, as compared to the U.S. average. Note that these results are in terms of Higher Heating Value (HHV) of natural gas, while the GCAM model uses Lower Heating Value (LHV), so needed to be subsequently adjusted.

Commented [ST5]: Report the LHV result here that aligns to GCAM.

Need to provide/cite the HHV to LHV values for the adjustment factor.

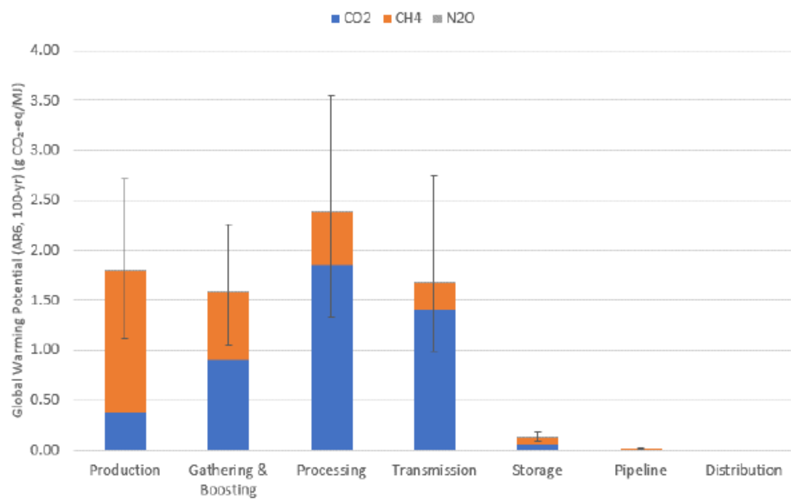


Figure 2. Life cycle GHG emissions from the 2020 U.S. average Natural Gas supply chain, HHV basis (Source: NETL 2023)

Commented [ST6]: Y-axis: units should read g CO2e/MJ before AR6, 100-year.

CO2e: removed hyphen between the "2" and "e".

Legend: need to subscript "2" and "4".

Past work by NETL also estimated the greenhouse gas emissions implications of the additional stages to produce and deliver U.S. average LNG around the world[19]. While these values are estimated on a per-MJ delivered basis, their presentation is complicated by the variability associated with the distance shipped, which can be large in many cases (LNG shipped relatively short distances has a significantly smaller GWP footprint than that shipped long distances). Using data from the 2019 NETL LNG report (cite), and adjusting to the basis here, LNG delivered from New Orleans to Rotterdam (8,990 km) would be expected to result in 17.9 g CO_2e/MJ delivered (IPCC AR6, 100-year basis, HHV). In short, the additional processes and natural gas needed to liquefy, ship, and regasify natural gas to Rotterdam adds about 10 g CO_2e/MJ delivered, which is more than double the impact of ~~merely~~ producing the gas and transmitting it to large scale users domestically (of 7.44 g CO_2e/MJ, HHV basis, given above). The GHG emissions intensity result on a per MJ NG delivered to liquefaction plant basis is 7.44 g CO_2e/MJ (AR6, 100-yr, HHV) but accounting for NG losses that occur in the downstream stages results in a higher volume of NG upstream, leading to an upstream emissions intensity of 8.44 g CO_2e/MJ NG delivered through low pressure distribution pipelines to small volume end users (e.g., commercial, residential, and some industrial users)~~to power plant~~ (AR6, 100-yr, HHV). Given the many possible delivery routes and distances for such LNG, these specific results are intended only to provide contextual perspective of the GWP intensity of the added LNG stages.[20]

Commented [ST7]: Needs completed.

Commented [ST8]: Please confirm that the US upstream was also adjusted to use the 2020 NG profile, as well as the GWP reference.

This change should also be noted in footnote 20.

Commented [ST9]: Per the 2020 report, this is the US average through distribution

[19] Roman-White, S., Rai, S., Littlefield, J., Cooney, G., & Skone, T. J. (2019). Life cycle greenhouse gas perspective on exporting liquefied natural gas from the Unites States: 2019 update. National Energy Technology Laboratory (NETL), Pittsburgh, September 12, 2019.

[20] Results from Roman-White 2019, Exhibit A-2, adjusted from g CO_2e/MWh to g CO_2e/MJ using heat rate of 145 kg natural gas/MWh, and higher heating value of 54.3 MJ/kg.

The previous NETL work on natural gas cited above are attributional studies of the domestic natural gas system. The results sought to identify and attribute the emissions associated with the various unit processes that created them. These methods differ in scope than consequential analysis which more broadly considers the global changes in GHG emissions when additional volumes of U.S. natural gas are produced and delivered across the world, or, in other words, the market-based effects of producing domestic natural gas and exporting it. Further discussion on how the LCA section of this project can support consequential analysis is discussed in Section V.G.

2. Market Adjustment Factors

In order to quantify the broad and global market effects associated with increasing exports of U.S. LNG, the GCAM results were used to estimate the change in global GHG emissions per unit of LNG exported between various scenarios. This market adjustment factor (MAF) is defined as:

Commented [ST10]: Page 51: MAF is defined as "market effect adjustment factor". Recommend removing effect for consistency with in the report.

Commented [ST11]: The equation below's font size is too large to match the document style.

$$MAF_{scenario\ n} = \frac{Global\ Emissions_{scenario\ n} - Global\ Emissions_{scenario\ 1}}{US\ LNG\ Exports_{scenario\ n} - US\ LNG\ Exports_{scenario\ 1}}$$

and represents a ratio of the change in GHG emissions for a given scenario compared to a base scenario, versus the change in U.S. LNG exports between the same two scenarios. For example, a comparison of Scenario *S2* vs. Scenario *S1* would compare the differences in GCAM values for these two scenarios. This MAF can be calculated for every model year (2015-2050) and can also use linearly interpolated values for the non-modeled years.

V. RESULTS

The following sections describe the results of the global analysis using GCAM, the U.S. analysis using NEMS, and the life-cycle analysis in that order. To highlight the implications of the availability of additional U.S. LNG in the global market, we first compare *S1* and *S2*. We then discuss *S6* and *S7* to illustrate the implications of additional U.S. LNG in the global market under a global transition toward 1.5^{0}C. Subsequently, we discuss results from the remaining scenarios (*S2-S5*).

A. U.S. LNG exports

Across all the scenarios, the U.S. is a net exporter of natural gas. As shown in Figure 3, U.S. LNG exports increased beyond existing and planned capacity in all scenarios by 2050, except *S1* in which U.S. LNG export volumes followed AEO2023 and *S6* in which export volumes were limited to AEO2023 by design. Under *S2,* in which all outcomes – including U.S. LNG exports – are economically driven and market-based, U.S. LNG exports increased to ~47 Bcf/day in 2050.

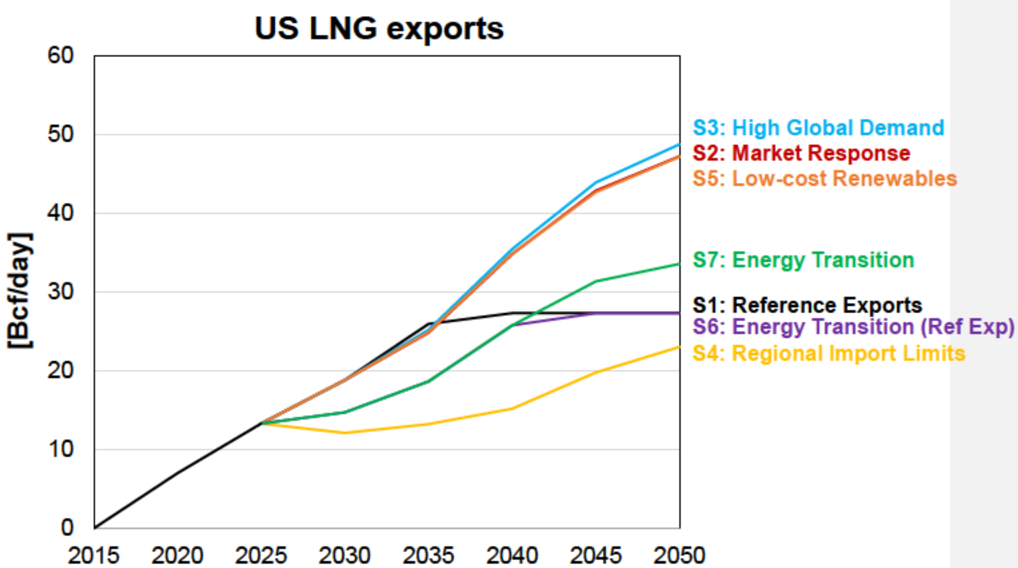


Figure 3. U.S. LNG exports across the scenarios. Note that the U.S. LNG export outcomes for S2 and S5 are very close to each other.

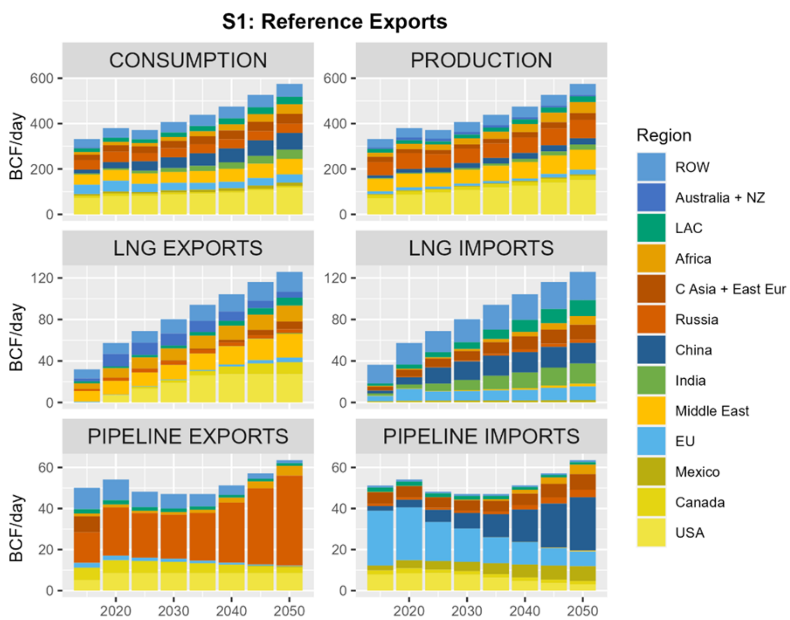
U.S. LNG exports under *S3*, the scenario with increased global population, increased to 49 Bcf/day in 2050, emerging as the upper bound. With higher population assumptions in *S3*, total energy demand – and consequently natural gas demand – outside the U.S. increased compared to *S2*, resulting in an increase in U.S. LNG exports to satisfy the increased international demand. However, the increase was not proportional to the increase in population because part of the higher demand in *S3* was supplied by an increase in international production.

U.S. LNG exports under *S4* increased only to ~23 Bcf/day in 2050, emerging as the lower bound. The lower increase in U.S. LNG exports in *S4* compared to other scenarios was driven by international limits on natural gas imports to maximize the use of locally produced gas.

U.S. LNG exports under *S5* increased to approximately the same level as *S2* in 2050. This was mainly because cheaper solar and wind technologies in this scenario mostly displaced fuels other than natural gas (e.g., biomass). Hence, the demand for natural gas and consequently, U.S. LNG exports, remained materially unaffected compared to *S2*. Under *S7,* which assumes a global transition toward 1.5°C, U.S. LNG exports continued to increase, albeit at a lower level than *S2,* to ~34 Bcf/day in 2050. As discussed below, the lower increase in U.S. LNG exports in this scenario compared to *S2* was driven by the economy-wide transition to low-carbon fuels to meet emission reduction commitments and pledges.

B. Global Natural Gas Consumption, Production, and Trade Under Scenarios *S1* And *S2*

As shown in Figure 4, under *S1*, production, consumption, and trade of natural gas increased in all regions, globally driven by growing demands in the electricity generation, industrial, and buildings sectors (see Figure A-1 in appendix A). Under *S1*, U.S. LNG exports followed the AEO2023 Reference case to grow to 27.34 BCF/day by 2050 (by design).



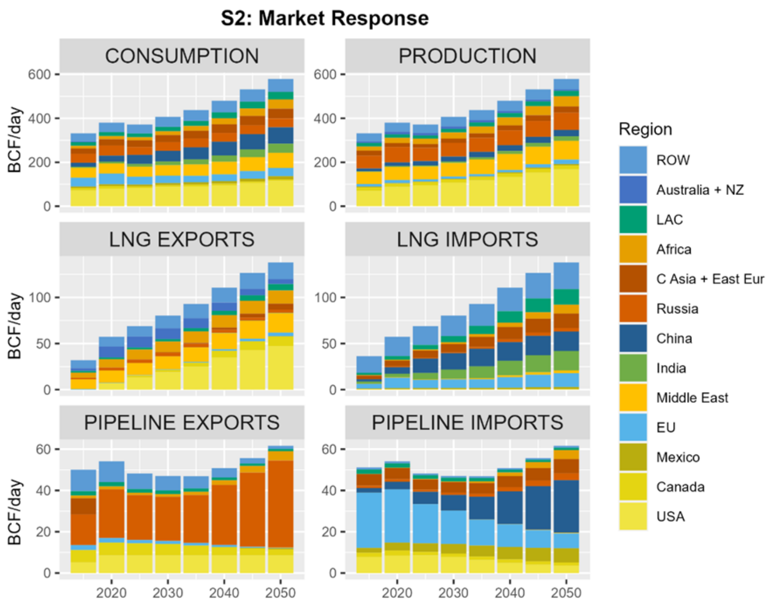


Figure 4 Natural gas consumption, production, and trade by region under S1 (upper) and S2 (lower)

As shown in Figure 5, under *S2*, in which U.S. LNG exports were determined by market equilibrium, U.S. natural gas production and LNG exports increased compared to *S1* to satisfy the growing demands of natural gas globally. Under *S2*, U.S. LNG exports grew to ~47 Bcf/day by 2050. In this scenario, the availability of additional U.S. natural gas in the global natural gas market at competitive prices resulted in a reduction in production and LNG exports from other parts of the world. The increased availability of U.S. LNG in the global market also resulted in higher LNG imports and reduced pipeline trade outside of the U.S. However, global natural gas consumption in *S2* increased only by a very small amount (<5% by 2050 globally compared to *S1*). This is mainly because the availability of additional U.S. LNG in the global market did not materially affect the relative competitiveness of natural gas compared to other fuels (e.g., coal, oil, renewables, and nuclear) globally. In addition, current emission reduction policies in the U.S. and internationally, which were included in the assumptions for all scenarios, limited the potential for global natural gas consumption to grow in response to the increased availability of U.S. natural gas. Consequently, global primary energy consumption and GHG emissions under *S2* did not change much compared to *S1*, as shown in Figure 6.

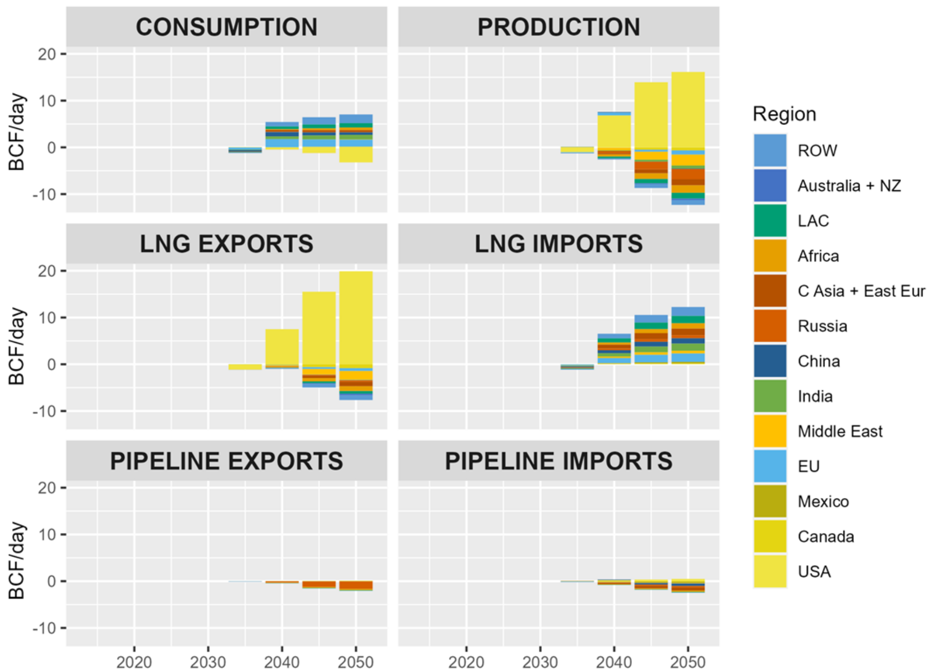


Figure 5. Changes in natural gas consumption, production, and trade by region in S2 vs. S1

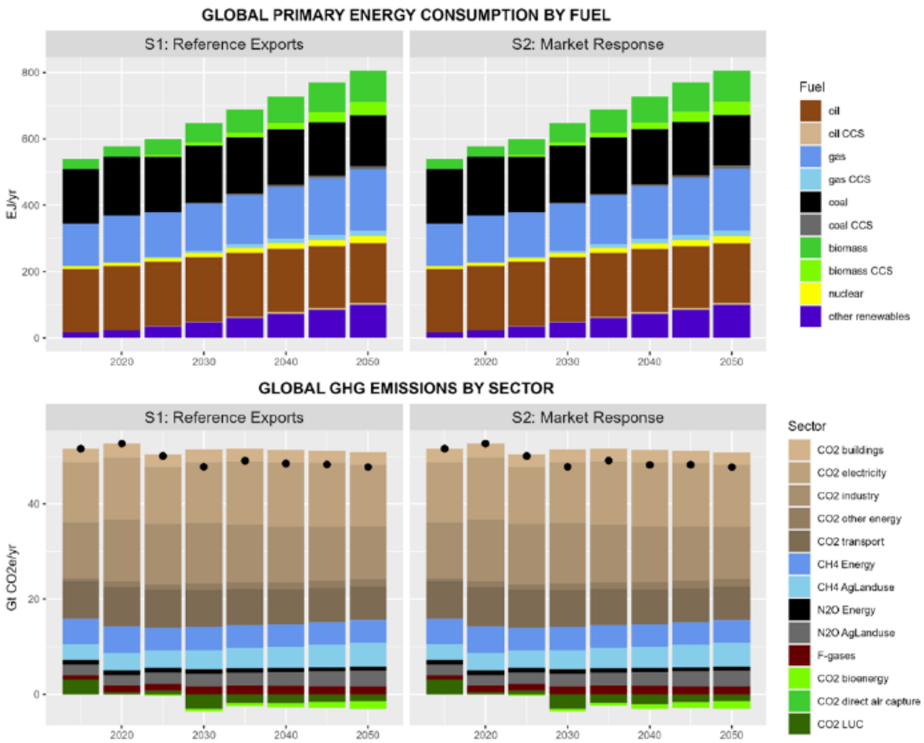


Figure 6. Global primary energy consumption by fuel and GHG emissions by sector under S2 and S1. Net GHG emissions are shown as a dot in each bar.

Commented [ST12]: Need S2 minus S1 delta figures.

C. Global Primary Energy Consumption by Fuel and GHG Emissions by Sector Under *S6* And *S7*

Under *S6* and *S7*, global GHG emissions from all sectors of the economy reduced significantly compared to *S1* and *S2* as shown in Figure 7 and Figure 8. This was by design as these scenarios were assumed to include emissions pledges and constraints on emissions consistent with limiting global temperature change this century to 1.5°C. These scenarios were characterized by a combination of the following decarbonization strategies: i) a reduction in fossil fuel consumption without carbon capture utilization and storage (CCUS), ii) increased deployment of CCUS with fossil fuels, iii) increased deployment of renewables, iv) a net reduction in energy consumption, and v) increased deployment of carbon dioxide removal (CDR) applications such as bioenergy in combination with CCUS (BECCS), afforestation, and direct air capture (DAC) compared with *S1* and *S2*.

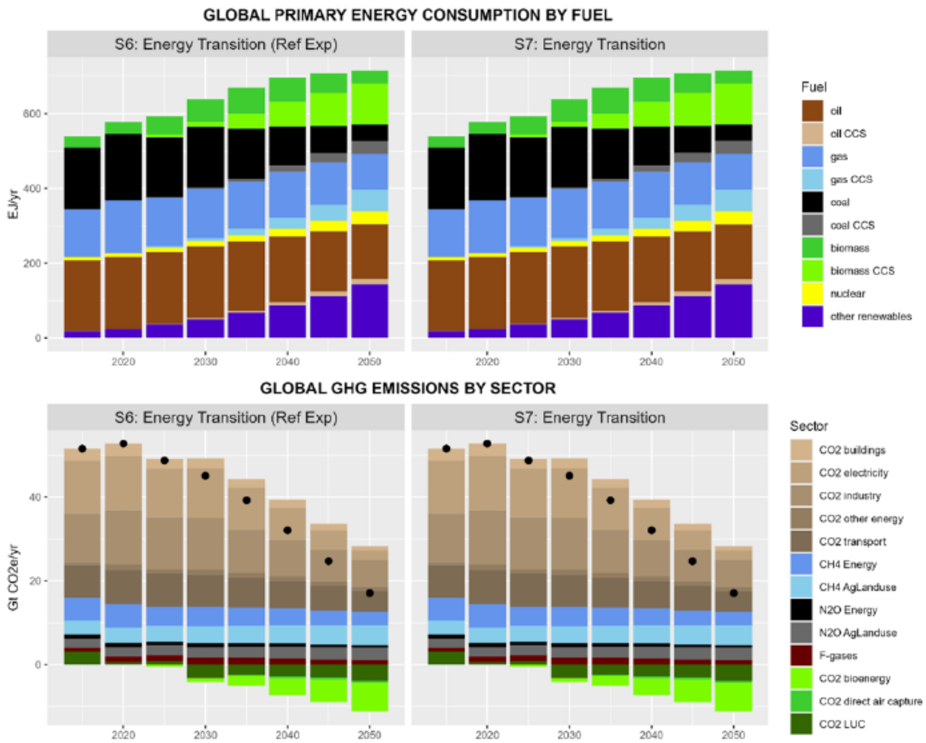


Figure 7. Global primary energy consumption by fuel and GHG emissions by sector under S6 and S7. Net GHG emissions are shown as a dot in each bar.

Commented [ST13]: Need S7 minus S6 delta figures.

Notably, the scale and distribution of CDR deployment varied by type and region. By 2050, about 6.8, 4, and 0.4 $GtCO_2e$ respectively of BECCS, afforestation, and DAC were deployed globally in *S6* and *S7*, as shown in Figure 9. While BECCS and afforestation were distributed more evenly across regions, most of the DAC was deployed in the U.S. primarily due to the availability of carbon storage.

Note that *S6* and *S7* did not assume the availability of any emissions trading or offset mechanisms. Hence, countries with net-zero pledges – such as the U.S. – were assumed to meet those pledges in the stated target years through a combination of the above decarbonization strategies including CDR deployment within their own geographic boundaries. Under these scenarios, although global GHG emissions are net-positive (~20 $GtCO_2e$), global CO_2 emissions were ~0 in 2050. These global emissions outcomes were broadly consistent with 1.5°C scenarios in the literature.[21]

[21] Riahi et al. 2022, Chapter 3 in the Sixth Assessment Report of the IPCC

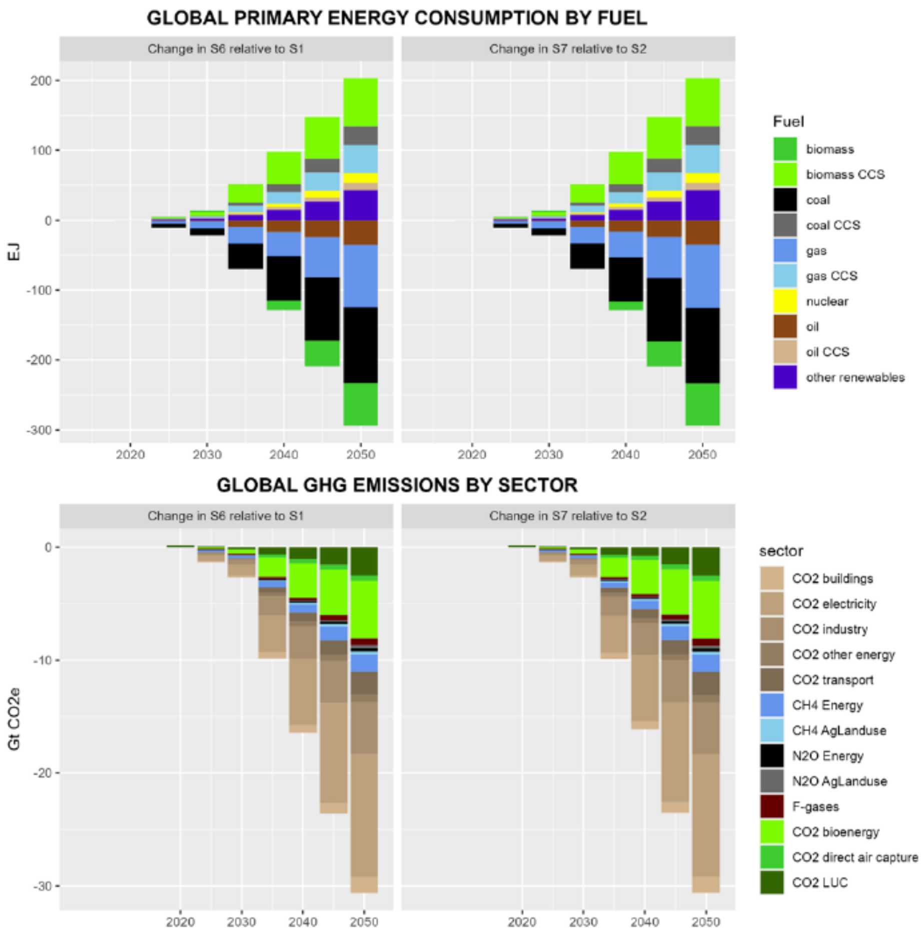


Figure 8. Changes in global primary energy consumption and GHG emissions under S6 and S7 relative to S1 and S2 respectively

Commented [ST14]: Recommend removing this figure. It is not related to LNG Exports. This result can easily be mis-interpreted given the focus of the project. This project is not about how effective climate policy is.

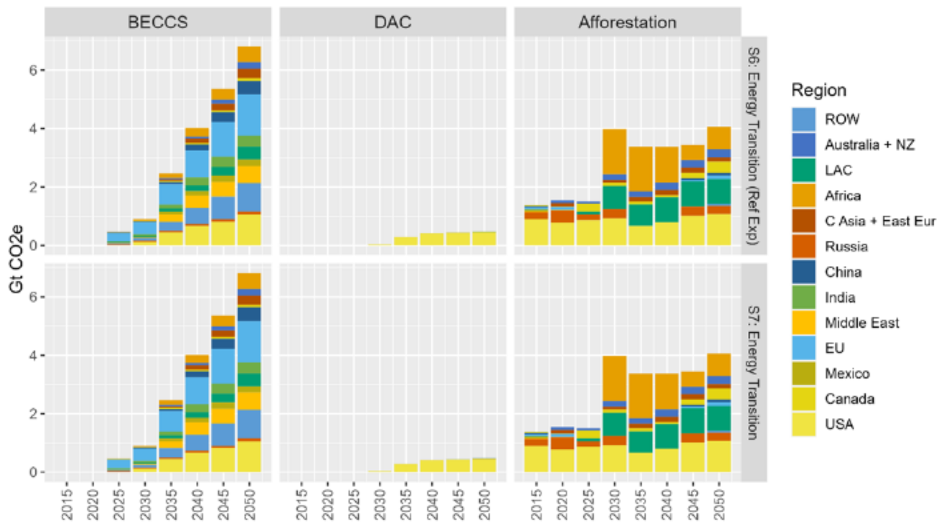


Figure 9. CDR deployment by type and region in S6 and S7

> **Commented [ST15]:** Need delta figures. The key message is "what changed" when we increase exports. I can not ascertain this result from the current results display.
>
> The question of how/if renewables or other energy sources are displaced by natural gas is also not apparent in any of these results.
>
> What countries changed their energy consumption profile because the US increased exports?
>
> Did each countries response to change in energy consumption pattern increase or decrease their GHG emissions footprint?
> ...what sectors within each country?
>
> Next - figures are nice, but would like to see full tabulated results in an Excel workbook be made available to provide transparency to the public on GCAM, NEMS, and LCA results.

D. Global Natural Gas Consumption, Production, and Trade Under Scenarios *S6* and *S7*

As shown in Figures 10 and 11, under *S6* and *S7*, natural gas consumption decreased compared to *S1* and *S2* in most regions largely driven by official net-zero pledges that require complete decarbonization of energy systems by 2050. However, in some regions with net-zero pledges that extend beyond 2050 (e.g., India), natural gas demand continued to grow through 2050 and consumption did not change much compared to *S1* and *S2*. Globally, although natural gas consumption in *S6* and *S7* was lower compared to *S1* and *S2*, it continued to grow due to the deployment of natural gas with CCUS in power and industrial sectors and direct air capture (DAC) applications (see Figure A-2 in appendix). The lower natural gas consumption in *S6* and *S7* compared to *S1* and *S2* resulted in lower global production, LNG exports, and LNG imports.

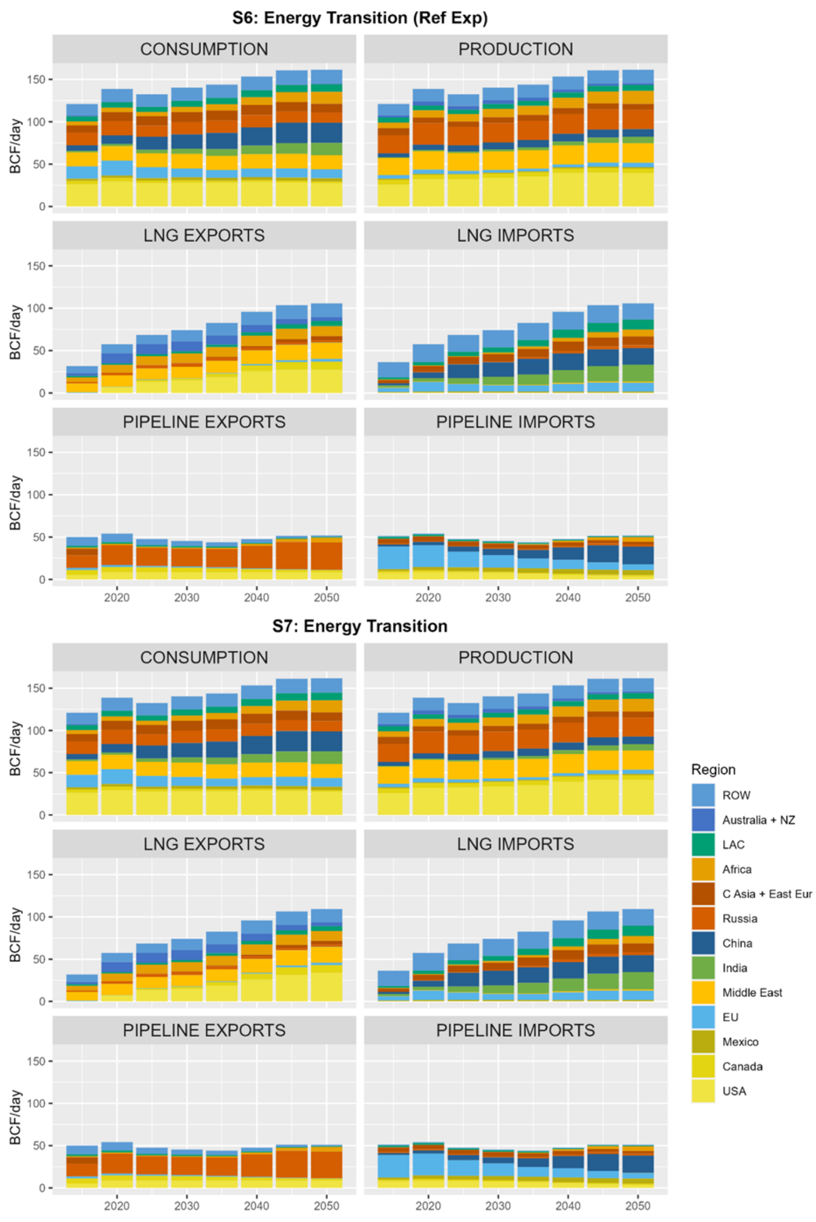


Figure 10. Natural gas consumption, production, consumption, and trade by region under S6 and S7

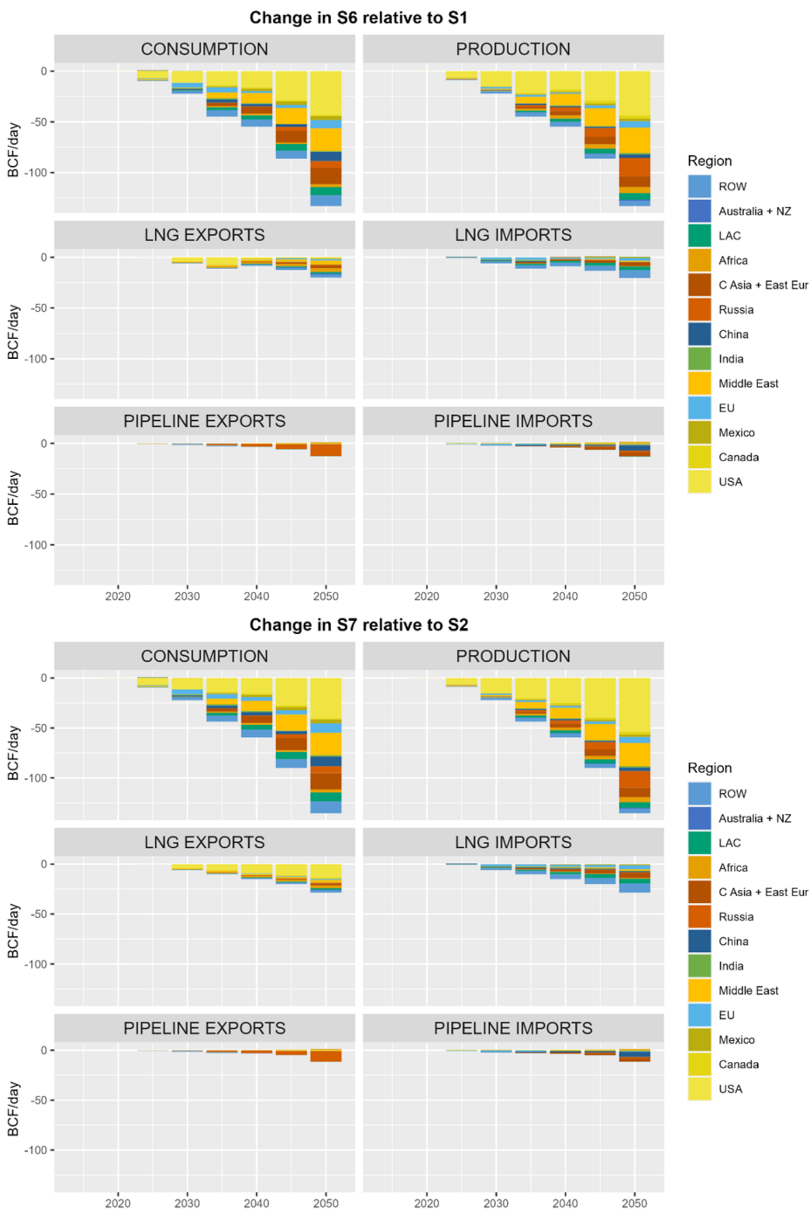


Figure 11. Changes in natural gas consumption, production, and trade by region: S6 vs S1 and S7 vs S2

As shown in Figure 12, *S6* and *S7* differed in the role of U.S. LNG exports in the global natural gas market. By 2050, U.S. LNG exports in *S6* were not different from *S1* because this scenario assumed the *S1* values (which are based on AEO2023) as an upper bound. Under *S7*, which assumes economically driven outcomes, U.S. LNG exports continued to grow and increase beyond *S6* – particularly after 2040 – to meet the global demand for natural gas, a growing share of which was deployed in combination with CCUS in the power and industrial sectors (see Figure A-1 in the appendix). Similar to the comparison between *S1* and *S2*, the availability of additional U.S. LNG in *S7* resulted in a very small increase in natural gas consumption, reduction in production, reduction in LNG exports, increase in LNG imports, and reduction in pipeline trade in the rest of the world compared to *S6*.

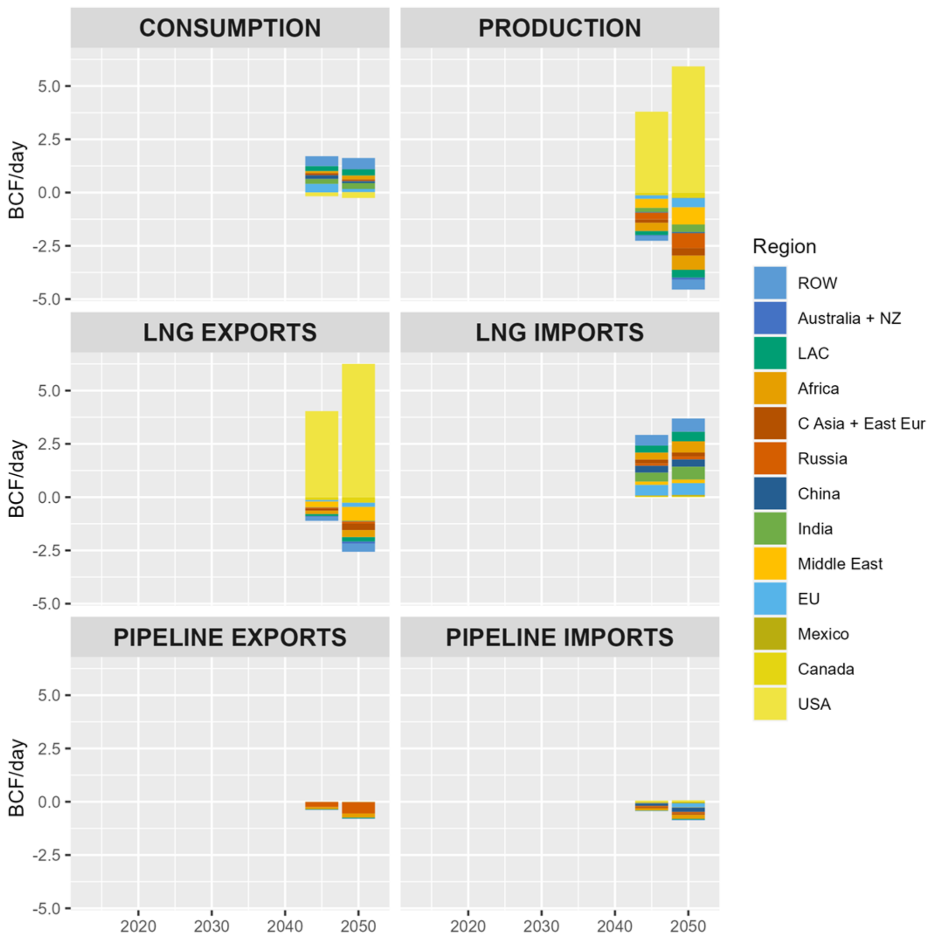


Figure 12. Changes in natural gas markets in S7 vs. S6

E. Global Primary Energy Consumption and GHG Emissions Across All Scenarios

Overall, the seven scenarios explored in this study resulted in a range of outcomes for global primary energy consumption and emissions by 2050. As shown in Figure 13, the fuel composition of primary energy consumption and the sectoral allocation of GHG emissions were not very different across scenarios *S1* through *S5*. Total primary energy consumption and GHG emissions were highest under the S3 scenario driven by higher population growth and associated increases in energy demand.

Total emissions in 2050 under scenarios *S1* through *S5* were relatively similar to 2015 levels because these scenarios included current policies and measures to deploy lower emission technologies. However, total primary energy consumption in 2050 under these scenarios was significantly higher compared to 2015 primarily driven by population and economic growth.

By contrast, total energy and emissions were lowest in scenarios *S6* and *S7* due to assumptions about countries meeting emission pledges and further emission declines to reach a global temperature change of 1.5°C by the end of century. As described earlier, these scenarios were also characterized by significant changes in the fuel composition of global energy consumption and the deployment of carbon dioxide removal technologies.

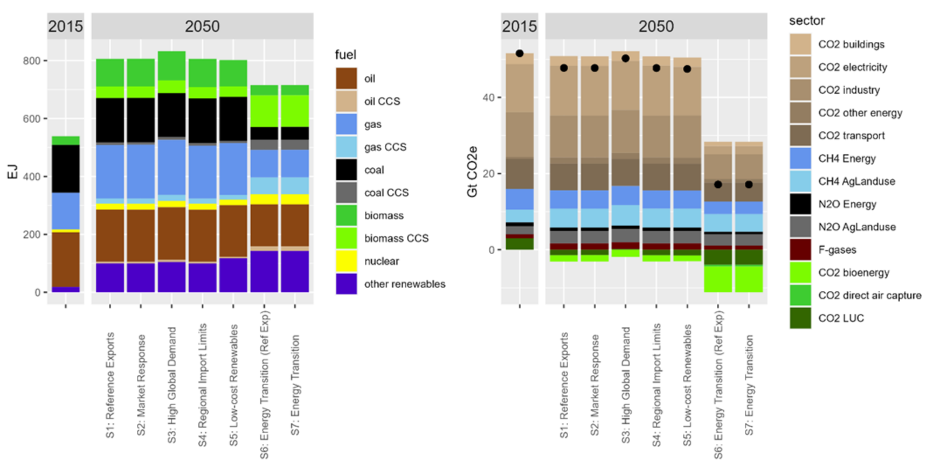


Figure 13. Primary energy consumption by fuel and GHG emissions by sector under all scenarios

F. NEMS Analysis: Implications for U.S. Energy Systems

1. Energy Impacts

AEO2023-NEMS and FECM-NEMS were used to model U.S.-specific results for *S1* through *S5* and *S6* through *S7*, respectively. Similar to global energy consumption, primary energy consumption in the U.S. grew over time in each scenario.

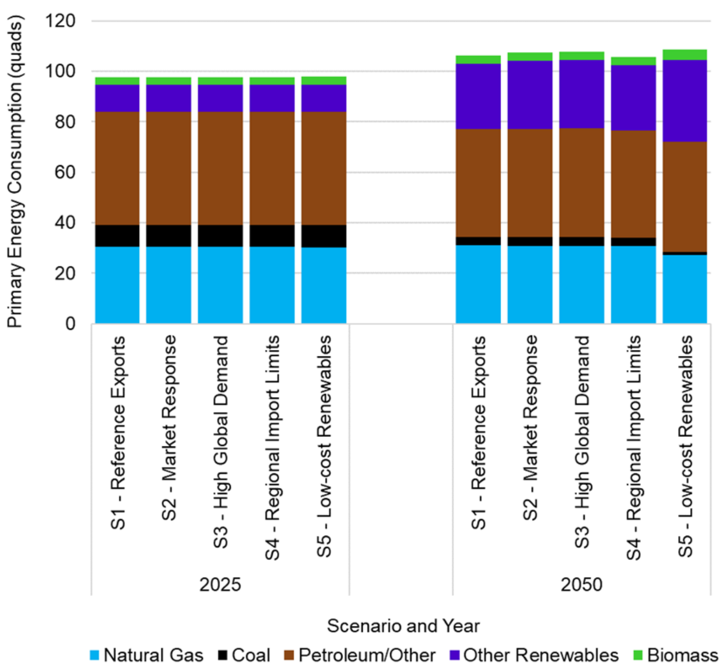


Figure 14. U.S. primary energy consumption, S1 through S5

In 2025, the primary energy consumption was at approximately 98 quadrillion BTUs in scenarios *S1* through *S5,* as shown in in Figure 14. By 2050, all scenarios saw an increase in total energy consumption, exceeding 105 quadrillion BTUs. The highest energy consumption was recorded in scenario *S5* at 109 quadrillion BTUs, and the lowest consumption was in scenario *S4* at 105 quadrillion BTUs.

The availability of low-cost renewables in scenario *S5* fosters the deployment of biomass and other renewable energy sources. A substantial decrease was noted in coal usage, with the most significant reduction occurring in scenario *S5*. Natural gas consumption remained steady across scenarios *S1* through *S4*, hovering around 31 quadrillion BTUs, but experienced a decline to 27 quadrillion BTUs in scenario *S5*.

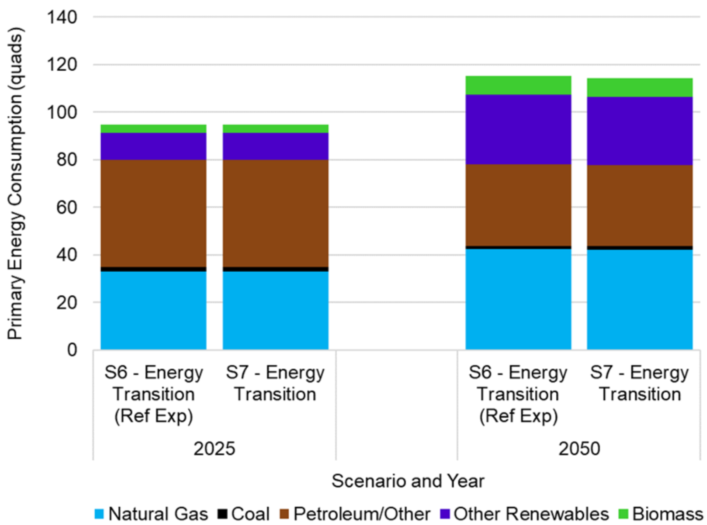


Figure 15. U.S. primary energy consumption S6 and S7

Figure 15 shows U.S. primary energy consumption across *S6* and *S7* in 2025 and 2050. In 2025, U.S. primary energy consumption was predominantly driven by fossil fuels, which accounted for 85% of the total energy use. By 2050, energy consumption rose across both scenarios relative to 2025, distinguished by a notable increase in biomass and other renewables. Relative to *S6*, increased LNG exports in *S7* put pressure on the natural gas market, leading to slightly higher end-use prices and more expensive GHG mitigation strategies. Biomass and other renewable sources grew by 22.3 and 22.1 quadrillion BTUs from 2025 in the *S6* and *S7* cases respectively, thereby contributing 32.1% of the total energy consumption in both cases. Natural gas consumption increased from 33 quadrillion BTUs in 2025 to 42.5 and 42.1 quadrillion BTUs in the energy transition scenarios *S6* and *S7* respectively. Remaining primary energy, primarily petroleum, decreased across both cases from 45.2 quadrillion BTUs in 2025 to 34.4 quadrillion BTUs in *S6* and 34.0 quadrillion BTUs in *S7* by 2050.

2. Natural Gas Production and Consumption Impacts

U.S. natural gas production increased across most cases to maintain projected export volumes. U.S. natural gas consumption, on the other hand, was relatively unchanged across the first four scenarios. Figure 16 plots total U.S. natural gas production, consumption, and export values over time. The LNG export values were identical to those plotted in Figure 3 and are included here as reference.

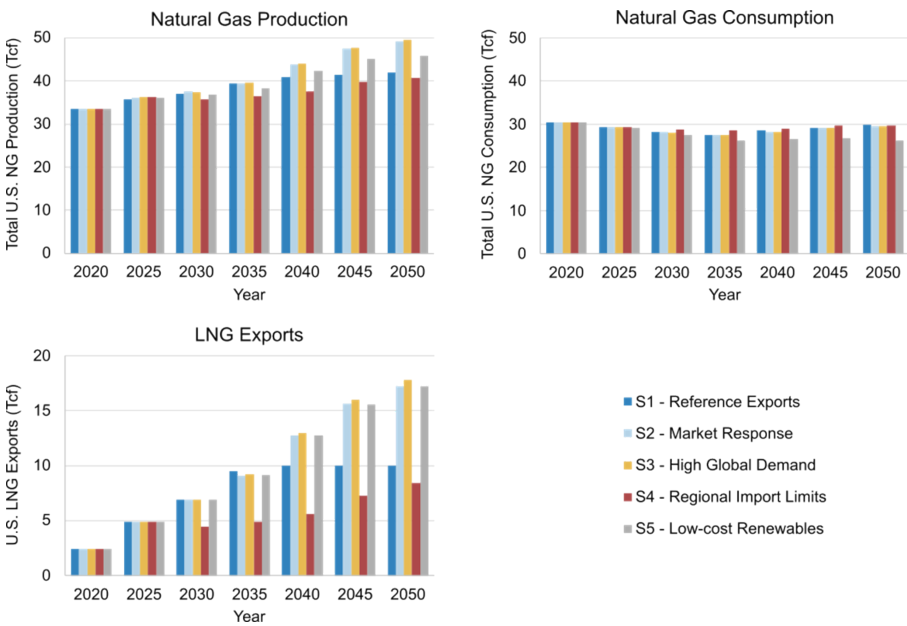


Figure 16. Total U.S. natural gas production, consumption, and export volumes over time, by scenario

From a starting point of 33.5 Tcf (91.5 Bcf/d) of natural gas production in 2020, production in each scenario increased, following a path that correlated with their LNG export curve. Natural gas production in *S1*, *S2*, and *S3* followed a similar trajectory by 2035, reaching 39.4-39.5 Tcf. *S1* production then slowed through 2040 and reached a peak of 42.0 Tcf by 2050. *S2* and *S3* production values accelerated through 2050, reaching 49.0 Tcf and 49.5 Tcf, respectively. Similar to the trends in LNG exports, *S4* production exhibited the lowest values, ending slightly below *S1* at 40.7 Tcf in 2050. *S5* production exhibited the same general path as *S2* and *S3*, but grew more slowly, reaching 38.2 Tcf and 45.7 Tcf in 2035 and 2050, respectively.

The natural gas consumption volumes from *S1-S3* followed similar paths, dipping from 30.5 Tcf in 2020 to 27.4-27.6 Tcf in 2035 before ramping up to 29.6-29.8 Tcf in 2050. Although *S4* had exhibited lower LNG export and natural gas production quantities, the consumption volumes in *S4* remained slightly higher than the volumes in *S1-S3* through most of model years, equalizing with *S1-S3* in the final timestep. *S4* reported 28.5 Tcf of natural gas consumption in 2035 and 29.8 Tcf in 2050. *S5* was the largest outlier with the lowest consumption of 26.2 Tcf in 2035 and almost no change in consumption values between 2035 and 2050.

The lower natural gas production and consumption volumes in *S5* (when compared to *S2* and *S3*) are explained by the effect of low renewables costs on the energy system. *S5* adopted many of the same inputs as EIA's AEO2023-NEMS low zero-carbon technology cost case. These inputs drove down the cost of renewables and caused *S5* to switch from natural gas to cheaper renewable energy sources, affecting both production and consumption. The remaining scenarios showed similar levels of natural gas consumption, but different levels of natural gas production, suggesting that most increases in natural gas production were passing directly to LNG exports.

Figure 17 plots the natural gas production, consumption, and exports for the two net-zero scenarios. Natural gas production in Scenarios *S6* and *S7* is 37.6 Tcf and 37.1 Tcf in 2035, respectively, but quickly rise to 54.7 Tcf and 56.5 Tcf by 2050. *S6* and *S7* exhibited a flatter trend in total consumption through 2040, but reached 41.9 Tcf and 41.5 Tcf, respectively, by 2050. The differences between the two net-zero scenarios were similar to differences observed between *S1* through *S5*: changes in production were correlated with changes in LNG exports, but differences in consumption between scenarios were minimal.

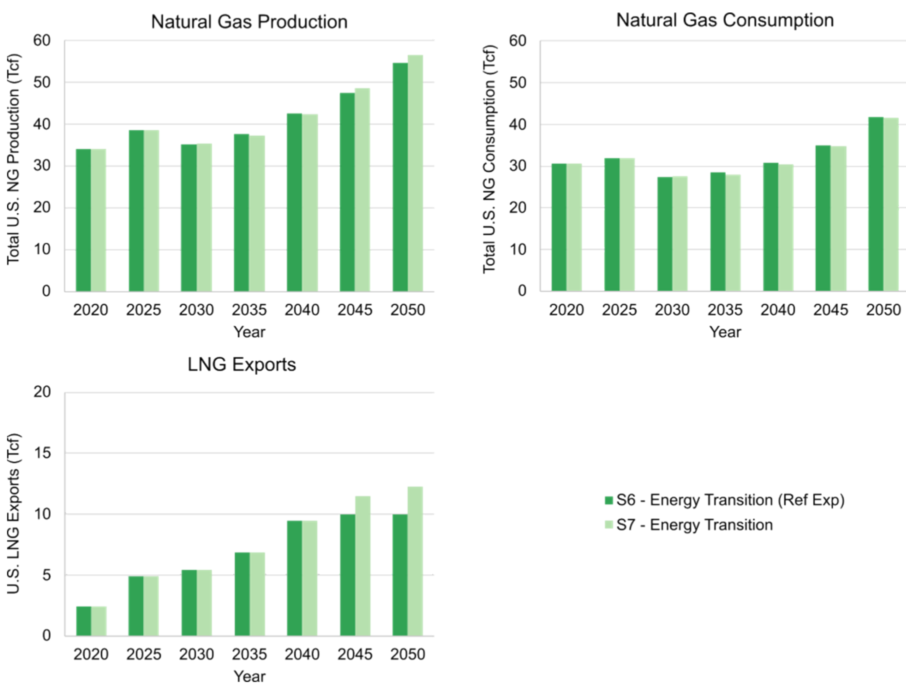


Figure 17. Total U.S. natural gas production, consumption, and export volumes, net-zero scenarios

The rapid increase in natural gas production and consumption for the net-zero scenarios after 2040 came from a substantial increase in natural gas to power direct air capture (DAC) facilities, plotted in Figure B-5 of the appendices. Natural gas consumption accounted for 16.8 Tcf and 16.2 Tcf in 2050 for *S6* and *S7*, respectively. More detail on CO_2 emissions and removals is provided in Section 1.F.5: "U.S. Greenhouse Gas Results".

3. Natural Gas Henry Hub Prices Impacts

Although total U.S. natural gas consumption volumes were similar across the first five scenarios, the increased LNG exports had a moderate effect on natural gas prices. The natural gas price of the net-zero scenarios rose above the prices from *S1* through *S5*, driven mostly by demand for natural gas to power DAC facilities. Figure 18 plots the natural gas price at the Henry Hub in $2022/Mcf over time for all scenarios.

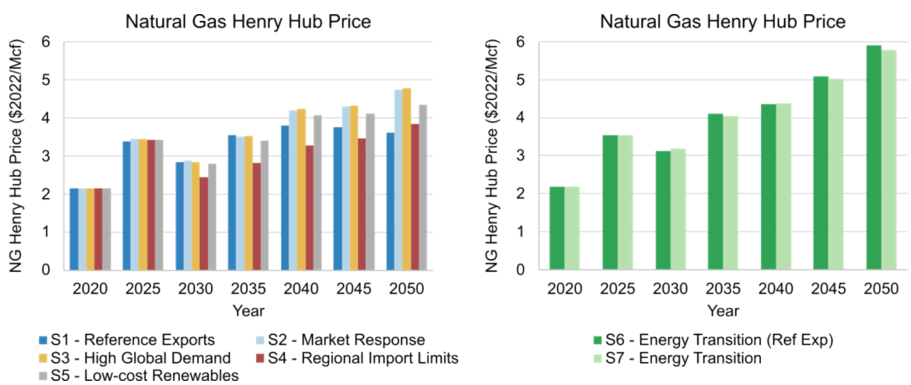


Figure 18. Total U.S. natural gas Henry Hub price by scenario ($2022)

The natural gas price in *S1* increased to a maximum of $3.80/Mcf in 2040 before moderating to $3.61/Mcf in 2050. The natural gas prices in *S2*, *S3*, and *S5* were mostly consistent with the reference case through 2035 but ultimately rose to levels of $4.74/Mcf, $4.79/Mcf, and $4.35/Mcf, respectively, by 2050. The difference in prices correlated with the differences in LNG export curves, while LNG exports in *S1* plateaued after 2035 and saw a drop in natural gas prices. Scenarios *S2*, *S3*, and *S5* all exhibited both increasing exports and prices. *S4* had lower natural gas prices over most of the modeling period, but ultimately exceeded *S1* in 2050 with a price of $3.84/Mcf; the persistent increase in *S4* prices after 2030 was consistent with increases in LNG exports throughout the same time period. Prices remained below $5.00/Mcf for all timesteps in *S1* through *S5*.

The influence of LNG exports on natural gas prices shown in Figure 18 was similar to the effect reported by EIA in their May 2023 "Issues in Focus" report on LNG.[22] The EIA's "Fast Builds Plus High LNG Price" case, which modeled the effect on U.S. energy markets of accelerated construction of LNG infrastructure in an environment with elevated international demand for LNG, reported a 2050 natural gas price of $4.81/MMBtu (equal to $4.64/Mcf) at 48.2 Bcf/d of exports. These values are close to the results from *S2* of $4.74/Mcf at 47.2 Bcf/d of exports and demonstrate good agreement between the two studies on the relationship between LNG exports and natural gas prices.

Overall U.S. natural gas consumption did not change appreciably in response to higher prices, but there were some shifts in consumption behavior on a sector-by-sector basis. These sector-specific differences are presented in greater detail in the Appendix in Figure B-3.

The natural gas price of the net-zero scenarios rose above the prices from *S1* through *S5*, driven mostly by demand for natural gas to power DAC facilities. Natural gas prices for S6 and S7 were similar to prices in *S1* through 2030, but afterwards rapidly increased on a trajectory consistent with the growth of DAC.

[22] U.S. EIA (2023). AEO2023 Issues in Focus: Effects of Liquefied Natural Gas Exports on the U.S. Natural Gas Market. Available at: https://www.eia.gov/outlooks/aeo/IIF_LNG/pdf/LNG_Issue_in_Focus.pdf.

S6 and *S7* reached prices of $5.90/Mcf and $5.77/Mcf, respectively, by 2050. The difference in price between *S6* and *S7* was within the tolerance of the model.

4. U.S. Macroeconomic Outcomes

While NEMS has rich detail about the energy system, a separate macroeconomic activity module (MAM) provides projections of economic drivers underpinning NEMS' energy supply, demand, and conversion modules. The MAM incorporates IHS Markit's (now S&P Global's) model of the U.S. economy, along with EIA's extensions of industrial output, employment, and models of regional economies. The S&P Global module is modified to include EIA's assumptions on key assumptions, such as world oil price, yielding a baseline trajectory of the economy. The baseline cannot appropriately respond to the wider economic changes in the net-zero scenarios, so such analysis is not included here. Within a NEMS scenario, feedback from the other NEMS modules includes:

- Production of energy, including coal, natural gas, petroleum, biomass, and other fuels;
- Trade in energy, including net exports coal, petroleum, natural gas, and biofuels;
- Total and end-use demand for energy, including sales of electricity;
- Consumer spending on energy, disaggregated to fuel oil motor fuels, electricity, natural gas, and highway consumption of gasoline;
- Energy prices, including a price index for consumer prices and wholesale prices; and
- Industrial production indices for oil and gas extraction and coal mining.

Since the MAM does not track individual projects, GDP estimates do not include economic activity associated with specific export facilities and thus the impacts are approximate.

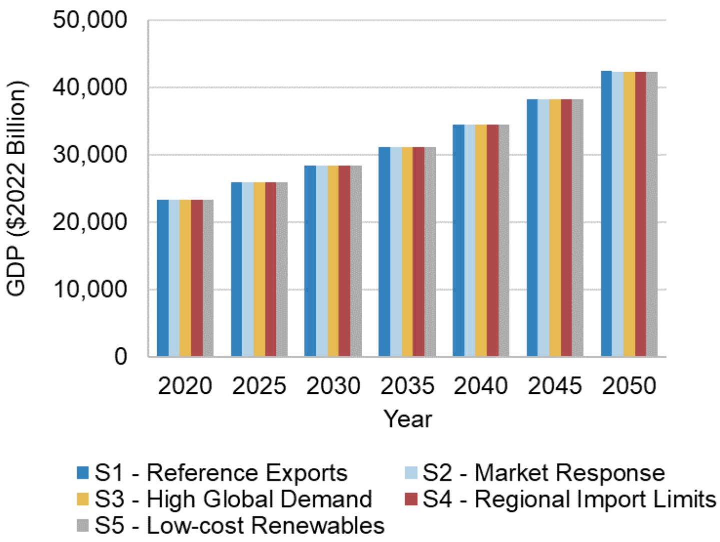


Figure 19. U.S. real GDP changes

As shown in Figure 19, U.S. GDP growth rate through 2045 remained essentially constant across all five scenarios, increasing at 1.9% annually. Higher natural gas exports resulted in higher prices, reducing economic activity in some sectors but increasing in others. The impact of increased LNG exports was positive on GDP by less than 0.1% across scenarios the through 2045. Accelerating natural gas prices in the last five years of the projection period in S2 reduced consumption on other products and tended to slightly reduce the overall rate of economic growth relative to *S1*. Overall, GDP changes in 2050 relative to 2020 were within 0.3% across all five scenarios.

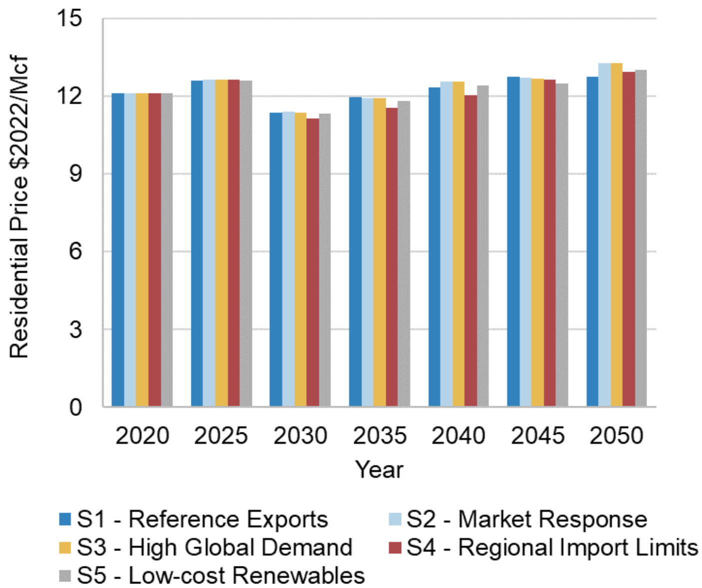


Figure 20. U.S. residential natural gas prices

Figure 20 shows the residential natural gas price in each of the five key scenarios. In 2050, natural gas prices in *S3* (when exports are the highest) were 4% higher than S1, when exports were the lowest. Overall, natural gas price differences between the scenarios were generally close to 1-2% across the scenarios.

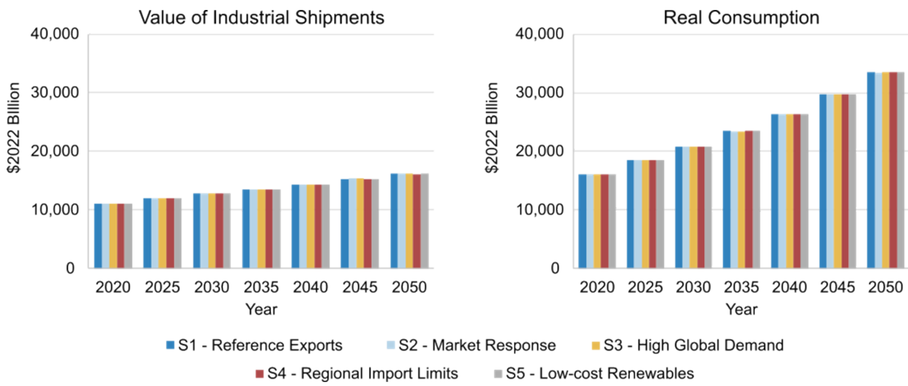


Figure 21. U.S. value of industrial shipments and real consumption

One component of GDP tracked by NEMS is the value of industrial shipments, shown in Figure 21. Industrial processes are sensitive to natural gas prices, which were generally higher than *S1*. However, increased production, processing, and transportation of natural gas requires additional equipment which tends to increase industrial shipments. Overall, NEMS showed a very slight increase in the value of industrial shipments in *S2* relative to *S1* of 0.2% in 2050. The value declined in S4 vs S1, reflecting lower natural gas production and exports.

The NEMS analysis shows NG exports could benefit consumers through increased labor income and the return on capital expended on facilities to produce and export the commodity. Exports increased the value of the dollar, decreasing the cost of some imports. However, increased demand for natural gas, including exports, raised the price of natural gas and the costs of products that require natural gas as an input. This can be observed in the change in aggregate consumption which is another component of GDP. When energy prices rise, consumers must pay more for natural gas, but purchases of other goods decrease. Across all the scenarios, this effect was small, and, while wealth transfers may occur between consumers as some groups benefit more than others through increased production, this was not reflected in the aggregate output of the model. Changes across all the scenarios were essentially flat. Overall, by 2050 consumption changes were less than 0.2%.

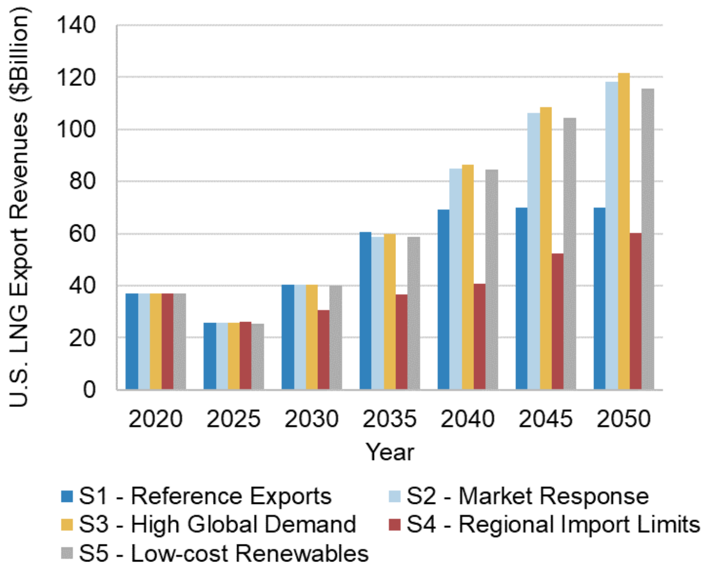


Figure 22. U.S. LNG export revenues

In a fully competitive market, the delivered price of LNG should be sufficient to fully accommodate the cost of production, liquefaction, and transportation of natural gas. Since much of this activity occurs domestically, it is a rough proxy for economic activity engendered by LNG exports. A representative price would be the price of imports to the EU. Figure 22 shows estimates of export revenues as the product of the LNG export volumes and the EU LNG price.

5. U.S. GHG Results

AEO2023-NEMS tracks CO_2 emissions from the combustion and use of fossil fuels. These CO_2 emissions did not change significantly between scenarios in response to varying LNG export levels. Figure 23 plots CO_2 emissions from fossil fuels for *S1* through *S5*.

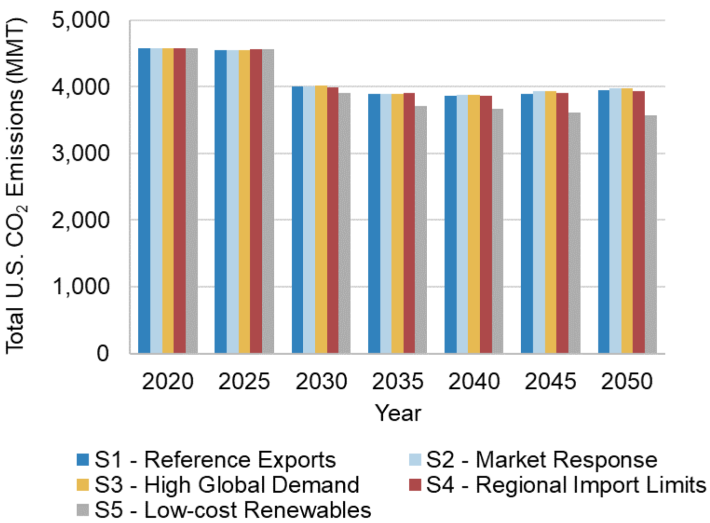


Figure 23. Total U.S. CO_2 emissions from fossil fuel combustion

From a starting point of 4,580 MMT CO_2 emissions in the U.S. in 2020, the first four scenarios declined to between 3,990 and 4,020 MMT CO_2 in 2030 and followed a flatter trajectory to 3930-3980 MMT CO_2 in 2050. There was a weak connection between LNG exports and CO_2 emissions: cases with the highest exports (*S2* and *S3*) had slightly higher CO_2 emissions levels in 2050 of 3970 and 3980 MMT, respectively, whereas cases with lower exports (*S1* and *S4*) reported respective CO_2 emissions of 3040 and 3030 MMT. The relationship was small, however, and accounted for only a 1% difference in emissions. The small differences between the first four scenarios were consistent with the relatively unchanged natural gas consumption volumes observed in Figure 16. *S5* was an outlier, continuing to decrease through 2030 (3910 MMT CO_2) and reaching 3570 MMT CO_2 emissions by 2050. The lower emissions from *S5* were explained by the assumptions used for low renewable costs rather than by changes in LNG exports.

S6 and *S7* were modeled in FECM-NEMS, which endogenously calculated some additional emissions that AEO2023-NEMS is missing (most relevant being CH_4 leakage from natural gas production and processing infrastructure). To retain consistency between the two models, only the CO_2 emissions reported by FECM-NEMS were included in the analysis and used to define the net-zero GHG scenarios. The remaining non-CO_2 emissions (which still contributed to the overall net-zero GHG cap) were calculated endogenously within GCAM and used in FECM-NEMS as an exogenous input.

Figure 24 plots the CO_2 emissions and removals for *S6* and *S7*. Both scenarios had both lower emissions than *S1* and significant amounts of CO_2 removals, reaching net-zero by 2050.

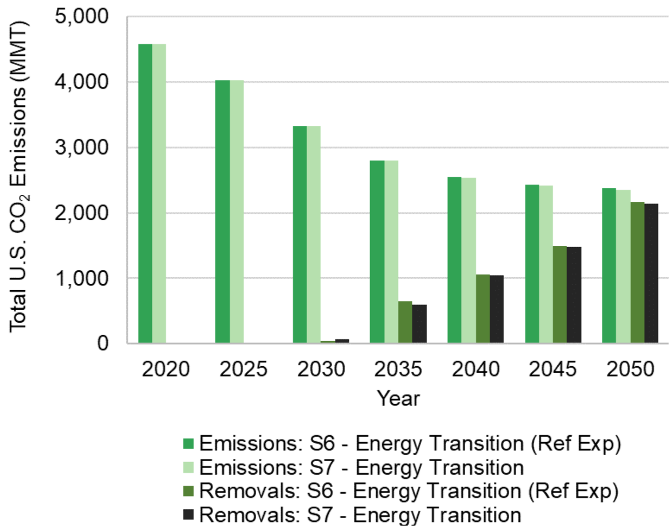


Figure 24. Total U.S. CO_2 emissions from fossil fuel combustion and removals, S6 and S7

CO_2 emissions from *S6* and *S7* began at 4,580 MMT and declined continuously through 2050, ending at 2,370 and 2,350 MMT CO_2, respectively. These declines were primarily driven by electrification of broad sections of the economy with a combination of renewables and CCS. The decline in emissions was accompanied by an increase in removals, which started growing rapidly in 2030 and eventually reached 2,160 MMT CO_2 for *S6* and 2,130 MMT CO_2 for *S7* in 2050. The majority of removals (87-89% by 2050) came from DAC, with the remainder coming from H_2 production with biomass and BECCS. The specific breakdown of removal technologies is explored in Section D of Appendix B. While the removals did not completely cancel out the 2,350-2,370 MMT of CO_2 emissions, the difference is balanced out by the non-CO_2 emissions calculated within GCAM and used as exogenous inputs, which were net negative.

G. NETL Life Cycle Analysis

The goals of the LCA component of this project were twofold: first, to help contextualize how the other results of this study (i.e., NEMS and GCAM models) connect to past studies of U.S. natural gas and LNG operations and, second, to leverage the results of the other models to quantitatively represent the international global warming potential (GWP) consequences from changes in quantities of U.S. exported LNG.

In support of the first goal, the following work was completed:

- Assessed whether NEMS results suggested significant changes in domestic supply (and thus, resulting in potential future upstream GWP intensity or emissions changes).
- Compared and aligned GCAM and NETL results to create a representation of the global natural gas supply chain that is consistent with existing NETL natural gas LCA studies.

In support of the second goal, the following work was completed:

- Developed a quantitative "market effect adjustment factor" that represents the consequences of additional export volumes of U.S. LNG, such as how additional available quantities of natural gas led to changes in the energy sectors of countries that purchase the LNG. These consequential effects were estimated by tracking differences in global GHG emissions and quantities of U.S. LNG exported from the GCAM model scenarios and assessed in comparison to existing NETL quantitative estimates of the upstream natural gas production.

In this project, the NEMS and GCAM models sought to represent economic and environmental changes associated with the defined changes in U.S. LNG exports. The GCAM model estimated global GHG emissions effects, including emissions associated with upstream natural gas. To compare the GCAM results with ~~past~~ the NETL life cycle analysis work used by DOE in support of natural gas and LNG export decisions, NETL assessed and aligned the emissions estimates per unit of gas produced and delivered to large end users (e.g., LNG export facilities) of the ~~two~~ GCAM and NEMS models to the NETL life cycle GHG intensity for U.S. average natural gas production and delivery to large end users. Non-U.S country natural gas production and delivery GHG emissions intensity values were also adjusted to align with NETL life cycle GHG intensity values based on the difference between the GCAM U.S. GHG emissions intensity for natural gas compared to each non-U.S. natural gas exporting countries GHG emissions intensity in GCAM. This process was conducted for each year reported by GCAM.

Commented [ST16]: Results were not aligned to the past NETL work on LNG exports. Work was aligned to the current NETL 2020 natutal gas upstream thru transmission to a large end user U.S. average GHG emissions per unit of natual gas delivered.

1. Assessment of NEMS Domestic Natural Gas Production by Region

The NEMS modeling focused on domestic changes that would be expected to occur in the seven scenarios modeled. NETL evaluated the regional sources of natural gas using outputs from NEMS to compare them to the mix of regions NETL uses in existing assessments of upstream natural gas emissions.

As shown in Appendix C, the NEMS results suggested only modest changes in the production mix by region and thus would not be expected to substantially change the domestic average GHG intensity per MJ of natural gas produced compared to previous analyses. As such, no regional adjustments were made to the U.S. results.

2. Comparison of GCAM and NETL Estimates of GHG Emissions of the Natural Gas sector

As discussed above, the GCAM model represents economic activity (and associated GHG emissions) by sectors and technologies, and their respective inputs and outputs, for regions, years, and scenarios. However, only a subset of these was relevant to the scope of the natural gas LCA-focused effort.

Only three sectors in the GCAM model include greenhouse gas emissions of the natural gas sector: *natural gas*, *gas pipeline*, and *other industrial energy use* (see Appendix C for more detail). Using the basis of process stages as represented in the NETL Natural Gas model, Figure 25 shows the relevant GCAM sectors that have associated CO_2 and non-CO_2 emissions. While the overall GCAM model has 16 species of GHG emissions, for the three sectors above relevant to the upstream natural gas sector, only emissions of CO_2, CH_4, and N_2O were represented.

As summarized in Figure 25, all stages of the NETL LCA are explicitly represented in GCAM except for Ocean Transport, which was included as part of other industrial energy use but could not be separated out for this analysis. As a result, the comparison in this report was focused on a comparison of emissions from production of natural gas in the U.S. through delivery to a large end user rather than LNG delivered around the world.

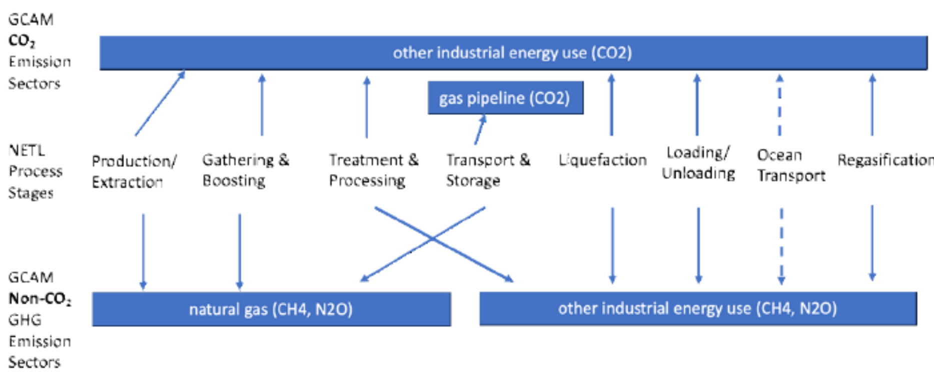


Figure 25. Mapping of NETL natural gas stages to GCAM sectors

Quantitative values of emissions intensities in the year 2020 of the various GCAM sectors for the USA region for the three natural gas-relevant sectors are listed and compared to NETL natural gas model results in Appendix C. Note that in order to compare NETL and GCAM results, NETL model results were regenerated using LHV basis and differ from those published (as HHV by default) in the report.

Overall, the estimated upstream emissions for the USA in the GCAM model in the year 2020 were about 8.52 g CO_2e/MJ (on an IPCC AR6 100-year, LHV basis), which is slightly higher than those of the NETL model for the boundary of production through transmission to large end user (8.18 g CO_2e/MJ, LHV basis). Using the relationship between those estimates, emissions results in the three GCAM natural gas sectors were adjusted by a factor of 8.18/8.52, or 0.96 (a 4% reduction) to maintain consistency with past NETL studies. This adjustment factor was used for all regions and for all years in the model. Similar adjustment factors were found for IPCC AR6 20-year and IPCC AR5 100-year and 20-year bases (see Appendix C for further details).

For context, in the GCAM results for *S1* in Year 2020, total global GHG emissions are approximately 53,000 Tg. The NETL adjustment post-processing of the GCAM model results on the IPCC AR6 100-year basis of the *gas pipeline* and *natural gas* sectors reduces emissions by about -7 and -35 Tg CO_2e, respectively, when considering those of *S1* in the Year 2020. Post-processing adjustments of the GCAM model results of the *other industrial energy use* sector reduce emissions by about -10 Tg CO_2e when considering those of *S1* in the Year 2020. The adjustments for these three sectors needed to align with past NETL studies have the cumulative effect of reducing estimated emissions from the GCAM model by about 0.2% (in *S1* in the Year 2020).

This same process was undertaken for different IPCC GWP values, and the resulting alignment tables and adjustment factors are provided in Appendix C.

Commented [ST17]: Labels in "blue" boxes need capitalized.

Subscript the 2 and 4 in CO2, CH4, and N2O.

NETL Process Stage labels should be centered with the arrows.

Commented [ST18]: The rest of the report uses "U.S." instead of "USA".

Commented [ST19]: See previous comment, this numeric values used need to be stated.

Commented [ST20]: Is the GCAM value consistent over the 35 year time horizon?

Is this the levelized average over 35 years that includes performance improvements within GCAM? Or is it the year 2020 value?

Are the values different for S7/S6 when climate pledges and net zero are considered? How did this effect the MAF calculation when considering temporal and economic variability?

Commented [ST21R20]: Need to state that the 8.52 is **the year 2020 GHG emissions intensity.**

Added to text - please confirm edit.

After reading the report, I don't think the value is levelized over 35 years. Unclear how GCAM GHG intensity per unit of LNG changes over time within the GCAM model (or NEMS).

Commented [ST22]: Why the italicized label? Not italicized in other parts of the report?

3. Market Adjustment Factor Results

Market adjustment factors (MAF) quantitatively estimate the consequential effect on global emissions as a function of U.S. LNG exported. MAFs for *S2* were estimated versus a baseline of *S1*, while the MAF for *S7* was estimated versus a baseline of *S6* given the significantly different global economy modeled in these scenarios.

MAFs were calculated using the post-processed NETL-adjusted GCAM results described previously. The MAF was calculated for each scenario by aggregate annual values over the time horizon of the model (i.e., the MAF for *S2* versus *S1* was defined as the total difference in annually-estimated global emissions over the 35-year period divided by the total difference in annually estimated exported LNG over the same period).

All MAFs were found using a variety of IPCC Assessment Report GWP values over 20- and 100-year time horizons, and with the raw and post-processed NETL adjusted GCAM results. MAF results from the IPCC Sixth Assessment Report on a 100-year time horizon are presented, and results for other IPCC Assessment Report and time horizons (and all raw GCAM results) are shown in Appendix C.

Table 4 shows the MAFs for *S2* (vs. *S1*), which varied from -5.34 to -5.35 g CO_2e/MJ on a 100-year time horizon (LHV basis). Also included is a summary reminder of the differences in the modeled scenarios (e.g., where *S1* is the baseline and *S2* added an economic solution for LNG exports, making a direct comparison of the two appropriate).

Table 4. Market Adjustment Factors for S2 vs. S1 (IPCC AR6, 100 year)

Results (g CO_2e/ MJ, LHV)			
MAF Case	GCAM	GCAM with LHV NETL adjustment	Scenario Difference
S2* vs. *S1	-5.34	-5.35	Adds economic solution for LNG exports.

Table 5 shows market adjustment factors for *S7* vs. *S6*, both of which represented significantly different energy and economic investments in support of a low-carbon economy through climate policies. The *S7* MFAs vary from -2.81 to -3.01 on a 100-year time horizon (LHV).

Table 5. Market Adjustment Factors for S7 vs. S6 (IPCC AR6, 100 year)

Results (g CO_2e/ MJ, LHV)			
MAF Case	GCAM	GCAM with LHV NETL adjustment	Scenario Difference
S7* vs. *S6	-3.01	-2.95	S6 1.5°C pathway, economic solution for LNG exports

4. Interpretation of Market Adjustment Factor Results

On an IPCC AR6 100-year basis, for *S2-S1*, the MAF result was approximately -5.4 g CO_2e/MJ (LHV). For purposes of comparison, NETL estimated natural gas upstream emissions prior to delivery to a large industrial end user (like an LNG terminal) are 8.18 g CO_2e/MJ (LHV), equivalent to 7.4 g CO_2e/MJ (HHV). The MAF indicated that as U.S. LNG exports increased, the induced global market effects result in an

Commented [ST23]: All results need to be on a HHV basis to document what will actually be used by NETL when added to the attributional results.

I am okay with report comparing to GCAM in LHV, however, that is not the result that needs documented for use in future export analyses that include consequential market effects. This report needs to document the values that will be used in future work.

Commented [ST24]: Add HHV results.

Commented [ST25]: Add HHV results.

Commented [ST26]: Reported as 7.44 previously in the report.

Commented [ST27]: Also report the result in LHV with the HHV result. (8.18 g CO2e/MJ, LHV basis) overall reduction in GHG emissions that is about 70% of the estimated upstream emissions associated with production through delivery of the natural gas to a large industrial end user in the U.S.

The MAF result for *S7-S6* was about -3 g CO_2e/MJ (LHV). In a decarbonizing world, the overall reduction in emissions was 56% of the estimated upstream emissions associated with production through delivery of the natural gas to a large industrial end user in the U.S. This is consistent with the idea that as the global economy decarbonizes, the induced global decarbonization benefit of increased U.S. LNG will be less. Overall, both of these results were consistent with the overall GCAM results that increased U.S. exports did not lead to increased global GHG emissions. Global changes in GHG emissions were constant to slightly negative as U.S. natural gas exports increased and global energy demand increased. The GHG reductions represented by the negative MAF were not so large that U.S. LNG should be regarded as a global climate reduction strategy but, at the same time, a negative MAF suggested that increased U.S. LNG exports could be compatible with global decarbonization efforts. A positive MAF would suggest U.S. LNG was leading to overall increased global emissions.

The results were aggregated in relation to estimated future volumes of exported LNG from the U.S. in the context of a global model. They represent overall expected effects and not those of individual shipments or authorizations of LNG. It is not possible to conclude that every MJ of exported LNG from domestic natural gas sources would directly lead to lower GHG emissions results when supplied around the world.

VI. CONCLUSIONS

The purpose of this study was to examine the potential global and U.S. energy system and greenhouse gas (GHG) emissions implications of a wide range of economic levels of U.S. LNG exports. The study comprised three coordinated analyses: 1) **a Global Analysis** to explore a wide range of scenarios of U.S. LNG exports under alternative assumptions about future socioeconomic growth, regional preferences for domestically produced natural gas, pace of technological change in competing technologies (e.g., renewables), and countries' announced GHG emissions pledges and policies; 2) **a U.S. Domestic Analysis** of the implications of the various U.S. LNG export levels derived from the Global Analysis for the supply and demand of natural gas within the U.S. and the U.S. economy; and 3) **a Life Cycle Analysis** to examine the life cycle emissions implications of the various levels of U.S. LNG exports derived from the Domestic and Global analyses. A number of key insights from this study are summarized below. Table 6 includes a summary of the key results across scenarios.

1. Across all modeled scenarios, U.S. LNG exports continue to grow beyond current operational export capacity (14.3 Bcf/day) through 2050. In addition, U.S. natural gas production grow beyond current levels through 2050. Across all the scenarios, LNG exports range from 23-47 Bcf/day. The range of U.S. LNG exports from this study is consistent with the U.S. EIA's analysis (15-48 Bcf/day.)[23] Compared to a scenario in which U.S. LNG exports follow the Reference Case from the AEO2023 (*S1*, growing to 27.3 Bcf/day by 2050), a scenario that assumes economically-driven LNG export levels (*S2*) results in significant growth in U.S. LNG exports to 47 Bcf/day by 2050. The availability of additional U.S. natural gas at competitive prices in the global natural gas

[23] U.S. EIA. (2023). Issues in Focus: Effects of Liquefied Natural Gas Exports on the U.S. Natural Gas. Available at: Markethttps://www.eia.gov/outlooks/aeo/IIF_LNG/

Commented [ST28]: I calculate a 66% reduction. 70% is generous rounding.

Commented [ST29]: Results need to be also reported in context of delivered LNG to provide a more complete perspective on the actual magnitude of percent change in delivered LNG cargo.

I understand that distance, and their emissions, from LNG facility to receiving country varies. However, some perspective is needed for the reader here and in the main conclusions. On page, x, you state that liquefaction plus ocean transport is "more than double" the upstream GHG footprint. This perspective through delivered LNG is an equally if not more important framing for the context of global market effects of "LNG exports". As written, the take-aways are grounded in production to delivery to a LNG facility only.

See page 26 for delivered LNG reference; excerpt below for reference:

Commented [ST30]: Add: result through delivered LNG.

E.g.

7.44 g HHV, equals 8.18 g LHV

HHV to LHV Adjustment Factor: 1.0995

17.9 g HHV (delivered to Europe), equals... 19.6811

Commented [ST31]: This paragraph needs to explain how -3 translates to a 56% reduction upstream NG emission profile to support the key insights.

I also prefer it be converted and discussed in terms of US LNG delivered to Europe and Asia markets.

See prior comment on S1/S2 above.

Commented [ST32]: Was there any change in the upstream profile in S7/S6 when compared to S2/S1 for the US gas?

S2/S1 data:
For purposes of comparison, NETL estimated natural gas upstream emissions prior to delivery to a large industrial end user (like an LNG terminal) are 8.18 g CO2e/MJ (LHV), equivalent to 7.4 g CO2e/MJ (HHV).

market in the latter scenario (*S2*) results in a reduction in production, reduction in LNG exports, increase in LNG imports, and reduction in pipeline trade outside of the U.S.

2. Global natural gas consumption increases only slightly (<1 percent) under a scenario with increased availability of U.S. natural gas in the global market that reflects economically driven LNG export levels (*S2*) compared to the reference scenario (*S1*), as the availability of additional U.S. natural gas in the global market does not materially affect the competitiveness of natural gas relative to other fuels globally. Instead, it results in a shift in the regional composition of natural gas production and trade. The majority of U.S. natural gas substitutes for other global sources of natural gas.
3. U.S. natural gas prices as measured at the Henry Hub increases modestly when comparing a scenario that reflects global market demand for exports (*S2*) to the reference scenario (*S1*). Across those scenarios, 2050 Henry Hub prices are projected to increase from $3.61/Mcf to $4.74/Mcf, both of which are less than the reference 2050 price expected in the most recent study DOE[5] commissioned on the economic impacts from U.S. LNG exports in 2018.
4. U.S. residential prices are projected to be 4% higher in 2050 when comparing a scenario that reflects global market demand for exports (*S2*) to the reference scenario (*S1*). In none of the scenarios did the change in residential prices exceed 4% and generally by substantially less.
5. The value of industrial shipments remains essentially unchanged (increasing less than 0.1% by 2050) when comparing a scenario that reflects global market demand for exports *(S2*) to the reference scenario *(S1).* The impact of increased LNG exports on GDP is essentially flat, positive by less than 0.1% across scenarios through 2045 while all changes are within 0.3% in 2050.
6. Even though U.S. LNG exports continue to grow beyond existing and planned nameplate capacity across scenarios *S1* through *S5* to 23-47 Bcf/day by 2050, global and U.S. GHG emissions do not change appreciably. Global emissions in these scenarios range from 47.5-50.3 $GtCO_2e$ and U.S. emissions range from 4.3-4.6 $GtCO_2e$ across these scenarios.
7. The induced global market effects of a case that reflects global market demand for exports (S2) compared to the reference case (*S1*) are equivalent to an overall reduction in GHG emissions of about 70% of the estimated upstream emissions associated with production through delivery of the natural gas to a large industrial end user (e.g., to an LNG export facility) in the U.S.
8. When compared to the other scenarios, *S6* and *S7* – in which countries are assumed to achieve their GHG emissions pledges and pursue ambitious GHG mitigation policies consistent with limiting global warming to 1.5°C – are characterized by a global transition resulting in lower in natural gas, coal, and oil consumption without CCUS; higher deployment of gas, coal and biomass with CCUS, and renewables; higher deployment of carbon dioxide removal strategies; and lower overall energy consumption. While in scenario *S6*, in which U.S. LNG exports are limited to the values from the AEO2023 Reference case (by design) and grow to 27.34 Bcf/day by 2050, *S7* assume economically-driven outcomes resulting in U.S. LNG exports growing to 34 Bcf/day by 2050. The higher growth in U.S. LNG exports in *S7* compared to *S6* is driven by increased global demand for natural gas with CCUS in the power and industrial sectors. Similar to the comparison between *S1* and *S2*, the availability of additional U.S. LNG in *S7* in the global natural gas market results in a very small increase in natural gas consumption, reduction in production, reduction in LNG exports, increase in LNG imports, and reduction in pipeline trade in the rest of the world compared to *S6*. Furthermore, with the higher U.S. LNG exports in *S7*

Commented [ST33]: Consider splitting the conclusions into two parts: S1/S2 and S6/S7 to improve clarity.

Commented [ST34]: Did we run another set of S6 and S7 results with and without CCUS? Where do these findings come from without CCUS?

compared to *S6*, U.S. natural gas prices are essentially unchanged within modeling tolerance, reaching $5.90/Mcf in *S6* and $5.77/Mcf in *S7* by 2050.

Commented [ST35]: Equivalent level of results are missing for S6/S7 as reported in Items #1 thru #7. MAF for S6/S7 is not discussed in the conclusion section, for example.

Table 6. Key Results for U.S. and globe in 2050 across scenarios

Scenarios	U.S. LNG Exports (Bcf/d)	U.S. NG Henry Hub Price ($2022/Mcf)	US Net GHG Emissions ($GtCO_2e$)	Global Net GHG Emissions ($GtCO_2e$)
S1	27.3	$3.61	4.5	48
S2-S5	23.1 – 48.7	$3.84-$4.79	4.3-4.6	47-50
S6-S7	27.3 – 33.6	$5.77-$5.90	0	17

Appendix A: Global Analysis and Description of GCAM

A. Additional detail about GCAM's energy system

GCAM's energy system contains representations of fossil resources (coal, oil, gas), uranium, and renewable sources (wind, solar, geothermal, hydro, biomass, and traditional biomass) along with processes that transform these resources to final energy carriers (electricity generation, refining, hydrogen production, natural gas processing, and district heat) which are ultimately used to deliver goods and services demanded by end use sectors (residential buildings, commercial buildings, transportation, and industry). Each of the sectors in GCAM includes technological detail. For example, the electricity generation sector includes several different technology options to convert coal to electricity such as pulverized coal with and without carbon capture, utilization, and storage (CCUS), and coal integrated gasification combined cycle (IGCC) with and without CCUS. The full list of technologies in various sectors in GCAM is documented in the GCAM documentation page (http://jgcri.github.io/gcam-doc/).

In every sector within GCAM, individual technologies compete for market share based on the levelized cost of a technology. The cost of a technology in any period depends on (1) its exogenously specified non-energy cost, (2) its endogenously calculated fuel cost, and (3) any cost of emissions as determined by the climate policy. The first term, non-energy cost, represents capital, fixed and variable operating and maintenance (O&M) costs incurred over the lifetime of the equipment (except for fuel or electricity costs), expressed per unit of output. For example, the non-energy cost of coal-fired power plant is calculated as the sum of overnight capital cost (amortized using a capital recovery factor and converted to dollars per unit of energy output by applying a capacity factor), fixed and variable operations and maintenance costs. The second term, fuel or electricity cost, depends on the specified efficiency of the technology, which determines the amount of fuel or electricity required to produce each unit of output, as well as the cost of the fuel or electricity. The various data sources and assumptions are documented in the GCAM documentation page (http://jgcri.github.io/gcam-doc/). The prices of fossil fuels and uranium are calculated endogenously. Fossil fuel resource supply in GCAM is modeled using graded resource supply curves that represent increasing cost of extraction as cumulative extraction increases. Wind and rooftop PV technologies include resource costs that are also calculated from exogenous supply curves that represent marginal costs that increase with deployment, such as long-distance transmission line costs that would be required to produce power from remote wind resources. Utility-scale solar photovoltaic and concentrated solar power technologies are assumed to have constant marginal resource costs regardless of deployment levels.

In GCAM, technology choice is determined by market competition. The market share captured by a technology increases as its costs decline, but GCAM uses a logit model of market competition. This approach is designed to represent decision making among competing options when only some characteristics of the options can be observed and avoids a "winner take all" response.

B. Additional detail about scenario design

Table A-1. Detailed assumptions in the S4: Regional Import Limits scenario

Region Type	GCAM Regions	High-level target / sanction
Developed countries, natural gas importers with sufficient domestic resources	EU-12, EU-15, Europe_Eastern, Europe_Non_EU	Reduce gross imports to 90% by 2035 and zero by 2040
Developed countries, natural gas importers with low domestic natural gas resources	Japan, South Korea, Taiwan	Maintain current import dependence through 2050
Developing countries, natural gas importers	Brazil, China, India, Pakistan, Southeast Asia, Mexico, South Africa	Maintain current import dependence through 2050
Natural gas exporters	USA, Africa_Eastern, Africa_Northern, Africa_Southern, Africa_Western, Australia_NZ, Canada, Central America and Caribbean, Central Asia, European Free Trade Association, Indonesia, Middle East, South America_Southern, South America_Northern, South Asia, Colombia, Argentina	Reduce gross imports to 90% by 2035 and zero by 2040
Russia	Russia	Same as *S2*

C. Additional GCAM results

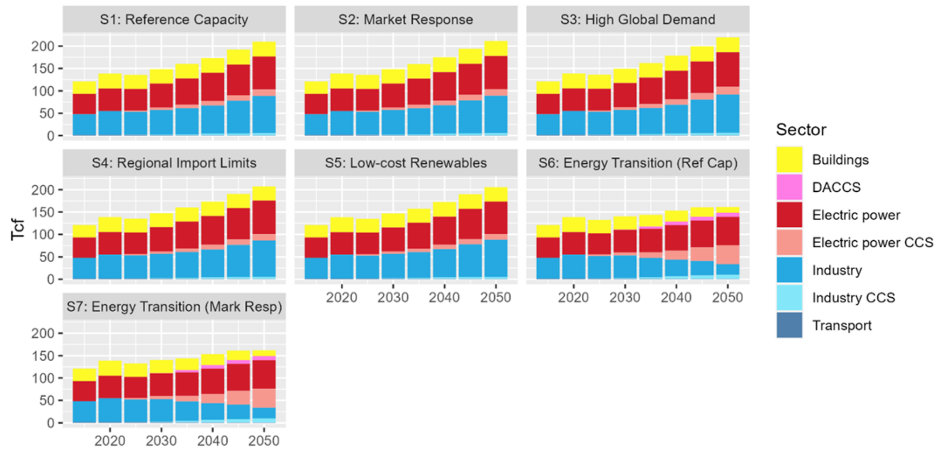


Figure A-1. Global natural gas consumption by sector across all scenarios

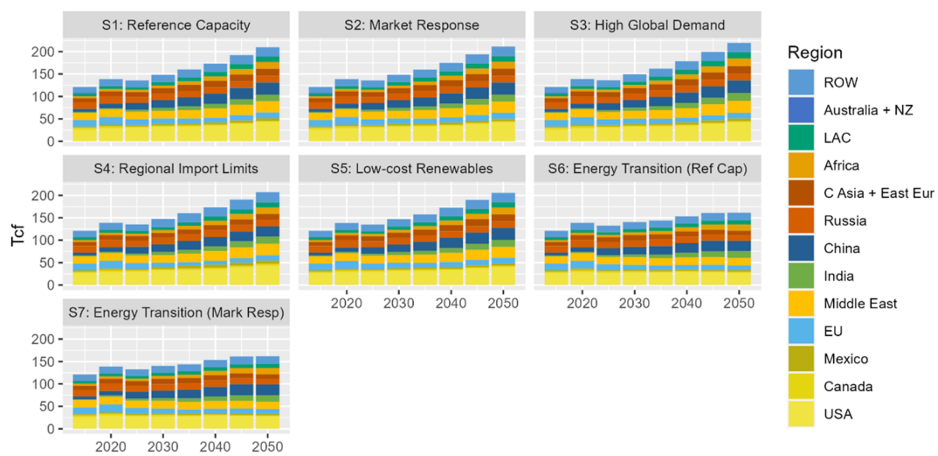


Figure A-2. Global natural gas consumption by region across all scenarios

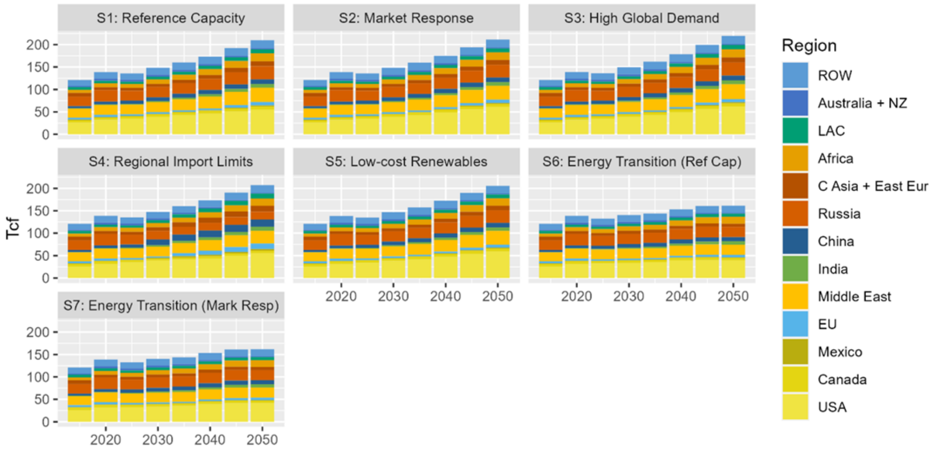


Figure A-3. Global natural gas production by region across all scenarios

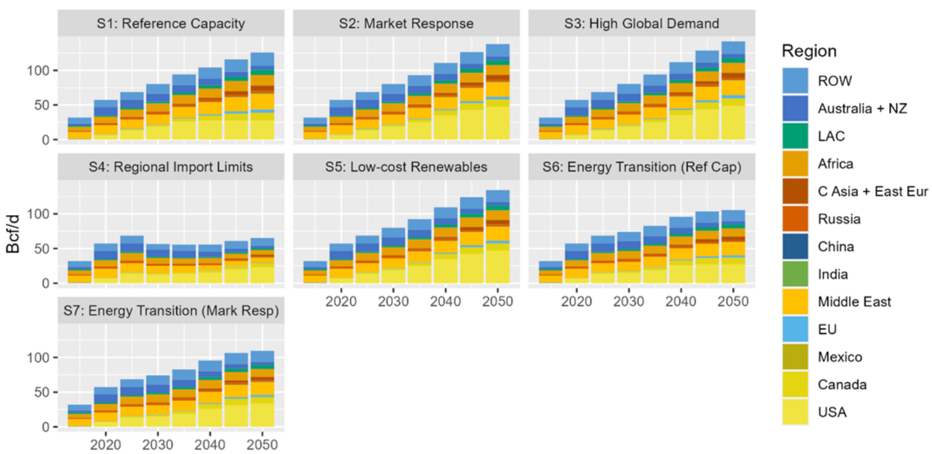


Figure A-4. Global LNG exports by region across all scenarios

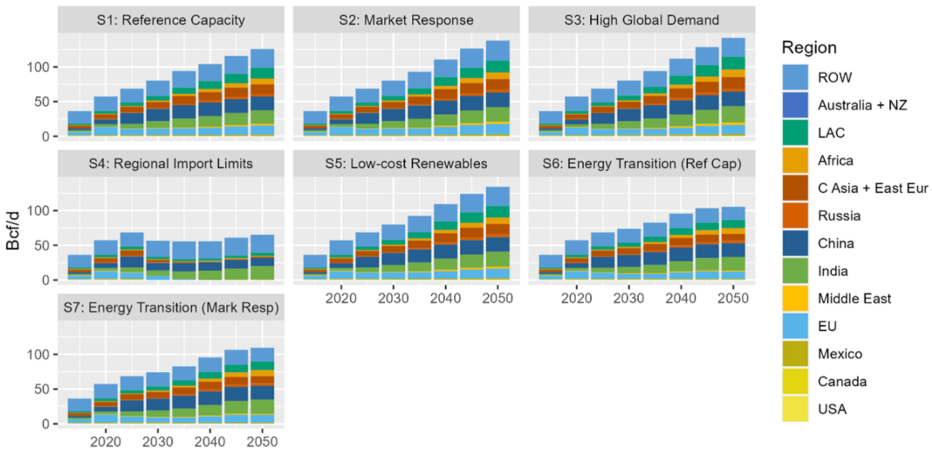


Figure A-5. Global LNG imports by region across all scenarios

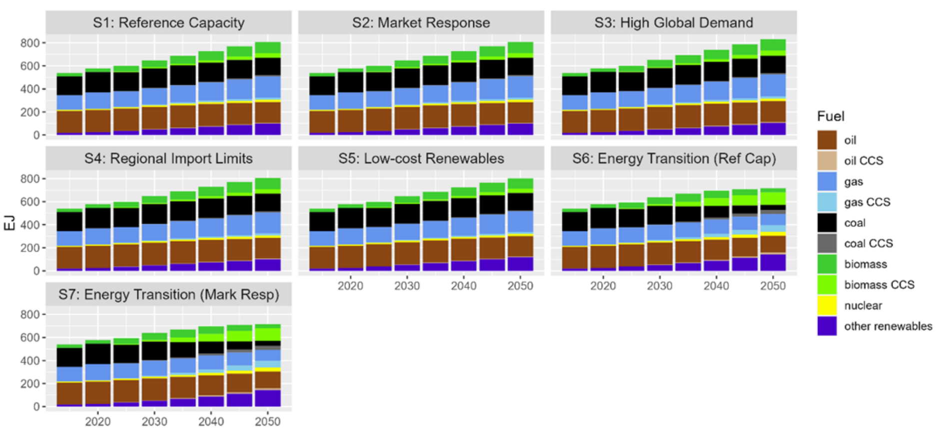


Figure A-6. Global primary energy consumption by fuel across all scenarios

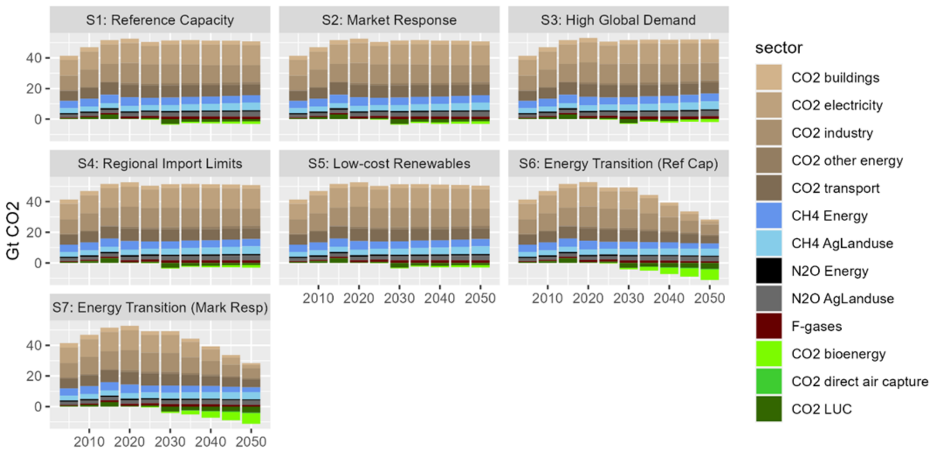


Figure A-7. Global GHG emissions by sector across all scenarios

APPENDIX B: U.S. ANALYSIS AND DESCRIPTION OF AEO2023-NEMS AND FECM-NEMS

A. Modeling U.S. LNG exports

AEO2023-NEMS and FECM-NEMS have two methods available to calculate LNG export capacity: endogenous and exogenous. There is a switch in the input files that can be toggled between the two methods before executing a run. *S1* uses the EIA AEO2023 reference case, which calculates LNG export capacity endogenously; *S2* through *S6* are initialized with exogenous export capacity, which use exogenous LNG export values from the GCAM model for each scenario. Both AEO2023-NEMS and FECM-NEMS follow a similar process with only minor differences in a small number of input values. In most cases (including all cases discussed in this report) LNG exports will equal LNG export capacity because the cost to construct capacity is so high that capacity will rarely be left unused once built. Therefore, the following description can be treated as an explanation for how AEO2023-NEMS and FECM-NEMS calculate LNG Export volumes.

The algorithm for calculating LNG export capacity endogenously has two steps. In the first step, AEO2023-NEMS considers LNG exports from existing or planned LNG export facilities. Beginning with Cheniere's Sabine Pass facility, which started exporting LNG in 2016, AEO2023-NEMS runs through a list of export facilities specified in an input file. This list is updated with each version of the AEO; AEO2023-NEMS includes existing and planned facilities expected to start or expand production by the end of 2025. For each facility, AEO2023-NEMS slowly increases production over the first few months to represent an export facility ramping up to full capacity.

The second step in the endogenous algorithm involves a prediction of future LNG exports. AEO2023-NEMS uses a set of exogenous values in an input file to specify how much demand Europe and Asia will have for LNG imports, as well as how much supply of non-U.S. LNG will exist on the market. Then, considering the volume of U.S. LNG exports at a given model year, AEO2023-NEMS calculates how the ratio of supply and demand changes over time. This ratio, together with the world oil price, is used to calculate the price at which international customers will purchase U.S. LNG. The purchase price algorithm is constructed in such a way that rises in the oil price, decreases or slowdowns in future LNG supply, or increases in future LNG demand will all increase the purchase price of LNG, and vice-versa. The influence that each factor has on LNG purchase price is controlled by several input parameters.

In addition to a purchase price, AEO2023-NEMS calculates the price at which U.S. LNG could be sold for. This "sale price" combines the natural gas Henry Hub price with various costs that represent the stages of preparing pipeline gas for LNG transport (including liquefaction, fuel consumption, shipping, and regasification). AEO2023-NEMS then compares the sale price to purchase prices at different destinations and determines a discounted net present value (NPV) of new LNG construction over the subsequent 20 years. Depending on the NPV, AEO2023-NEMS will decide to increase LNG export capacity by 0 to 600 Bcf/d. The increase in capacity takes effect after a four year "construction" period and brief "phase-in" period.

The algorithm in AEO2023-NEMS to calculate LNG export capacity exogenously is far simpler. A table in an input file lists LNG export capacity by year; these values are used by AEO2023-NEMS to set LNG exports for that year. In *S2* through *S6*, various parameters, including LNG export volumes, are calculated by the GCAM model. The LNG export volumes are converted to the correct input format and adopted by AEO2023-NEMS as the exogenous LNG export capacity.

B. Additional detail on U.S. natural gas markets

1. Regional natural gas production

Figure B-1 and Figure B-2 plot onshore natural gas production by region for the first five scenarios and the net-zero scenarios, respectively, in 2025 and 2050. Offshore natural gas production comprises a small portion of the total (<4 % in all scenarios and years) and is omitted from these figures.

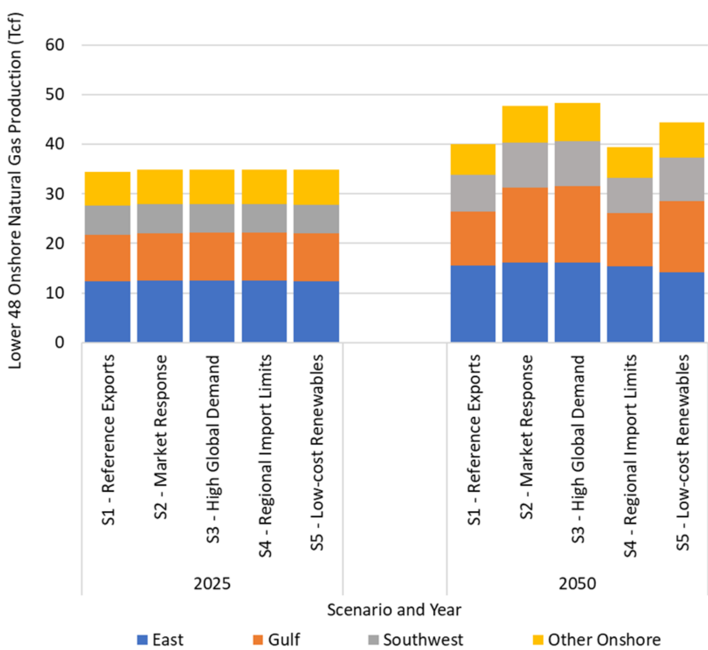


Figure B-1. U.S. Regional Natural gas production, S1 through S5

Natural gas production experienced an upward trend across all scenarios by 2050, equaling or exceeding 39 Tcf. *S3* exhibited the highest production level at 48 Tcf, influenced by the global demand for natural gas. Expansion is primarily characterized by a significant increase in production in the Gulf region, subsequently followed by the Southwest and the East. Conversely, scenario *S4* sees the lowest natural gas production at 39 Tcf with least production growth in the Gulf region.

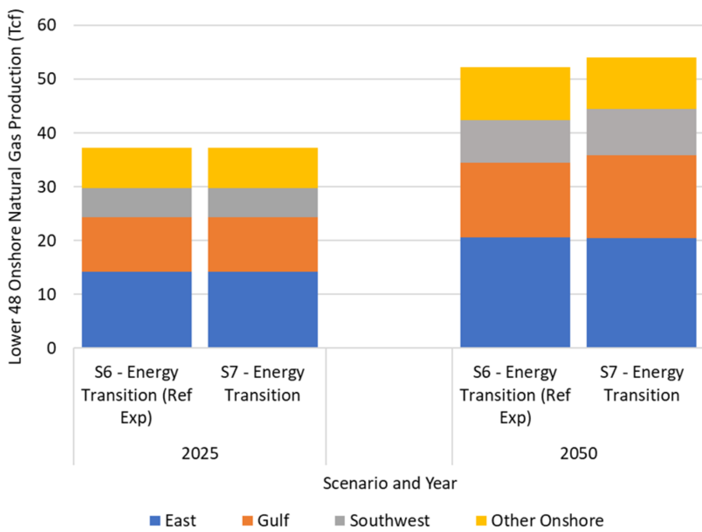


Figure B-2. U.S. regional natural gas production in S6 and S7

Onshore natural gas production grows significantly from 2025 to 2050 for both net-zero scenarios, rising from 37 Tcf in 2025 to 52 Tcf in *S6* and 54 Tcf in *S7*, respectively, by 2050. The large growth in natural gas production is primarily due to demand from DAC facilities, with only a small increase associated with elevated LNG exports in the *S7* scenario. Natural gas production rises in all regions, with the largest absolute increases coming from the East (6.4 Tcf in *S6* and 6.2 Tcf in *S7*) and Gulf (3.8 Tcf in *S6* and 5.3 Tcf in *S7*) regions and the largest increase by percentage coming from the Southwest (47% in *S6* and 58% in *S7*).

2. Natural gas consumption by economic sector

Figure B-3 plots natural gas consumption for electric power, industry, residential use, commercial use, and transportation over time for *S1* through *S5*.

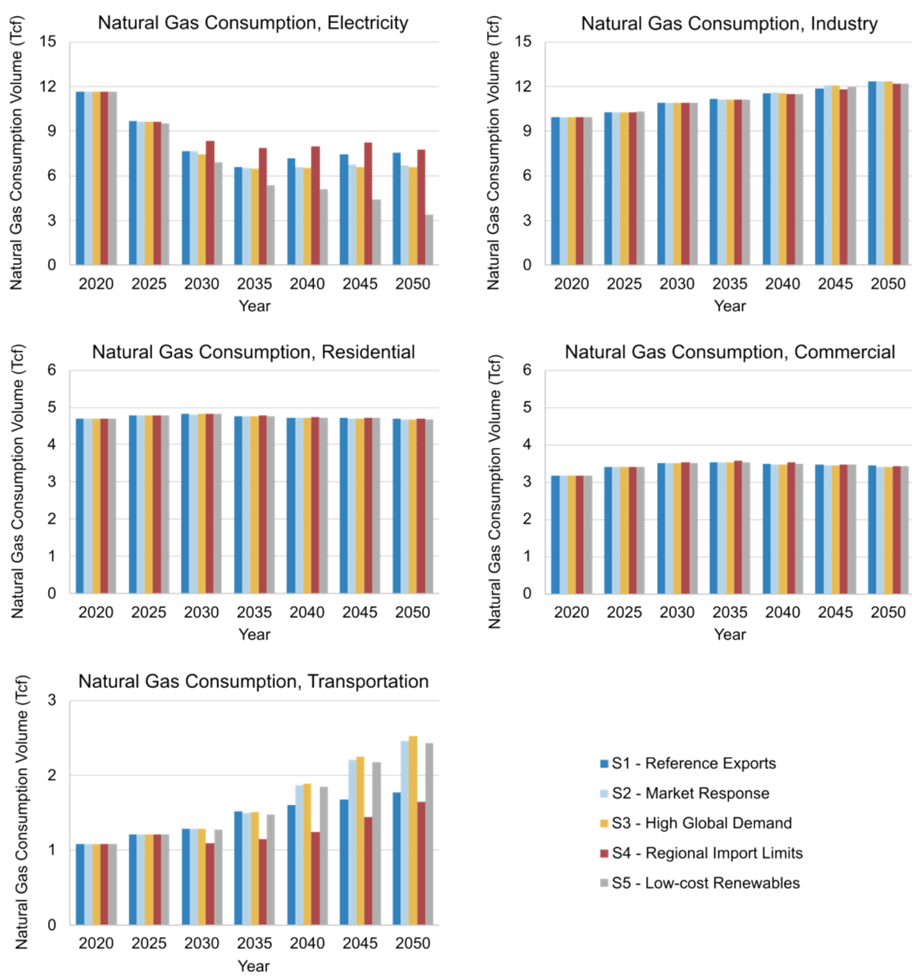


Figure B-3. U.S. natural gas consumption by sector, S1 through S5

Natural gas consumed for electricity was inversely correlated with LNG exports and natural gas prices for *S1*-*S4*. From a starting point of 11.6 Tcf in 2020, the first three scenarios drop to similar consumption volumes of 6.5-6.6 Tcf in 2035 before slightly increasing to 7.6 Tcf (*S1*) or plateauing at 6.7 and 6.6 Tcf (*S2* and *S3*, respectively) in 2050. The increased consumption of natural gas for electricity in *S1* can be explained as a response to price reductions caused by plateauing LNG exports, whereas high prices and exports in *S2* and *S3* lead to a flat consumption trend. *S4* – the scenario with the fewest exports and lowest prices through the first half of the model – exhibited the highest consumption for electricity in 2035 of 7.9 Tcf, which rises and falls slightly to a similar level to *S1* in 2050 (7.8 Tcf). *S5* is again an outlier here, reporting consistently lower natural gas consumption that hit a minimum of 3.4 Tcf in 2050. This trend is a consequence of its low renewable costs reducing the demand for natural gas in the electric sector.

Unlike for electricity, there was no significant difference between scenarios in the rate of natural gas consumption in the industrial, residential, or commercial sectors. Industrial natural gas consumption rises from 9.9 Tcf in 2020 to 12.2-12.4 Tcf in 2050 across the five scenarios; residential consumption remains relatively unchanged at 4.7 Tcf from 2020 to 2050 with some small variations; and commercial consumption rises and falls slightly from 3.2 Tcf in 2020 to 3.4 Tcf in 2050.

Natural gas consumed for transportation has a different response to changes in LNG exports, compared with the other consumptions sectors. The transportation category is dominated by pipeline fuel: natural gas consumed to power infrastructure underlying the natural gas supply chain, which includes LNG exports. Increases in natural gas consumption for transportation therefore correlate strongly with the quantity of LNG exports; *S3* exhibits the highest consumption in the transportation sector by 2050, followed by *S2* and *S5*, *S1*, and finally *S4*.

The sector-by-sector changes across the five scenarios end up cancelling each other out for *S1*-*S4*, leading to nearly identical total natural gas consumption values, as seen in Figure 16 in the main text. Only *S5*, thanks to its low renewable costs, exhibits a lower overall U.S. natural gas consumption trend.

Comparisons of *S1* through *S5* with *S6* and *S7* are complicated because of the many significant changes to the energy economy (going from AEO2023-NEMS to FECM22-NEMS) that occur to satisfy the net-zero criteria. Relative to *S1*, natural gas consumption values decline across most sectors in *S6* and *S7* but are substantially higher in the industry sector (where DAC consumption is categorized). Figure B-4 plots natural gas consumption for the net-zero cases on a sector-by-sector basis.

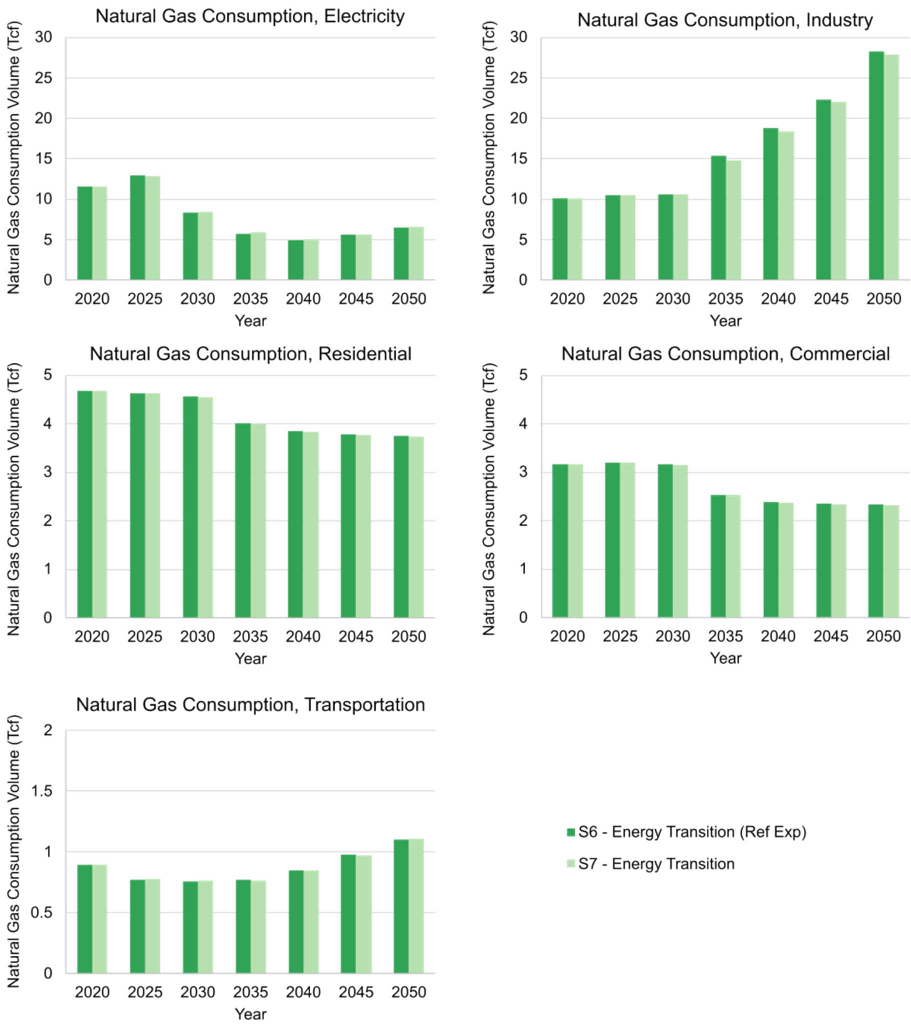


Figure B-4. U.S. natural gas consumption by sector, net-zero scenarios

Differences in historical natural gas consumption and subsequent short-term effects cause a difference in natural gas consumption for electricity in 2020 and 2025 between *S6* and *S7* (from the FECM-NEMS model) and *S1* through *S5* (from the AEO2023-NEMS model). Similar differences in the historical data exist for all sector-specific consumption values. Volumes of natural gas consumed for electricity track closely between the two net-zero cases across most of the modeling years, ranging from 5.7 to 5.9 Tcf in 2035 for *S6* and *S7*, respectively, and rising in later years to 6.5 Tcf and 6.6 Tcf. *S6* reports a lower

natural gas consumption value in 2050 than *S1* (7.6 Tcf), but the corresponding result for *S7* is fairly close to *S2* (6.7 Tcf).

Industry-sector natural gas consumption exhibits the largest change between S6 and S7 and *S1* through *S5*, thanks to the strong influence of DAC. Whereas industry consumption of natural gas in *S1* and *S2* both increase from 9.9 Tcf to 12.3 Tcf over the 50 model years, the net-zero scenarios diverge after 2030 and grow rapidly to 28.2 and 27.8 Tcf for *S6* and *S7*, respectively, by 2050. The difference in consumption values is consistent with the natural gas consumption for DAC, which is plotted below in Figure B-5.

Residential- and commercial-sector natural gas consumption follow similar behavior. These values decrease in both net-zero scenarios across the model years from 4.7 to 3.7 Tcf (residential) and from 3.2 to 2.3 Tcf (commercial). By comparison, both *S1* and *S2* have static or slightly increasing trends, with both reporting 4.7 Tcf in 2020 and 2050 for residential consumption and 3.2 to 3.4 Tcf from 2020 to 2050 for commercial consumption.

Transportation is the smallest of the five sectors in terms of natural gas consumption volumes, and calculation differences between AEO2023-NEMS and FECM-NEMS lead to large impacts on the consumption values. As a result, these values are not directly comparable between the three scenarios. *S6* and *S7* have nearly identical volumes of natural gas consumed for the transportation sector, varying from 0.9 Tcf in 2020 to 0.8 Tcf in 2035 and 1.1 Tcf in 2050. By comparison, *S1* and *S2* report consistently higher natural gas consumption for transportation across the model years, ranging from 1.1 Tcf in 2020 to 1.8 and 2.3 Tcf, respectively, in 2050.

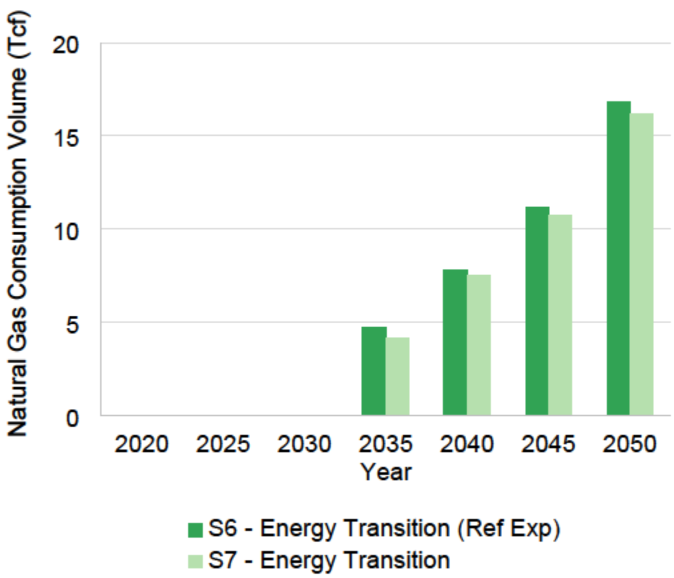


Figure B-5. Natural gas consumed for DAC, net-zero scenarios

DAC is the main technology used by FECM-NEMS to meet the CO_2 cap and by 2050 is responsible for removing 1930 MMT CO_2 per year in *S6* and 1850 MMT CO_2 per year in *S7*. A considerable amount of natural gas is consumed to support these levels of DAC: 16.8 Tcf and 16.2 Tcf in 2050 for *S6* and *S7*, respectively. More detail on CO_2 removal technologies in FECM-NEMS is given in the section below.

In conclusion, even though four out of the five sectors exhibit decreases when comparing natural gas consumption in the net-zero scenarios to *S1* and *S2*, the strong increases in the industrial sector (mainly from increases in DAC) cause overall U.S. natural gas consumption to be significantly higher by 2050 in *S6* and *S7*. There is minimal difference between the *S6* and *S7* results, suggesting that the differences in LNG exports between the net-zero scenarios play a limited role in altering natural gas consumptions trends.

C. CO_2 removal technologies in FECM-NEMS

CO_2 removals in FECM-NEMS are driven by three technologies: production of hydrogen with sequestered biomass, BECCS, and DAC. Figure B-6 plots CO_2 removals for each technology and scenario by year.

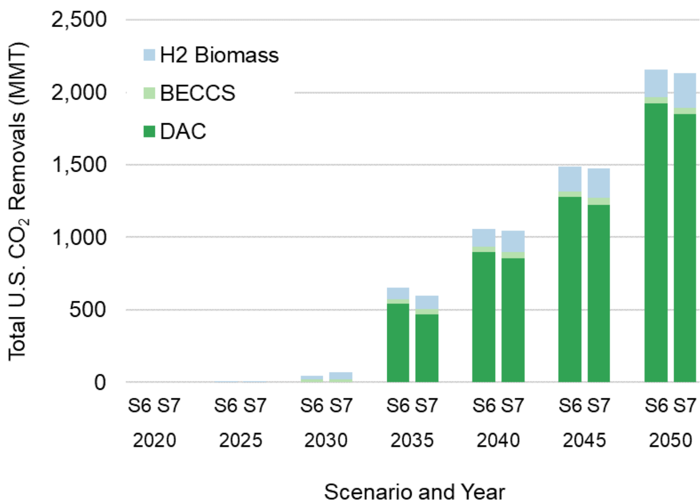


Figure B-6. U.S. CO_2 emissions and removals, net-zero scenarios

DAC is most widely used in both net-zero scenarios and scales up rapidly after 2030 to account for 1930 MMT CO_2 removed in *S6* and 1850 MMT CO_2 removed in *S7* (89% and 87% of total removals, respectively) by 2050. H2 biomass and BECCS see significantly less adoption by 2050 in both scenarios; the former reaches 200 (9% of total) and 240 (11% of total) MMT CO_2 removed in *S6* and *S7*, respectively, whereas the later reaches approximately 40 MMT CO_2 removed in both scenarios (2% of total removals).

FECM-NEMS relies on two sets of DAC technology assumptions: "grid", and "NG only," derived from the literature using updated cost and performance data from FECM.[24] Both use natural gas to power the capture process; DAC-grid offsets some of the natural gas demand by using electricity as well as lists the specific technical assumptions underlying the two DAC options.

Table B-1. DAC technology assumptions in FECM-NEMS

	Capex, $/ton-year	CRF	Capex, $/ton	Opex, $/ton	Electricity demand, kwhr/ton	Natural gas demand, MMBtu/ton
Grid	$1,300	7.1%	$112	$71	450	8.75
NG Only	$1,500	7.1%	$129	$83.6	0	9.27

The effect of DAC on natural gas markets in *S6* and *S7* can be seen in the rapid growth of total natural gas consumption and subsequent rise in natural gas prices (Figure 18) in the main text. By 2050, natural gas consumption equals 16.8 Tcf and 16.2 Tcf for *S6*, and *S7*, respectively, reaching natural gas prices of $5.90 2022/Mcf and $5.77 2022/Mcf.

FECM-NEMS models the deployment of carbon removal technologies by determining a CO_2 price that represents the market equilibrium cost to capture and abate CO_2 emissions. FECM-NEMS adjusts the CO_2 price in accordance with the imposed carbon cap to ensure that the correct number of CO_2 emissions are abated each year.

[24] National Academies of Sciences, Engineering, and Medicine. (2019). Negative Emissions Technologies and Reliable Sequestration: A Research Agenda. Washington, DC: The National Academies Press. https://doi.org/10.17226/25259.

Appendix C: Supporting LCA Analysis

A. NEMS and NETL LCA model comparison

The NEMS modeling done in this project focused on domestic changes that would be expected to occur in the seven scenarios modeled. NETL reviewed the NEMS data to evaluate if the regional production mix of natural gas would be expected to change over time. If the NEMS results suggested that production would be expected to shift significantly from the current mix of regions, and especially if to distinctly higher or lower intensity regions, then adjustments would be recommended to the assumed GHG intensity for U.S. natural gas in the results.

For *S1* - *S7*, NEMS modeled data of dry natural gas production of "Production by OGSM District" was mapped to a state and then to an NETL natural gas model region as shown in Table C- 1. Note that several "states" are offshore regions.

Table C- 1. Matching NEMS (OGMP States) to NETL states and subsequently regions

Production by OGSM District	State	Region
Alabama, North	Alabama	Southeast
Alabama, South	Alabama	Southeast
Arizona	Arizona	Southwest
Arkansas	Arkansas	Southeast
California	California	Pacific
Colorado	Colorado	Rocky Mountain
Connecticut	Connecticut	Northeast
Delaware	Delaware	Northeast
Washington, D.C.	Washington	Pacific
Florida	Florida	Southeast
Georgia	Georgia	Southeast
Idaho	Idaho	Rocky Mountain
Illinois	Illinois	Midwest
Indiana	Indiana	Midwest
Iowa	Iowa	Midwest
Kansas	Kansas	Midwest
Kentucky	Kentucky	Southeast
Louisiana, North	Louisiana	Southeast
Louisiana, South	Louisiana	Southeast
Maryland	Maryland	Northeast
Massachusetts	Massachusetts	Northeast
Michigan	Michigan	Midwest
Minnesota	Minnesota	Midwest
Mississippi, North	Mississippi	Southeast
Mississippi, South	Mississippi	Southeast
Missouri	Missouri	Midwest

Commented [ST36]: Washington, D.C. is not a match for the State of Washington.

Are these intended to align OMGP States to NETL States?

Production by OGSM District	State	Region
Montana	Montana	Rocky Mountain
Nebraska	Nebraska	Midwest
Nevada	Nevada	Rocky Mountain
New Hampshire	New York	Northeast
New Jersey	New Jersey	Northeast
New Mexico, East	New Mexico	Southwest
New Mexico, West	New Mexico	Southwest
New York	New York	Northeast
North Carolina	North Carolina	Southeast
North Dakota	North Dakota	Midwest
Ohio	Ohio	Midwest
Oklahoma	Oklahoma	Southwest
Oregon	Oregon	Pacific
Pennsylvania	Pennsylvania	Northeast
Rhode Island	Rhode Island	Northeast
South Carolina	South Carolina	Southeast
South Dakota	South Dakota	Midwest
Tennessee	Tennessee	Southeast
Texas RRC 1	Texas	Southwest
Texas RRC 2	Texas	Southwest
Texas RRC 3	Texas	Southwest
Texas RRC 4	Texas	Southwest
Texas RRC 5	Texas	Southwest
Texas RRC 6	Texas	Southwest
Texas RRC 7B	Texas	Southwest
Texas RRC 7C	Texas	Southwest
Texas RRC 8	Texas	Southwest
Texas RRC 8A	Texas	Southwest
Texas RRC 9	Texas	Southwest
Texas RRC 10	Texas	Southwest
Utah	Utah	Rocky Mountain
Virginia	Virginia	Northeast
Washington	Washington	Pacific
West Virginia	West Virginia	Northeast
Wisconsin	Wisconsin	Midwest
Wyoming	Wyoming	Rocky Mountain
North Atlantic State Offshore	North Carolina	Southeast
South Atlantic State Offshore	South Carolina	Southeast
Alabama State Offshore	Alabama	Southeast
Louisiana State Offshore	Louisiana	Southeast

Commented [ST37]: Should this be NH to NH?

Commented [ST38]: Would this be north of the mason dixon line?

Commented [ST39]: Should all "offshore" align to an NETL off-shore profile instead of and end-use/consumption region?

Production by OGSM District	State	Region
Texas State Offshore	Texas	Southwest
California State Offshore	California	Pacific
North Atlantic Federal Offshore	North Carolina	Southeast
Mid Atlantic Federal Offshore	Federal Offshore - GoM	Southeast
South Atlantic Federal Offshore	South Carolina	Southeast
Eastern GOM Federal Offshore	Federal Offshore - GoM	Southeast
Central GOM Federal Offshore	Federal Offshore - GoM	Southeast
Western GOM Federal Offshore	Federal Offshore - GoM	Southeast
California Federal Offshore	California	Pacific
Northern Pacific Federal Offshore	Federal Offshore - GoM	Southeast
Alaska Federal Offshore	Federal Offshore - GoM	Southeast

This classification enables the aggregation of dry production data (excluding extraction losses) by region for each respective year, as summarized with every 10 years of data in Table C-2.

Table C-2 Regional dry production (trillion cubic feet) between 2020 and 2050, S1

Region	2020	2030	2040	2050
Midwest	3.26778	2.82406	2.40796	2.094116
Northeast	9.540964	11.14082	13.03394	14.08478
Pacific	0.163061	0.285247	0.296763	0.280681
Rocky Mountain	3.328845	2.899944	2.796355	2.687115
Southeast	4.587738	6.084166	6.64734	5.720366
Southwest	12.2792	13.3737	15.27886	16.65195

From this aggregated data, the production ratio is calculated by dividing the region-specific production by the total U.S. production for each year and summarized in Table C-3.

Table C-3 Regional dry production ratio, S1

Region	2020	2030	2040	2041	2050
Midwest	9.85	7.71	5.95	5.79	5.04
Northeast	28.77	30.43	32.21	32.75	33.92
Pacific	0.49	0.78	0.73	0.71	0.68
Rocky Mountain	10.04	7.92	6.91	6.94	6.47
Southeast	13.83	16.62	16.43	15.94	13.78
Southwest	37.02	36.53	37.76	37.87	40.11

Figure C-1 shows the percent of natural gas dry production for each region of *S1* as compared to total production in each year between 2020 and 2050. The same process was done for the other scenarios.

Commented [ST40]: Why every 10 years of data when the raw data is provided on an annual basis from NEMS?

Commented [ST41]: How much variability in dry production volume is considered significant? Northeast is a 55% increase. 60% decrease in Midwest.

Commented [ST42]: No discussion of Table C-3.

Ratio compared to what?

I think these are annual percentages. Column sums to 100%.

Caption needs better clarity.

Commented [ST43]: Why 2041 results?

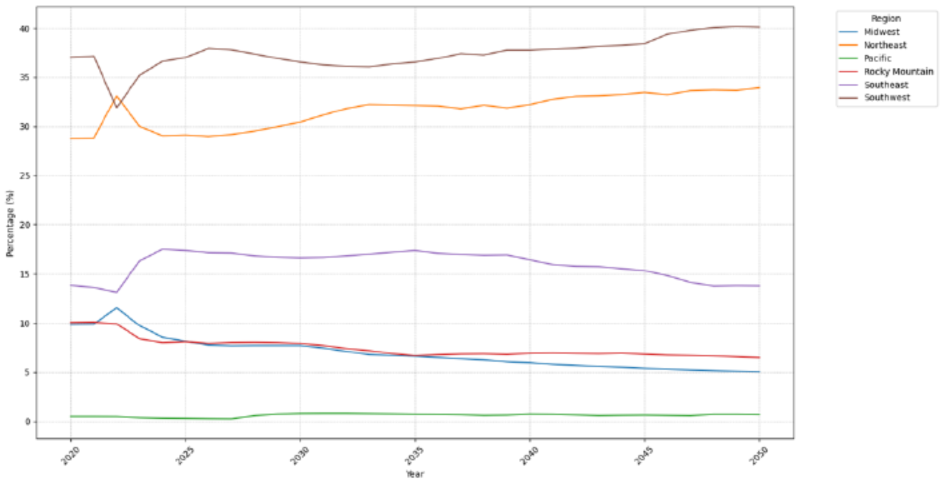


Figure C-1. Dry NG production percentage time-series for each region

This percentage can be multiplied with the 2020 GHG intensity values for each region from the NETL Natural Gas report[16] (shown in Table C-4) to estimate future GHG intensity results, as described in this mathematical representation:

$$GHG_{Midwest,2021} = GHG_{Midwest,2020} \times \ dry\ production\ ratio_{Midwest,\ 2021}$$

and finding the weighted US average GHG intensity across regions.

Table C-4. Regional GHG Intensities (g CO_2e/MJ) from 2020 NETL Natural Gas Report

Region	GHG (g CO_2e/MJ)
Midwest	8.44
Northeast	6.23
Pacific	11.3
Rocky Mountain	10.01
Southeast	9.02
Southwest	8.80

Overall, Figure C-2 suggests that the NEMS-modeled changes in domestic production by region across the scenarios are not expected to have a significant effect on the GHG intensity of domestic production (given the 2020 data on GHG intensity by region) if only the trend in "dry production" (based on delivery shares) is considered.

Commented [ST44]: Hanging text??? Old text???

Commented [ST45]: GHG Emissions Intensity

Commented [ST46]: There should be a space between the measurement unit and the descriptor of what was measured/reported.

E.g., g CO2e (with the 2 subscripted)

Commented [ST47]: How were the regional profiles converted to a single Weighted Average GHG Emissions Intensity value?

Commented [ST48]: GHG Emissions Intensity

Commented [ST49]: NEMS includes endogenous learning. How much did the GHG emissions intensity of natural gas by region change in the model?

Should be different for S1 set versus S6/S7 set of model runs.

Commented [ST50]: This is a large caveat! The analysis should consider both dry production and GHG emissions intensity differences by year.

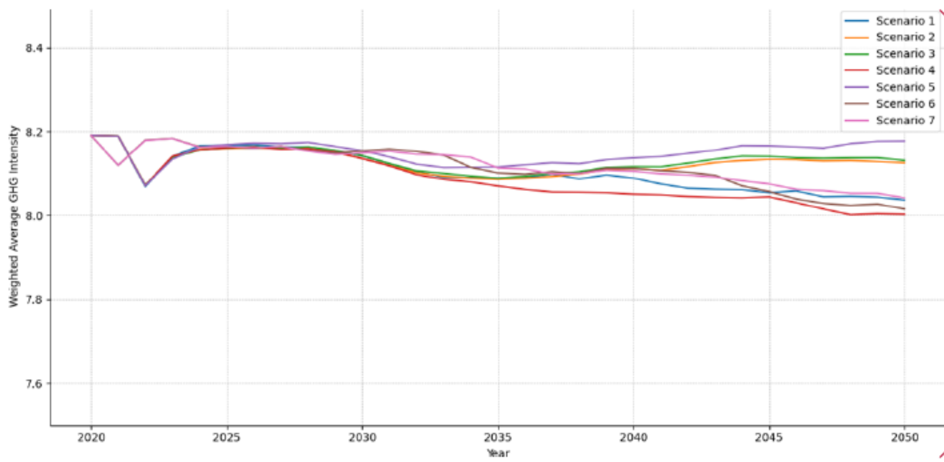


Figure C-2. Estimated U.S. Average GHG Intensity (g CO_2e/MJ) (S1 through S7), Production through Transmission (2020 - 2050)

B. Global Change Assessment Model – data inputs to LCA

The GCAM model is an input-output-based model primarily represented by sectors and technologies and their respective inputs and outputs for particular years and scenarios. Across all years and scenarios, GCAM has 105 discrete sectors, 377 discrete technologies, and many sector-technology pairs that can vary depending on the model configuration. However, only a subset of these factors is relevant to this analysis (i.e., with a focus on the natural gas sector).

Results provided by PNNL for the various Scenarios (1-7) and years modeled were provided as described in Table C-5, and were processed accordingly.

Table C-5. Provided set of GCAM Data Documentation

File	Data Represented
co2_em_tech_2023.06.22	Provides data showing CO_2 emissions in megatons per year (Mt CO_2/yr) for various sectors, energy sources or "technology" for 6 different scenarios across each of 37 regions.
non_co2_em_tech_2023.06.22	Provides data showing non-CO_2 emissions in Gigagrams (Gg) equivalent to metric kilotons or 1,000 metric tons, for various sectors, energy sources or "technology" and 6 different scenarios across each of 37 regions.
inputs.by.tech_2023.06.22	Provides detailed information about energy consumption and capacity in different regions and sectors along with specific technologies and years. It can be used to analyze and understand the energy landscape, make projections, and assess the impact of various factors on energy consumption and capacity (sub-sector is not applicable in this dataset).
outputs.by.tech_2023.06.22	Reports the energy production within the various regions, by sectors, (sub-sector is not applicable in this dataset) along with specific technologies and years.

Commented [ST51]: Y axis, add "Emissions" and units and GWP version to label; U.S. Weighted Average GHG Emissions Intensity, g CO2e/MJ (IPCC AR6 100-yr GWP)

Commented [ST52]: Why does S4 have a steeper and lower GHG emissions intensity per unit of gas produced in 2050 than S6 or S7?

Commented [ST53]: Quantitative data discussion is needed to justify why the change is "not significant" and that domestic market effects can be ignored.

The data and conclusion show that a change occurs. Southwest (permian) gas increase. Permian is high GHG intense gas. Why is this not a market effect that needs to be considered?

GCAM shows a reduction in GHGs from exports.

NEMS shows an increase in GHGs from exports.

The scale/magnitude of the GCAM results are -5 and -3 g CO2e/MJ.

What is the equivalent sum over 35 years for the change between S2 and S1, and S7 and S6? The 2050 value change appears very small.

I think the conclusion that domestic changes are less significant compared to non-US global changes is valid.

However, I am concerned about saying there is "no" domestic market effect which is the outcome when we choose to not include domestic market effects in the analysis.

We need to better defend and message this outcome, particularly when the NEMS data shows increases in GHG intense regions to meet future LNG export demand.

NETL - please provide more rationale and alternative concluding remarks/findings with respect to domestic market effects.

Commented [ST54]: Odd phrasing. The other "Data Represented" descriptions do not explain "how" to use the data set.

Columns	Description
scenario	Scenario or context for which the data is provided such as "S1: Existing Capacity," which suggests that the data corresponds to the existing capacity or infrastructure in the region.
Region	This column specifies the geo-political region under consideration.
Sector	This column categorizes the different sectors or areas of activity for which carbon dioxide emissions are being measured, e.g., "agricultural energy use", "cement", "air_CO_2", etc.
sub-sector	Within each sector, there may be further divisions or subcategories to specify the specific aspect of the sector being measured, e.g., "mobile", "stationary," etc. indicating different types of energy use within a single sector.
technology	This column identifies the specific technology or energy source being utilized within the subsector. For example, "refined liquids" and "biomass".
year	The specific year or time period for which the CO_2 emissions values are provided, this ranges from 2015 to 2050.
value	Corresponding carbon dioxide emissions values for the given combination of scenario, region, sector, subsector, technology, and year. The values represent the estimated or projected amount of CO_2 emissions in megatons per year in this specific file as depicted in the "Units" column (not mentioned separately in this table).
ghg	Refers to the greenhouse gas that is being emitted. It identifies the specific type of gas responsible for the emissions, e.g., CH4, N2O, HFC125, C2F6, etc.
input, output	Additional details or characteristics about the technology or process. It helps to differentiate between different aspects or variations within a specific technology. Examples in the datasets include "elect_td_ind" (electricity transmission and distribution for industrial use) and "H2 wholesale dispensing" (hydrogen wholesale dispensing).

C. GCAM and NETL emissions intensity comparison

As noted in the main report, only three sectors of the GCAM model have information relevant to the upstream natural gas supply chain. The GCAM *gas pipeline* and *natural gas* sectors are assumed to wholly incorporate natural gas-relevant emissions, and so total emissions are extracted from GCAM model output result files.

However, the *other industrial energy use* sector contains a diverse set of activities that are connected to overall gross domestic product (GDP) of each region, making it relatively difficult to explicitly identify emissions related to natural gas. GCAM incorporates a variety of data sources to represent activity in this sector. Relevant to natural gas activities for this sector, 2015 IEA data on energy use by oil and gas production activities used by the GCAM modeling team were provided and utilized to apportion GHG emissions associated with natural gas activity, as in Table C-6. The provided data (not shown) details what percent of energy use in the sector was from the IEA energy flows (e.g., 25% of total sectoral energy use in a region from Extraction and Gathering and Boosting). As 99.5% of GHG emissions in the *other industrial energy use* sector are CO_2, only the IEA data source was used and only CO_2 data for that sector was adjusted.

Commented [ST55]: Capitalization of column heading names seems to vary in this table. Intentional?

Commented [ST56]: The label for S1 and S2 were changed after the submission of this report. Capacity was changed " Exports".

S1: Reference Exports

S6 Energy Transition (Ref Exp)

Ref Exp = Reference Exports

Commented [ST57]: Subscript

Commented [ST58]: Is this the column heading or column response?

Table C-6. LCA Stage Cross-Mapping

NETL LCA stage	IEA energy flow	GCAM sector – energy & CO_2	CEDS sector	GCAM sector – non CO_2
Extraction	Oil and Gas Extraction	other industrial energy use	1B2b_Fugitive-NG-prod	natural gas
Gathering and Boosting	Oil and Gas Extraction	other industrial energy use	1B2b_Fugitive-NG-prod	natural gas
Processing	Gas works	other industrial energy use	1A1bc_Other-transformation	other industrial energy use
Domestic Pipeline Transport [1]	Pipeline Transport	gas pipeline	1B2b_Fugitive-NG-distr	natural gas
Liquefaction	Liquefaction (LNG) / Regasification Plants	other industrial energy use	1A1bc_Other-transformation	other industrial energy use
Ocean Transport	International Marine Bunkers [2]	trn_shipping_intl [2]	1A3di_International-shipping	trn_shipping_intl
Regasification	Liquefaction (LNG) / Regasification Plants	other industrial energy use	1A1bc_Other-transformation	other industrial energy use
Pipeline Transport (at destination) [1]	Pipeline Transport	gas pipeline	1B2b_Fugitive-NG-distr	natural gas

This IEA data is aggregated into oil and gas activities such as “Extraction, Gathering and Boosting”, “Processing”, and “Liquefaction and Regasification”. However, a challenge is that the IEA data represent extraction of both oil and gas resources, which were variously allocated for the natural gas products. Given the lack of data on liquefaction and regasification in the 2015 IEA data (including for the U.S.), emissions from those activities are excluded from the analysis, consistent with the focus on upstream natural gas effects.

The emissions intensity cells in Table C-7 show the underlying equation used to generate values on an AR6-100 basis, where the numerator is the total emissions from the GCAM model for the USA region for Scenario *S1* for the year 2020 for each of the three greenhouse gases (if available), normalized by the total production of U.S. natural gas and oil from the GCAM model in 2020 (32.46 EJ and 22.46 EJ, respectively). Units of emissions intensity follow those internal to the GCAM model, which are Tg CO_2 equivalent per Exajoule, which conveniently are equal to g CO_2e/MJ, the same units as used in the NETL model. Thus, the bottom rows in Table C-7show comparisons to those of the NETL model.

As implemented, this adjustment factor of 0.96 is directly applied to GHG emissions in all regions for the *natural gas* and *gas pipeline* sectors as they wholly related to natural gas activities. The existing methane mitigation trend in the GCAM emissions data for the *natural gas* sector was preserved by using this adjustment method.

For the *other industrial energy use* sector, the adjustment is complicated by the fact that the sector includes many activities beyond natural gas. If the adjustment factor were wholly applied to the GHG

Commented [ST59]: ??? Not described in the text.

Commented [ST60]: What does this mean? Unclear.

Commented [ST61]: How was it preserved?

Does the MAF change every year (model time step) due to endogenous learning in the model?

emissions of the sector, then the total emissions in GCAM would be reduced for both natural gas and non-natural gas activities. A compromise was made to estimate the total needed reductions in emissions associated with only natural gas activity for each region, and to reduce the emissions of the other industrial energy use sector by that amount. While this does not achieve a full alignment of these associated emissions (i.e., it does not lead to a 4% reduction in emissions intensity for the other industrial energy use sector), it avoids the outcome where that sector's emissions are reduced for all of the other activities.

These adjustments to emissions from all regions, all scenarios, and all years were applied to existing GCAM model results (i.e., the GCAM model was not re-run or scenarios optimized based on these adjustments).

Table C-7. GCAM Emissions Intensities for Sectors (S1, 2020, USA region, AR6-100 basis)

			Estimated GCAM Emissions Intensity (LHV) (Tg CO_2e / EJ, g CO_2e / MJ) [IPCC AR6 100 yr]		
GCAM Sector	**NETL LCA Stage**	**Comments/Potential mapping inaccuracy**	**CO_2**	**CH_4**	**N_2O**
gas pipeline	Transmission and Storage	Have assumed this fully represents the Transmission sector equivalent to the NETL NG model.	38.0/32.5 = 1.17	-	-
natural gas	Production + Gathering & Boosting + Processing	From discussions with GCAM team, this sector represents all other natural gas related activities, thus the mapping to all other NETL stages other than transmission.	-	139.0/32.5 = 4.28	.015/32.5 = 4.5 E-4
other industrial energy use (technology = gas or gas cogen)[a]	**For 2015**, Extraction, Gathering & Boosting	Estimates from IEA energy shares. For technology = gas or gas cogen, all GHG emissions allocated to the natural gas product. For technology = refined liquids or refined liquids cogen, GHG emissions are allocated to the	92.9/32.5 = 2.86	-	-
other industrial energy use (technology = refined liquids and refined liquids cogen)[a]			11/(32.5+22.5) = 0.2	-	-

other industrial energy use (electricity)[a]		natural gas and crude oil products on an energy (EJ) produced basis from GCAM output data.	-	-	-
Total GCAM by gas (LHV)			= 1.17 + 2.86 + .2 = 4.23	4.28	4.5 E-4
Total GCAM (LHV)			8.52		
Subtotal from NETL Model, Processing through Transmission boundary – LHV basis			8.18		
Adjustment factor (LHV)			8.18/8.52 = 0.96		

Using the same detailed approach, Tables C-8 through C-10 more succinctly summarize the provided GCAM values and adjustments identified for the IPCC AR values.

Table C-8. GCAM Emissions Intensities for Sectors (S1, 2020, USA region, AR6-20 basis)

	Estimated GCAM Emissions Intensity (Tg CO_2e / EJ, g CO_2e / MJ) [IPCC AR6 20 yr]		
GCAM Sector	**CO_2**	**CH_4**	**N_2O**
gas pipeline	1.17	-	-
natural gas	-	11.86	4.5 E-4
other industrial energy use (technology = gas or gas cogen)	2.86	-	-
other industrial energy use (technology = refined liquids and refined liquids cogen)	0.2	-	-
Total GCAM by gas (LHV)	= 1.17 + 2.86 + .2 = 4.23	11.86	4.5 E-4
Total GCAM (LHV)	16.1		
NETL (LHV basis)	13.8		
Adjustment Factor (LHV)	0.86		

Table C-9. GCAM Emissions Intensities for Sectors (S1, 2020, USA region, AR5-100 basis)

	Estimated GCAM Emissions Intensity ($Tg\ CO_2e$ / EJ, $g\ CO_2e$ / MJ) [IPCC AR5 100 yr]		
GCAM Sector	CO_2	CH_4	N_2O
gas pipeline	1.17	-	-
natural gas	-	5.18	4.9 E-4
other industrial energy use (technology = gas or gas cogen)	2.86	-	-
other industrial energy use (technology = refined liquids and refined liquids cogen)	0.2	-	-
Total GCAM by gas (LHV)	= 1.17 + 2.86 + .2 = 4.23	5.18	4.9 E-4
Total GCAM (LHV)	9.41		
NETL (LHV basis)	8.84		
Adjustment Factor (LHV)	0.94		

Table C-10. GCAM Emissions Intensities for Sectors (S1, 2020, USA region, AR5-20 basis)

	Estimated GCAM Emissions Intensity ($Tg\ CO_2e$ / EJ, $g\ CO_2e$ / MJ) [IPCC AR5 20 yr]		
GCAM Sector	CO_2	CH_4	N_2O
gas pipeline	1.17	-	-
natural gas	-	12.36	4.4 E-4
other industrial energy use (technology = gas or gas cogen)	2.86	-	-
other industrial energy use (technology = refined liquids and refined liquids cogen)	0.2	-	-
Total GCAM by gas (LHV)	= 1.17 + 2.86 + .2 = 4.23	12.36	4.4 E-4
Total GCAM (LHV)	16.6		
NETL (LHV basis)	14.2		
Adjustment Factor (LHV)	0.86		

Table C-11 shows the GWP of key greenhouse gases which were used in conjunction with the emissions factors to derive the overall life-cycle greenhouse gas intensity.

Table C-11. GWP Values used in this analysis

Greenhouse Gas	AR5-100 (with ccf)	AR5-20 (with ccf)	AR6-100	AR6-20
CH4 (fossil)	36	86	29.8	82.5
CH4 (non-fossil)	34	84	27.2	80.8
N2O (fossil)	298	268	273	273
N2O (non-fossil)	298	268	273	273
HFC125	3691	6207	3740	6740
HFC134a	1549	3789	1530	4140
HFC143a	5508	7064	5810	7840
HFC23	13856	11005	14600	12400
HFC32	817	2502	771	2690
SF6	26087	17783	24300	18200
HFC245fa	1032	2992	962	3170
HFC365mfc	966	2724	914	2920
C2F6	12340	8344	12400	8940
CF4	7349	4954	7380	5300
HFC43	1952	4403	1600	3960
HFC152a	167	524	164	591
HFC227ea	3860	3860	3600	5850
HFC236fa	8998	9810	8690	7450

Note that unlike the natural gas system-specific emission comparisons and adjustments discussed above which focus on CO_2, CH_4, and N_2O, GCAM estimates emissions of sixteen GHGs and all are included in this study.

1. Market Adjustment Factors for other IPCC GWP Values

Table C-12 shows all MAF results for Scenario 2.

Table C-12. NETL-adjusted MAF results for S2

Results (g CO_2e/ MJ, LHV basis)					
MAF Case	AR5, 100 with ccf	AR5, 20 with ccf	AR6-100	AR6-20	Scenario Difference
***S2* vs. *S1* - unadjusted**	-5.85	-9.17	-5.34	-8.86	Adds economic solution for LNG exports.
***S2* vs. *S1* - adjusted**	-5.86	-9.12	-5.35	-8.74	

Table C-13 shows all MAF results for *Scenario 7*.

Table C-13 NETL-adjusted MAF results for S7

Results (g CO_2e/ MJ, LHV basis)					
MAF Case	AR5, 100 with ccf	AR5, 20	AR6-100	AR6-20	Scenario Difference
***S7* vs. *S6* - unadjusted**	-3.54	-7.54	-3.01	-7.25	S6 1.5°C pathway, economic solution for LNG exports
***S7* vs. *S6* - adjusted**	-3.44	-7.26	-2.95	-6.61	

Table C-14 shows the underlying annual CO_2e emissions and US LNG export volumes used in the MAF calculations above for the AR6-100 case (with adjustments).

Table C-14. Annual Export Volumes of US LNG and Adjusted Global CO_2 Emissions (IPCC AR6, 100-yr GWP-~~100 basis~~)

Scenario	Year	US Export LNG (EJ)	Global CO_2e Emissions (Tg)
S1	2015	0.018	49656.4
S1	2016	0.538	50410.5
S1	2017	1.058	51164.6
S1	2018	1.578	51918.8
S1	2019	2.097	52672.9
S1	2020	2.617	53427.0
S1	2021	3.086	52816.1
S1	2022	3.555	52205.2
S1	2023	4.023	51594.3
S1	2024	4.492	50983.3
S1	2025	4.961	50372.4
S1	2026	5.372	50692.9
S1	2027	5.782	51013.5
S1	2028	6.193	51334.0
S1	2029	6.603	51654.5
S1	2030	7.014	51975.0
S1	2031	7.544	51974.5
S1	2032	8.074	51973.9
S1	2033	8.605	51973.4
S1	2034	9.135	51972.9
S1	2035	9.665	51972.3
S1	2036	9.766	51862.9
S1	2037	9.867	51753.5
S1	2038	9.968	51644.2
S1	2039	10.069	51534.8
S1	2040	10.170	51425.4

Commented [ST62]: What does "with adjustments mean?

Commented [ST63]: Break this table by Scenario.

Add to S2, S3, S4, and S5 a column showing the change in GHG Emissions by year compared to the S1 (the reference scenario).

Same comment for S7 with S6 comparison by year.

Commented [ST64]: HHV or LHV results?

Scenario	Year	US Export LNG (EJ)	Global CO_2e Emissions (Tg)
S1	2041	10.170	51339.6
S1	2042	10.170	51253.8
S1	2043	10.170	51168.0
S1	2044	10.170	51082.2
S1	2045	10.170	50996.5
S1	2046	10.170	50853.8
S1	2047	10.170	50711.2
S1	2048	10.170	50568.6
S1	2049	10.170	50426.0
S1	2050	10.170	50283.4
S2	2015	0.018	49656.4
S2	2016	0.538	50410.5
S2	2017	1.058	51164.6
S2	2018	1.578	51918.8
S2	2019	2.097	52672.9
S2	2020	2.617	53427.0
S2	2021	3.086	52816.1
S2	2022	3.555	52205.2
S2	2023	4.023	51594.3
S2	2024	4.492	50983.3
S2	2025	4.961	50372.4
S2	2026	5.372	50692.9
S2	2027	5.782	51013.5
S2	2028	6.193	51334.0
S2	2029	6.603	51654.5
S2	2030	7.014	51975.0
S2	2031	7.462	51975.0
S2	2032	7.910	51975.0
S2	2033	8.358	51975.0
S2	2034	8.806	51975.0
S2	2035	9.254	51975.0
S2	2036	9.996	51862.2
S2	2037	10.738	51749.4
S2	2038	11.481	51636.5
S2	2039	12.223	51523.7
S2	2040	12.965	51410.9
S2	2041	13.561	51323.2
S2	2042	14.157	51235.6
S2	2043	14.753	51147.9
S2	2044	15.350	51060.3

Scenario	Year	US Export LNG (EJ)	Global CO_2e Emissions (Tg)
S2	2045	15.946	50972.7
S2	2046	16.271	50824.2
S2	2047	16.597	50675.8
S2	2048	16.922	50527.3
S2	2049	17.248	50378.9
S2	2050	17.573	50230.4
S3	2015	0.018	49656.4
S3	2016	0.538	50440.8
S3	2017	1.058	51225.3
S3	2018	1.578	52009.7
S3	2019	2.097	52794.2
S3	2020	2.617	53578.6
S3	2021	3.086	52949.2
S3	2022	3.555	52319.7
S3	2023	4.023	51690.2
S3	2024	4.492	51060.8
S3	2025	4.961	50431.3
S3	2026	5.371	50776.7
S3	2027	5.781	51122.1
S3	2028	6.191	51467.5
S3	2029	6.601	51812.9
S3	2030	7.011	52158.3
S3	2031	7.486	52193.5
S3	2032	7.961	52228.6
S3	2033	8.435	52263.8
S3	2034	8.910	52298.9
S3	2035	9.385	52334.1
S3	2036	10.148	52260.8
S3	2037	10.910	52187.4
S3	2038	11.673	52114.0
S3	2039	12.435	52040.7
S3	2040	13.198	51967.3
S3	2041	13.826	51922.6
S3	2042	14.453	51877.9
S3	2043	15.081	51833.2
S3	2044	15.709	51788.5
S3	2045	16.337	51743.8
S3	2046	16.697	51646.1
S3	2047	17.057	51548.4
S3	2048	17.417	51450.7

Scenario	Year	US Export LNG (EJ)	Global CO_2e Emissions (Tg)
S3	2049	17.777	51353.0
S3	2050	18.136	51255.3
S4	2015	0.018	49656.4
S4	2016	0.538	50410.5
S4	2017	1.058	51164.6
S4	2018	1.578	51918.8
S4	2019	2.097	52672.9
S4	2020	2.617	53427.0
S4	2021	3.086	52816.7
S4	2022	3.555	52206.5
S4	2023	4.023	51596.2
S4	2024	4.492	50985.9
S4	2025	4.961	50375.7
S4	2026	4.873	50698.7
S4	2027	4.784	51021.8
S4	2028	4.696	51344.8
S4	2029	4.607	51667.8
S4	2030	4.519	51990.9
S4	2031	4.602	51989.4
S4	2032	4.685	51987.8
S4	2033	4.768	51986.3
S4	2034	4.851	51984.8
S4	2035	4.934	51983.2
S4	2036	5.080	51874.4
S4	2037	5.226	51765.6
S4	2038	5.371	51656.7
S4	2039	5.517	51547.9
S4	2040	5.662	51439.1
S4	2041	6.004	51348.5
S4	2042	6.345	51257.9
S4	2043	6.687	51167.4
S4	2044	7.028	51076.8
S4	2045	7.370	50986.3
S4	2046	7.612	50840.2
S4	2047	7.854	50694.2
S4	2048	8.096	50548.1
S4	2049	8.338	50402.1
S4	2050	8.580	50256.1
S5	2015	0.018	49656.4
S5	2016	0.538	50409.0

Scenario	Year	US Export LNG (EJ)	Global CO_2e Emissions (Tg)
S5	2017	1.058	51161.6
S5	2018	1.578	51914.1
S5	2019	2.097	52666.7
S5	2020	2.617	53419.3
S5	2021	3.086	52803.6
S5	2022	3.555	52187.8
S5	2023	4.023	51572.1
S5	2024	4.492	50956.3
S5	2025	4.961	50340.6
S5	2026	5.372	50661.1
S5	2027	5.782	50981.7
S5	2028	6.193	51302.2
S5	2029	6.604	51622.8
S5	2030	7.015	51943.3
S5	2031	7.467	51939.6
S5	2032	7.920	51935.9
S5	2033	8.373	51932.2
S5	2034	8.826	51928.5
S5	2035	9.279	51924.8
S5	2036	10.020	51808.5
S5	2037	10.760	51692.1
S5	2038	11.500	51575.8
S5	2039	12.241	51459.5
S5	2040	12.981	51343.2
S5	2041	13.561	51248.0
S5	2042	14.141	51152.9
S5	2043	14.722	51057.7
S5	2044	15.302	50962.5
S5	2045	15.882	50867.3
S5	2046	16.216	50710.9
S5	2047	16.550	50554.5
S5	2048	16.884	50398.1
S5	2049	17.219	50241.7
S5	2050	17.553	50085.3
S6	2015	0.018	49656.4
S6	2016	0.538	50410.9
S6	2017	1.058	51165.4
S6	2018	1.578	51920.0
S6	2019	2.097	52674.5
S6	2020	2.617	53429.0

Scenario	Year	US Export LNG (EJ)	Global CO_2e Emissions (Tg)
S6	2021	3.086	52542.1
S6	2022	3.555	51655.2
S6	2023	4.023	50768.2
S6	2024	4.492	49881.3
S6	2025	4.961	48994.3
S6	2026	5.067	49084.3
S6	2027	5.173	49174.3
S6	2028	5.278	49264.3
S6	2029	5.384	49354.3
S6	2030	5.490	49444.3
S6	2031	5.782	48082.7
S6	2032	6.075	46721.2
S6	2033	6.367	45359.6
S6	2034	6.659	43998.0
S6	2035	6.951	42636.4
S6	2036	7.481	41287.6
S6	2037	8.010	39938.9
S6	2038	8.539	38590.1
S6	2039	9.068	37241.3
S6	2040	9.597	35892.5
S6	2041	9.712	34455.5
S6	2042	9.827	33018.4
S6	2043	9.941	31581.4
S6	2044	10.056	30144.4
S6	2045	10.170	28707.3
S6	2046	10.170	27334.6
S6	2047	10.170	25961.9
S6	2048	10.170	24589.1
S6	2049	10.170	23216.4
S6	2050	10.170	21843.7
S7	2015	0.018	49656.4
S7	2016	0.538	50410.9
S7	2017	1.058	51165.4
S7	2018	1.578	51920.0
S7	2019	2.097	52674.5
S7	2020	2.617	53429.0
S7	2021	3.086	52542.1
S7	2022	3.555	51655.2
S7	2023	4.023	50768.2
S7	2024	4.492	49881.3

Scenario	Year	US Export LNG (EJ)	Global CO_2e Emissions (Tg)
S7	2025	4.961	48994.3
S7	2026	5.067	49084.3
S7	2027	5.173	49174.3
S7	2028	5.278	49264.3
S7	2029	5.384	49354.3
S7	2030	5.490	49444.3
S7	2031	5.782	48082.7
S7	2032	6.075	46721.2
S7	2033	6.367	45359.6
S7	2034	6.659	43998.0
S7	2035	6.951	42636.4
S7	2036	7.481	41287.6
S7	2037	8.010	39938.9
S7	2038	8.539	38590.1
S7	2039	9.068	37241.3
S7	2040	9.598	35892.5
S7	2041	10.012	34454.7
S7	2042	10.427	33016.8
S7	2043	10.842	31578.9
S7	2044	11.257	30141.1
S7	2045	11.671	28703.2
S7	2046	11.836	27329.8
S7	2047	12.001	25956.4
S7	2048	12.166	24583.1
S7	2049	12.331	23209.7
S7	2050	12.496	21836.3

Commented [ST65]: I expected to find the index of country GHG emissions intensity to show the relative differences before and after adjustment.

I also expected to see more detail on "what" changed within each countries energy portfolio as a result of increased US LNG exports.

There is a larger "report" decision that will need to be made regarding additional transparency needed to support the conclusions.

This would be more in-line with the expectations described in the August 17, 2023 email to Scott/Matt from Tim.

NO ACTION REQUIRED AT THIS TIME UNTIL FURTHE REPORT WIDE GUIDANCE ON TRANSPARNCY/LEVEL OF DETAIL PROVIDED

From: Matthews, Howard Scott (CONTR)
Sent: Mon, 14 Aug 2023 22:24:57 +0000
To: Jamieson, Matthew B.; Skone, Timothy
Subject: FW: File for Matt and Tim
Attachments: lng_nems_gcam_08072023-for-review.docx

Tim:

DRAFT-DELIBERATIVE-PRE-DECISIONAL

Got your email about wanting to see results before briefing in parallel to finishing this draft memo (what will eventually go into the chapter of the report). I had some to share Thursday last week, but missed you with OOO. It also turned out that we didn't immediately realize that the latest GCAM results are formatted differently (they added subsector detail not previously available) and frankly had to make tons of changes to the code that we had all ready to go for when they sent the new results.

Enclosed please find a draft of results. A few notes to be clear of up front:

1. As you'll see GCAM and NETL results are pretty close! **Thus, no adjustments or normalizations have been made to GCAM results** to better align with NETL (we can easily – but keep reading)
2. The adders in here are focused only on S2 - S1 and S7-S6 due to tons of discussions in the last week or so on the Friday meetings. We still internally have the adder results for S3/4/5 (all vs S1) and FYI they are (200, 0, -50)
3. Harsh and I finalizing the SCC results (not very exciting of course, just informational and meeting the original requested item)

Its still a draft, so please don't spend time thinking about formatting/etc - I know there are lots.

That said, happy to hear any comments. You mentioned wanting to talk before Friday, which is fine – we have all hands in MGT all day tomorrow but my NETL calendar is updated – best times would be wed before 10, 1130-1, or Thurs at 11. If these don't work please reply all (has my KL address so I can see it tomorrow while on site) and we can find another time.

Scott

From: Scott Matthews <scott.matthews@keylogic.com>
Sent: Monday, August 14, 2023 6:15 PM
To: Matthews, Howard Scott (CONTR) <Scott.Matthews@netl.doe.gov>
Subject: [EXTERNAL] File for Matt and Tim

Scott Matthews | **Principal Scientist**
he/him
m: (b) (6) | keylogic.com
3168 Collins Ferry Rd, Morgantown, WV 26505

DRAFT-DELIBERATIVE-PREDECISIONAL

To: Matt Jamieson and Tim Skone
From: Priyadarshini and Scott Matthews
CC: CC Name
Date: August 14, 2023
RE: Comparing the NETL Baseline Results and Framework with that of the Global Change Assessment Model (GCAM)

Note: this memo is now morphing between an informational memo updating on results and the imminently needed LCA section/chapter that will appear in the LNG report.

Some values in this memo are still using the June 22 basis GCAM results (will not affect message).

1 Introduction

The LNG Analysis project is a collaborative effort between NETL (specifically the LCA competency), On-Location (specifically the National Energy Modeling System (NEMS) modeling team), and Pacific Northwest National Laboratory (PNNL, specifically the Global Change Assessment, or GCAM, modeling team). This project seeks to quantitatively assess the expected global effects of different quantities of US LNG exports.

Past studies done by NETL on LNG have largely been techno-economic analyses focused on expected costs per unit delivered (landed) or attributional life cycle analyses that only estimate the emissions and other impacts associated with units of LNG delivered. These LCA studies are limited in that they have not, to date, considered the consequences of delivering LNG, such as how domestic or foreign energy markets may be affected by increasing the supply of natural gas (e.g., whether, given additional supply, natural gas-fired power plants in Europe might take market share from other types of electric plants). Such market-based effects could lead to increases or decreases in GHG emissions.

In this project, the three components are being done as follows:

- The National Energy Modeling Systems (NEMS) model component uses the energy-economics integration and energy technology performance basis to provide future predictions of production, imports, and energy consumption within the US macroeconomics.
- The PNNL/GCAM component is doing time-series modeling of different scenarios, with and without constraints on the US LNG market, to estimate future global greenhouse gas (GHG) emissions worldwide.
- The LCA component seeks to determine the consequences of additional exported volumes of US LNG, such as how additional available quantities of natural gas led to changes in the energy sectors of countries that purchase the LNG. These consequential effects will be estimated by tracking differences in global CO2 emissions and quantities of LNG exported from the GCAM model scenarios.

Commented [P1]: Sounds correct?

In this memo, we seek to describe in detail the various existing representations of the natural gas supply chain within the context of the NETL natural gas model and the GCAM model. The purpose of documenting these representations is to ensure they are correct in order to subsequently assess the differences in the two models at more detailed levels. We also expect that much of this text can/will be reused in the LCA section/chapter that will be a part of the overall LNG Analysis project report.

1.1 NETL Natural Gas Baseline Report

The NETL Natural Gas model (2020 version) is separated into five separate stages which generally aligns with categories used in the US EPA GHGRP and GHGI products. Similarly, past work by NETL modeling LNG has added another four stages, the data for these UPs however use older data (2017). The relative boundaries / included activities in these stages are listed in Table 1.

Commented [SM2]: Let's also verify year/etc basis of this data (2017?). also can you grab those and paste in below? We can ask Harsh to verify if needed.

Commented [P3R2]: I think its 2020?

Table 1. Global Warming Potential of the Natural Gas Life Cycle Stages and Liquified Natural Gas Supply Chain Stages, (GWP gCO2e/MJ)

Commented [P4]: If this is the correct interpretation, i.e. referring to the stages of Natural Gas as Life Cycle stages those of Liquified Natural Gas as Supply Chain stages/sectors; should this be higlighted elsewhere in the document (this might also justify the large difference in reported values and how the stages are described)

Stage Name	Description	gCOe/MJ or gCO2e/kg of LNG
Natural Gas Only		
Production	Exploration, drilling, construction of conventional and unconventional wells (e.g., from hydraulic fracturing), and extraction of gas, including liquids unloading operations	1.62E+00
Gathering and Boosting	Movement of natural gas from wells via gathering pipelines and delivered to treatment and/or processing plants. Boosting systems may include compressors, dehydration, and pneumatic devices and pumps.	1.76E+00
Treatment and Processing	Removal of impurities and compression of input gas to meet transmission pipeline standards. May include acid gas removal (AGR), dehydration), NGL recovery, etc.	2.09E+00
Transmission and Storage	Construction of pipelines, and movement of bulk quantities of natural gas in large pipelines to large users or city gates for subsequent distribution. Typically includes compressor stations along pipelines. Storage includes insertion of gas into units such as underground storage facilities.	1.97E+00 Transmission Station: 1.82E+00 Storage: 1.48E-01

Subtotal without distribution		**7.44 (7.29 without storage)**
Distribution (include?)	Movement of gas from transmission or storage facilities to city gates for subsequent to smaller consumers via small diameter pipelines.	9.89E-01 Transmission Pipeline: 8.74E-03 Distribution: 9.80E-01
Additional Stages for LNG		
Liquefaction	Pre-treatment of gas, liquefaction to low temperatures and storage	0.0219233 gCO2e/kg of LNG
Loading/Unloading	Process to load (and unload) LNG to and from tankers to facilities	
Ocean Transport	Shipment of LNG on ocean-going vessels of varying technology types to distant ports for subsequent regasification. Depending on technology, may use LNG as fuel.	0.03179 gCO2e/kg of LNG[a]
Regasification	Regasification of LNG and injection into transmission pipelines.	2.3745 gCO2e/kg of LNG
Transmission / Dist (include?)	Similar processes as described above, and not functionally different than as described for the natural gas only part.	

Graphically, using this same source (Natural Gas Extraction and Power Generation: U.S. 2020 Emissions Profile[2]), has estimated impacts by stage as shown in Figure 1. In short, from the perspective of upstream domestic natural gas production, without considering the impacts of the distribution stage, the US average total CO2-equivalent emissions are about 7.3 g CO2e/MJ.

[a] Note that this value is extracted from a result for transporting US LNG from the Gulf Coast to Rotterdam. Values for transport to Asian ports

Commented [P5]: Aggregated from the Liquefaction UP using

Total gCO2e/MJ = (GWP_CO2_flared * CO2_flared) + (GWP_CO2_fugitive * CO2_fugitive) + (GWP_CH4_flared * CH4_flared) + (GWP_CH4_fugitive * CH4_fugitive)

Commented [SM6]: Pri - can you grab these and paste in?

Commented [P7R6]: Is this what you were referring to in the comment at the first line of this section?

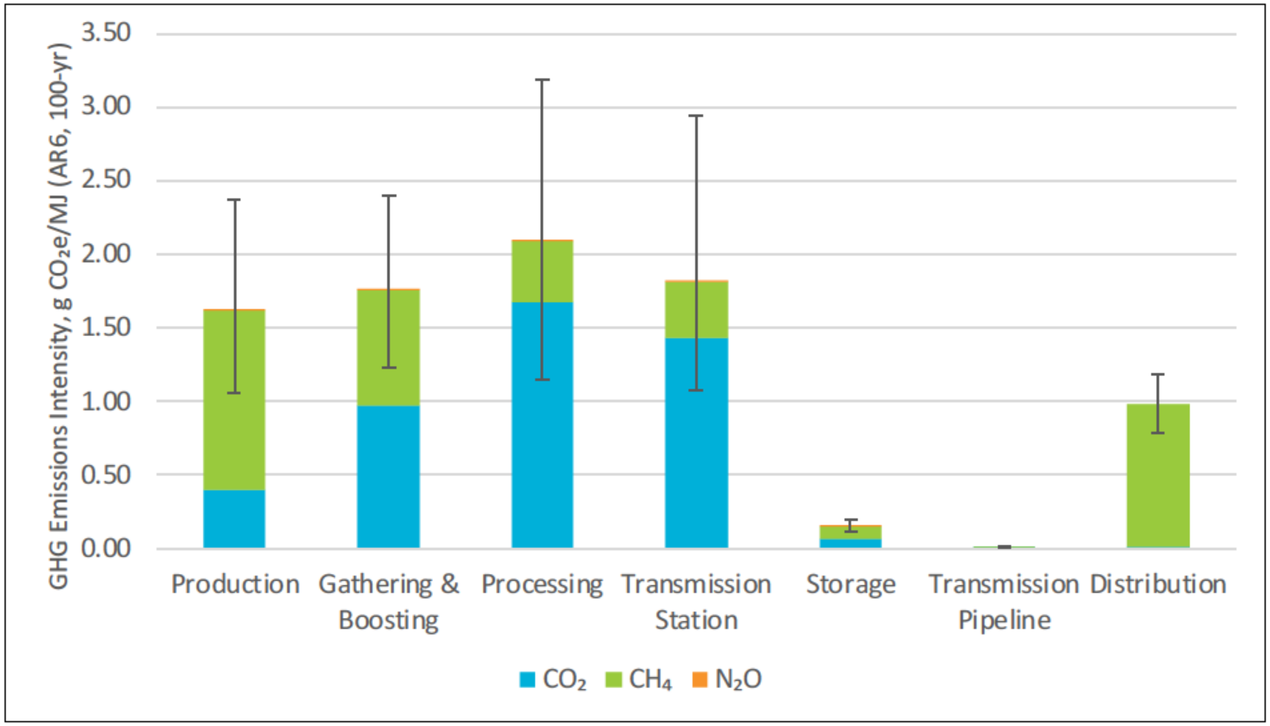


Figure 1. Life cycle GHG emissions from the 2020 U.S. average NG supply chain

The NETL natural gas model is an attributional study of the domestic natural gas system. It seeks only to identify and attribute the emissions associated with various processes that create them. It does not seek to more broadly consider the "what if" cases of what happens if there is additional US natural gas produced and delivered across the world, or, in other words, the market-based consequences and effects of producing domestic natural gas and exporting it (which are represented in the GCAM model).

Thus, an initial area of exploration of this study was to attempt to compare the upstream natural gas GWP impacts as represented in the GCAM model, which has similar but different data sources given its global nature. These comparisons are necessary because the DOE is familiar with the past NETL work, and if the GCAM results are substantially different, then accommodations would need to be made to rationalize the two models to more clearly identify effects.

As such, three goals of the LCA component of this project were to:

- Compare, to the best extent possible, the information regarding upstream supply chains in past NETL studies, and the NEMS and GCAM results of this study, and also against the US EPA's Greenhouse Gas Inventory (GHGI).
- Determine the appropriate incremental global GWP impacts associated with increasing exports of US LNG. This has been envisioned as a "consequential adder" that would be in addition to those shown above. However, as will be described below, a key challenge in determining this adder is coordinating the basis of systemwide emissions estimated from the GCAM model to those previously estimated in the NETL NG model and which are familiar to US DOE.
- To calculate the social cost of carbon associated with the various scenarios of the model, following previous guidance by US EPA and past work done by NETL/DOE.

NEMS vs. NETL Section - Placeholder for Pri's assessment of upstream NG forecasts in NEMS vs technobasins around here

- The basic issue we are about – is the carbon intensity of supplied domestic gas expected to change through 2050?
- What data did we get from the NEMS team – brief desciroption
- How we mapped it to our 2020 technobasin level analysis
- Using 2020 basis, how we think the carbon intensity of the mix will change based on what NEMS says
- Overall, is this an important effect?

GCAM vs. NETL comparison

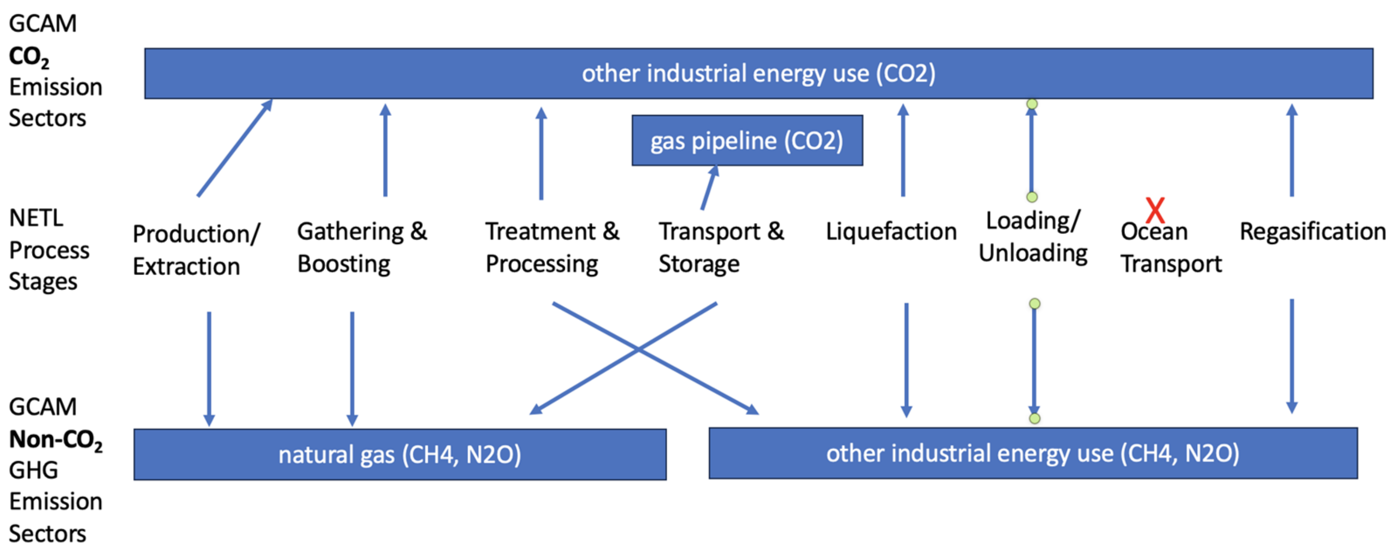
As described above, The GCAM model is represented by sectors and technologies, and their respective inputs and outputs, for particular years and scenarios. Across all years and scenarios, GCAM has 105 discrete sectors, 377 discrete technologies, and many sector-technology pairs that can vary depending on the model configuration. However, only a subset of these are relevant to this

Commented [P8]: Is there a specific number of sector-technology pairs?

Commented [SM9R8]: On second thought I dont think we need to specify the NN pairs in the model, we will just worry about the ones we need to.

analysis (i.e., with a focus on the domestic natural gas sector). Detailed investigation and discussion with the GCAM team identified that only three sectors in the model need to be considered in order to encompass the greenhouse gas emissions of the natural gas sector (natural gas, gas pipeline, and other industrial energy use, see Appendix for more detail). Using the basis of process stages as represented in the NETL Natural Gas model, Figure 2 below shows the relevant GCAM sectors that represent CO2 and non-CO2 emissions. In short, all stages are directly represented in GCAM except for Ocean Transport. GCAM results will not explicitly represent LNG transport via ocean. These (relatively small, in global terms) emissions should also be contained within GCAM's "other industrial energy use" sector. However, due to data limitations it was not deemed possible to explicitly extract these transport emissions from that sector. This is a limitation of this comparative analysis.

Figure 2: Mapping of NETL Natural Gas Stages to GCAM Sectors (still working on a better graphic)



Note however, that while the overall GCAM model has various species of GHG emissions, for the three sectors above relevant to the upstream natural gas sector, only emissions of CO2, CH4, and N2O are available. Table 1 shows the emissions of the various GCAM sectors for the USA region for the three natural gas-relevant sectors identified above. Note that the gas pipeline and natural gas sectors are assumed to wholly incorporate natural gas-relevant emissions, and so total emissions are shown. However, the other industrial energy use sector contains a diverse set of activities, thus it is difficult to completely identify those related to natural gas. As detailed in the Appendix, for this sector, data provided by the GCAM modeling team on IEA data on energy use were used to attempt to apportion GHG emissions associated with natural gas activity. A further challenge is that some of the IEA data singly represents extraction of both oil and gas, and so outputs from domestically produced oil and gas were identified in the GCAM model to create potential ranges of shares related to natural gas activity.

(*Note to team – we are still working with PNNL to further refine the GHG emissions of the other industrial energy use sector, based on CEDS data*).

The emissions intensity cells in Table 1 show the underlying equation used to generate values, where the numerator is the total emissions for the USA region for S1-2020 for each of the three greenhouse gases (if available), normalized by the total production of US natural gas in 2020 (33.13 EJ). Units of emissions intensity follow those of the GCAM model, which are Tg CO2 equivalent per Exajoule, which conveniently are equal to g CO2/MJ, the same units as used in the NETL model. Thus, in the bottom rows of the table are comparisons to those of the NETL model.

Table 2: CAM Emissions Intensities for Sectors (S1, 2020, USA region only, old June data still used)

			Estimated GCAM Emissions Intensity (Tg CO_2e / EJ, g CO_2e / MJ) [IPCC AR6 100 yr]		
GCAM Sector	**NETL LCA Stage**	**Comments/Potential mapping inaccuracy**	**CO_2**	**CH_4**	**N_2O**
gas pipeline	Transmission (Storage too?)	Have assumed this fully represents the Transmission sector equivalent to the NETL NG model.	38.2/33.1 = 1.15	-	-
natural gas	Production + Gathering &	From discussions with GCAM team, this sector represents all other natural gas related	-	171.4/33.1 = 5.18	.016/33.1 = 4.8 E-4

	Boosting + Processing	activities, thus the mapping to all other NETL stages other than transmission.			
other industrial energy use (gas/gas cogen)[a]	**For 2015**, Extraction, Gathering & Boosting	Current estimates are from IEA energy shares, awaiting GHG values from PNNL. But does not distinguish oil/gas (in extraction).. 2015 crude oil – 24.7 EJ, natural gas 26.2 (50%) 2020 – 22.5, 33.1 (NG is 60%)	81.3/33.1 = 2.46 50% = 1.23 60% = 1.48	.04/ 33.1 = .001	xx
other industrial energy use (liquids and liquids cogen)[a]			16.3/33.1 = 0.5 50% = 0.25 60% = 0.3	.4 / 33.1 = .01	xx
other industrial energy use (electricity)[a]			-	-	-
Total GCAM by gas (including <u>all</u> the *other industrial energy use* as above)			**= 1.15 + 2.46 + .5 = 4.11**	**5.18 + .001 + .01 = 5.19**	4.8 E-4
Total GCAM CO2e (including <u>all</u> the *other industrial energy use* as above)			**8.85**		
Total GCAM by gas (including <u>only 50% gas shares of *other ind* above</u>)			**= 1.15 + 1.23 + .25 = 2.63**	**5.18 + .0005 + .005 = 5.18**	4.8 E-4
Total GCAM by gas (including <u>only 50% gas shares of *other ind* above</u>)			**7.81**		

Subtotal from NETL Model without Distribution or Storage	**7.29**

Overall, the best guess of upstream emissions in the GCAM model are about 7.8 g CO2e/MJ, which are slightly higher than those of the NETL model (7.3 g CO2e/MJ). In addition, the GCAM values for the three sectors were compared to the EPA GHGI for the natural gas sector for 2020, and found to be within 10% of the EPA values, despite using different data sources (see Appendix). Overall, given the uncertainty in underlying energy and emissions data sources, and the small difference between g/MJ results in the two models, no further modification of the GCAM supply chain was deemed necessary.

Adders

In order to attempt to quantify the broad and global market effects associated with increasing exports of US LNG, an equation was proposed to use the available GCAM results to estimate the change in global GHG emissions per unit of LNG exported. This adjustment factor, or adder, is defined as:

$$Adder_{scenario\ n} = \frac{Global\ Emissions_{scenario\ n} - Global\ Emissions_{scenario\ 1}}{US\ LNG\ Exports_{scenario\ n} - US\ LNG\ Exports_{scenario\ 1}}$$

and represents a ratio of change in GHG emissions for a given scenario compared to a specific base scenario, versus the change in US LNG exports between the same two scenarios. This result is presumed to be valid only across the entire time horizon of results (2015-2050), and so while annual deltas are calculated, only the cumulative effect over all 36 model years is used. The GCAM model was run in 5-year increments. Values of GHG emissions and LNG exports were linearly interpolated for intervening years.

An important consideration and decision by the project was to focus only on the adders that compare Scenario 2 to Scenario 1 (aka S2-S1), and Scenario 7 to Scenario 6 (aka S7-S6). There are many reasons for this choice, most notably the large amount of differences in the world economy as modeled by Scenarios 3 to 5 which make it difficult to compare to the reference case. In addition, given the large differences between Scenarios 6 and 7 as compared to Scenario 1, it made more analytical sense to compare S6 and S7 than to compare either to S1.

Note that unlike the natural gas system-specific emissions discussed above, the overall GCAM results contain details of non-CO2 gases for many more GHGs and all are included in the study. Results were created for various GWP values from IPCC reports. Currently included are those for IPCC's 5th Assessment Report, for 100-year time horizons, including the effects of climate carbon feedback (see Appendix for GWP values used). *Only IPCC AR5-100 are shown here at this point*. The Appendix shows the annual summaries of GHG emissions, LNG export volumes, and deltas compared to baselines for each year of GCAM model runs.

	Results (g CO2e/ MJ)		
Adder Case	**AR5, 100 with ccf**	**AR6**	**Others?**
Scenario 2 vs. Scenario 1 (S2-S1)	-5.9		
Scenario 7 vs. Scenario 6 (S7-S6)	-3.5		

Interpretation of Adder Results

Following the broader conclusions already suggested by the GCAM section of the report on the GHG effects of the various scenarios, the adders estimated by this project, using the same GCAM simulation results, suggest that the consequences of increasing US LNG exports broadly lead to decarbonization in the global economy. For S2-S1, the adder result is approximately -6 g CO2e/MJ, or put another way, would almost fully eliminate the +7.3 g CO2e/MJ upstream values estimated by the NETL NG model. For S7-S6, the adder result is slightly lower (about -3.5 g CO2e/MJ), but would reduce the domestic upstream GWP impacts by about 5%.

These results are important as modeled, but also should be presented with various caveats:

- The GCAM simulations represent broad modeling of the global economy, and despite tremendous sectoral detail, can not represent all technologies in detail, or fully encapsulate all activities (e.g., see discussion of Ocean Transport above)
- What else?

- In short, while useful from this analytical method done here, it is not possible to explicitly say that every MJ of domestically produced natural gas approved for export would directly lead to negative GHG emissions results (or credits) when supplied around the world.

Social Cost of Carbon (still in progress)…

Following previous DOE and NETL studies, this part of the project also estimated the annual and cumulative social costs of carbon (SCC) of each of the seven Scenarios over the 2015-2050 time horizon. Table X shows the annual values of SCC in dollars (see Appendix for the detailed values of underlying emissions used).

Effects of future mitigation in GCAM…. Not sure we still need to be modeling this..

Scroll down to see Appendix..

Appendix to LCA section (not very well organized yet)

GLOBAL CHANGE ASSESSMENT MODEL – DATA INPUTS TO LCA

The GCAM model is an input-output-based model primarily represented by sectors and technologies and their respective inputs and outputs for particular years and scenarios. Across all years and scenarios, GCAM has 105 discrete sectors, 377 discrete technologies, and many sector-technology pairs that can vary depending on the model configuration. However, only a subset of these are relevant to this analysis (i.e., with a focus on the natural gas sector).

Commented [P10]: Is there a specific number of sector-technology pairs?

Commented [SM11R10]: On second thought I dont think we need to specify the NN pairs in the model, we will just worry about the ones we need to.

We used R code explicitly developed for this project to process the CSV file results provided by PNNL for the various Scenarios (1-7 and years modeled. Specifically, we were provided data files described in Table 3.

Table 3. Provided set of GCAM Data Documentation

File	Data Represented
co2_em_tech_2023.06.22	Provides data showing CO_2 emissions in megatons per year ($MtCO_2$/yr) for various sectors, energy sources or "technology" for 6 different scenarios across each of 37 regions.
co2_seq_tech_2023.06.22	Provides data showing CO_2 emissions in megatons per year ($MtCO_2$/yr) for various sectors, energy sources or "technology" for 6 different scenarios across each of 37 regions.
non_co2_em_tech_2023.06.22	Provides data showing non-CO_2 emissions in Gigagrams (Gg) equivalent to metric kilotons or 1,000 metric tons, for various sectors, energy sources or "technology" and 6 different scenarios across each of 37 regions.
inputs.by.tech_2023.06.22	Provides detailed information about energy consumption and capacity in different regions, sectors along with specific technologies and years. It can be

	used to analyze and understand the energy landscape, make projections, and assess the impact of various factors on energy consumption and capacity (sub-sector is not applicable in this dataset).
outputs.by.tech_2023.06.22	Reports the energy production within the various regions, by sectors, (sub-sector is not applicable in this dataset) along with specific technologies and years.
luc_em_2023.06.22	contains information about CO2 emissions (in million metric tons per year) for different regions and years.
Columns	**Description**
scenario	scenario or context for which the data is provided such as "S1: Existing Capacity," which suggests that the data corresponds to the existing capacity or infrastructure in the region.
region	This column specifies the geo-political region under consideration.
sector	This column categorizes the different sectors or areas of activity for which carbon dioxide emissions are being measured, e.g., “agricultural energy use”, “cement”, “air_CO_2”, etc.
sub-sector	Within each sector, there may be further divisions or subcategories to specify the specific aspect of the sector being measured, e.g., "mobile”, "stationary," etc. indicating different types of energy use within a single sector
technology	This column identifies the specific technology or energy source being utilized within the subsector. For example, "refined liquids" and "biomass"
year	The specific year or time period for which the CO2 emissions values are provided, this ranges from 2015 to 2050.

value	corresponding carbon dioxide emissions values for the given combination of scenario, region, sector, subsector, technology, and year. The values represent the estimated or projected amount of CO2 emissions in megatons per year in this specific file as depicted in the "Units" column (not mentioned separately in this table).
ghg	Refers to the greenhouse gas that is being emitted. It identifies the specific type of gas responsible for the emissions, e.g., HFC125, HFC134a, HFC143a, HFC23, HFC32, SF6, HFC245fa, HFC365mfc, C2F6, etc.
input, output	Additional details or characteristics about the technology or process. It helps to differentiate between different aspects or variations within a specific technology. Examples in the datasets include "elect_td_ind" (electricity transmission and distribution for industrial use) and "H2 wholesale dispensing" (hydrogen wholesale dispensing).

Amongst many data sources used in GCAM relevant to the natural gas and LNG, two are of importance – IEA data on energy and GHG emissions flows and the Community Emissions Data System (CEDS). We were provided detailed information on how the sectors of the NETL natural gas model may best align with those in the GCAM model, as in the table below.

Table XX

LCA stage	**IEA energy flow**	**GCAM sector – energy & CO_2**	**CEDS sector**	**GCAM sector – nonCO_2**
Extraction	Oil and Gas Extraction	other industrial energy use	1B2b_Fugitive-NG-prod	natural gas
Gathering and Boosting	Oil and Gas Extraction	other industrial energy use	1B2b_Fugitive-NG-prod	natural gas
Processing	Gas works	other industrial energy use	1A1bc_Other-transformation	other industrial energy use

Domestic Pipeline Transport [1]	Pipeline Transport	gas pipeline	1B2b_Fugitive-NG-distr	natural gas
Liquefaction	Liquefaction (LNG) / Regasification Plants	other industrial energy use	1A1bc_Other-transformation	other industrial energy use
Ocean Transport	International Marine Bunkers [2]	trn_shipping_intl [2]	1A3di_International-shipping	trn_shipping_intl
Regasification	Liquefaction (LNG) / Regasification Plants	other industrial energy use	1A1bc_Other-transformation	other industrial energy use
Pipeline Transport (at destination) [1]	Pipeline Transport	gas pipeline	1B2b_Fugitive-NG-distr	natural gas

Initially, to aid in identifying supply connections in the model, our team scripted separate R code to perform a "backward trace" of outputs of interest to see the inputs from sector-technology "pairs" and connect them throughout the upstream supply chain. The focus was on exemplar of pairs relevant to this analysis. In producing **Error! Reference source not found.**, a trace was run on the "delivered gas" output – the name of the output of natural gas that is ready to be used by large-scale customers such as power plants. Connected outputs and inputs can be seen in alternating rows (the blue arrow demonstrates the first such connection).

As shown in Table 4, our analysis uncovered the input-output pairs for each sector which is used to generate the emission values by dividing the GCAM output values with the total gCO2 equivalent for each sector. For comparability purposes, this value is further scaled based on scaling factors for both input and output to then generate the "scaled" emissions in gCO2e/MJ of output.

However, subsequent analysis has suggested that the trace algorithm is insufficient in tracking the entire upstream supply chain of activities, as there are various GCAM sectors that support natural gas activity but that are disconnected from the supply chain that is identified using the described algorithm. Nonetheless, the backwards trace example is maintained here to help to explain upstream supply chain connections in GCAM. Additional sectors from GCAM have been added at the bottom of Table 3 to account for these activities.

In the final columns of Table 3 are the global and US-only estimated GCAM emissions associated with natural gas for Scenario 1 for the Year 2020. (Note these are still using the mid-June values but are not expected to significantly differ in the final report).

Table 4. Traced GCAM CO2 and non-CO2 emissions for each sector and corresponding technology (Scenario 1, Year 2020, mid June results)

					Global GHG Emissions	**US GHG Emissions**

Sector	Technology	Input	Output	Description	CO_2 (Tg)	Non-CO2 (Tg)	CO_2 (Tg)	Non-CO2 (Tg)
Pairs from trace of NG sector								
Delivered gas	Delivered gas	Gas pipeline	Delivered gas	Seems to only be a market exchange sector	0	0	0	0
Gas pipeline	Gas pipeline	Gas processing	Gas pipeline	PNNL confirms this to be the expected pair, but IEA data may be spotty	186.2	0	38.2	0
Gas processing	Natural gas	Regional natural gas	Gas processin g	We assume this is intended to be comparable to gas processing in NETL model, but e-mail discussions with PNNL have indicated their scope is not as comprehensive as ours.	0	0	0	0
Regional natural gas	Domestic natural gas	Natural gas	Regional natural gas		0	0	0	0
Regional natural gas	Imported LNG	Traded LNG	Regional natural gas		0	0	0	0

Regional natural gas	Imported N American pipeline gas	Traded N. Amer pipeline gas	Regional natural gas		0	0	0	0
Additional sectors separately identified as relevant								
Other industrial energy use	gas/gas cogen	N/A	Mentioned by PNNL as sector where emissions from extraction, G&B, processing, liquefaction, regasification would occur		255[b]	2.4	81.3	.03
Other industrial energy use	Refined liquids/refined liquids cogen				39[a]	5.7	16.3	.4
Natural gas	Natural gas		Identified by PNNL team		0	1164.2	0	171.5
Total (GCAM)					**480**	**1172**	**42.4**	**171.5**
Total (GHGI)							**36.5**	**185.3**

Commented [P12]: no more regional gas related sector (within scenario 1)

In terms of validation, the US values in Table 3 (which sum to 214 Tg CO2e) have been compared to the US EPA Greenhouse Gas Inventory (GHGI) for 2020. GHGI suggests that the total emissions of "Natural Gas Systems" are 36.5 Tg CO2 and 185.3 Tg of

[b] The values currently listed here are generated from allocations of energy use from the underlying IEA data – they will be replaced with direct estimates of GHG emissions when provided by PNNL. Total GHG emissions from GCAM in these two sector-technology pairs are 1514 and 731 Tg, respectively **and are NOT separated between oil and gas**. We do not expect significant differences when these are received.

methane in CO2e (221.8 Tg CO2e total). Both the CO2 and non-CO2 values are within 10% of the EPA GHGI value. The total values differ only by about 5**%. Note however that the GHGI does not include CO2 emissions other than flaring in those of the "Natural Gas Systems" category – other non-flaring CO2 emissions from natural gas are in the broadly used "Fossil fuel combustion" category and can not easily be disaggregated.**

In addition, the GCAM values can be normalized by the modeled final demands of natural gas produced in the US in S1/2020,

For appendix: In terms of comparing GCAM results of the natural gas sector with the NETL model, the emissions from appropriate total production value for a country is given by the output 'natural gas' from the sector-technology pair 'natural gas'. In 2020, the US total production in 'natural gas' is 33.13 EJ.

Old Mapping text

Given the information identified above, Table 4 demonstrates the intended correspondence of categories between the NETL NG model results and the GCAM model results.

Table 5. Potential Mapping of GCAM sector-technology pair with NETL stages

GCAM Sector	NETL LCA Stage	Comments/Potential mapping inaccuracy
delivered gas	NA	No CO2 or non-CO2 emission values for this GCAM sector (possible market exchange sector), therefore the mapping of this sector with the NETL stage isn't feasible.
gas processing	NA	No CO2 or non-CO2 emission values for this GCAM sector therefore the mapping of this sector with the NETL stage isn't feasible.
regional natural gas	NA	No CO2 or non-CO2 emission values for this GCAM sector therefore the mapping of this sector with the NETL stage isn't feasible.

		Also, "Region" in GCAM model stands for geopolitical region, which for the NETL stage was assumed as consisting of all the natural gas production through storage stages, since it considers the case of United States only.
gas pipeline	Transmission (Storage too?)	Have assumed this fully represents the Transmission sector equivalent to the NETL NG model.
natural gas	Production + Gathering & Boosting + Processing	From discussions with GCAM team, this sector represents all other natural gas related activities, thus the mapping to all other NETL stages other than transmission.
other industrial energy use (gas/gas cogen and liquids and liquids cogen)	WHAT HERE	WHAT HERE

Table 5 was the potential GCAM Sector mapping with NETL LCA Stages, prepared in order to analyze the relation between the two methodologies concerning natural gas processing, pipeline and distribution. The mapping is not accurate for reasons such as the geographical and technological context of data coverage and calculations within the two models/methodologies creates varying values (with vastly differing units) with do not perfectly align with one another in order to make a direct comparison, which was attempted in **Error! Reference source not found.**.

GWP Values used in this section (IPCC AR5, 100-yr with ccf)

1	CH4	36
2	CH4_AGR	36
3	CH4_AWB	36
4	N2O	298
5	N2O_AGR	298
6	N2O_AWB	298
7	HFC125	3691

8	HFC134a	1549
9	HFC143a	5508
10	HFC23	13856
11	HFC32	817
12	SF6	26087
13	HFC245fa	1032
14	HFC365mfc	966
15	C2F6	12340
16	CF4	7349
17	HFC43	164
18	HFC152a	167
19	HFC227ea	3860
20	HFC236fa	9810

S2-S1 – Detailed Background Data

	Scenario 1			Scenario 2				
year	global_lng	us_export_lng	global_co2_eq	global_lng_s2	us_export_lng_s2	global_tg_co2_eq	Δ_co2_eq	Δ _us_export_lng
2015	11.858	0.018	52488.031	11.858	0.018	52488.031	0.000	0.000
2016	13.753	0.538	53270.409	13.753	0.538	53270.409	0.000	0.000
2017	15.648	1.058	54052.788	15.648	1.058	54052.788	0.000	0.000
2018	17.543	1.578	54835.166	17.543	1.578	54835.166	0.000	0.000
2019	19.438	2.097	55617.545	19.438	2.097	55617.545	0.000	0.000
2020	21.333	2.617	56399.923	21.333	2.617	56399.923	0.000	0.000
2021	22.180	3.086	55750.013	22.180	3.086	55750.013	0.000	0.000
2022	23.027	3.555	55100.103	23.027	3.555	55100.103	0.000	0.000
2023	23.874	4.023	54450.193	23.874	4.023	54450.193	0.000	0.000
2024	24.722	4.492	53800.283	24.722	4.492	53800.283	0.000	0.000
2025	25.569	4.961	53150.373	25.569	4.961	53150.373	0.000	0.000
2026	26.428	5.372	53501.087	26.428	5.372	53501.087	0.000	0.000
2027	27.287	5.782	53851.802	27.287	5.782	53851.802	0.000	0.000
2028	28.147	6.193	54202.516	28.147	6.193	54202.516	0.000	0.000
2029	29.006	6.603	54553.230	29.006	6.603	54553.230	0.000	0.000
2030	29.865	7.014	54903.945	29.865	7.014	54903.945	0.000	0.000
2031	30.896	7.544	54924.381	30.811	7.462	54924.986	0.605	-0.082
2032	31.928	8.074	54944.818	31.756	7.910	54946.028	1.210	-0.164
2033	32.959	8.605	54965.254	32.702	8.358	54967.069	1.815	-0.246
2034	33.991	9.135	54985.691	33.648	8.806	54988.111	2.420	-0.328
2035	35.022	9.665	55006.127	34.594	9.254	55009.152	3.025	-0.411
2036	35.768	9.766	54910.372	35.911	9.996	54909.429	-0.943	0.230

2037	36.514	9.867	54814.616	37.229	10.738	54809.706	-4.910	0.871
2038	37.260	9.968	54718.861	38.546	11.481	54709.983	-8.877	1.513
2039	38.005	10.069	54623.105	39.864	12.223	54610.260	-12.845	2.154
2040	38.751	10.170	54527.350	41.182	12.965	54510.537	-16.812	2.795
2041	39.631	10.170	54466.246	42.361	13.561	54447.487	-18.760	3.391
2042	40.511	10.170	54405.143	43.540	14.157	54384.436	-20.707	3.987
2043	41.391	10.170	54344.040	44.719	14.753	54321.385	-22.655	4.583
2044	42.271	10.170	54282.937	45.898	15.350	54258.335	-24.602	5.180
2045	43.151	10.170	54221.834	47.077	15.946	54195.284	-26.550	5.776
2046	43.875	10.170	54100.302	47.928	16.271	54067.774	-32.528	6.101
2047	44.600	10.170	53978.770	48.779	16.597	53940.263	-38.507	6.427
2048	45.324	10.170	53857.239	49.629	16.922	53812.753	-44.486	6.752
2049	46.048	10.170	53735.707	50.480	17.248	53685.243	-50.464	7.078
2050	46.773	10.170	53614.176	51.331	17.573	53557.732	-56.443	7.403

S7-S6 – Detailed Background Data

	Scenario 6			Scenario 7				
year	global_lng	us_export_lng	global_co2_eq	global_lng_s2	us_export_lng_s2	global_tg_co2_eq	Δ_co2_eq	Δ _us_export_lng
2015	11.858	0.018	52488.032	11.858	0.018	52488.032	0.000	0.000
2016	13.753	0.538	53270.734	13.753	0.538	53270.734	0.000	0.000
2017	15.648	1.058	54053.436	15.648	1.058	54053.436	0.000	0.000
2018	17.543	1.578	54836.137	17.543	1.578	54836.137	0.000	0.000
2019	19.438	2.097	55618.839	19.438	2.097	55618.839	0.000	0.000
2020	21.333	2.617	56401.540	21.333	2.617	56401.540	0.000	0.000
2021	22.169	3.086	55465.461	22.169	3.086	55465.461	0.000	0.000
2022	23.005	3.555	54529.382	23.005	3.555	54529.382	0.000	0.000

2023	23.841	4.023	53593.303	23.841	4.023	53593.303	0.000	0.000
2024	24.677	4.492	52657.223	24.677	4.492	52657.223	0.000	0.000
2025	25.513	4.961	51721.144	25.513	4.961	51721.144	0.000	0.000
2026	25.931	5.067	51838.068	25.931	5.067	51838.068	0.000	0.000
2027	26.349	5.173	51954.992	26.349	5.173	51954.992	0.000	0.000
2028	26.766	5.278	52071.916	26.766	5.278	52071.916	0.000	0.000
2029	27.184	5.384	52188.840	27.184	5.384	52188.840	0.000	0.000
2030	27.602	5.490	52305.764	27.602	5.490	52305.764	0.000	0.000
2031	28.237	5.782	50941.678	28.237	5.782	50941.679	0.001	0.000
2032	28.871	6.075	49577.593	28.871	6.075	49577.595	0.002	0.000
2033	29.506	6.367	48213.507	29.506	6.367	48213.510	0.003	0.000
2034	30.141	6.659	46849.421	30.141	6.659	46849.425	0.004	0.000
2035	30.776	6.951	45485.335	30.776	6.951	45485.340	0.005	0.000
2036	31.740	7.481	44135.034	31.740	7.481	44135.038	0.004	0.000
2037	32.705	8.010	42784.733	32.705	8.010	42784.736	0.002	0.000
2038	33.669	8.539	41434.433	33.669	8.539	41434.434	0.001	0.000
2039	34.633	9.068	40084.132	34.633	9.068	40084.131	0.000	0.000
2040	35.598	9.597	38733.831	35.598	9.598	38733.829	-0.002	0.000
2041	36.181	9.712	37288.808	36.398	10.012	37287.814	-0.994	0.300
2042	36.764	9.827	35843.786	37.199	10.427	35841.799	-1.987	0.601
2043	37.347	9.941	34398.763	37.999	10.842	34395.784	-2.979	0.901
2044	37.930	10.056	32953.741	38.800	11.257	32949.769	-3.972	1.201
2045	38.513	10.170	31508.718	39.600	11.671	31503.754	-4.964	1.501
2046	38.673	10.170	30133.387	39.817	11.836	30127.643	-5.745	1.666
2047	38.833	10.170	28758.057	40.034	12.001	28751.532	-6.525	1.831
2048	38.992	10.170	27382.726	40.251	12.166	27375.421	-7.305	1.996
2049	39.152	10.170	26007.395	40.468	12.331	25999.310	-8.085	2.161
2050	39.312	10.170	24632.065	40.685	12.496	24623.199	-8.865	2.326

REFERENCES

[1] “Technology needs for net-zero emissions – Energy Technology Perspectives 2020 – Analysis,” IEA. https://www.iea.org/reports/energy-technology-perspectives-2020/technology-needs-for-net-zero-emissions (accessed Jul. 13, 2023).

[2] H. Khutal, K. Kirchner-Ortiz, M. Blackhurst, N. Willems, H.S. Matthews, S. Rai, G. Yanai, K. Chivukula, Priyadarshini, H. Hoffman, M. B. Jamieson, T. J. Skone, "Life Cycle Analysis of Natural Gas Extraction and Power Generation: U.S. 2020 Emissions Profile," National Energy Technology Laboratory, Pittsburgh, July 7, 2023.

From: Matthews, Howard Scott (CONTR)
Sent: Thu, 26 Oct 2023 15:42:38 +0000
To: Skone, Timothy; Jamieson, Matthew B (NETL)
Subject: RE: Draft LNG Study MAF Interpretations Memo for FECM
Attachments: LNG MAF Interpretation Memo_TS.docx

Tim and Matt:

Sorry for slight delay while verifying the plans for the report, but I suggested edits in the two places Tim had flagged on Friday. To save you time, I have pasted them here – but whole document is still attached.

1)

An overall takeaway from this analysis is that the "regional MAFs" in the most prominent importers are generally bounded to a range of approximately -5 to +10 g CO_2e/MJ of gas imported. And it might be more appropriate to refer to this range of values in the main report.

(I did not add to the memo, but a point here is that if we suggest this range we WILL need to figure out how to justify and report all of the regional values, despite the slight pushback from the GCAM team on how regional modeling was not the intention or focus of the Scenario design).

2)

While the decisions or authorizations are connected to these annual emission and MAF results, there are biases that could be introduced if only the annual (or 5-year cumulative period) MAFs were used (for example, a five year period with a positive or negative value when the cumulative is the opposite). It thus seems appropriate given the results in hand to assume that exports would continue for the foreseeable future into the global market, and while the graphical results show how they might vary year to year, the cumulative result over the entire 35 year period of the GCAM model results is the appropriate metric.

Let me know how we can best facilitate sending this up the chain.

Scott

H. Scott Matthews *(he/him)*
Principal Scientist
NETL Support Contractor
National Energy Technology Laboratory
U.S. Department of Energy
Pittsburgh, PA (Eastern Time)

Mobile: (b) (6)
scott.matthews@netl.doe.gov

NETL.DOE.gov

From: Skone, Timothy <timothy.skone@hq.doe.gov>
Sent: Friday, October 20, 2023 11:39 AM
To: Matthews, Howard Scott (CONTR) <Scott.Matthews@netl.doe.gov>; Jamieson, Matthew B. <Matthew.Jamieson@NETL.DOE.GOV>
Subject: RE: Draft LNG Study MAF Interpretations Memo for FECM

Thanks Scott!

Two initial reactions in the attached.

Also, what was the general thinking from the broader modeling group on adjusting the MAF conclusion.

Tim

From: Matthews, Howard Scott (CONTR) <Scott.Matthews@netl.doe.gov>
Sent: Friday, October 20, 2023 10:50 AM
To: Skone, Timothy <timothy.skone@hq.doe.gov>; Jamieson, Matthew B (NETL) <matthew.jamieson@netl.doe.gov>
Subject: Draft LNG Study MAF Interpretations Memo for FECM

Gentlemen: Apologies for the delay, but there were some productive discussions with the GCAM team that have been incorporated beyond what we previously had done and discussed.

It ended up being longer than expected, but frankly it is because I included all tables and graphs we have been discussing. Its possible we can cut several of them (or move them to an appendix) to keep it briefing-friendly.

Regardless, any comments are welcomed.

Scott

Scott Matthews | **Principal Scientist**
he/him
m: (b) (6) | keylogic.com
3168 Collins Ferry Rd, Morgantown, WV 26505
KEYLOGIC

DRAFT-DELIBERATIVE-PREDECISIONAL

To: Matt Jamieson and Tim Skone
From: Scott Matthews
CC:
Date: October 20, 2023
RE: Synthesis of Thoughts on Interpreting the Market Adjustment Factors in the FECM LNG Export Study

INTRODUCTION

The LNG Analysis project is a collaborative effort between NETL (specifically the LCA competency), On-Location (specifically the National Energy Modeling System (NEMS) modeling team), and Pacific Northwest National Laboratory (PNNL, specifically the Global Change Assessment, or GCAM, modeling team). This project seeks to quantitatively assess the expected global effects of different quantities of US LNG exports.

Past studies done by NETL on LNG have largely been techno-economic analyses focused on expected costs per unit delivered (landed) or attributional life cycle analyses that only estimate the emissions and other impacts associated with units of LNG delivered. These LCA studies are limited in that they have not, to date, considered the consequences of delivering LNG, such as how domestic or foreign energy markets may be affected by increasing the supply of natural gas (e.g., whether, given additional supply, natural gas-fired power plants in Europe might take market share from other types of electric plants). Such market-based effects could lead to increases or decreases in GHG emissions.

In this project, the LCA component seeks to determine the consequences of additional exported volumes of US LNG, such as how additional available quantities of natural gas led to changes in the energy sectors of countries that purchase the LNG. These consequential effects are estimated by tracking differences in global CO_2 emissions and quantities of US LNG exported from the GCAM model scenarios. The result is a market adjustment factor (MAF) using the following equation, and would be considered a value to be combined with usual upstream LCA results for production of natural gas (currently -5.3 on an IPCC AR6-100 year basis).

$$MAF_{scenario\ n} = \frac{Global\ Emissions_{scenario\ n} - Global\ Emissions_{scenario\ 1}}{US\ LNG\ Exports_{scenario\ n} - US\ LNG\ Exports_{scenario\ 1}}$$

In this memo, we seek to provide additional background context on the data and methods that lead to the currently drafted MAF results (which may not appear in the final report), to ensure internal stakeholders are aware of them and to attempt to converge on appropriate text that frames these contextual issues.

ADDITIONAL ANALYSIS

Application of the MAF equation leverages GCAM results (and uses past NETL reports to harmonize them) that are meant to quantify the effect on global CO_2e emissions from increased US LNG exports. This global MAF is *calculated annually*, including interpolation of GHG and LNG scenario results between the 5-year GCAM timesteps, and is *reported cumulatively* over the 35-year time horizon of the study. In the recently reviewed version of the report, the global MAFs on an IPCC AR6-100 basis for Scenario 2 (vs. Scenario 1) was estimated at -5 g CO_2e/MJ and for Scenario 7 (vs. Scenario 6) was estimated at -3 g CO_2e/MJ. These results suggest that export of US NG leads to lower global emissions.

Such a result might be applied to support US LNG export authorization decisions. While these export authorizations are not contingent on knowing where the LNG might go, the reality is the LNG will go to a specific region and not to "the world" (and as discussed throughout the project, GCAM has a global LNG pool from which regions import it, and does not model explicit trades of LNG to or from any region).

We elected to attempt to look at the GCAM results *regionally* to attempt to quantify similar MAF values for all regions, but especially for expected future importers of LNG (e.g., China, India, Europe, Japan, and South Korea). As such, we developed a slightly different MAF equation of "delta CO2e for each region" divided by "delta ***imported*** LNG" for that region. We note that this creates several issues:

- This was not the focus of the original model, which was set up to focus on changes of exporting US LNG (as the control variable)
- GCAM has a global pool and thus we can not associate their reductions with US LNG
- By focusing on delta imported LNG, rather than "delta NG consumption" overall, we miss potential differences that exist from how regional markets choose local, pipeline, or LNG in its consumption mix, and such interactions are a feature of GCAM that is lost

In these hypothetical results, some are positive and some are negative. Table 1 summarizes these regional MAFs for a subset of GCAM regions From Table 1, China, Japan and EU-15 regions have slightly positive regional MAFs (suggesting emissions would increase), and the South Korea and India regions are slightly negative (decreasing emissions). Not obvious in the table is that if all four European GCAM regions are aggregated, its result is -4 g CO_2e/MJ. Some regions with large absolute values of MAFs are an order of magnitude higher, but they are small importers in the GCAM results.

An overall takeaway from this analysis is that the "regional MAFs" in the most prominent importers are generally bounded to a range of approximately -5 to +10 g CO_2e/MJ of gas imported. And it might be more appropriate to refer to this range of values in the main report.

Commented [ST1]: Are you recommending this range as the study results on MAF values to replace the single -5 value?

If yes, what do recommend as a the expected value? Asusming -5 and +10 braket the likley range (not sure what the correct statistical terms should be).

Table 1: Hypothetical Regional Market Adjustment Factors for GCAM Regions (S2)

Region	**Cumulative MAF**
USA	45.74
Australia_NZ	45.50
Africa_Eastern	16.40
Pakistan	9.40
Japan	**9.21**
EU-15	**7.94**
Southeast Asia	4.46
Taiwan	3.63
Mexico	2.53
China	**2.30**
South Korea	**-0.81**
Europe_Non_EU	-1.93
Africa_Southern	-2.02
South Africa	-2.57
India	**-4.36**
Brazil	-4.94
Colombia	-6.04
European Free Trade Association	-6.59
Argentina	-9.58
Africa_Western	-17.36
Middle East	-19.24
Europe_Eastern	-25.47
South America_Northern	-26.29
Russia	-29.71
Indonesia	-32.31
Central Asia	-33.27
Canada	-50.11
EU-12	-54.76
Africa_Northern	-64.61
South America_Southern	-66.75
Central America and Caribbean	-87.06

Note: (note that USA and Australia do import a small amount of LNG, which is why the large MAFs –net imports were not modeled, but it would not affect the main regions of interest).

Another underlying dynamic to synthesize is the issue of calculating and reporting the MAF annually vs. cumulatively. Figures 1 and 2 show the annual (red lines) and cumulative MAF values (blue lines) for the same subset of regions and also a zoom in on just the selected regions highlighted above. The value of the blue line at 2050 in these figures is the value in the table above.

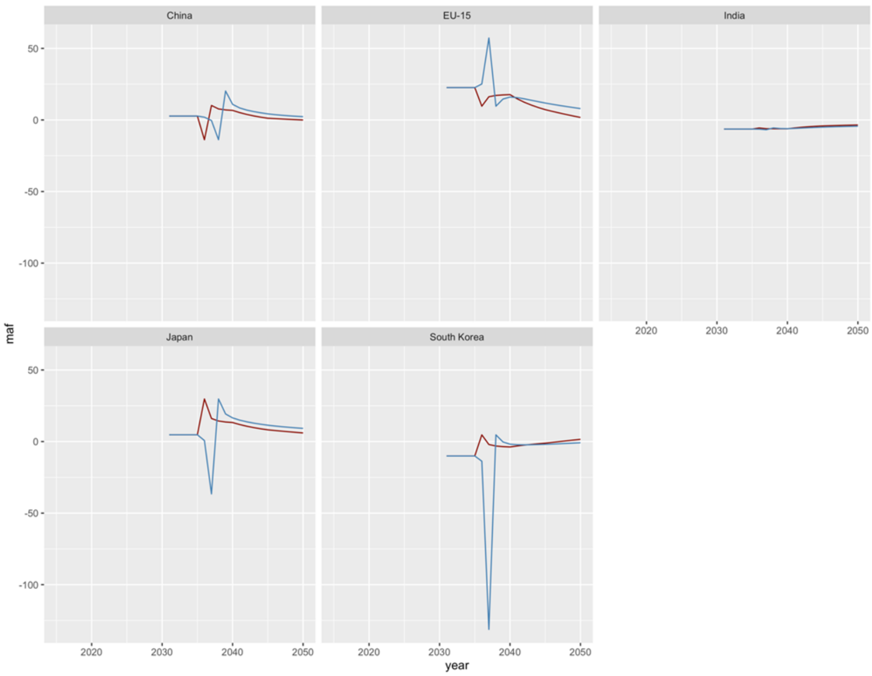


Figure 1: Hypothetical Regional MAFs for Expected Top Import Partners for US LNG in the Future

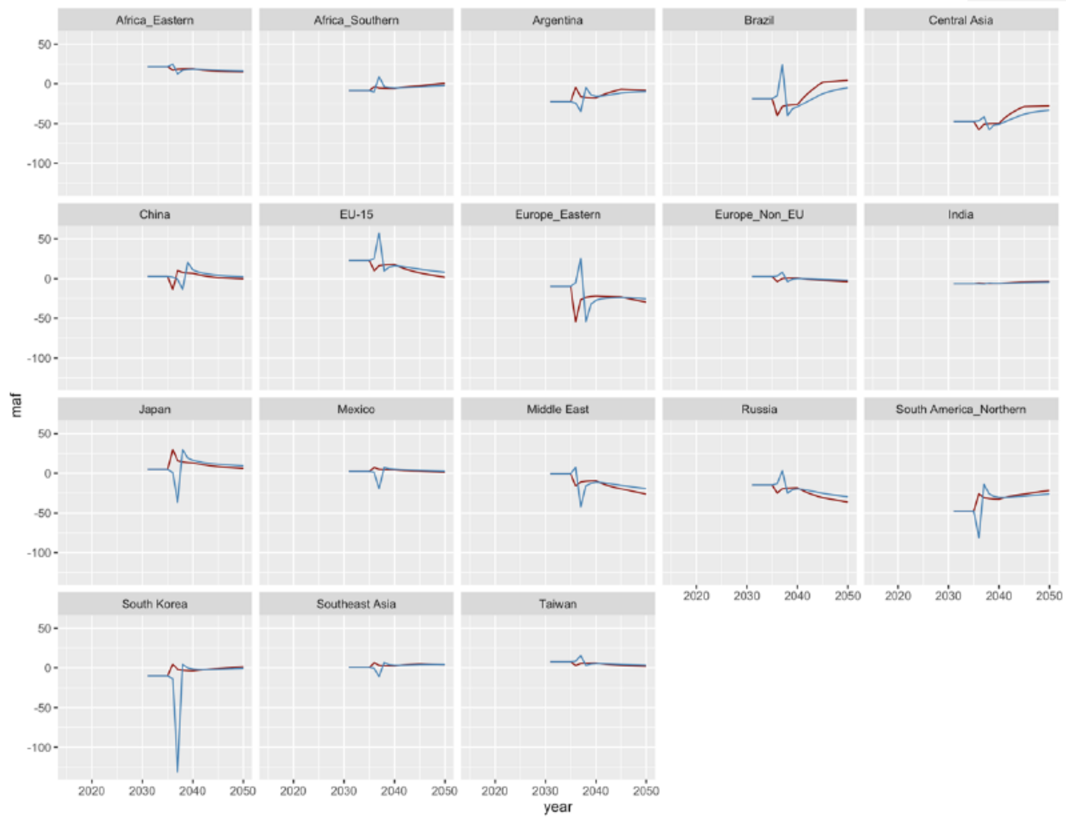


Figure 2: Hypothetical Regional Results for Expected Top Import Partners for US LNG in the Future

Figure 3 shows the not previously shown time series of annual and *global* MAF values that have been previously summarized in the report (and memo, above).

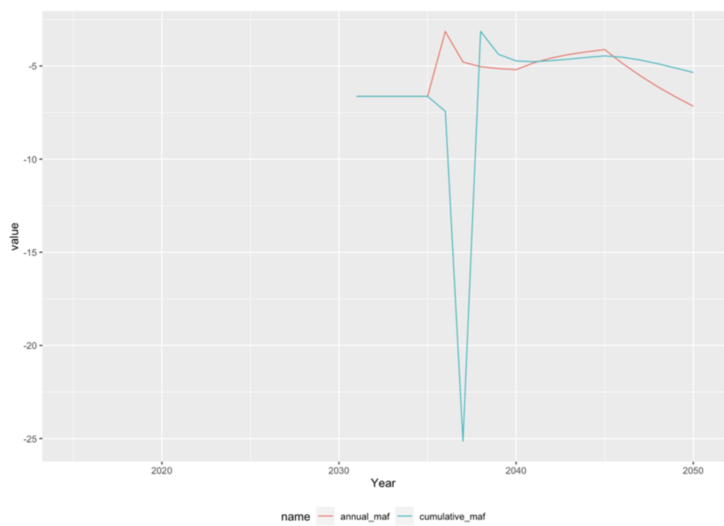


Figure 3: Global Annual and Cumulative MAFs

These results show that there are some negative-positive spikes of annual MAF values in the period 2035-2040, which happen due to a few reasons:

(1) The scenario results for CO_2e and LNG finally start to differ in that time period (but recalling that S1 and S2 separately depend on GCAM or NEMS for the underlying LNG export values)

(2) As they only differ in this time period by a small amount in this time period, small and less than 1 values in the (delta LNG) denominator can lead to visible (swings in) MAF results.

(3) There are changes in the sign of the CO2e and LNG deltas or the MAF (e.g., initially negative/negative = positive and then a slight change in one value and its then -/+ = negative), and vice versa

(4) Interpolating the underlying values (CO_2 emissions, LNG exports) between 5-year model timesteps separately before dividing them, rather than interpolating the every 5 year MAF results.

Finally, additional care may be needed in describing the presentation and application of the cumulative MAF values as the default metric in the study. While LNG is going to be exported in a particular year into the global market (e.g., 2025), which would lead to a specific set of emissions (if we believed the model, it would be the specific value shown for that year in the graph), the *cumulative* MAF (blue line value at 2050) is what is summarized in the study.

While the decisions or authorizations are connected to these annual emission and MAF results, there are biases that could be introduced if only the annual (or 5-year cumulative period) MAFs were used (for example, a five year period with a positive or negative value when the cumulative is the opposite). It thus seems appropriate given the results in hand to assume that exports would continue for the foreseeable future into the global market, and while the graphical results show how they might vary year to year, the cumulative result over the entire 35 year period of the GCAM model results is ~~an~~ the appropriate metric.

Commented [ST2]: At what time step interval? 15, 20, 30, 35, 50 years? How do we determine the correct cumulative time period? Basing it on the export authorization time period for consistency? Or a point with greater market certainty?

From: Matthews, Howard Scott (CONTR)
Sent: Wed, 11 Oct 2023 18:20:48 +0000
To: Jamieson, Matthew B (NETL); Skone, Timothy
Subject: updated LNG report
Attachments: DOE_FECM_LNG_Analysis_Report_Comments_28Sep23_Responses_local.docx, DOE_FECM_LNG_Analysis_Report_Comments_28Sep23_Responses_local_clean.docx

Gentlemen:

Attached please find the current draft, with all edits (not just LCA). Tracked and clean versions.

Edits focused on (clean version) pages 17-21 , 47-51, and Appendix C (pp 70-). Still formatting our results table.

Aside from addressing all previous comments.. I have NOT tried to update our collective thought on how to portray or use the MAF results (-5, zero, tipping points, etc). Open to thoughts or edits for those.

Goal is to finalize in next few days, as tech editing team is already involved.

Scott

H. Scott Matthews
NETL Support Contractor
Department of Energy National Energy Technology Laboratory
scott.matthews@netl.doe.gov

ENERGY, ECONOMIC, AND ENVIRONMENTAL ASSESSMENT OF U.S. LNG EXPORTS

FINAL REVIEW DRAFT September 5, 2023

Prepared for:

Office of Resource Sustainability
U.S. DEPARTMENT OF ENERGY | Fossil Energy and Carbon Management

Prepared by:

OnLocation, Inc.
501 Church St NE, Suite 300
Vienna, VA 22180

Joint Global Change Research Institute
Pacific Northwest National Laboratory
5825 University Research Ct
College Park, MD 20740

National Energy Technology Laboratory
Department of Energy
3610 Collins Ferry Road
Morgantown, WV 26505

Table of Contents

I. Executive Summary 1

II. Background on LNG Export Studies Commissioned by Department of Energy 5

III. Introduction 7

A. Project Background 7

B. Purpose of Study 7

C. Organization of the Report 9

IV. Scenarios, Methodology, and Key Assumptions 10

A. GCAM Model and Global Scenarios Design 10

B. NEMS Models and Analysis Methodology 14

1. AEO2023-NEMS 14

2. FECM-NEMS 14

3. Harmonizing GCAM and NEMS 15

C. NETL Life Cycle Analysis Model Methodology 16

1. Past NETL Natural Gas Life Cycle Reports 17

2. Market Adjustment Factors 20

V. Results 21

A. U.S. LNG exports 21

B. Global Natural Gas Consumption, Production, and Trade Under Scenarios *S1* And *S2* 22

C. Global Primary Energy Consumption by Fuel and GHG Emissions by Sector Under *S6* And *S7* 25

D. Global Natural Gas Consumption, Production, and Trade Under Scenarios *S6* and *S7* 28

E. Global Primary Energy Consumption and GHG Emissions Across All Scenarios 32

F. NEMS Analysis: Implications for U.S. Energy Systems 33

1. Energy Impacts 33

2. Natural Gas Production and Consumption Impacts 34

3. Natural Gas Henry Hub Prices Impacts 37

4. U.S. Macroeconomic Outcomes 38

5. U.S. GHG Results 42

G. NETL Life Cycle Analysis 43

1. Assessment of NEMS Domestic Natural Gas Production by Region 44

2. Comparison of GCAM and NETL Estimates of GHG Emissions of the Natural Gas sector 44

3. Market Adjustment Factor Results 46

4. Interpretation of Market Adjustment Factor Results 47

VI. Conclusions 47
Appendix A: Global Analysis and Description of GCAM....................50
A. Additional detail about GCAM's energy system 50
B. Additional detail about scenario design 51
C. Additional GCAM results....................52
Appendix B: U.S. Analysis and Description of AEO2023-NEMS and FECM-NEMS 56
A. Modeling U.S. LNG exports....................56
B. Additional detail on U.S. natural gas markets 57
1. Regional natural gas production....................57
2. Natural gas consumption by economic sector....................58
C. CO_2 removal technologies and carbon prices in FECM-NEMS....................63
Appendix C: Supporting LCA Analysis 65
A. NEMS and NETL LCA model comparison 65
B. Global Change Assessment Model – data inputs to LCA 69
C. GCAM and NETL emissions intensity comparison 70
1. Market Adjustment Factors for other IPCC GWP Values....................75
Appendix D: Tabulated Values from Figures 83

List of Figures

Figure ES-1. U.S. LNG exports across the scenarios explored in this study. 4
Figure 1. U.S. GHG emissions and removals in the net-zero scenarios 16
Figure 2. Life cycle GHG emissions from the 2020 U.S. average Natural Gas supply chain, HHV basis......19
Figure 3. U.S. LNG exports across the scenarios.....................21
Figure 4 Natural gas consumption, production, and trade by region....................23
Figure 5. Changes in natural gas consumption, production, and trade by region in S2 vs. S1 24
Figure 6. Global primary energy consumption by fuel and GHG emissions by sector under S2 and S1.....25
Figure 7. Global primary energy consumption by fuel and GHG emissions by sector under S6 and S7.....26
Figure 8. Changes in global primary energy consumption and GHG emissions under S6 and S7..............27
Figure 9. CDR deployment by type and region in S6 and S7....................28
Figure 10. Natural gas consumption, production, consumption, and trade by region under S6 and S7....29
Figure 11. Changes in natural gas consumption, production, and trade by region: S6 vs S1 and S7 vs S2 30
Figure 12. Changes in natural gas markets in S7 vs. S6 31
Figure 13. Primary energy consumption by fuel and GHG emissions by sector under all scenarios..........32
Figure 14. U.S. primary energy consumption, S1 through S5....................33
Figure 15. U.S. primary energy consumption S6 and S7....................34
Figure 16. Total U.S. natural gas production, consumption, and export volumes over time, by scenario.35

Figure 17. Total U.S. natural gas production, consumption, and export volumes, net-zero scenarios......36
Figure 18. Total U.S. natural gas Henry Hub price by scenario ($2022) 37
Figure 19. U.S. real GDP changes...38
Figure 20. U.S. residential natural gas prices...39
Figure 21. U.S. value of industrial shipments and real consumption 40
Figure 22. U.S. LNG export revenues 41
Figure 23. Total U.S. CO_2 emissions from fossil fuel combustion 42
Figure 24. Total U.S. CO_2 emissions from fossil fuel combustion and removals, S6 and S7 43
Figure 25. Mapping of NETL natural gas stages to GCAM sectors...45

Appendix A Figures

Figure A-1. Global natural gas consumption by sector across all scenarios 52
Figure A-2. Global natural gas consumption by region across all scenarios..52
Figure A-3. Global natural gas production by region across all scenarios 53
Figure A-4. Global LNG exports by region across all scenarios..53
Figure A-5. Global LNG imports by region across all scenarios 54
Figure A-6. Global primary energy consumption by fuel across all scenarios 54
Figure A-7. Global GHG emissions by sector across all scenarios..55

Appendix B Figures

Figure B-1. U.S. Regional Natural gas production, S1 through S5 57
Figure B-2. U.S. regional natural gas production in S6 and S7..58
Figure B-3. U.S. natural gas consumption by sector, S1 through S5..59
Figure B-4. U.S. natural gas consumption by sector, net-zero scenarios 61
Figure B-5. Natural gas consumed for DAC, net-zero scenarios 62
Figure B-6. U.S. CO_2 emissions and removals, net-zero scenarios...63

Appendix C Figures

Figure C-1. Dry NG production percentage time-series for each region 68
Figure C-2. Estimated U.S. Average GHG Intensity (g CO_2e/MJ) (S1 through S7), ...69

List of Tables

Table 1. Previous Studies..5
Table 2. Scenario Descriptions..13
Table 3. Natural Gas and Liquefied Natural Gas Life Cycle Stages...17
Table 4. Market Adjustment Factors for S2 vs. S1...46
Table 5. Market Adjustment Factors for S7 vs. S6...46
Table 6. Key Results for U.S. and globe in 2050 across scenarios...49

Table A-1. Detailed assumptions in the S4: Regional Import Limits scenario..51

Table B-1. DAC technology assumptions in FECM-NEMS 64
Table C-1. Matching NEMS (OGMP States) to NETL states and subsequently regions....65
Table C-2 Regional dry production (trillion cubic feet) between 2020 and 2050, S1 67
Table C-3 Regional dry production ratio, S1 67
Table C-4. Regional GHG Intensities (g CO_2e/MJ) from 2020 NETL Natural Gas Report....68
Table C-5. Provided set of GCAM Data Documentation 69
Table C-6. LCA Stage Cross-Mapping 71
Table C-7. GCAM Emissions Intensities for Sectors (S1, 2020, USA region, AR6-100 basis) 72
Table C-8. GCAM Emissions Intensities for Sectors (S1, 2020, USA region, AR6-20 basis) 73
Table C-9. GCAM Emissions Intensities for Sectors (S1, 2020, USA region, AR5-100 basis) 74
Table C-10. GCAM Emissions Intensities for Sectors (S1, 2020, USA region, AR5-20 basis) 74
Table C-11. GWP Values used in this analysis....75
Table C-12. NETL-adjusted MAF results for S2 75
Table C-13 NETL-adjusted MAF results for S7 76
Table C-14. Annual Export Volumes of US LNG and Adjusted Global CO_2 Emissions (IPCC AR6, 100-yr GWP)....76
Table D-1. U.S. GHG emissions and removals scenarios S6 and S7, by year (Figure 1) 83
Table D-2. U.S. primary energy consumption, S1 through S5, tabulated by year (Figure 14) 83
Table D-3. U.S. primary energy consumption, S6 and S7, by year (Figure 15) 84
Table D-4. Total U.S. natural gas production, consumption, and export volumes, S1 through S5, by year (Figure 16) 85
Table D-5. Total U.S. natural gas production, consumption, and export volumes, S6 and S7, by year (Figure 17) 85
Table D-6. U.S. natural gas Henry Hub price, S1 through S7, tabulated by year (Figure 18)....86
Table D-7. U.S. real GDP, S1 through S5, by year (Figure 19) 86
Table D-8. U.S. residential natural gas prices, S1 through S5, by year (Figure 20) 86
Table D-9. U.S. value of industrial shipments and real consumption, S1 through S5, by year (Figure 21).87
Table D-10. U.S. LNG export revenues, S1 through S5, by year (Figure 22) 87
Table D-11. Total U.S. CO_2 emissions from fossil fuel combustion, S1 through S5, by year (Figure 23).....87
Table D-12. U.S. CO_2 emissions, fossil fuel combustion and removals, S6 and S7, by year (Figure 24)......88
Table D-13. U.S. regional onshore natural gas production, S1 through S5, by year (Figure B-1) 88
Table D-14. U.S. regional onshore natural gas production, S6 and S7, by year (Figure B-2) 89
Table D-15. U.S. natural gas consumption by sector, S1 through S5, by year (Figure B-3) 89
Table D-16. U.S. sectoral natural gas consumption by sector, S6 and S7, by year (Figure B-4) 91
Table D-17. U.S. regional natural gas consumption for DAC, S6 and S7, by year (Figure B-5)....91
Table D-18. U.S. CO_2 removals by technology, S6 and S7, by year (Figure B-6) 91

Acronyms and Abbreviations

AEO	Annual Energy Outlook
BECCS	Bioenergy with carbon capture and storage
Bcf	Billion cubic feet
BIL	Bipartisan Infrastructure Law
BP	British Petroleum
BTU	British Thermal Unit
~~**CAFE**~~	~~Corporate Average Fuel Economy~~
CCS	Carbon capture and storage
CCUS	Carbon capture, utilization, and storage
CDR	Carbon dioxide removal
CH_4	Methane
CO_2	Carbon dioxide
DAC	Direct air capture
DOE	Department of Energy
EIA	Energy Information Administration
EJ	Exajoule (10^{18} joules)
EPA	Environmental Protection Agency
EU	European Union
FECM	Fossil Energy and Carbon Management
GHG	Greenhouse gas
GCAM	Global Change Analysis Model
GNGM	Global Natural Gas Model
Gt	Gigaton
GWP	Global warming potential
HMM	Hydrogen Market Module
IPCC	Intergovernmental Panel on Climate Change
ITC	Investment tax credit
IRA	Inflation Reduction Act

Commented [AA1]: Consider deleting. You only mention this once.

Commented [PW2R1]: ok

Commented [PW3]: Deleted CAFE, as per AA

Kwhr	Kilowatt-hour
LHV	Lower heating value
LNG	Liquefied natural gas
LULUCF	Land use, land use change, and forestry
MAF	Market Adjustment Factor
Mcf	Million cubic feet
MJ	Megajoule
MMT	Million metric Tons
NERA	NERA Economic Consulting
NEMS	National Energy Modeling System
NETL	National Energy Technology Laboratory
NGA	Natural Gas Act
NGP	Natural gas processing
NHTSA	National Highway Traffic Safety Administration
NREL	National Renewable Energy Laboratory
N2O	Nitrous oxide
OGSM	Oil and Gas Supply Module
OPEX	Operating Expenses
PNNL	Pacific Northwest National Laboratory
PTC	Production tax credit
S&P	Standard & Poor's
Tcf	Trillion cubic feet
Tg	Teragram (10^{12} grams)

I. EXECUTIVE SUMMARY

The Department of Energy (DOE) is responsible for authorizing exports of U.S. natural gas, including liquefied natural gas (LNG), to foreign countries pursuant to section 3 of the Natural Gas Act (NGA), 15 U.S.C. 717b. Under the NGA provisions, applications requesting authority for the import or export of natural gas, including LNG, from and to a nation with which there is in effect a free trade agreement (FTA) requiring national treatment for trade in natural gas, and/or the import of LNG from other international sources, are deemed consistent with the public interest and granted without modification or delay. For ~~A~~authorizations~~Authorizations~~ relating to those countries with which the United States does not have such an FTA ~~requiring national treatment trade in natural gas and with which trade is not prohibited by U.S. law or policy~~, then pursuant to Section 3(a) of the NGA, DOE is required to grant a permit to export domestically produced natural gas unless it finds that such action is not consistent with the public interest.

To inform its ~~P~~public ~~I~~interest~~Public Interest~~ determination, since 2012, the Office of Fossil Energy and Carbon Management (DOE-FECM) and its predecessor, the Office of Fossil Energy, ~~previously~~ has commissioned five studies to assess the effects of different levels of LNG exports on the U.S. economy and energy markets. This sixth updated study, like the previous ones, ~~served~~ will serve~~sd~~ as an input to be considered in the evaluation of applications to export LNG from the United States under Section 3 of the NGA.

The purpose of this latest study ~~was~~ is to examine the potential global and U.S. energy system and greenhouse gas (GHG) emissions implications of a wide range of economic levels of U.S. LNG exports. The study was comprised of three coordinated analyses: 1) **a Global Analysis** to explore a wide range of scenarios of U.S. LNG exports under alternative assumptions about future ~~socioeconomic~~ population and economic growth, regional preferences for domestically produced natural gas, pace of technological change in competing technologies (e.g. renewables), and countries' announced GHG emissions pledges and policies; 2) **a U.S. Domestic Analysis** of the implications of the various U.S. LNG export levels derived from the Global Analysis for the supply and demand of natural gas within the U.S. and the U.S. economy; and 3) **a Life Cycle Analysis** to examine the life cycle emissions implications of the various levels of U.S. LNG exports derived from the Domestic and Global analyses.

As part of the **Global Analysis**, ~~we~~ DOE-FECM explored seven scenarios spanning a range of plausible U.S. LNG export outcomes by 2050 using the Pacific Northwest National Laboratory's Global Change Analysis Model (GCAM). GCAM is a model of ~~the~~ global energy, economy, agriculture, land use, water, and climate systems with regional detail in 32 geopolitical regions. This includes major economies as single-country regions (e.g., U.S., Canada, China, India, Russia). The seven scenarios explored in this study are shown in Table ES-1.

Commented [TC4]: Let's add a paragraph on general limitations on modeling, consistent with the discussion at and following the leadership briefing. The Exec Summary should have a summary of caveats and the introduction should have a broader discussion.

Commented [TC5]: Global comments:
-The report needs an edit to improve consistency of voice.
-Make sure there is consistency in units. Consistent report units. GCAM uses EJ and NEMS is quads (quadrillion Btu). 1 quad = 1.-5506 EJ
a.There is a mix in the report currently.
i.Primary Energy: quads and EJ
ii.Gas production/Exports/Imports: Tcf and Bcf/day
iii.GHG emissions: Gigatonnes (metric tons), MMT (million metric tons)
iv.LCA/GHG: grams per megajoule
b.Recommend energy and mass be in metric units and volume (of gaseous natural gas) be reported in English units of cubic feet (industry standard convention).
-Move away from qualitative descriptions like "modest" or "small" and toward quantitative information with context for the reader to make a qualitative assessment.
-Include detailed data that can be used by the reader to understand figures in new appendices.
-In general, the report would benefit from more discussion of why the trends or results we are seeing are consistent with expectations. For example, making comments about US prices increasing in response to increased demand for natural gas.
-As we are developing responses to the IA and GC comments in separate documents, we should look to add context to this report.

Commented [ZA6]: This is not an (b)(5) [redacted], and it is currently framed as such. (b)(5) [redacted].

Commented [LBD7]: I'm not familiar with "growth" as a noun modified by this word... if this is meant to mean both population growth and economic growth, suggest saying both. Or maybe it's just "economic growth"?

Commented [IGC8R7]: It refers to population and economic growth.

Table ES-1. Scenario Descriptions

Scenario	Description	U.S. LNG Export Volumes (Bcf/d)
***S1*: Reference Exports**	~~Reference scenario in which~~ U.S. LNG exports follow Energy Information Administration's (EIA's) 2023 Annual Energy Outlook (AEO). Incorporates U.S. policy assumptions (including the 2022 Inflation Reduction Act). Assumes existing policies and measures, globally.	Grows to 27.34 Bcf/d by 2050
***S2*: Market Response**	Assumes policies consistent with *S1*, but U.S. LNG exports are determined by global market equilibrium.	GCAM Market Response
***S3*: High Global Demand**	Same assumptions as *S2*, U.S. LNG exports determined by global market equilibrium, but assumes higher population growth outside of the U.S.	
***S4*: Regional Import Limits**	Same assumptions as *S2*, U.S. LNG exports determined by global market equilibrium, but includes constraints on importing and exporting natural gas with a global focus to maximize use of domestic gas.	
***S5*: Low-cost Renewables**	Same assumptions as *S2*, U.S. LNG exports determined by global market equilibrium, but assumes lower capital costs for renewable energy technologies.	
***S6*: Energy Transition (Ref Exp)**	Assumes an emissions pathway consistent with a global temperature change of 1.5°C by end of century. Countries' emissions are constrained to announced GHG pledges, including the U.S. following a path to net-zero GHG emissions by 2050. NEMS follows CO_2 emissions constraint from GCAM. U.S. LNG exports are limited to the values from the AEO 2023 Reference scenario.	Grows to 27.34 Bcf/d by 2050
***S7*: Energy Transition**	Same emissions pathway assumptions as *S6*, but U.S. LNG exports are determined by global market equilibrium.	GCAM Market Response

Commented [UP9]: Do we have to show by 2 digits in 2050? EIA's TIE article for example rounds to just 1-digit showing 27.3 Bcf/d which prob is better. https://www.eia.gov/todayinenergy/detail.php?id=56600

Commented [PW10R9]: Revised, thank you.

Commented [UP11]: S6 has a different background color than the other sections of the table? Also on the third column why is GCAM Market Response "white background" for S2-S5 but then "blue" for S7?

All of the scenarios include representations of the 2022 Inflation Reduction Act (IRA) in the U.S. and existing emission policies in the rest of the world. The scenarios also include a constraint on Russian exports. The modeling and analysis for this report was completed by August 2023.

The **U.S.** ~~domestic~~ Ddomestic Aa**nalysis** was conducted using the National Energy Modeling System (NEMS). U.S. LNG exports (for all scenarios except *S1*) and CO_2 emissions (in scenarios *S6* and *S7*) used in NEMS were harmonized to values from GCAM. NEMS was then used to explore the implications of the seven global scenarios ~~for~~ on domestic gas prices, the energy system, and the macro-economy within the U.S.

Finally, the **Life Cycle Analysis** of natural gas used for export was enhanced by comparing the results provided from the domestic and global analyses to previously completed National Energy Technology Laboratory (NETL) studies of the natural gas life cycle. GCAM results were assessed against existing DOE life cycle studies of natural gas and aligned to have the same GHG intensity for the purposes of consistency. The main results of this analysis were a series of estimated market adjustment factors that supplement the previous life cycle analyses and better represent the total global change in emissions per unit of U.S. LNG exported.

A number of key insights emerged from this study:

1. Across all modeled scenarios, U.S. LNG exports and U.S. natural gas production increase beyond current levels-through 2050 (Figure ES-1). In these scenarios, U.S. LNG exports range from 23 to 49 Bcf/day. The range of U.S. LNG exports from this study is consistent with the U.S. EIA's analysis (15-48 Bcf/day).[1]
2. Global natural gas consumption increases ~~only slightly (by less than~~ <1-%~~percent)~~ under a scenario with increased availability of U.S. natural gas in the global market that reflects economically-driven LNG export levels (S2) compared to the reference scenario (S1). ~~The majority of~~Most of the additional U.S. natural gas substitutes for other global sources of natural gas.
3. By 2050, U.S. natural gas prices as measured at the Henry Hub increase ~~modestly~~ when comparing a scenario that reflects global market demand for exports (S2) to the reference scenario (S1). Across those scenarios, 2050 Henry Hub prices ~~were~~ are projected to increase from $3.88~~61~~/Mcf to $~~4.74~~5.09/Mcf ($2022), both of which are less than the reference 2050 price expected in the most recent study[5] commissioned on the economic impacts from U.S. LNG exports in 2018. While LNG export profiles were different, natural gas prices in S2 were comparable to the "Fast Builds Plus High LNG Price" scenario ($4.98/Mcf).
4. U.S. residential prices ~~were~~ are projected to be 4% higher in 2050 when comparing a scenario that reflects global market demand for exports (S2) to the reference scenario (S1).
5. The value of industrial shipments remains essentially unchanged (increasing less than 0.1% by 2050) under a scenario that reflects global market demand for exports (S2) compared to the reference scenario (S1). The impact of increased LNG exports on GDP is essentially flat: positive by less than 0.1% across scenarios through 2045 while all changes are within 0.3% in 2050.

[1] U.S. EIA. (2023). Issues in Focus: Effects of Liquefied Natural Gas Exports on the U.S. Natural Gas. Available at: Markethttps://www.eia.gov/outlooks/aeo/IIF_LNG/

Commented [UP12]: Should "economically driven" have a hyphen or not? We seem to sometimes hyphenate it and sometimes not. I added hyphens but can be reversed.

Commented [IGC13R12]: I am OK with economically-driven, with the hyphen.

Commented [ZA14]: Is a 30% price increase modest?

Commented [LBD15]: Hard to describe as a "modest" increase, if in constant dollars. The increase is almost 1/3.

Commented [PW16R15]: Removed.

Commented [LBD17]: Suggest specify real or current dollars

Commented [PW18R17]: Added constant dollrs

Commented [AA19]: Just FYI for tech writer: Previous references were not italicized.

6. Global and U.S. GHG emissions do not change appreciably across the scenarios with current climate policy assumptions (S2 to S5) even though these scenarios vary widely in terms of U.S. LNG export outcomes. In these scenarios, global net GHG emissions range from 47.5-50.3 $GtCO_2e$ ~~global net GHG emissions ($GtCO_2e$)Gt CO_2e~~ and U.S. emissions range from 4.3-4.6 ~~$GtCO_2e$Gt CO_2e while U.S. LNG exports range from 23 to 47 Bcf/day~~.
7. The induced global market effects per unit of increased U.S. LNG exports in a scenario that reflects global market demand for exports (S2) compared to the reference scenario (S1) are equivalent to an overall reduction in GHG emissions that is about 70% of the estimated upstream emissions associated with production through delivery of the natural gas through the transmission system in the U.S.
8. Relative to the other scenarios, the scenarios in which countries are assumed to achieve GHG emissions pledges and pursue ambitious GHG mitigation policies (S6 and S7) are characterized by lower energy consumption; lower fossil fuel consumption without carbon capture, utilization, and storage (CCUS)~~;~~; higher deployment of renewables and fossil fuels and biomass with CCUS; and higher deployment of carbon dioxide removal strategies.

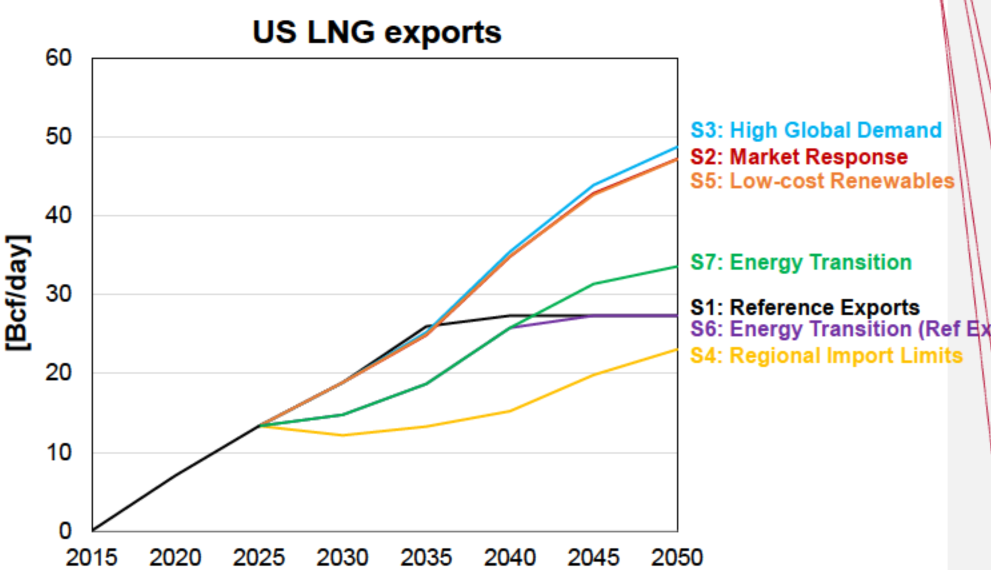


Figure ES-1. U.S. LNG exports across the scenarios explored in this study. Note that the U.S. LNG export outcomes for S2 and S5 were very close to each other.

Several considerations are required in interpreting this study and its results. Foremost, this study is not intended to serve as forecasts of U.S. LNG exports. Rather, it is an exercise in exploring alternative conditional "what-if" scenarios of future U.S. LNG exports and examining their implications for the global and U.S. energy and economic systems, and GHG emissions. Such scenario analysis is a well-established analytical approach for exploring complex relationships across a range of variables. In addition, the scenarios explored in this study are meant to span a range of plausible U.S. LNG export

Commented [UP20]: Shouldn't this be 49 Bcf/d based on S3 scenario (see page 21)?

Commented [WS21]: There is a notable difference in the way we present the data from our conclusions. When we reference GDP, gas consumption, and prices, we scale the effect against the global or national total, resulting in small percentage changes. When we talk about GHGs we scale the effect to units of gas exported. But the table in the appendix shows that the reduction in emissions between S2 and S1 is 50 million tons – or roughly 0.01% of global emissions. I recommend that we take a more consistent approach to characterizing the model results.

Commented [PW22R21]: This result is relevant to extending the LCA analysis, and results from a distinct methodolg.. LCA are always expressed per unit.

Suggest adding In order to enhance the LCA analysis of LNG exports.

Commented [WS23]: This sentence has way too many elements and needs to be re-written.

Commented [LBD24]: It's not completely clear to me why this comparison is made – it seems like there is a projected reduction in GHG emissions from S1 to S2, but it's small? A global reduction equal to 70% of the LC emissions of one large industrial user? If that's correct, it might be clearer to just present the percentage reduction, or say that it was essentially the same level of emissions.

Commented [ST25]: Did we run a non-CCUS S6 and S7 case?

What supports this finding?

Commented [IGC26R25]: All of our scenarios include both fossil fuel technologies w/ and w/o CCUS. The point of this statement is to compare S6 and S7 that have climate policy with other scenarios S1-S5 without climate policy. Compared to the scenarios *without* climate policy (S1-S5), the scenarios *with* climate policy (S6-S7) have lower fossil w/o CCUS.

Commented [IGC27]: I've copied this paragraph here – including an expanded discussion – from the Introduction. May need to rephrase some of the sentences here or simply delete this paragraph from the Intro section.

Commented [IGC28R27]: Update: I think we decided to keep in both places.

outcomes by 2050. However, they hinge on many assumptions about a wide range of domestic and international, and economic and non-economic factors such as future socioeconomic development, technology and resource availability, technological advancement, institutional change, etc. A full uncertainty analysis encompassing all of the above factors was beyond the scope of this study. This study does not attach probabilities to any of the scenarios and no inference about the likelihood of these scenarios occurring should be made. Finally, scenarios S6 and S7 that incorporate countries' climate pledges do not explicitly model the actual policy instruments and mechanisms that countries might adopt to meet their pledges – due to lack of sufficient literature on policies and regulations over the longer time horizon of focus in this study. Instead, these scenarios assume that countries achieve their pledges within their geographic boundaries through a combination of cost-effective strategies. The results from these scenarios described in this report could be different depending on the actual policies and mechanisms countries use to meet their pledges.

II. Background on LNG Export Studies Commissioned by Department of Energy

Since 2012, the Office of Fossil Energy and Carbon Management (DOE-FECM) and its predecessor, the Office of Fossil Energy, ~~previously~~ has commissioned five studies on the effects of increased LNG exports on the U.S. economy and energy markets. The previous studies of the impact of LNG exports are listed in Table 1.

Commented [UP29]: Table 1 should be moved back to below paragraph 1 where it is mentioned.

Commented [PW30R29]: Done

The EIA 2012 study examined four different levels of exports across four domestic natural gas supply scenarios for a total of 16 scenarios. Exports ranged from 6 to 12 Bcf/day with varying trajectories. The supply scenarios were: AEO2011 Reference, High Shale Estimated Ultimate Recovery (EUR), the Low Shale EUR, and High Economic Growth. Key results demonstrate that domestic natural gas markets balanced the increased exports through increased supply and prices and a reduction in demand for power generation and in the other sectors.

The NERA 2012 report used NERA's Global Natural Gas Model (GNGM) and NewERA energy-economy model to look at the domestic economic effects of LNG exports. Building upon the EIA 2012 study, the NERA 2012 report examined sixteen scenarios from the earlier study using different assumptions on natural gas supply and demand. The report additionally included scenarios examining the global demand for U.S. LNG exports and the macroeconomic impact of increased LNG exports on the economy.

The EIA 2014 study included updated export scenarios from 12 to 20 Bcf/day and domestic natural gas supply scenarios from AEO2014: the Low and High Oil and Gas Resource scenarios, High Economic Growth, and Accelerated Coal and Nuclear Retirements. Increased exports led to increased natural gas production and prices relative to respective base scenarios, ~~though also~~as well as higher primary energy consumption and energy-related CO_2 emissions.

Table 1. Previous Studies

Report Name	Organization	Short Name
Effect of Increased Natural Gas Exports on Domestic Energy Markets[2]	EIA	EIA 2012
Effect of Increased Natural Gas Exports on Domestic Energy Markets[3]	NERA	NERA 2012
Effect of Increased Levels of Liquefied Natural Gas Exports on U.S. Energy Market[4]	EIA	EIA 2014

[2] U.S. EIA. (2012). Effects of Increased Natural Gas Exports on Domestic Energy Markets. Available at: https://energy.gov/sites/prod/files/2013/04/f0/fe_eia_lng.pdf
[3] NERA Economic Consulting. (2012). Macroeconomic Impacts of LNG Exports from the United States. Available at: https://energy.gov/sites/prod/files/2013/04/f0/nera_lng_report.pdf
[4] U.S. EIA. (2014). Effect of Increased Levels of Liquefied Natural Gas Exports on U.S. Energy Markets. Available at: https://www.eia.gov/analysis/requests/fe/pdf/lng.pdf

Report Name	Organization	Short Name
The Macroeconomic Impact of Increasing U.S. LNG Exports[5]	Baker Institute/ Oxford Economics	Baker 2018
Macroeconomic Outcomes of Market Determined Levels of U.S. LNG Exports[6]	NERA	NERA 2018

The Baker 2015 study examined U.S. LNG exports of 12 and 20 Bcf/day. Two models were used: an international natural gas model (from the Baker institute) and a global economic model from Oxford Economics. This study outlined the international conditions that could result in a market for over 20 Bcf/day of LNG exports and examined ~~in~~ the impact on the U.S. economy of scenarios with 12 and 20 Bcf/day of LNG exports ~~and~~ with low gas resource recovery, high gas resource recovery, and high natural gas demand.

The NERA 2018 study again used NERA's Global Natural Gas Model and the NewERA energy-economy model to look at the domestic economic effects of LNG exports. LNG exports were determined by the model for each scenario. The study included 54 different scenarios capturing a broad range of domestic and international gas supply and demand conditions, and probabilities on the likelihood of each of the 54 export scenarios. In general, high levels of LNG exports corresponded to high oil and gas supply but higher prices. Since approximately 80% of the exports resulted from increased production rather than decreased demand, the general economic impact was positive across the scenarios. The report concluded that the impact on energy-intensive~~sensitive~~ industries was ~~very small~~minimal while increased investment attributed to LNG exports raised GDP.

[5] Cooper, A., Kleiman, M., Livermore, S., & Medlock III, K. B. (2015). The Macroeconomic Impact of Increasing US LNG Exports. Available at: https://energy.gov/sites/prod/files/2015/12/f27/20151113_macro_impact_of_lng_exports_0.pdf

[6] NERA Economic Consulting. (2018). Macroeconomic Outcomes of Market Determined Levels of U.S. LNG Exports. Available at: https://www.energy.gov/sites/prod/files/2018/06/f52/Macroeconomic%20LNG%20Export%20Study%202018.pdf

III. INTRODUCTION

Commented [AA31]: Perhaps I missed it, but it would be nice to have a section on "limitations" or a disclaimer or a brief description of what this study did not/cannot do.

Commented [PW32R31]: Paragraph on limitations now last paragraph of Purpose of Study

A. Project Background

The Department of Energy (DOE) is responsible for authorizing exports of natural gas, including LNG, to foreign countries pursuant to Section 3 of the Natural Gas Act (NGA), 15 U.S.C. 717b. Under the NGA ~~provisions~~, applications requesting authority for the import or export of natural gas, including LNG, from and to a nation with which there is in effect a free trade agreement (FTA) requiring national treatment for trade in natural gas, and/or the import of LNG from other international sources, are deemed consistent with the public interest and granted without modification or delay. For ~~A~~authorizations~~Authorizations~~ relating to those countries with which the United States does not have such an FTA ~~requiring national treatment trade in natural gas,~~ and with which trade is not prohibited by the United States law or policy, ~~pursuant to~~ Section 3(a) of the NGA ~~,~~ requires DOE to grant a permit to export domestically produced natural gas unless it finds that such action is not consistent with the public interest.[7]

Commented [ZA33]: Same

Commented [PW34R33]: See above

DOE has identified a range of factors that it evaluates when reviewing an application for LNG export authorization. Specifically, DOE's review of export applications has focused on: "(i) the domestic need for the natural gas proposed to be exported, (ii) whether the proposed exports pose a threat to the security of domestic natural gas supplies, (iii) whether the arrangement is consistent with DOE's policy of promoting market competition, and (iv) any other factors bearing on the public interest as determined by DOE, such as international and environmental impacts."[8]

To inform its ~~P~~public ~~I~~interest~~Public Interest~~ determination, since 2012, the Office of Fossil Energy and Carbon Management (DOE-FECM) and its predecessor, the Office of Fossil Energy, has commissioned five studies on the effects of increased LNG exports on the U.S. economy and energy markets. The studies examined the impacts of increasing demand, including exports, on the domestic natural gas market.

This updated study, similar to the previous studies, ~~was~~ is intended to serve as ~~an input~~a reference to be considered in the evaluation of applications to export LNG from the United States under Section 3 of the Natural Gas Act. DOE-FECM commissioned OnLocation, Inc., Pacific Northwest National Laboratory (PNNL), and the National Energy Technology Laboratory (NETL) to assess the economic level of U.S. LNG exports across seven scenarios representing a broad range of economic, environmental, and political scenarios, along with changes to global greenhouse gas emissions at differing levels of U.S. LNG exports. U.S. LNG exports ~~volumes~~levels (?) were found using a global equilibrium model and were then input~~ted~~ into the domestic model to examine the market effects of increased LNG exports, including natural gas price and consumption across sectors and changes in U.S. greenhouse gas emissions. Finally, the incumbent life cycle analysis of U.S. LNG exports was expanded to incorporate market effects from the results of this study.

Commented [LBD35]: "input" seems awkward. "a reference"?

Commented [PW36R35]: Reference

Commented [UP37]: Not sure what we mean by LNG exports were found in GCAM? I am assuming the volumes or level of LNG exports?

Commented [UP38]: What's the incumbent life cycle analysis? Is that different than the Life Cycle Analysis described in the Executive Summary?

[7] Natural Gas Act. 15 U.S.C. 717b.

[8] Order Amending Long-Term Authorization to Export Liquefied Natural Gas to Non-Free Trade Agreement Nations at 43, Magnolia LLC, Docket 13-132-LNG (April 2022).

B. Purpose of Study

Since the NERA 2018 report was published, several events have altered the explicit and implicit assumptions underpinning the global and U.S. natural gas markets. These include: i) the issuance of additional DOE LNG export authorizations, ii) the Russia-Ukraine war, iii) global and U.S. greenhouse gas policy developments, iv) technological change in production, transmission, storage, and end-use of natural gas, iv) and the passage of significant energy-related legislation in the U.S. (the Infrastructure Investment and Jobs Act[9] also known as the Bipartisan Infrastructure Law (BIL) and Inflation Reduction Act[10] (IRA)). This report ~~updated~~updates~~d~~ previous analytical work in line with current laws and regulations, as well as economic and technology conditions using newly derived scenarios. The defined seven scenarios ~~included~~are:

***S1*: Reference Exports** (Reference scenario in which U.S. LNG exports follow the Reference case from the U.S. Energy Information Administration's 2023 Annual Energy Outlook (AEO))

***S2*: Market Response** (U.S. LNG exports determined by global market equilibrium)

***S3*: High Global Demand** (U.S. LNG exports determined by global market equilibrium, higher population growth outside of the U.S.)

***S4*: Regional Import Limits** (U.S. LNG exports determined by global market equilibrium, global focus on maximizing consumption of local energy sources)

***S5*: Low-cost Renewables** (U.S. LNG exports determined by global market equilibrium, lower costs for variable renewable energy technologies)

***S6*: Energy Transition (Ref Exp)** (U.S. LNG exports are limited to the values from the AEO 2023 Reference case, countries achieve emissions pledges and pursue ambitious GHG mitigation policies consistent with limiting global warming to 1.5°C, U.S. emissions to net-zero by 2050)

***S7*: Energy Transition** (U.S. LNG exports determined by global market equilibrium, countries achieve emissions pledges and pursue ambitious GHG mitigation policies consistent with limiting global warming to 1.5°C, U.S. emissions to net-zero by 2050)

These scenarios are described in more detail in Section 1.A.

Several considerations ~~were~~ are required in interpreting this study and its results. Foremost, this study ~~was~~ is not intended to serve as forecasts of U.S. LNG exports. ~~, R~~ ~~r~~ather, it ~~was~~ is an exercise in exploring alternative conditional "what-if" scenarios of future U.S. LNG exports and examining their implications for the global and U.S. energy and economic systems, and GHG emissions. Such scenario analysis is a well-established analytical approach for exploring complex relationships across a range of variables. In addition, the scenarios explored in this study ~~were~~ are meant to span a range of plausible U.S. LNG export outcomes by 2050. However, they hinge~~d~~ on many assumptions about a wide range of domestic and international, and economic and non-economic factors such as future socioeconomic development,

Commented [UP39]: Should we say "regional energy sources" as in the bolded heading? Local seems like in-country ng source is available versus in the region.

Commented [IGC40R39]: In the way this scenario is implemented in GCAM, each GCAM region - many of which are individual countries - is incentivized to maximize production within their geographic boundaries (through constraints on imports). Hence, "locally" is probably better. But thoughts welcome.

Commented [IGC41]: Should we delete this section since it appears in the Exec summary as well (per Tom's comment).

Commented [PW42R41]: Best in both.

[9] Infrastructure Investment and Jobs Act, Pub. L. 117-58, (November 15, 2021), https://www.congress.gov/117/plaws/publ58/PLAW-117publ58.pdf.
[10] Inflation Reduction Act, Pub. L. 117-169, (August 16, 2022), https://www.congress.gov/117/plaws/publ169/PLAW-117publ169.pdf.

technology and resource availability, technological advancedidment, institutional change, etc. A full uncertainty analysis encompassing all of the above factors was beyond the scope of this study. This study did does not attach probabilities to any of the scenarios and no inference about the likelihood of these scenarios occurring should be made. Finally, scenarios S6 and S7 that incorporate countries' climate pledges do not explicitly model the actual policy instruments and mechanisms that countries might adopt to meet their pledges – due to lack of sufficient literature on policies and regulations over the longer time horizon of focus in this study. Instead, these scenarios assume that countries achieve their pledges within their geographic boundaries through a combination of cost-effective strategies. The results from these scenarios could be different depending on the actual policies and mechanisms that countries use to meet their pledges in reality.

Commented [AA43]: Should this be advancement?

Commented [TC44]: Expand this discussion consistent with the discussion during and after the leadership briefing about the general considerations evaluating and interpreting model results.

Commented [IGC45R44]: I've expanded this discussion to include the points raised during the briefing as suggested.

C. Organization of the Report

Following the Background of LNG Export Studies and Introduction sections of the Report, Section IV of the report presents a more detailed review of the study methodology, scenario design, and key assumptions. Thise section introduces the scenarios, the versions of GCAM and NEMS models used for the analysis, Global and the life cycle Domestic Aanalyseis, respectively, and the Llife Ccycle Aanalysis methodology. Section V of the report includes key results by scenario:

- Levels of U.S. LNG exports by scenario
- Global natural gas and primary energy consumptionmetrics including including natural gas production consumption and trade, and primary global energy consumption and GHG emissions
- Implications for U.S. energy systems
- Life cycle analysis

Section VI summarizes the conclusions drawn from the report.

IV. Scenarios, Methodology, and Key Assumptions

Three primary analytical frameworks were used for this analysis: i) the Global Change Analysis Model (GCAM) developed and maintained at the Pacific Northwest National Laboratory's (PNNL's) Joint Global Change Research Institute, ii) the National Energy Modeling System (NEMS) developed by EIA and modified for this study by OnLocation, and iii) the natural gas system life cycle analysis (LCA) model developed and maintained by NETL. These frameworks and key assumptions are described below.

A. GCAM Model and Global Scenarios Design

GCAM is a model of ~~the~~ global energy, economy, agriculture, land use, water, and climate systems.[11] These systems are represented in 32 geopolitical regions, 384 land subregions, and 235 water basins across the globe. GCAM operates in five-year time-steps from 2015 (calibration year) to 2100 by solving for equilibrium prices and quantities of various energy, agricultural, water, land use, and greenhouse gas (GHG) markets in each time period and in each region. Outcomes of GCAM are driven by exogenous assumptions about population growth, labor participation rates and labor productivity in the 32 geo-political regions, along with representations of resources, technologies, and policy.

Commented [WS46]: When was this model created?

Commented [IGC47R46]: The model was first built in the 80's.

GCAM tracks emissions of twenty-four gases, including GHGs, short-lived species, and ozone precursors, endogenously based on the resulting energy, agriculture, and land use systems. GCAM's energy system contains representations of fossil resources (coal, oil, and gas), uranium, and renewable sources (wind, solar, geothermal, hydro, biomass, and traditional biomass) along with processes that transform these resources to final energy carriers (electricity generation, refining, hydrogen production, natural gas processing (NGP), ~~,~~ and district heat), which are ultimately used to deliver goods and services demanded by end use sectors (residential buildings, commercial buildings, transportation, and industry). Natural gas competes for share with other fuels in the electricity generation sector, and with other fuels and electricity in the buildings, industrial, and transportation sectors. Each of the sectors in GCAM includes technological detail. In every sector within GCAM, individual technologies compete for market share based on the levelized cost of a technology (see appendix for more details). The version of GCAM used in this study also ~~included~~ includes a representation of three carbon dioxide (CO_2) removal strategies that were deployed in scenarios with emissions policies, namely, direct air capture (DAC), bioenergy in combination with carbon capture, utilization, and storage (BECCS), and afforestation.

Commented [AA48]: Consider defining or briefly explaining the difference between these two.

Commented [IGC49R48]: That could be a distraction for this study, since biomass is not a focus of this study. More details are available in the GCAM documentation page:

http://jgcri.github.io/gcam-doc/supply_energy.html which is referenced in the first sentence of the report.

The version of GCAM used in this study includes a representation of natural gas trade that creates price-based competition between domestic and imported natural gas. This representation introduces realistic inertia in the evolution of trade from current patterns. Natural gas can be imported as liquefied natural gas (LNG) or through pipelines. Traded LNG is represented as a single global market. All producers of natural gas can export to a global LNG pool from which importers can import. While the price of domestic gas is based on extraction costs that are derived from long-term regional resource supply curves, the price of imported LNG includes costs for shipping, liquefaction, and regasification in addition to extraction costs. Traded pipeline gas is represented in six regional markets (North America, Latin America, Europe, Russia+, Africa and Middle East, and Asia-Pacific). Exporters of pipeline gas export to

[11] The full documentation of the model is available at the GCAM documentation page (http://jgcri.github.io/gcam-doc/), and the description here and in the appendix is a summary of the online documentation.

one of the six regional pipeline blocs from which importers can import. Inter-pipeline bloc trade can also occur. For example, GCAM's China region exports only to the "Asia-Pacific" pipeline bloc but can import from the "Russia+" pipeline bloc and the "Asia-Pacific" pipeline bloc. These pipeline trade relationships are based on existing relationships. The price of imported pipeline gas includes the costs of building and operating pipeline infrastructure in addition to resource extraction costs. Gross exports and imports of LNG and pipeline gas are calibrated to historical data in GCAM's historical calibration year (2015). In a future model period, trade volumes evolve from historical patterns depending on future demands and prices. For the purposes of this project, historical natural gas producer prices in the U.S. are calibrated to the Henry Hub prices from the ~~Energy Information Administration (~~EIA~~)~~[12] and in Canada, they are calibrated to Alberta marker prices from the BP Statistical Review.[13] For the rest of the world, natural gas producer prices in each GCAM region are based on the cost, insurance, and freight (CIF) prices from S&P (see Table A-1 in the appendix).[14] In a future model period, as demand changes, the change in regional producer prices from the historical calibrated values are calculated endogenously using regional supply curves that represent increasing cost of extraction as cumulative extraction increases. GCAM also tracks turnover of trade infrastructure (e.g., liquefaction and regasification units, and pipelines). Trade infrastructure can either retire naturally or in response to economic changes (e.g., those driven by an emissions policy).

Using GCAM, we explored~~d~~ seven scenarios spanning a range of plausible U.S. LNG export outcomes by 2050 (Table 2). All of our scenarios include the 2022 Inflation Reduction Act in the U.S. and current emission policies in the rest of the world. The scenarios also include a constraint on Russian exports such that Russian pipeline exports to European Union (EU) declined to a level below current levels by 2035 and then remain flat, LNG exports from Russia remain flat beyond 2025, and Russian pipeline exports to the east (e.g., to China) continue to increase. Our scenarios include planned and existing LNG capacity additions in major economies including the U.S., Middle East, Australia, Canada, Southeast Asia, and Africa. Socioeconomic (population and economic growth) assumptions for the U.S. were harmonized to the AEO2023 Reference scenario.

The seven scenarios include:

> ***S1: Reference Exports.*** This scenario assumes that the U.S. LNG exports follow the trajectory from the Reference case of ~~the U.S. Energy Information Administration's (~~EIA's~~)~~ ~~2023 Annual Energy Outlook (~~AEO2023~~)~~ to grow to 27.34 Bcf/day in 2050. The AEO2023 Reference case incorporated U.S. LNG export projects that were either operating or under construction as of August 2022 and then added capacity based on the cost-competitiveness of exporting U.S. LNG to the international market including an annual capacity build-constraint. More specifically, in AEO2023, LNG export facilities had a combined operating capacity of 10.3 Bcf/d with an additional 4.5 Bcf/d of operating capacity under construction. AEO2023 projected an additional

Commented [AA50]: Or "case". The paper uses both terms.

Commented [IGC51R50]: Note to tech editor to ensure consistency across the report while referring to AEO Reference Case/ AEO Reference Scenario.

[12] U.S. EIA (2023). Henry Hub Natural Gas Spot Price. Available at: https://www.eia.gov/dnav/ng/hist/rngwhhda.htm

[13] BP (2022). bp Statistical Review of World Energy. 71st edition. Available at: https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2022-full-report.pdf

[14] S&P Global (2023). S&P Global Commodity Insights. Historical and forecasted LNG prices data sheet.

12.6 Bcf/d of operating capacity that was assumed to be constructed in response to international demand for U.S. LNG.

S2: Market Response. This scenario has assumptions consistent with S1 and assumes economically-driven, market-based outcomes for U.S. LNG exports.

S3: High Global Demand. This scenario includes the same assumptions as in *S2*, but assumes a higher population growth in regions outside of the U.S. consistent with the Shared Socioeconomic Pathways – 3.[15] This results in ~~≈1~~approximately one billion more people globally in *S3* by 2050 compared to *S1 and S2* and explores the effects of higher U.S. LNG exports driven by higher demand for all energy sources (including natural gas) compared to *S2*.

S4. Regional Import Limits. This scenario includes the same assumptions as in *S2*, but with constraints on natural gas imports globally to maximize the use of domestically produced natural gas across the world ~~(Table A-1)~~. This scenario explores the effects of lower U.S. and global LNG exports driven by global energy security concerns and trade limitations.

S5: Low-cost Renewables. *S5* includes the same assumptions as in *S2* but assumes lower capital costs for renewable energy technologies such as onshore and offshore wind, solar photovoltaic, concentrated solar power, and geothermal. This scenario explores the effects of faster technological improvements in competing technologies. While technology cost assumptions in other scenarios are consistent with NREL's Annual Technology Baseline (ATB) "Medium" assumptions, capital cost assumptions for onshore and offshore wind, solar photovoltaic, concentrated solar power, and geothermal technologies under *S5* are based on the "Low" assumptions.

S6: Energy Transition (Ref Cap) **and** ***S7: Energy Transition***. Both scenarios assume an emission pathway that is consistent with a global temperature change of 1.5°C by 2100 derived from published peer-reviewed literature.[16,17,18] Both of these scenarios assume that countries achieve their emission pledges as made during the 26th Conference of Parties of the United Nations Framework on Climate Change held in Glasgow, Scotland, United Kingdom.~~.~~ The pledges include nationally-determined contributions that outline emission reduction plans through 2030, long-term strategies, and net-zero pledges through mid-century. The U.S. is assumed to reduce economy-wide greenhouse gas emissions by 51% in 2030 and 100% by 2050. Countries without pledges are assumed to follow an emissions pathway defined by a minimum decarbonization rate of 8% that is indicative of strong mitigation policies and significant departure from historically observed decarbonization rates. The scenarios assume that countries achieve their pledges within their geographic boundaries without trading emissions. Scenario *S6* differs from *S7* in that it also ~~limits~~ retains U.S. LNG exports to the values from the AEO2023 Reference case. A key distinction between scenarios *S1* and *S6* is that while the former assumes the U.S. LNG

[15] Samir, K. C., & Lutz, W. (2017). The human core of the shared socioeconomic pathways: Population scenarios by age, sex and level of education for all countries to 2100. Global Environmental Change, 42, 181-192.
[16] Fawcett, A. A., et al. (2015). Can Paris pledges avert severe climate change? Science, 350(6265), 1168-1169.
[17] Ou, Y., Iyer, G., et al. (2021). Can updated climate pledges limit warming well below 2°C? Science, 374(6568), 693-695.
[18] Iyer, G., Ou, Y., et al. (2022). Ratcheting of climate pledges needed to limit peak global warming. Nature Climate Change, 12(12), 1129-1135.

exports to follow the AEO2023 Reference case exactly, the latter assumes the values from the AEO2023 Reference case to be an upper bound. Nevertheless, scenario *S6* enables comparisons with *S1*, and scenario *S7* enables comparisons with *S2*.

Table 2. Scenario Descriptions

Scenario	Description	U.S. LNG Export Volumes (Bcf/d)
***S1*: Reference Exports**	Reference scenario in which U.S. LNG exports follow EIA's 2023 Annual Energy Outlook (AEO). Incorporates U.S. policy assumptions (including the 2022 Inflation Reduction Act). Assumes existing policies and measures, globally.	Grow to 27.34 Bcf/d by 2050
***S2*: Market Response**	Assumes policies consistent with *S1*, but U.S. LNG exports are determined by global market equilibrium.	GCAM Market Response
***S3*: High Global Demand**	Same assumptions as *S2*, U.S. LNG exports determined by global market equilibrium, but assumes higher population growth outside of the U.S.	
***S4*: Regional Import Limits**	Same assumptions as *S2*, U.S. LNG exports determined by global market equilibrium, but includes constraints on importing and exporting natural gas with a global focus to maximize use of domestic gas.	
***S5*: Low-cost Renewables**	Same assumptions as *S2*, U.S. LNG exports determined by global market equilibrium, but assumes lower capital costs for renewable energy technologies.	
***S6*: Energy Transition (Ref Exp)**	Assumes an emissions pathway consistent with a global temperature change of 1.5°C by end of century. Countries' emissions are constrained to announced GHG pledges, including the U.S. following a path to net-zero GHG emissions by 2050. NEMS follows CO_2 emissions constraint from GCAM. U.S. LNG exports are limited to the values from the AEO 2023 Reference scenario.	Grow to 27.34 Bcf/d by 2050
***S7*: Energy Transition**	Same emissions pathway assumptions as *S6*, but U.S. LNG exports are determined by global market equilibrium.	GCAM Market Response

Commented [UP52]: Here the Table although the same as in Executive Summary has different coloring. Personally I think looks better blue/white versus two shades of blue throughout.

Commented [UP53]: Same comment on the 2-digits Bcf/d as I had in Executive Summary section. 1-digit would be better to show in a report.

B. NEMS Models and Analysis Methodology

NEMS is ~~an~~a national~~n~~ energy-economic model of the U.S. It projects supply, demand ~~conversion~~, imports, and exports of major energy commodities, and drivers such as macroeconomic conditions, world energy markets, technology choices and costs, resource availability, and demographics. The NEMS model includes both cost minimization representative of competitive markets and behavioral representations of the energy market.

The NEMS model ~~is a modular energy system model. There are~~includes four supply modules covering oil, natural gas, coal, and renewables. There are two conversion modules ~~:~~ converting primary fuels into electricity and petroleum and other liquids into liquid fuel products, respectively. There are four demand modules covering the residential, commercial, industrial, and transportation sectors. Other modules include the macroeconomic module, emissions policy modules, and an integrating module that synthesizes the output across all other modules. NEMS solves iteratively to reach a general market equilibrium across the energy economy. The EIA provides an archive of the NEMS model with source code and input sufficient to reproduce the reference and side cases comprising the Annual Energy Outlook.

1. AEO2023-NEMS

AEO2023-NEMS is OnLocation's version of the NEMS model, modified to allow exogenous input of U.S. LNG exports. The AEO2023 reference scenario has a macroeconomic growth assumption of 1.9% average growth per year. The model has the EIA's interpretation of the Inflation Reduction Act (IRA) which includes most major provisions of the law~~policy~~. The model does not include carbon capture at industrial sites (ethanol, hydrogen, NGP, and cement) or direct air capture (DAC). Therefore, the IRA 45Q credit for DAC is not included. Similarly, IRA 45V hydrogen credits are also not represented in the AEO2023 version of NEMS as it does not have the hydrogen module.

2. FECM-NEMS

FECM-NEMS is a version of NEMS that is based on OnLocation's version of the Annual Energy Outlook 2022 (AEO2022) NEMS model and includes updates that allow for the modeling of deep decarbonization technologies and strategies. FECM-NEMS models the ~~Inflation Reduction Act~~IRA based on FECM's interpretation of the policy. It includes major IRA energy-related provisions including but not limited to the extension of 45Q CO_2 sequestration credits, clean vehicle tax credits, energy efficient home tax credits and rebate programs, clean energy Production Tax Credit (PTC) and Investment Tax Credit (ITC~~,~~), zero emission nuclear credits, and hydrogen tax credits. Additional modeling updates include provisions from the Bipartisan Infrastructure Law (BIL) such as funding for carbon capture demos, CO_2 transportation and storage infrastructure, and updated EPA/NHTSA Corporate Average Fuel Economy~~CAFE~~ standards. For consistency with updated economic assumptions, FECM-NEMS uses the low economic growth assumption from AEO2022, assuming a real GDP average growth of 1.8% per year to 2050.

~~Given the carbon capture opportunities and the net negative carbon technologies such as DAC and bioenergy with CCS (BECCS,), the FECM-NEMS model allows the economy to achieve a net-zero carbon emission scenario.~~

Commented [AA54]: Consider: "It projects supply, demand conversion, imports, exports of major energy commodities, **and** drivers such as macroeconomic conditions..."

Commented [DH55R54]: Agreed, added "and" to improve readability

FECM-NEMS is based on OnLocation's version of the Annual Energy Outlook 2022 (AEO2022) NEMS model. For consistency with updated economic assumptions, FECM-NEMS uses the low economic growth assumption from AEO2022, assuming a real GDP average growth of 1.8% per year to 2050. Under the FECM's Office of Carbon Management Policy & Analysis,, DOE-FECM, the standard NEMS has been enhanced to FECM-NEMS represents several CO_2 mitigation technologies including carbon capture and sequestration (CCS), DAC, bioenergy with CCS (BECCS), and hydrogen (H_2) processes included in the Hydrogen Market Module (HMM). These technologies allow the economy modeled by FECM-NEMS to fully decarbonize and enable the modeling of scenarios with net-zero carbon emissions. Industrial carbon capture is found in the liquid fuels module which allows for the construction of new hydrogen and ethanol facilities with CCS. It also allows for existing hydrogen, ethanol, and natural gas processing plants to retrofit CCS capability. The cement industry has also been enhanced to include CCS opportunities. Industries have the option to send captured CO_2 to an enhanced oil recovery market or store it in saline aquifers.

Commented [AA56]: This is a little duplicative of paragraph one and two of this section. Consider revising this section to eliminate repetitiveness.

Commented [DH57R56]: We reorganized this section to remove some of the redundant information

The HMM is integrated into NEMS to produce hydrogen via conventional and low carbon processes. The hydrogen production technologies available in the HMM include steam methane reformation (SMR), SMR with CCS, biomass gasification with CCS, and electrolysis.

The NEMS macroeconomic module uses a commercial econometric model designed to provide economic feedback from the broader economy with input perturbations from the energy baseline provided by NEMS. The *S6* and *S7* scenarios represent such profound changes that the EIA's baseline is no longer useful. As a result, FECM-NEMS does not utilize the macroeconomic module when modeling net-zero scenarios.

3. Harmonizing GCAM and NEMS

While GCAM and NEMS are distinct models, coordination between them was is necessary to maintain consistency and tie the NEMS results back to the global LNG market forecast. Harmonization efforts ensured that LNG exports (for all scenarios) and CO_2 emissions (in the net-zero scenarios) were consistent between the two models.

The EIA's AEO2023 reference case was selected to define *S1*. In AEO2023-NEMS, the AEO2023 reference case solution file was adopted for all variables. LNG exports from the AEO2023 reference case were then used as exogenous inputs into the GCAM model in place of endogenous estimates. For *S2* through *S7*, the process was reversed: the scenarios were first run in the GCAM model, from which endogenously-calculated LNG export curves were taken and input exogenously into AEO2023-NEMS. The endogenous algorithm used by NEMS to calculate LNG exports was turned off for these scenarios. Since a key driver of LNG exports is the differential between domestic and world natural gas prices, domestic natural gas prices from NEMS were then compared with North American prices in GCAM. In all scenarios except *S5*, technology and resource were aligned between GCAM and the AEO2023 reference scenario. In *S5*, both models adjusted power generation technology assumptions consistent with the AEO2023 Low Renewable Cost scenario from the AEO.

For *S6* and *S7*, the net-zero scenarios were first run in the GCAM model, which uses global interactions and feedback to model U.S. LNG under a criteria of net-zero GHG by 2050. As part of the modeling process, GCAM generates a set of emissions curves that list quantities of GHG emissions of CO_2, methane (CH_4), nitrous oxide (N_2O), and fluorinated gases emitted inof various economic sectorss and

~~gases (CO2, CH4, N2O, F), as well as~~including emissions and removals from land use, land-use change, and forestry (LULUCF). These curves were outputs of the model, although the sum of individual emissions was defined in the model inputs such that they reached or exceeded a net-zero target in 2050. The output emissions curves from GCAM were used to specify how the net-zero scenario was implemented in FECM-NEMS.

Commented [AA58]: Spell out if this is the first time mentioning these gases.

Commented [DH59R58]: Spelled out CH4 and N2O, and removed F, which is not used later in the report. Also reorganized the section slightly to improve readability

The values of CO_2 emissions from the energy sector were taken from the GCAM output and used explicitly as the carbon cap in FECM-NEMS to model the net-zero scenarios. The carbon cap curve (used to define both *S6* and *S7*) is plotted in Figure 1.

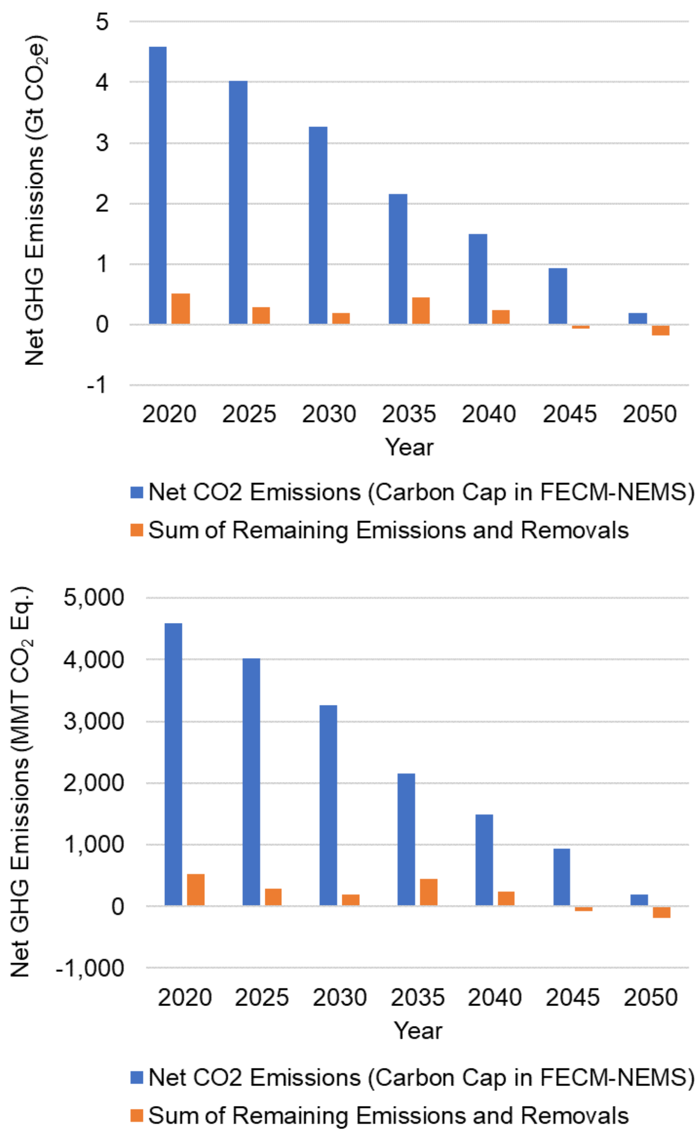


Figure 1. U.S. GHG emissions and removals in the net-zero scenarios

Referring to this carbon cap each model year, FECM-NEMS calculates emissions and removals throughout the model and adjusts a carbon price to equalize them with the carbon cap. With this method, FECM-NEMS ensures that the CO_2 emissions from the energy sector match the corresponding emissions from GCAM. Although FECM-NEMS calculates CH_4 emissions from natural gas systems, they were excluded from the carbon cap in favor of adopting the values calculated by GCAM.

The carbon cap used in FECM-NEMS for both net-zero scenarios ended with 0.1987 MMT Gt CO_2 in 2050. Although this value does not equal zero, it was balanced by the sum of non-energy CO_2, non-CO_2 GHGs, and LULUCF-sector emissions and removals calculated by the GCAM model which added together total -185 0.19 MMTGt CO_2 equivalent (the total was negative because of large quantities of LULUCF-sector removals). The remaining emissions and removals (non-energy CO_2, non-CO_2 GHGs, and LULUCF) were treated as exogenous to FECM-NEMS and could be added with the endogenous CO_2 emissions to calculate net total GHG emissions (which would equal near-zero in 2050). The sum of non-energy CO_2, non-CO_2 GHGs, and LULUCF-sector emissions and removals is also plotted in Figure 1.

C. NETL Life Cycle Analysis Model Methodology

Past life cycle studies conducted by NETL on natural gas and LNG have been attributional studies that estimate the emissions and other impacts associated with current units of natural gas/LNG delivered. These LCA studies have not, to date, considered the *consequences* of delivering LNG, such as how domestic or foreign energy markets may be affected by increasing the supply of natural gas (e.g., whether different sources of natural gas compete in the market, or whether, given additional supply, natural gas-fired power plants in Europe might take market share from other types of electric plants). Such market-based effects could lead to consequential increases or decreases in GHG emissions. As part of this study, these consequential effects were estimated by tracking differences in global GHG emissions and quantities of LNG exported from the GCAM model results.

This section details the various existing representations of the natural gas supply chain within the context of the NETL natural gas model and the GCAM model. The purpose of documenting these representations is to subsequently apply the insights from the GCAM model to the NETL LCA framework.

1. Past NETL Natural Gas Life Cycle Reports

As shown in the top half of Table 3, the NETL Natural Gas model[19] is separated into five stages that generally align with categories used in other federal efforts such as the US EPA's Greenhouse Gas Reporting Program (GHGRP)[20] and Greenhouse Gas Inventory (GHGI)[21]. Results of this model are provided for two scopes: Production through Transmission (e.g., for large scale industrial users, like power plants and LNG facilities that are directly connected to a pipeline), and Production through Distribution (e.g., for residential or smaller industrial users where the natural gas is delivered through smaller distribution pipelines). Results are provided for various techno-basins of production, regions, and U.S. average production, using a variety of Intergovernmental Panel on Climate Change (IPCC) Assessment Report Global Warming Potential (GWP) values on 100-year or 20-year basis.

[19] Khutal, H., et al. Life Cycle Analysis of Natural Gas Extraction and Power Generation: U.S. 2020 Emissions Profile. National Energy Technology Laboratory, Pittsburgh, July 7, 2023

[20] US EPA Greenhouse Gas Reporting Program, https://www.epa.gov/ghgreporting, last accessed Sept 1, 2023.

[21] US EPA , Inventory of U.S. Greenhouse Gas Emissions and Sinks, https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks, last accessed Sept 1, 2023.

Commented [TC60]: I believe Tim has had discussions with the modeling team since adding comments to this draft, the comments here may have already been shared with the team.

Commented [AA61]: Consider adding as parenthetical to the title of Table 3 - (NETL Natural Gas Model).

Commented [SM62R61]: Done

Commented [ST63]: The 2020 report and model are not public. The reference will need updated upon release of the 2020 report.

I checked the ISSST Presentation and it is marked "do not cite" and does not contain the production thru transmission result of 7.4 g. Not a good reference.

Evaluating U.S. Natural Gas Environmental Performance, ISSST 2023 Conference, June 14, 2023, Fort Collins, CO.

Commented [SM64R63]: We believe that the 2020 report will be released imminently, and thus available when this LNG study is released.

Commented [AA65]: Spell out because this is the first time mentioning the IPCC.

In addition, past work by NETL has modeled the additional processing stages to produce and deliver LNG, adding another four stages in the bottom half of Table 3.

Table 3. Natural Gas and Liquefied Natural Gas Life Cycle Stages (as in NETL Natural Gas Model)

Stage Name	Description
Natural Gas Production Only Stages	
Production	Drilling and construction of conventional and unconventional wells (e.g., from hydraulic fracturing), and extraction of gas, including liquids unloading operations.
Gathering and Boosting	Movement of natural gas from wells via gathering pipelines and delivered to treatment and/or processing plants. Boosting systems may include compressors, dehydration, and pneumatic devices and pumps.
Treatment and Processing	Removal of impurities and compression of input gas to meet transmission pipeline standards. May include acid gas removal (AGR), dehydration), ~~NGL~~ natural gas liquids recovery, etc.
Transmission and Storage	Construction of pipelines, and movement of bulk quantities of natural gas in large pipelines to large users or city gates for subsequent distribution. Typically includes compressor stations along pipelines. Storage includes insertion of gas into units such as underground storage facilities as well as additional gas processing and compression after removal from storage before injection into the transmission pipeline network.
Distribution*	Movement of gas from transmission or storage facilities to city gates for subsequent delivery to smaller consumers via small diameter pipelines. (*may or may not be included depending on scope)
Additional Stages to Produce and Deliver LNG	
Liquefaction	Pre-treatment of gas, liquefaction to low temperatures and storage.
Loading/Unloading	Process to load (and unload) LNG to and from tankers to facilities.
Ocean Transport	Shipment of LNG on ocean-going vessels of varying technology types to distant ports for subsequent regasification. Depending on technology, may use LNG as fuel.
Regasification	Regasification of LNG and injection into transmission pipelines.

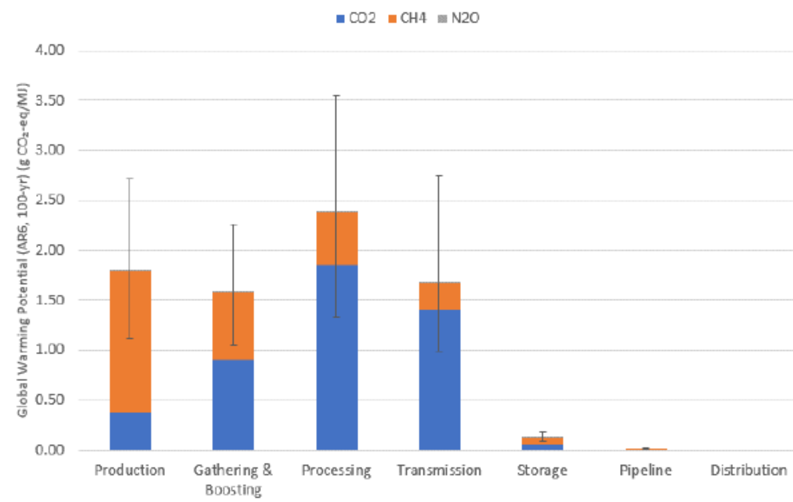
Destination Transmission / Distribution	Similar processes as described above, and not functionally different than as described for the natural gas only part.

Quantitatively, the NETL natural gas model has estimated ranges of GHG emissions by species and by stage for the domestic natural gas supply chain as shown in Figure 2. Given the scope of domestic natural gas production through the transmission stage, the mean U.S. average total CO_2-equivalent emissions are about 7.44 g CO_2e/~~MJ~~ Megajoule (MJ) (IPCC AR6, 100-year basis), with a confidence interval of the mean of 4.6-11.1 g CO_2e/MJ. The GCAM model results generated in ~~This~~ this report ~~also~~ estimated GWP intensity of natural gas extraction in different geographic regions of the US, which have higher or lower intensity, as compared to the U.S. average. ~~Note~~However, ~~that~~ these results are in terms of Higher Heating Value (HHV) of natural gas, while the GCAM model uses Lower Heating Value (LHV), so it needed to be subsequently adjusted, resulting in a value of 8.18 g CO_2e/MJ (IPCC AR6, 100-year, LHV basis). Further discussion of these adjustments are discussed below.

Commented [ST66]: Report the LHV result here that aligns to GCAM.

Need to provide/cite the HHV to LHV values for the adjustment factor.

Commented [SM67R66]: Done. These are in appendix also.



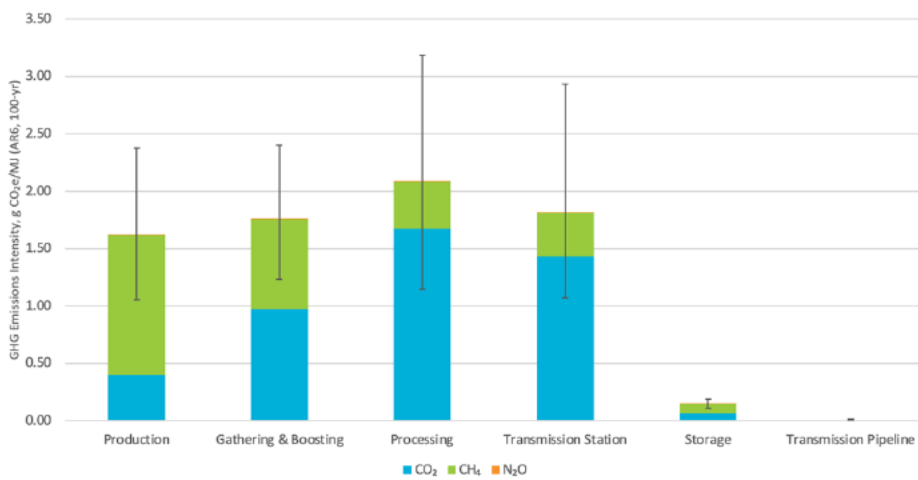


Figure 2. Life cycle GHG emissions from the 2020 U.S. average Natural Gas supply chain, HHV basis (Source: NETL 2023)

Past work by NETL also estimated the greenhouse gas emissions implications of the additional stages to produce and deliver U.S. average LNG around the world. While these values are estimated on a per-MJ delivered basis, their presentation is complicated by the variability associated with the distance shipped, which can be large in many cases (LNG shipped relatively short distances has a significantly smaller GWP

Commented [ST68]: Y-axis: units should read g CO2e/MJ before AR6, 100-year.

CO2e: removed hyphen between the "2" and "e".

Legend: need to subscript "2" and "4".

footprint than that shipped long distances). Using data from the 2019 NETL LNG report[22]. ~~While these values are estimated on a per-MJ delivered basis, their presentation is complicated by the variability associated with the distance shipped, which can be large in many cases (LNG shipped relatively short distances has a significantly smaller GWP footprint than that shipped long distances). Using data from the 2019 NETL LNG report (cite),~~ and adjusting to the 2020 NETL NG report and GHGRP basis used here, LNG delivered from New Orleans to Rotterdam (8,990 km) would be expected to result in ~~17.9~~20 g CO_2e/MJ delivered to regasification facility (IPCC AR6, 100-year basis, ~~HHV~~LHV) or 18.1 g CO_2e/MJ (HHV). In short, the additional processes and natural gas needed to liquefy~~,~~ and ship~~, and regasify~~ natural gas to Rotterdam adds about ~~10~~ 9.9 g CO_2e/MJ delivered (IPCC AR6, 100-year basis, LHV~~,~~). The GHG emissions intensity result on a per MJ NG delivered to liquefaction plant basis is 8.2 g CO2e/MJ (AR6, 100-yr, LHV) but accounting for NG losses that occur in the downstream stages results in a higher volume of NG needed upstream, leading to a contribution of 10.2 g CO_2e/MJ NG delivered to the regasification facility (AR6, 100-yr, LHV) by the upstream NG supply chain stages (production through transmission network)[23]. Given the many possible delivery routes and distances for such LNG, these specific results are intended only to provide contextual perspective of the GWP intensity of the added LNG stages.

~~which is more than double the impact of merely producing the gas and transmitting it to large scale users domestically (of 7.44 g CO_2e/MJ, HHV basis, given above). The GHG emissions intensity result on a per MJ NG delivered to liquefaction plant basis is 7.44 g CO_2e/MJ (AR6, 100-yr, HHV) but accounting for NG losses that occur in the downstream stages results in a higher volume of NG upstream, leading to an upstream emissions intensity of 8.44 g CO_2e/MJ NG delivered through low pressure distribution pipelines to small volume end users (e.g., commercial, residential, and some industrial users)to power plant (AR6, 100-yr, HHV). Given the many possible delivery routes and distances for such LNG, these specific results are intended only to provide contextual perspective of the GWP intensity of the added LNG stages.[24]~~

The previous NETL work on natural gas cited above are attributional ~~studies~~ analyses of the domestic natural gas system. The results sought to identify and attribute the emissions associated with the various unit processes that created them. These methods differ in scope than consequential analysis, which more broadly considers the global changes in GHG emissions when additional volumes of U.S. natural gas are produced and delivered across the world, or, in other words, the market-based effects of producing domestic natural gas and exporting it. Further discussion on how the LCA section of this project can support consequential analysis is discussed in Section V.G.

Commented [ST69]: Needs completed.

Commented [ST70]: Please confirm that the US upstream was also adjusted to use the 2020 NG profile, as well as the GWP reference.

This change should also be noted in footnote 20.

Commented [ST71]: Per the 2020 report, this is the US average through distribution

Commented [SM72R71]: Apologies that previous text was confusing - a coincidental result of 8.4 but have updated with consistently HHV values. Deleted text that was added that implied that production through distribution values had been used.

Regardless the important point is that this was NOT meant to be discussing "through distribution"

Commented [AA73]: A word appears to be missing here.

Commented [SM74R73]: Reworded paragraph to hopefully make this more clear.

[22] Roman-White, S., Rai, S., Littlefield, J., Cooney, G., & Skone, T. J. (2019). Life cycle greenhouse gas perspective on exporting liquefied natural gas from the Unites States: 2019 update. National Energy Technology Laboratory (NETL), Pittsburgh, September 12, 2019.

[23] Results from Roman-White 2019, Exhibit A-2, adjusted from g CO_2e/MWh to g CO_2e/MJ using heat rate of 145 kg natural gas/MWh, and higher heating value of 54.3 MJ/kg.

~~[24] Results from Roman-White 2019, Exhibit A-2, adjusted from g CO_2e/MWh to g CO_2e/MJ using heat rate of 145 kg natural gas/MWh, and higher heating value of 54.3 MJ/kg.~~

2. Market Adjustment Factors

In order to quantify the broad and global market effects associated with increasing exports of U.S. LNG, the GCAM results were used to estimate the change in global GHG emissions per unit of LNG exported between various scenarios. This market adjustment factor (MAF) is defined as:

$$MAF_{scenario\ n} = \frac{Global\ Emissions_{scenario\ n} - Global\ Emissions_{scenario\ 1}}{US\ LNG\ Exports_{scenario\ n} - US\ LNG\ Exports_{scenario\ 1}}$$

$$MAF_{scenario\ n} = \frac{Global\ Emissions_{scenario\ n} - Global\ Emissions_{scenario\ 1}}{US\ LNG\ Exports_{scenario\ n} - US\ LNG\ Exports_{scenario\ 1}}$$

and represents a ratio of the change in GHG emissions for a given scenario compared to a base scenario, versus the change in U.S. LNG exports between the same two scenarios. For example, a comparison of Scenario *S2* vs. Scenario *S1* would compare the differences in GCAM values for these two scenarios. TheisThis MAF can be calculated for every model year (2015-2050) and can also use linearly interpolated values of emissions and US LNG exports for the non-modeled years.

Commented [LBD75]: Unclear what these two dimensions/adjectives are; could this just be "global market effects"?

Commented [ST76]: Page 51: MAF is defined as "market effect adjustment factor". Recommend removing effect for consistency with in the report.

Commented [ST77]: The equation below's font size is too large to match the document style.

~~IV.~~V. RESULTS

The following sections describe the results of the global analysis using GCAM, the U.S. analysis using NEMS, and the life-cycle analysis in that order. We begin our discussion with a description of U.S. LNG export outcomes across scenarios (section VA). Subsequently, ~~To~~ we highlight the implications of the availability of additional U.S. LNG in the global market, by~~we first compare~~ comparing *S1* and *S2* (section VB). We then discuss *S6* and *S7* to illustrate the implications of additional U.S. LNG in the global market under a global transition toward 1.5^{o}C (sections VC and VD). Subsequently, we discuss results from the remaining scenarios (~~S2~~*S3*-*S5*) (section VE).

A. U.S. LNG exports

Across all ~~the~~ scenarios, the U.S. is a net exporter of natural gas. As shown in Figure 3, U.S. LNG exports increase~~d~~ beyond existing and planned capacity in all scenarios by 2050, except *S1* in which U.S. LNG export volumes follow~~ed~~ AEO2023 and *S6* in which export volumes were limited to AEO2023 by design. Across all the scenarios, LNG exports range from 23-49 Bcf/day. This range is consistent with the U.S. EIA's analysis (15-48 Bcf/day).[25] ~~Under *S2*, in which all outcomes – including U.S. LNG exports – are economically- driven and market-based, U.S. LNG exports increased to ~47 Bcf/day in 2050.~~

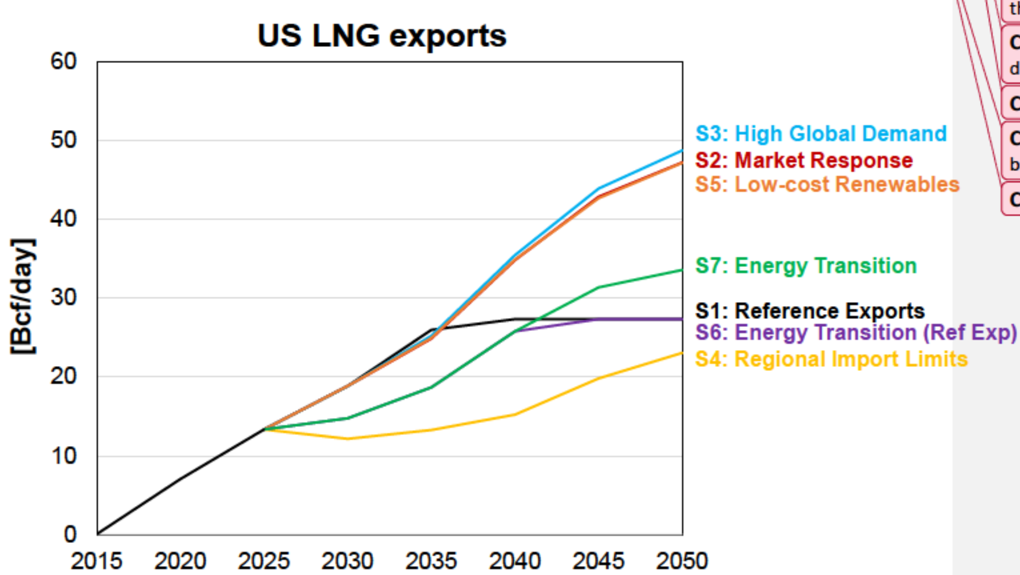


Figure 3. U.S. LNG exports across the scenarios. Note that the U.S. LNG export outcomes for S2 and S5 are very close to each other.

[25] U.S. EIA. (2023). Issues in Focus: Effects of Liquefied Natural Gas Exports on the U.S. Natural Gas. Available at: Markethttps://www.eia.gov/outlooks/aeo/IIF_LNG/

Commented [LBD78]: This stated order doesn't seem to start until after Section A?

Maybe it could be better explained here -- this seems to apply to Section B (S1 & S2) and C/D (S6 & S7), and then all scenarios together in other sections.

Section A treats the 7 scenarios in numerical order for export volumes, setting the stage for following sections.

Commented [IGC79R78]: Thanks. We've clarified this.

Commented [LBD80]: S3? S2 would have been discussed along with S1.

Commented [IGC81R80]: Agreed. Thanks.

Commented [UP82]: Shouldn't this be 49 Bcf/d based on S3 scenario (see page 21)?

Commented [IGC83R82]: Yes. Thanks.

Under *S2*, in which all outcomes – including U.S. LNG exports – are economically-driven and market-based, U.S. LNG exports increase to approximately 47 Bcf/day in 2050.

U.S. LNG exports under *S3*, the scenario with increased global population, increased to 49 Bcf/day in 2050, emerging as the upper bound. With higher population assumptions in *S3*, total energy demand – and consequently natural gas demand – outside the U.S. increased compared to *S2*, resulting in an increase in U.S. LNG exports to satisfy the increased international demand. However, the increase was is not proportional to the increase in population because part of the higher demand in *S3* was is supplied by an increase in international production.

U.S. LNG exports under *S4* increased only to ~approximately 23 Bcf/day in 2050, emerging as the lower bound. The lower increase in U.S. LNG exports in *S4* compared to other scenarios was is driven by international limits on natural gas imports to maximize the use of locally produced natural gas.

U.S. LNG exports under *S5* increased to approximately the same level as *S2* in 2050. This was is mainly because, cheaper solar and wind technologies in this scenario mostly displaced fuels other than natural gas (e.g., biomass). Hence, the demand for natural gas and consequently, U.S. LNG exports, remained materially unaffected compared to *S2*. Under *S7*, which assumes a global transition toward 1.5°C, U.S. LNG exports continued to increase, albeit at a lower level than *S2*, to ~approximately 34 Bcf/day in 2050. As discussed below, the lower increase in U.S. LNG exports in this scenario compared to *S2* was is driven by the economy-wide transition to low-carbon fuels to meet emission reduction commitments and pledges.

B. Global Natural Gas Consumption, Production, and Trade Under Scenarios *S1* And *S2*

As shown in Figure 4, under *S1*, production, consumption, and trade of natural gas increasesd in all regions, globally driven by growing demands in the electricity generation, industrial, and buildings sectors (see Figure A-1 in Aappendix A). Under *S1*, U.S. LNG exports followed follows the AEO2023 Reference case to grow to 27.34 BCF/day by 2050 (by design).

Commented [UP84]: Is this an assumption where all importing countries have readily available locally-produced natural gas they can use instead? Should we say regionally vs locally?

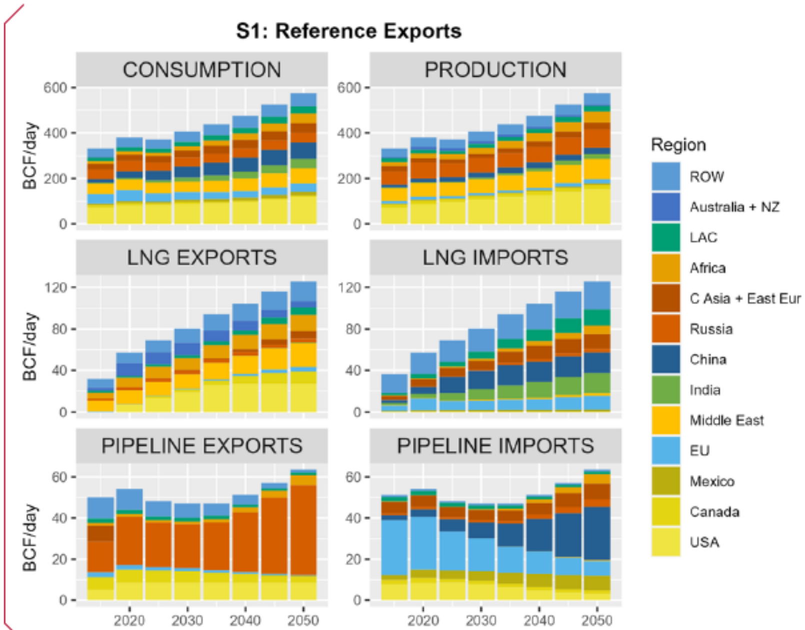
Commented [IGC85R84]: The detailed assumptions for this scenario are in Table A-1. I am OK with "locally" but open to other thoughts.

Commented [AA86]: Recommend spelling out instead of using symbol.

Commented [IGC87]: Note to tech editor: Please make sure we're consistent throughout about AEO2023 Reference case vs. AEO2023 Reference scenario.

Commented [WS88]: Global comment: this report consistently uses bar charts rather than actual figures. Can we include all these figures in appendices?

Commented [IGC89R88]: Yes.



Commented [WS90]: S1 shows global gas consumption increasing to 2050 (and maybe beyond?). Even S6 and S7 seem to show global gas consumption plateauing in 2045 (but not decreasing event then). Meanwhile, we understand that this month the IEA will release a global outlook document that will project gas consumption peaking this decade. This seems like a vast discrepancy and perhaps one that should be addressed. Is it feasible to run another scenario? If not, how would we defend the validity of our assumptions as compared to those of others?

Commented [IGC91R90]: Please see our response in the consolidated response document.

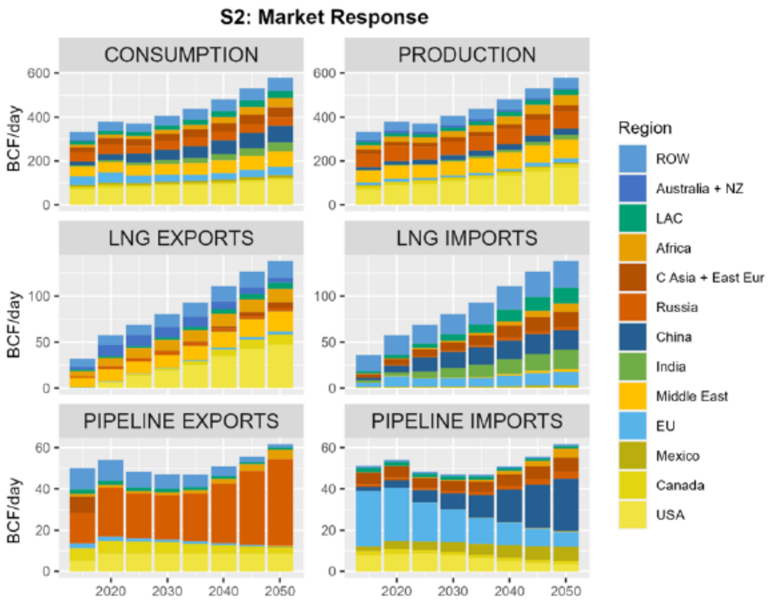


Figure 4 Natural gas consumption, production, and trade by region under S1 (upper) and S2 (lower) To convert from BCF/day to TCF/ yr and vice versa, the conversion factors are as follows: 1 TCF/yr = 2.74 Bcf/day and 1 BCF/day = 0.36 TCF/yr.

UAsAlternatively, as shown in Figure 5, Uunder *S2*, in which U.S. LNG exports were are determined by market equilibrium, U.S. natural gas production and LNG exports increased compared to *S1* to satisfy the growing demands of natural gas globally. Under *S2*, U.S. LNG exports greow to ~approximately 47 Bcf/day by 2050. Figure 5 shows the changes in natural gas consumption, production, and trade by region in *S2* versus *S1*. In this scenario, The additional U.S. LNG exports in *S2* compared to *S1* is 20 Bcf/day in 2050. The availability of additional U.S. natural gas in the global natural gas market at competitive prices results under *S2* in a reduction in production and LNG exports from other parts of the world compared to *S1*. The increased availability of U.S. LNG under *S2* also results in higher LNG imports and reduced pipeline trade outside of the U.S. In addition, natural gas consumption outside of the U.S. increases by 7 Bcf/day compared to *S1*. However, U.S. natural gas consumption under *S2* decreases (by 3 Bcf/day in 2050) driven by domestic price increases in response to increased domestic production. Thus, the net increase in global natural gas consumption in *S2* compared to *S1* is 4 Bcf/day. Compared to the total natural gas consumption globally in 2050 in *S1* (574 Bcf/day), this change is <1%. the availability of additional U.S. natural gas in the global natural gas market at competitive prices resulted in a reduction in production and LNG exports from other parts of the world. The increased availability of U.S. LNG in the global market also resulted in higher LNG imports and reduced pipeline trade outside of the U.S. However, global natural gas consumption in *S2* increased only by a very small amount (<5% by 2050 globally compared to *S1*). This is mainly because the availability of additional U.S. LNG in the global market did not materially affect the relative competitiveness of natural gas compared to other fuels

Commented [WS92]: Looking at the bar chart in figure 5, it appears that global gas consumption increases by roughly 5 bcf/day between S2 and S1. In other words, for every 4 Bcf/d of incremental US exports, global consumption goes up by roughly 1 Bcf/d. This does not seem accurately characterized as going up by a very small amount.

Commented [IGC93R92]: As discussed in our consolidated response document, we have added more context to these results for clarity (see sentences above).

Commented [WS94]: Introduction says under 1%.

(e.g., coal, oil, renewables, and nuclear) globally. Figure 5 shows the changes in natural gas consumption, production, and trade by region in *S2* versus *S1.*

In addition, current emission reduction policies in the U.S. and internationally, which were included in the assumptions for all scenarios, limited the potential for global natural gas consumption to grow in response to the increased availability of U.S. natural gas. Consequently, global primary energy consumption and GHG emissions under *S2* did do not change much compared to *S1*, as shown in Figure 6.

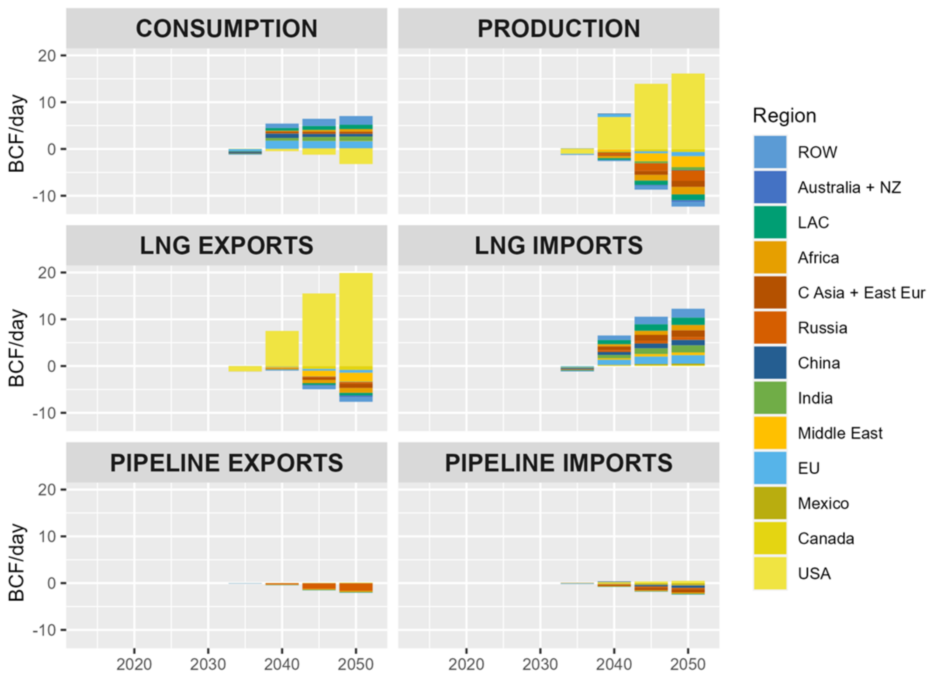


Figure 5. Changes in natural gas consumption, production, and trade by region in S2 vs. S1 To convert from BCF/day to TCF/ yr and vice versa, the conversion factors are as follows: 1 TCF/yr = 2.74 Bcf/day and 1 BCF/day = 0.36 TCF/yr.

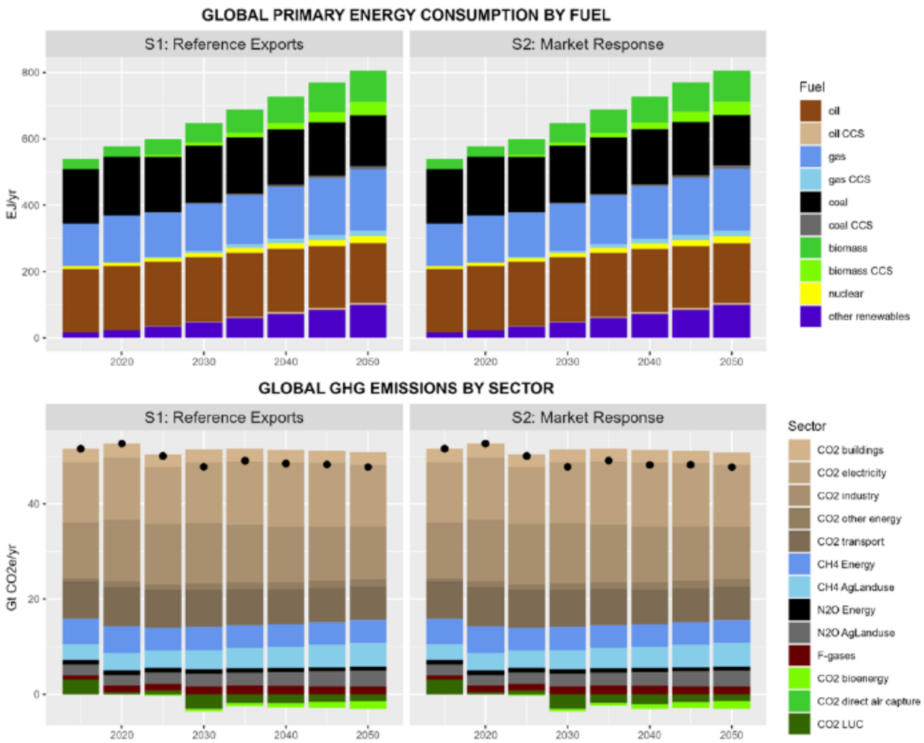


Figure 6. Global primary energy consumption by fuel and GHG emissions by sector under S2 and S1. Changes in S2 relative to S1 are <1% and are presented in the data tables in Appendix A. Net GHG emissions are shown as a dot in each bar.

C. Global Primary Energy Consumption by Fuel and GHG Emissions by Sector Under *S6* And *S7*

Under *S6* and *S7*, global GHG emissions from all sectors of the economy are reduced significantly compared to *S1* and *S2*, as shown in Figure 6 and Figure 7. Figure 7 ~~and Figure 8.~~ This ~~was~~ is by design as these scenarios ~~were~~ are assumed to include emissions pledges and constraints on emissions consistent with limiting global temperature change this century to 1.5°C. Under these scenarios, although global GHG emissions are net-positive (approximately 17 $GtCO_2e$), global CO_2 emissions are approximately 0 in 2050. These global emissions outcomes are broadly consistent with 1.5°C scenarios in the literature.[26]

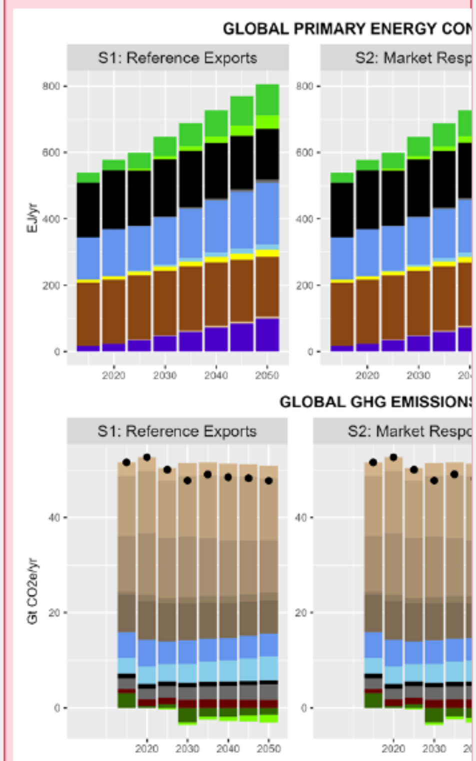
These scenarios ~~were~~ are characterized by a combination of the following decarbonization strategies: i) a reduction in fossil fuel consumption without carbon capture utilization and storage (CCUS), ii) increased deployment of CCUS with fossil fuels, iii) increased deployment of renewables, iv) a net

[26] Riahi et al. 2022, Chapter 3 in the Sixth Assessment Report of the IPCC

Commented [ST95]: Need S2 minus S1 delta figures.

Commented [IGC96R95]: We prefer not to show the delta figures here since the changes very small (<1%) and within solution tolerance. We instead point to the data tables in the appendix. In addition, the revised text now includes a description of the small changes.

Below is a version with deltas. As you can see, the deltas are really small and can be distracting.



Commented [WS97]: Figure 6 is almost impossible to read. It seems like there are differences between S1 and S2 but the reader can't judge the magnitude just by looking at the bar charts.

Commented [IGC98R97]: We have included data tables for this all other figures in the Appendix. We have also included additional panels in Figure 6 showing the changes in S2 relative to S1.

reduction in energy consumption, and v) increased deployment of carbon dioxide removal (CDR) applications such as bioenergy in combination with CCUS (BECCS), afforestation, and direct air capture (DAC~~)~~), compared with *S1* and *S2*. Notably, the scale and distribution of CDR deployment varies by type and region. By 2050, about 6.8, 4, and 0.4 GtCO_2e respectively of BECCS, afforestation, and DAC are deployed globally in *S6* and *S7*, as shown in Figure 9Figure 9. While BECCS and afforestation are distributed more evenly across regions, most of the DAC is deployed in the U.S. primarily due to the availability of carbon storage.

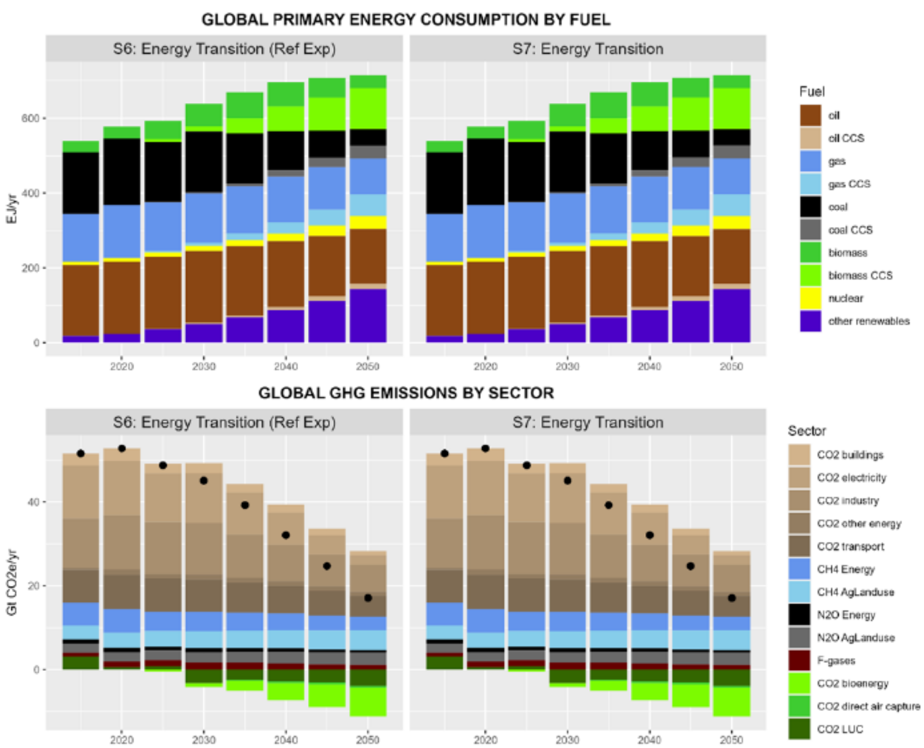


Figure 7. Global primary energy consumption by fuel and GHG emissions by sector under S6 and S7. Changes in S7 relative to S6 are presented in the data tables in Appendix A.

. Net GHG emissions are shown as a dot in each bar.

~~*Net GHG emissions are shown as a dot in each bar.*~~

~~Notably, the scale and distribution of CDR deployment varied by type and region. By 2050, about 6.8, 4, and 0.4 GtCO_2e respectively of BECCS, afforestation, and DAC were deployed globally in *S6* and *S7*, as~~

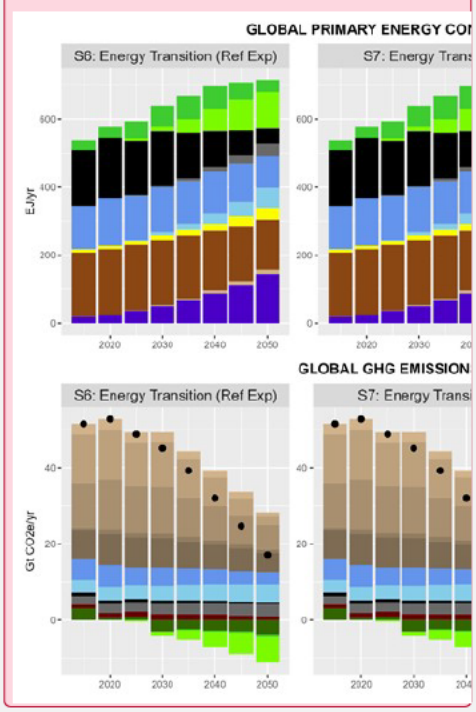
Commented [UP99]: Is this discussion related to Figure 8 or 9? Looks like one of these charts was dropped in and has no written content. All charts should be referenced with content. Prefer no drop and run charts.

Commented [IGC100R99]: This should point to Figure 9.

Commented [ST101]: Need S7 minus S6 delta figures.

Commented [IGC102R101]: We prefer not to show the delta figures here since the changes very small (<1%) and within solution tolerance. We instead point to the data tables in the appendix. In addition, the revised text now includes a description of the small changes.

Below is a version with deltas. As you can see, the deltas are really small and can be distracting.



shown in Figure 9. While BECCS and afforestation were distributed more evenly across regions, most of the DAC was deployed in the U.S. primarily due to the availability of carbon storage.

Note, that *S6* and *S7* did not assume the availability of any emissions trading or offset mechanisms. Hence, countries with net-zero pledges – such as the U.S. – were assumed to meet those pledges in the stated target years through a combination of the above decarbonization strategies including CDR deployment within their own geographic boundaries. Under these scenarios, although global GHG emissions are net-positive (~20 $GtCO_2e$), global CO_2 emissions were ~0 in 2050. These global emissions outcomes were broadly consistent with 1.5°C scenarios in the literature.[27]

Commented [UP103]: Is this discussion related to Figure 8 or 9? Looks like one of these charts was dropped in and has no written content. All charts should be referenced with content. Prefer no drop and run charts 😉.

[27] Riahi et al. 2022, Chapter 3 in the Sixth Assessment Report of the IPCC

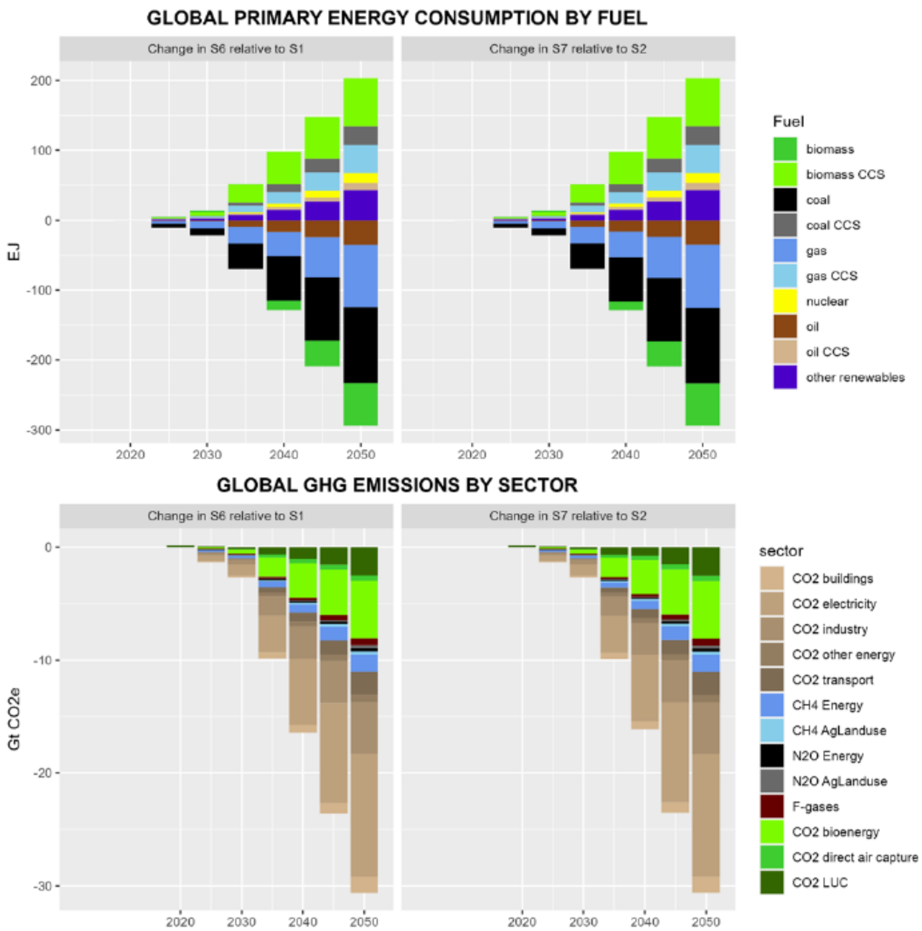


Figure 8. Changes in global primary energy consumption and GHG emissions under S6 and S7 relative to S1 and S2 respectively

Commented [ST104]: Recommend removing this figure. It is not related to LNG Exports. This result can easily be mis-interpreted given the focus of the project. This project is not about how effective climate policy is.

Commented [IGC105R104]: I think this figure is helpful in explaining that gas consumption in S6 and S7 are significantly lower than S1 and S2. Yet, demand for gas continues to grow because of deployment of gas-CCUS. That said, I do not have a strong opinion on this and happy to move this to the Appendix. If we decide to do that, we will need to work on figure numbering throughout the report.

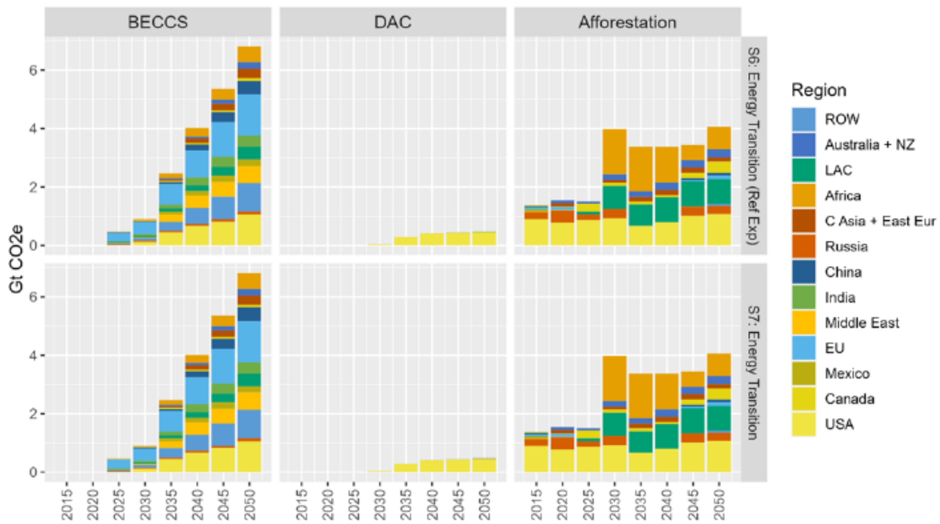


Figure 9. CDR deployment by type and region in S6 and S7

Interpretation of the energy transformation and emissions outcomes under *S6* and *S7* – particularly, those surrounding the regional and sectoral allocations – requires two careful considerations. First, these scenarios do not explicitly model the actual policy instruments and mechanisms that countries might adopt to meet their pledges – due to lack of sufficient literature on policies and regulations over the longer time horizon of focus in this study. Instead, these scenarios assume that countries achieve their pledges cost-effectively through a combination of decarbonization strategies discussed above. Second, *S6* and *S7* do not assume the availability of any emissions trading or offset mechanisms for countries to meet their pledges. Hence, countries with net-zero pledges – such as the U.S. – are assumed to meet those pledges in the stated target years through a combination of decarbonization strategies discussed above, including CDR deployment within their own geographic boundaries. The sectoral and geographic distributions of energy system transitions and emissions outcomes could be different depending on the actual policies and mechanisms that countries use to meet their pledges in reality.

Commented [ST106]: Need delta figures. The key message is "what changed" when we increase exports. I can not ascertain this result from the current results display.

The question of how/if renewables or other energy sources are displaced by natural gas is also not apparent in any of these results.

What countries changed their energy consumption profile because the US increased exports?

Did each countries response to change in energy consumption pattern increase or decrease their GHG emissions footprint?
...what sectors within each country?

Next - figures are nice, but would like to see full tabulated results in an Excel workbook be made available to provide transparency to the public on GCAM, NEMS, and LCA results.

Commented [IGC107R106]: Need delta figures. The key message is "what changed" when we increase exports. I can not ascertain this result from the current results display.

Response: As discussed in a previous response, we prefer not showing the delta figures here because the changes are really small (less than 1%) and within solution tolerance. Instead, we point to the data tables in the appendix which contain differences.

The question of how/if renewables or other energy sources are displaced by natural gas is also not apparent in any of these results.

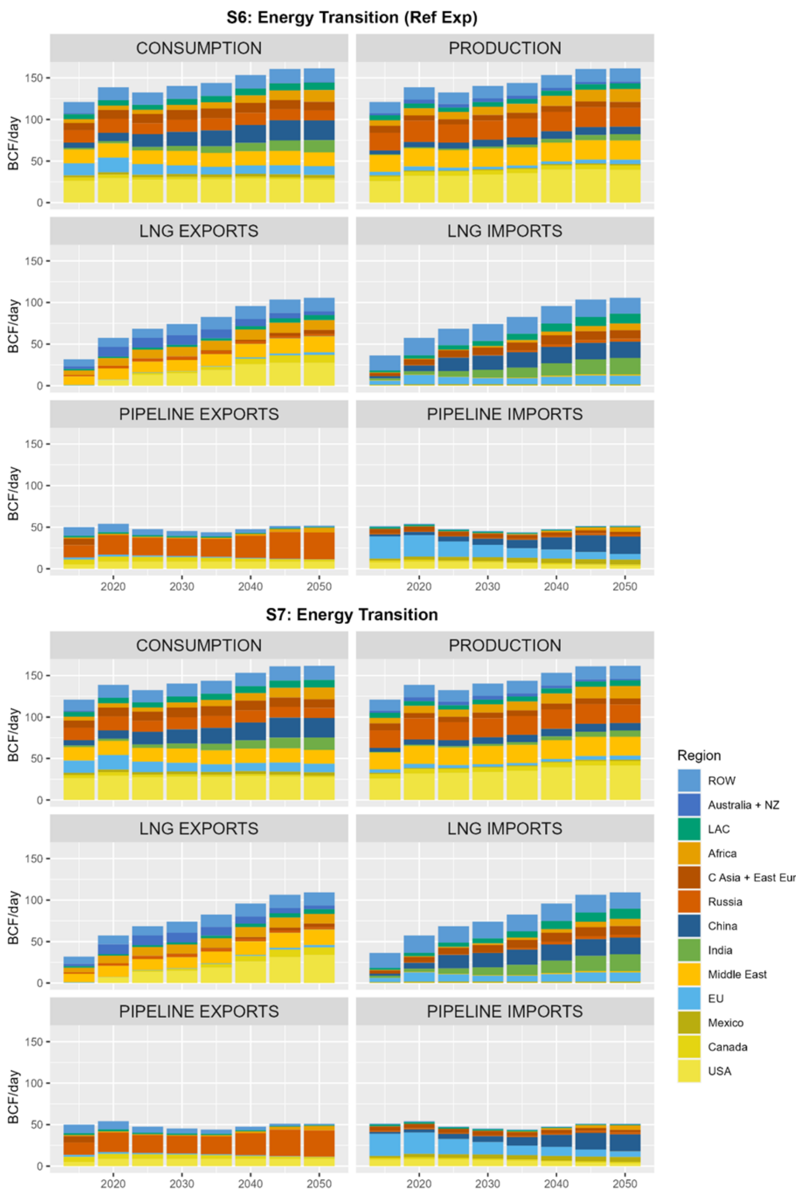
Response: Again, these changes are really small and within solution tolerance. The data tables in the appendix contain these details.

What countries changed their energy consumption profile because the US increased exports? Did each countries response to change in energy consumption pattern increase or decrease their GHG emissions footprint?
...what sectors within each country?

Response: Note again that gas consumption changes, fuel substitution, and emissions changes in response to additional US LNG exports are all really small (<1%) and within solution tolerance. The description in this

D. Global Natural Gas Consumption, Production, and Trade Under Scenarios *S6* and *S7*

As shown in Figures 10 and 11, under *S6* and *S7*, natural gas consumption ~~decreased~~ decreases compared to *S1* and *S2* in most regions largely driven by official net-zero pledges that require complete decarbonization of energy systems by 2050. However, in some regions with net-zero pledges that extend beyond 2050 (e.g., India), natural gas demand ~~continued~~ continues to grow through 2050 and consumption ~~did~~ does not change much compared to *S1* and *S2*. Globally, although natural gas consumption in *S6* and *S7* ~~was~~ is lower compared to *S1* and *S2*, it continuesd to grow due to the deployment of natural gas with CCUS in power and industrial sectors and direct air capture (DAC) applications (see Figure A-2 in appendix). The lower natural gas consumption in *S6* and *S7* compared to *S1* and *S2* ~~resulted~~ results in lower global production, LNG exports, and LNG imports.


S6: Energy Transition (Ref Exp)
CONSUMPTION
PRODUCTION
LNG EXPORTS
LNG IMPORTS
PIPELINE EXPORTS
PIPELINE IMPORTS
BCF/day
0
50
100
150
2020
2030
2040
2050
S7: Energy Transition
Region
ROW
Australia + NZ
LAC
Africa
C Asia + East Eur
Russia
China
India
Middle East
EU
Mexico
Canada
USA

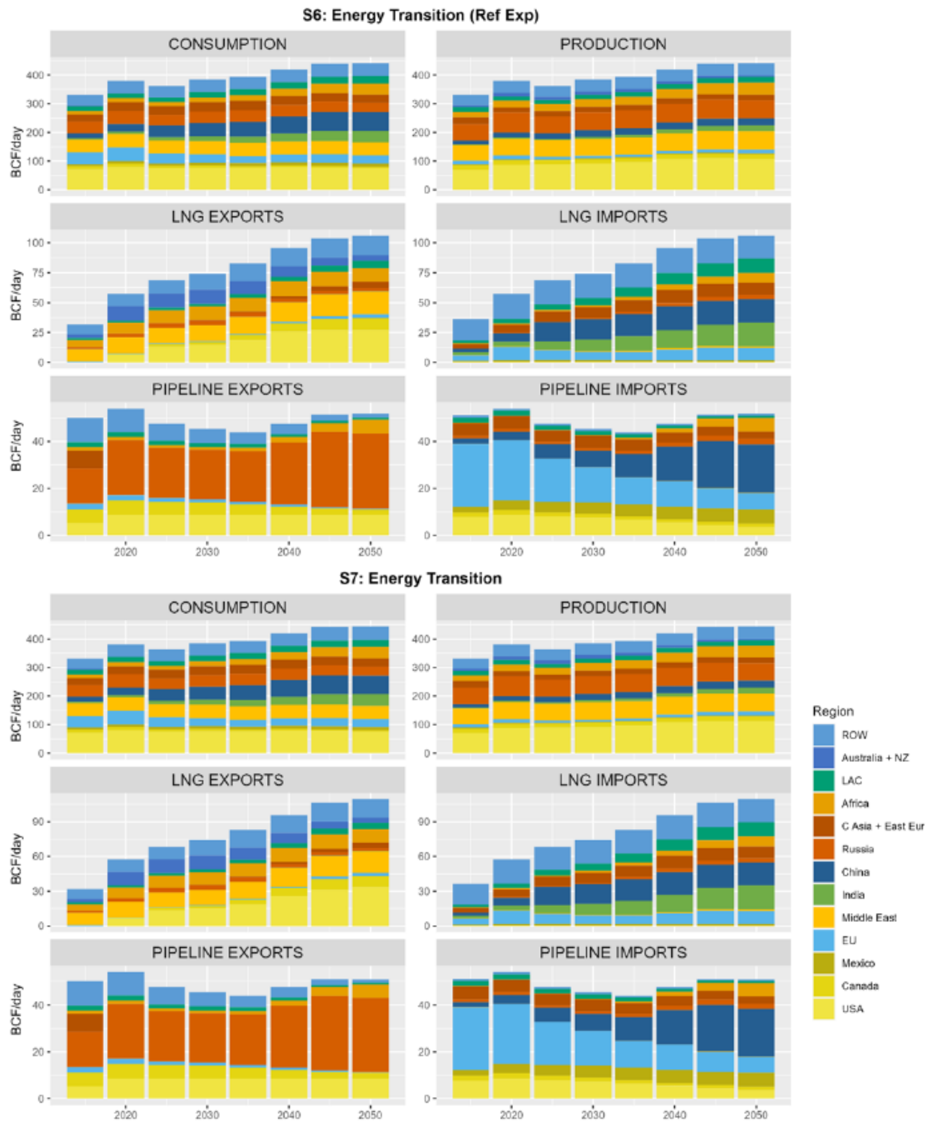
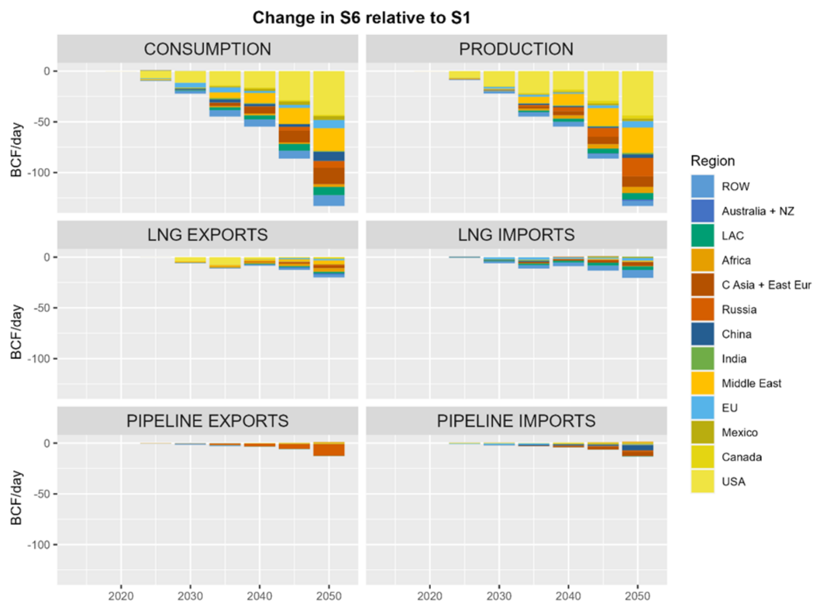
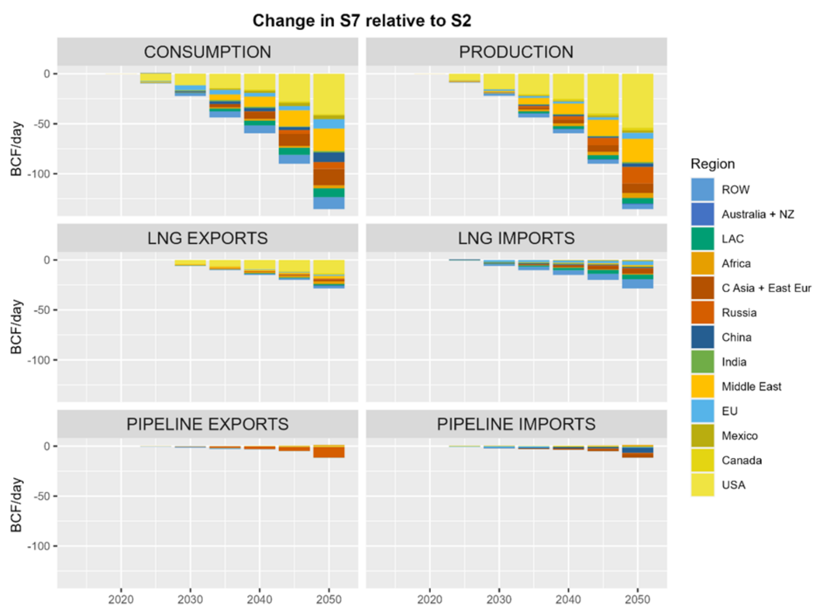


Figure 10. Natural gas consumption, production, consumption, and trade by region under S6 and S7 To convert from BCF/day to TCF/ yr and vice versa, the conversion factors are as follows: 1 TCF/yr = 2.74 Bcf/day and 1 BCF/day = 0.36 TCF/yr.

Commented [UP108]: Needs charts check. Looks like something going on with the Consumption and Production axis that are labeled as Bcf/d but with a max of 150 as the vertical axis (the way it was in prior draft in Tcf vs now Bcf/d). See also similar charts showing 600 Bcf/d on pages 22 and 23 for vertical axis which make more sense? Also the LNG exports between S6 and S7 hard to tell any difference with such small charts. They look identical with similar axis labels although difference may be small between 27.3 and 34 Bcf/d for the U.S.

Commented [IGC109R108]: Corrected.


Change in S6 relative to S1
CONSUMPTION
PRODUCTION
LNG EXPORTS
LNG IMPORTS
PIPELINE EXPORTS
PIPELINE IMPORTS
BCF/day
0
-50
-100
2020
2030
2040
2050
Region
ROW
Australia + NZ
LAC
Africa
C Asia + East Eur
Russia
China
India
Middle East
EU
Mexico
Canada
USA


Change in S7 relative to S2
CONSUMPTION
PRODUCTION
LNG EXPORTS
LNG IMPORTS
PIPELINE EXPORTS
PIPELINE IMPORTS
BCF/day
0
-50
-100
2020
2030
2040
2050
Region
ROW
Australia + NZ
LAC
Africa
C Asia + East Eur
Russia
China
India
Middle East
EU
Mexico
Canada
USA

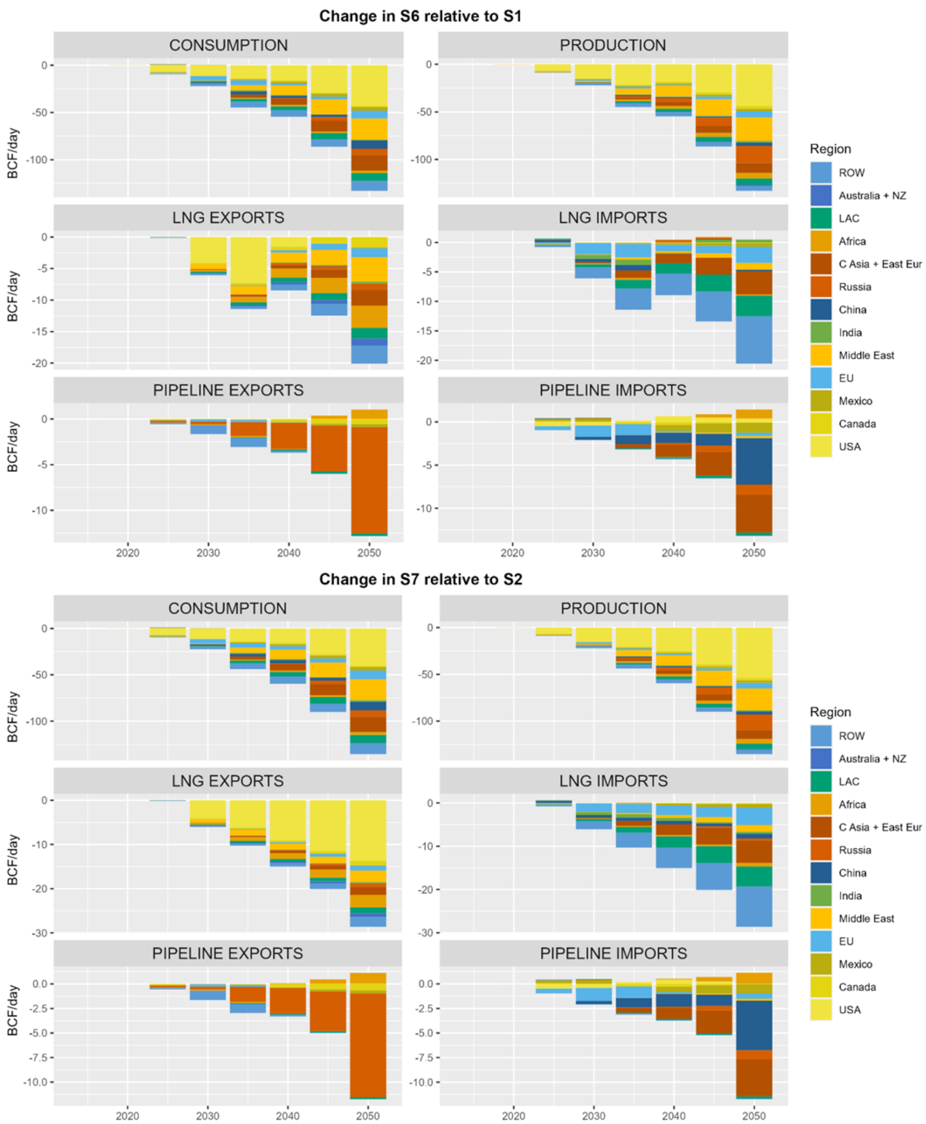


Figure 11. Changes in natural gas consumption, production, and trade by region: S6 vs S1 and S7 vs S2To convert from BCF/day to TCF/ yr and vice versa, the conversion factors are as follows: 1 TCF/yr = 2.74 Bcf/day and 1 BCF/day = 0.36 TCF/yr.

As shown in Figure 12Figure 12, *S6* and *S7* differed in the role of U.S. LNG exports in the global natural gas market. By 2050, U.S. LNG exports in *S6* were are not different from *S1* because this scenario assumed the *S1* values (which are based on the AEO2023 Reference case) as an upper bound. Under *S7*, which assumes economically-driven outcomes, U.S. LNG exports increase by 6.3 Bcf/day to 34 Bcf/day in 2050. Similar to the comparison between *S1* and *S2*, the availability of additional U.S. LNG in *S7* results in a reduction in natural gas production, reduction in LNG exports, increase in LNG imports, and reduction in pipeline trade outside of the U.S. compared to *S6*. The availability of additional U.S. LNG in *S7* also results in a net increase in natural gas consumption of 1.6 Bcf/day outside of the U.S. In addition, U.S. natural gas consumption under *S7* decreases by 0.25 Bcf/day in 2050 compared to S6 (driven by domestic price increases in response to increased domestic production). Thus, the net increase in consumption globally in S7 compared with S6 is 1.37 Bcf/day. Compared to the total natural gas consumption globally in 2050 in S6 (442 Bcf/day), this change is a <1% increase. Consequently, global primary energy consumption under *S7* does not change much compared to *S6*, as shown in Figure 7. Note that there is no change in global emissions under *S7* relative to *S6* since both scenarios are constrained to the same values by design.

continued to grow and increase beyond *S6* – particularly after 2040 – to meet the global demand for natural gas, a growing share of which was deployed in combination with CCUS in the power and industrial sectors (see Figure A-1 in the appendix). Similar to the comparison between *S1* and *S2*, the availability of additional U.S. LNG in *S7* resulted in a very small increase in natural gas consumption, reduction in production, reduction in LNG exports, increase in LNG imports, and reduction in pipeline trade in the rest of the world compared to *S6*.

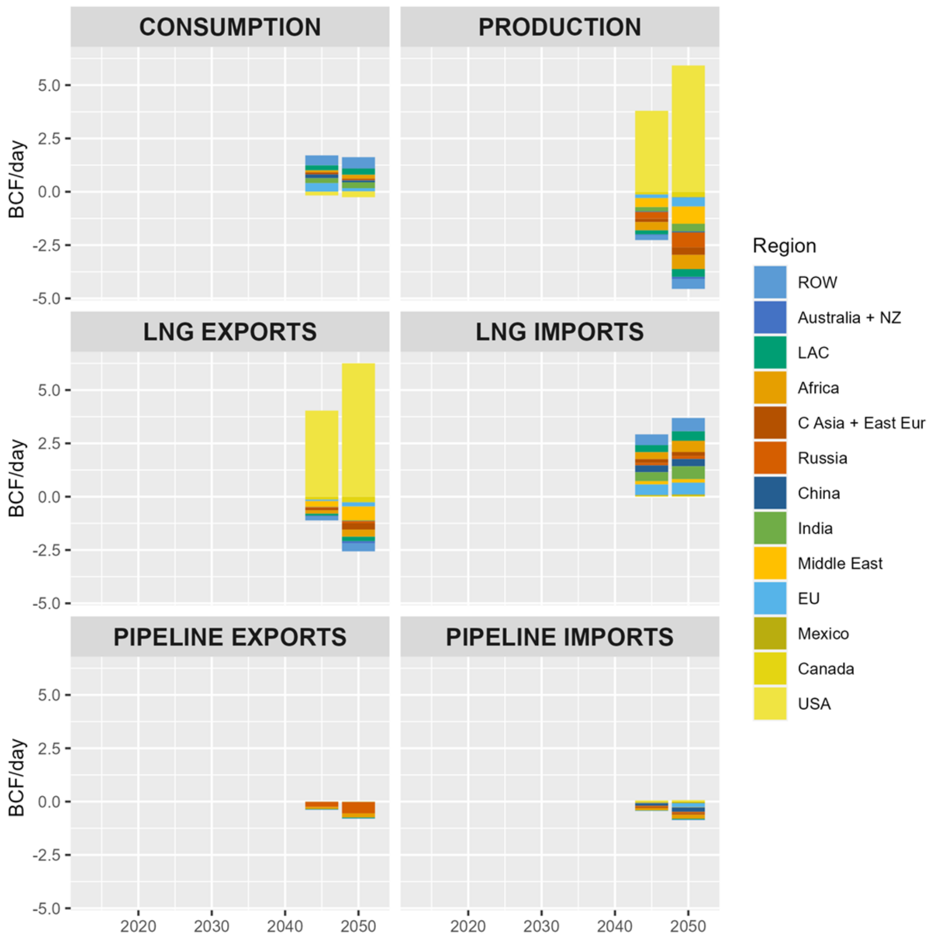


Figure 12. Changes in natural gas markets in S7 vs. S6To convert from BCF/day to TCF/ yr and vice versa, the conversion factors are as follows: 1 TCF/yr = 2.74 Bcf/day and 1 BCF/day = 0.36 TCF/yr.

E. Global Primary Energy Consumption and GHG Emissions Across All Scenarios

Overall, as shown in Figure 13, the seven scenarios explored in this study result~~ed~~ in a range of outcomes for global primary energy consumption and emissions by 2050~~. As shown in Figure 13~~. Across *S1-S5*, ~~, t~~global primary energy consumption in 2050 ranges from 802 to 833 EJ ~~he~~ and global emissions range from 47.5 to 50.3 GtCO2e. In addition, the fuel composition of primary energy consumption and sectoral allocation of emissions ~~and the sectoral allocation of GHG emissions were~~ are not very different across *S1-S5* ~~across scenarios *S1* through *S5*~~. Total primary energy consumption and GHG emissions ~~were~~ are highest under ~~*the S3 scenario*~~*S3* driven by higher population growth and associated increases in energy demand.

Notably, ~~T~~total emissions in 2050 under scenarios *S1* through *S5* ~~were~~ are relatively similar to 2015 levels because these scenarios include~~d~~ current policies and measures to deploy lower emission technologies. However, total primary energy consumption in 2050 under these scenarios ~~was~~ is significantly higher compared to 2015 primarily driven by population and economic growth.

By contrast, total energy and emissions ~~were~~ are lowest ~~in~~ under ~~scenarios~~ *S6* and *S7* due to assumptions about countries ~~meeting emission pledges and further emission declines~~limiting emissions consistent with their pledges ~~to reach a global temperature change of 1.5°C by the end of century~~. Under these scenarios, global primary energy consumption in 2050 is 716 EJ and global GHG emission is 17 $GtCO_2e$. As described earlier, these scenarios ~~were~~ are also characterized by significant changes in the fuel composition of global energy consumption and the deployment of carbon dioxide removal technologies compared with *S1-S5*~~.~~.

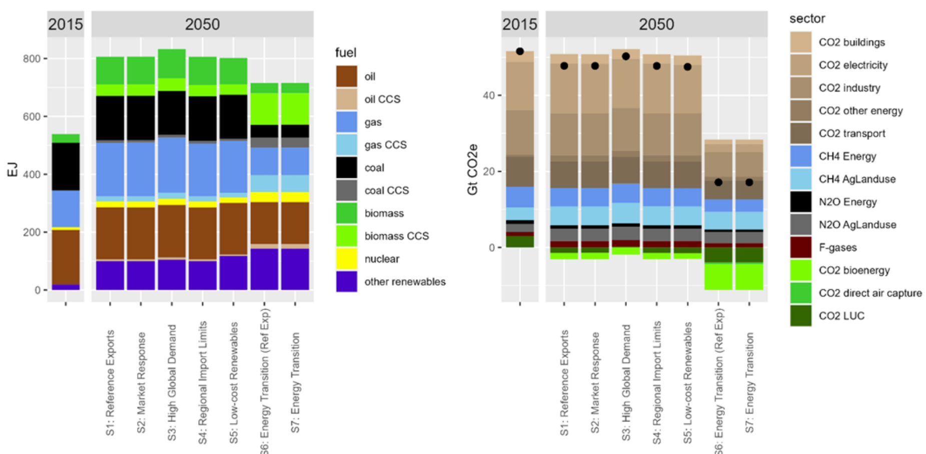
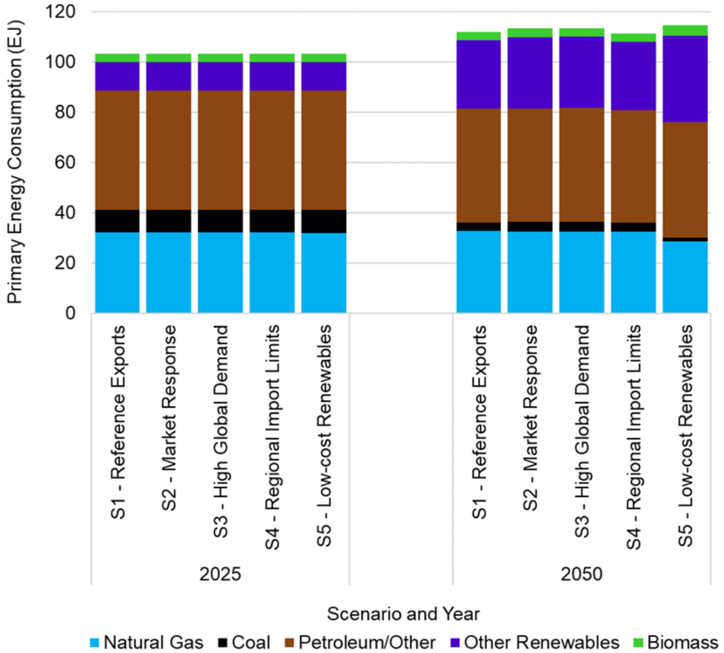


Figure 13. Primary energy consumption by fuel and GHG emissions by sector under all scenarios

F. NEMS Analysis: Implications for U.S. Energy Systems

1. Energy Impacts

AEO2023-NEMS and FECM-NEMS were used to model U.S.-specific results for *S1* through *S5*, and *S6* through *S7*, respectively. Similar to global energy consumption, primary energy consumption in the U.S. grew over time in each scenario.


Primary Energy Consumption (EJ)
120
100
80
60
40
20
0
S1 - Reference Exports
S2 - Market Response
S3 - High Global Demand
S4 - Regional Import Limits
S5 - Low-cost Renewables
2025
2050
Scenario and Year
Natural Gas
Coal
Petroleum/Other
Other Renewables
Biomass

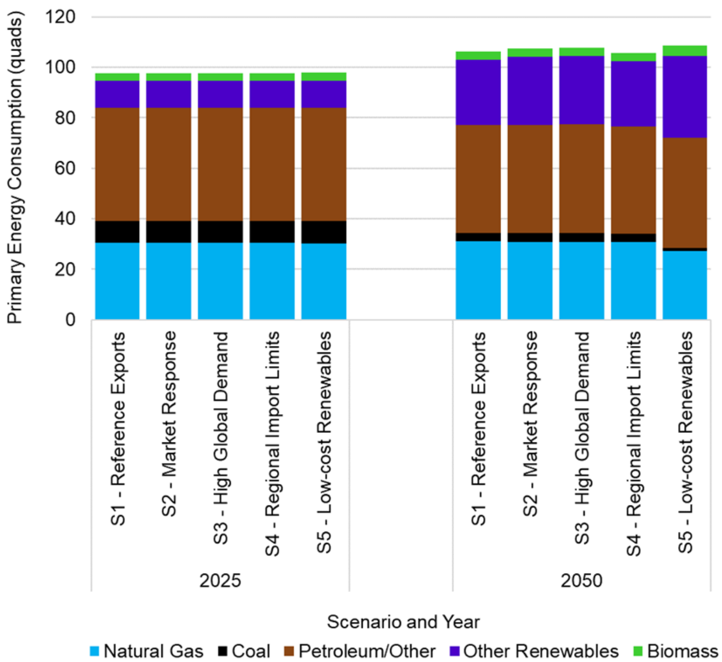


Figure 14. U.S. primary energy consumption, S1 through S5

In 2025, the primary energy consumption was at approximately 103 ~~98 quadrillion BTUs~~EJ in scenarios *S1* through *S5,* as shown in in Figure 14. By 2050, all scenarios saw an increase in total energy consumption, exceeding 11005 ~~quadrillion BTUs~~EJ. The highest energy consumption was recorded in scenario *S5* at 11509 ~~quadrillion BTUs~~ EJ, and the lowest consumption was in scenario *S4* at 11105 ~~quadrillion BTUs~~EJ.

The availability of low-cost renewables in scenario *S5* fosters the deployment of biomass and other renewable energy sources. A substantial decrease was noted in coal usage, with the most significant reduction occurring in scenario *S5*. Natural gas consumption remained steady across scenarios *S1* through *S4*, hovering around 32.1-32.71 ~~quadrillion BTUs~~EJ, but experienced a decline to 278.6 ~~quadrillion BTUs~~EJ in scenario *S5*.

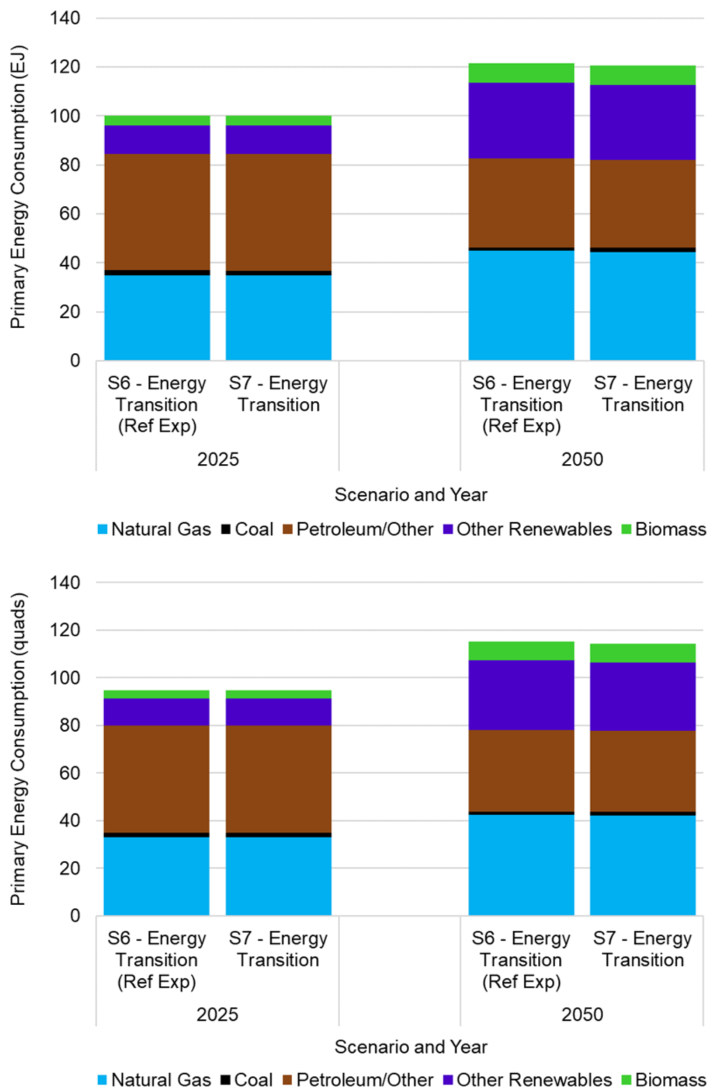
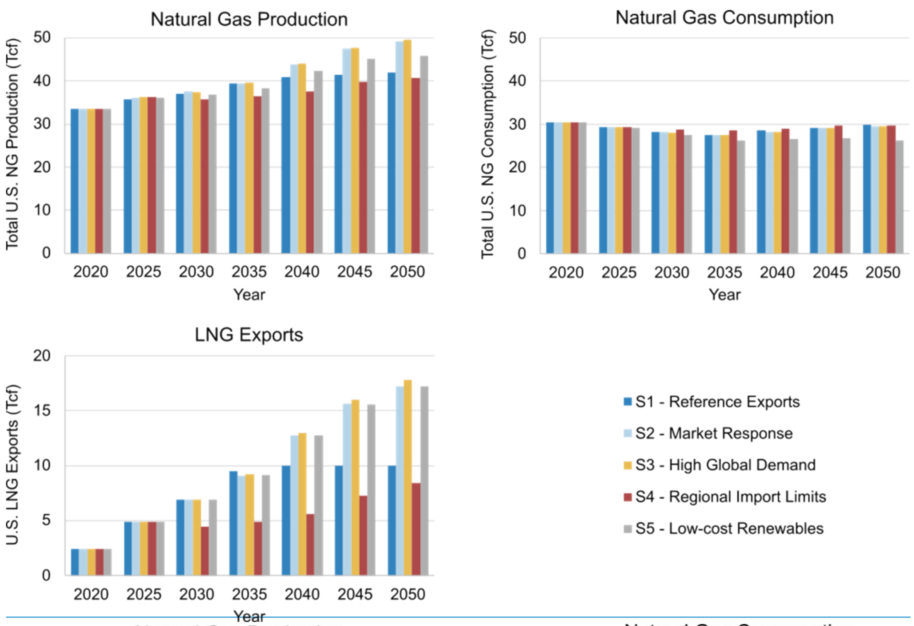


Figure 15. U.S. primary energy consumption S6 and S7

Figure 15 shows U.S. primary energy consumption across *S6* and *S7* in 2025 and 2050. In 2025, U.S. primary energy consumption was predominantly driven by fossil fuels, which accounted for 85% of the total energy use. By 2050, energy consumption rose across both scenarios relative to 2025, is distinguished by a notable increase in biomass and other renewables. Relative to *S6*, the increased LNG export trajectorys in *S7* put pressure on the natural gas market, leading by 2050 to slightly higher end-use prices and more expensive GHG mitigation strategies but ultimately a slight (.8%) decrease in U.S. natural gas consumption. Biomass and other renewable sources grew by 23.62.3 and 23.32.1 EJquadrillion BTUs from 2025 to 2050 in the *S6* and *S7* cases respectively, thereby contributing 32.1% of the total energy consumption in both cases. Natural gas consumption increased from 35.0 and 34.93 quadrillion BTUs EJ in 2025 to 42.54.8 and 44.42.1 quadrillion BTUsEJ in the energy transition scenarios *S6* and *S7* respectively. Remaining primary energy, primarily petroleum, decreased across both cases from 45.27.7 quadrillion BTUsEJ in 2025 to 36.24.4 EJquadrillion BTUs in *S6* and 35.84.0 quadrillion BTUs EJ in *S7* by 2050.

2. Natural Gas Production and Consumption Impacts

U.S. natural gas production increased across most cases to maintain projected export volumes. U.S. natural gas consumption, on the other hand, was relatively unchanged across the first four scenarios. Figure 16 plots total U.S. natural gas production, consumption, and export values over time. The LNG export values were identical to those plotted in Figure 3 and are included here as reference.



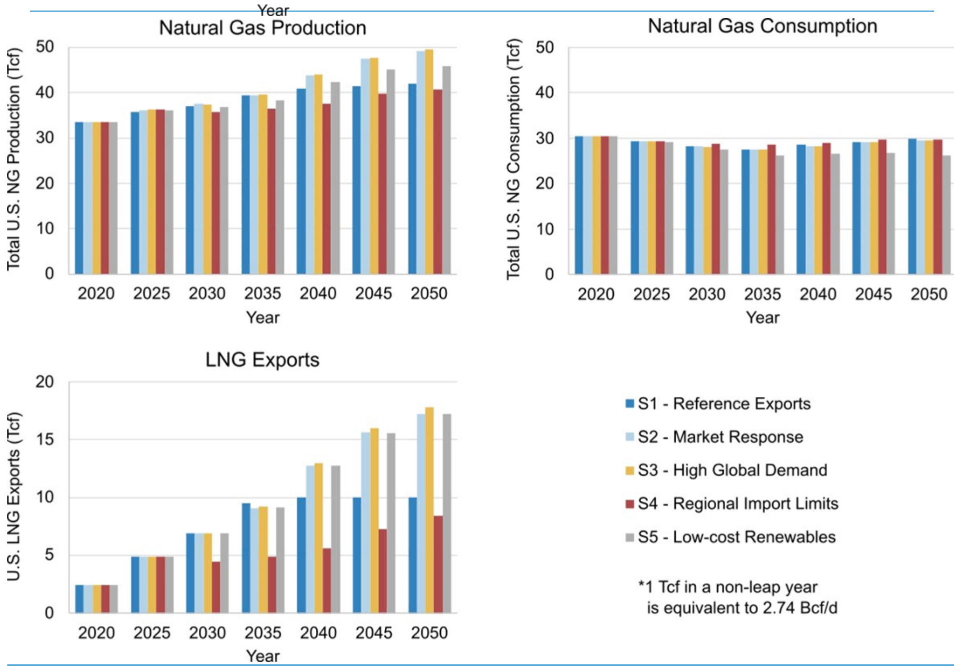


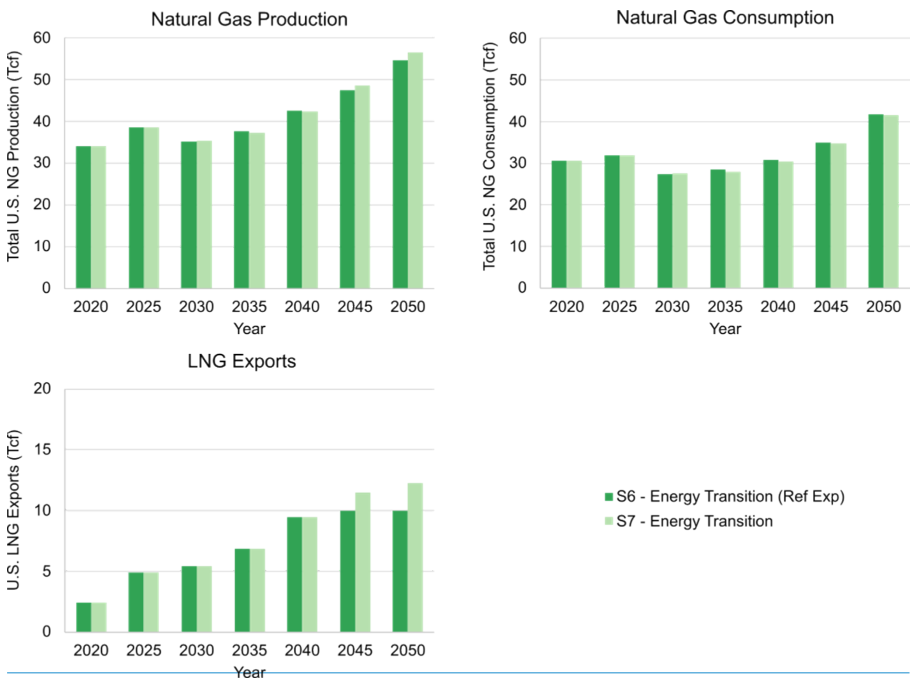
Figure 16. Total U.S. natural gas production, consumption, and export volumes over time, by scenario

From a starting point of 33.5 Tcf (91.5 Bcf/d) of natural gas production in 2020, production in each scenario increased, following a path that correlated with their LNG export curve. Natural gas production in *S1*, *S2*, and *S3* followed a similar trajectory by 2035, reaching 39.5, 39.4, and ~~-~~39.5 Tcf respectively. *S1* production then slowed through 2040 and reached a peak of 42.0 Tcf by 2050. *S2* and *S3* production values accelerated through 2050, reaching 49.0 Tcf and 49.5 Tcf, respectively. Similar to the trends in LNG exports, *S4* production exhibited the lowest values, ending slightly below *S1* at 40.7 Tcf in 2050. *S5* production exhibited the same general path as *S2* and *S3*, but grew more slowly, reaching 38.2 Tcf and 45.7 Tcf in 2035 and 2050~~, respectively~~.

The natural gas consumption volumes from *S1*-*S3* followed similar paths, dipping from 30.5 Tcf in 2020 to 27.6, 27.5~~4~~, and ~~-~~27.4~~6~~ Tcf in 2035 before ramping up to ~~29.6~~ 29.8, 29.6 and 29.6 Tcf in 2050 in these scenarios. Although *S4* had exhibited lower LNG export and natural gas production quantities, the consumption volumes in *S4* remained slightly higher than the volumes in *S1*-*S3* through most ~~of~~ model years, equalizing with *S1*-*S3* in the final timestep. *S4* reported 28.5 Tcf of natural gas consumption in 2035 and 29.8 Tcf in 2050. *S5* was the largest outlier with the lowest consumption of 26.2 Tcf in 2035 and almost no change in consumption values between 2035 and remaining flat at 26.2 Tcf in 2050.

The lower natural gas production and consumption volumes in *S5* (when compared to *S2* and *S3*) are explained by the effect of low renewables costs on the energy system. *S5* adopted many of the same inputs as EIA's AEO2023-NEMS low zero-carbon technology cost case. These inputs drove down the cost of renewables and caused *S5* to switch from natural gas to cheaper renewable energy sources, affecting both production and consumption. The remaining scenarios showed similar levels of natural gas consumption, but different levels of natural gas production, suggesting that most increases in natural gas production were passing directly to LNG exports.

Figure 17 plots the natural gas production, consumption, and exports for the two net-zero scenarios. Natural gas production in Scenarios *S6* and *S7* is 37.6 Tcf and 37.1 Tcf in 2035, respectively, but quickly rise to 54.7 Tcf and 56.5 Tcf by 2050. *S6* and *S7* exhibited a flatter trend in total consumption through 2040, but reached 41.9 Tcf and 41.5 Tcf, respectively, by 2050. The differences between the two net-zero scenarios were similar to differences observed between *S1* through *S5*: changes in production were correlated with changes in LNG exports, but differences in consumption between scenarios were minimal.


Natural Gas Production
Total U.S. NG Production (Tcf)
60
50
40
30
20
10
0
2020 2025 2030 2035 2040 2045 2050
Year
Natural Gas Consumption
Total U.S. NG Consumption (Tcf)
60
50
40
30
20
10
0
2020 2025 2030 2035 2040 2045 2050
Year
LNG Exports
U.S. LNG Exports (Tcf)
20
15
10
5
0
2020 2025 2030 2035 2040 2045 2050
Year
S6 - Energy Transition (Ref Exp)
S7 - Energy Transition

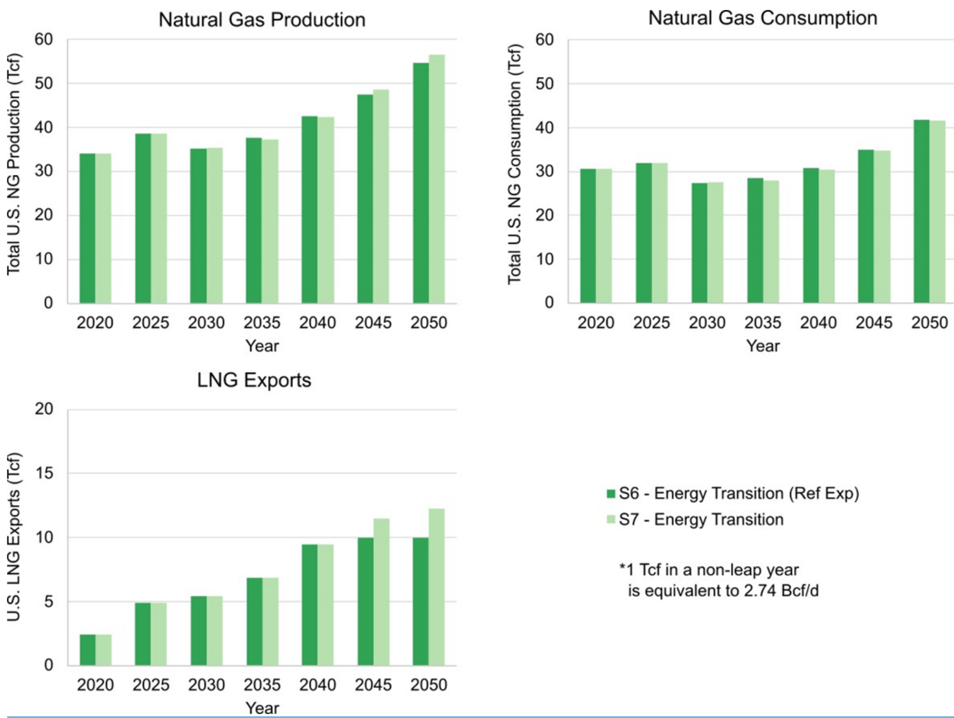
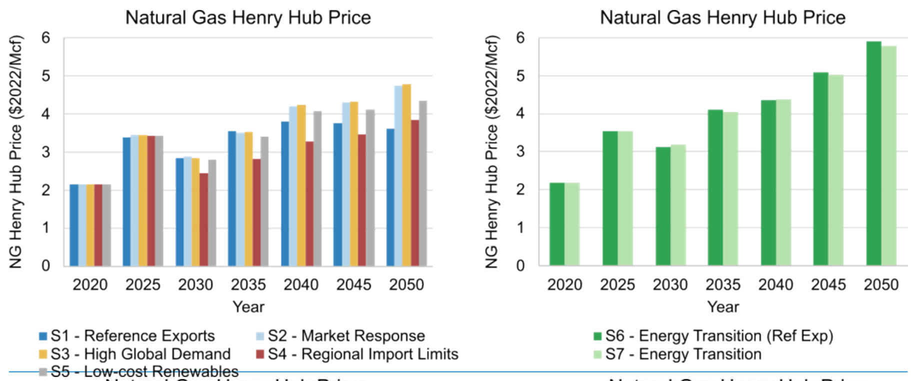


Figure 17. Total U.S. natural gas production, consumption, and export volumes, net-zero scenarios

The rapid increase in natural gas production and consumption for the net-zero scenarios after 2040 came from a substantial increase in natural gas to power direct air capture (DAC) facilities, plotted in Figure B-5 of the appendices. Natural gas consumption accounted for 16.8 Tcf and 16.2 Tcf in 2050 for *S6* and *S7*, respectively. More detail on CO_2 emissions and removals is provided in the Section ~~1.F.5:~~ "U.S. Greenhouse Gas Results".

3. Natural Gas Henry Hub Prices Impacts

Although total U.S. natural gas consumption volumes were similar across the first five scenarios, ~~the~~ higher~~increased~~ LNG exports ~~had a moderate effect on~~increased natural gas prices by up to 33% in 2050. The natural gas price of the net-zero scenarios rose above the prices from *S1* through *S5*, driven mostly by demand for natural gas to power DAC facilities. Figure 18 plots the natural gas price at the Henry Hub in $2022/Mcf over time for all scenarios.



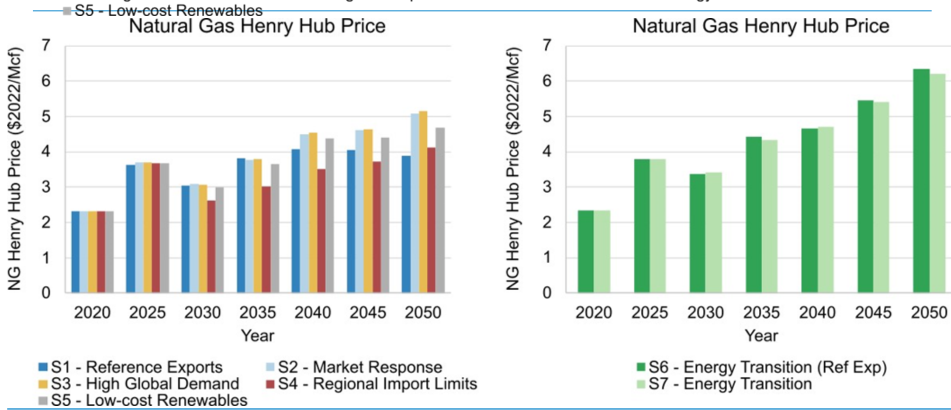


Figure 18. Total U.S. natural gas Henry Hub price by scenario ($2022)

The natural gas price in *S1* increased to a maximum of $~~3.80~~4.08/Mcf in 2040 before moderating to $3.~~61~~88/Mcf in 2050. The natural gas prices in *S2*, *S3*, and *S5* were mostly consistent with the reference case through 2035 but ultimately rose to levels of $~~4.74~~5.09/Mcf, $~~4.79~~5.15/Mcf, and $~~4.35~~4.67/Mcf, respectively, by 2050. The difference in prices correlated with the differences in LNG export curves, while LNG exports in *S1* plateaued after 2035 and saw a drop in natural gas prices. Scenarios *S2*, *S3*, and *S5* all exhibited both increasing exports and prices. *S4* had lower natural gas prices over most of the modeling period, but ultimately exceeded *S1* in 2050 with a price of $~~3.84~~4.12/Mcf; the persistent increase in *S4* prices after 2030 was consistent with increases in LNG exports throughout the same time period. ~~Prices remained below $5.00/Mcf for all timesteps in *S1* through *S5*.~~

The influence of LNG exports on natural gas prices shown in Figure 18 was similar to the effect reported by EIA in their May 2023 "Issues in Focus" report on LNG.[28] The EIA's "Fast Builds Plus High LNG Price" case, which modeled the effect on U.S. energy markets of accelerated construction of LNG infrastructure in an environment with elevated international demand for LNG, reported a 2050 natural gas price of

[28] U.S. EIA (2023). AEO2023 Issues in Focus: Effects of Liquefied Natural Gas Exports on the U.S. Natural Gas Market. Available at: https://www.eia.gov/outlooks/aeo/IIF_LNG/pdf/LNG_Issue_in_Focus.pdf.

$4.81/MMBtu (equal to $4.98~~64~~/Mcf) at 48.2 Bcf/d of exports. These values are close to the results from *S2* of $5.09~~4.74~~/Mcf at 47.2 Bcf/d of exports and demonstrate good agreement between the two studies on the relationship between LNG exports and natural gas prices.

Overall U.S. natural gas consumption did not change appreciably in response to higher prices, but there were some shifts in consumption behavior on a sector-by-sector basis. These sector-specific differences are presented in greater detail in the Appendix in Figure B-3.

The natural gas price of the net-zero scenarios rose above the prices from *S1* through *S5*, driven mostly by demand for natural gas to power DAC facilities. Natural gas prices for S6 and S7 were similar to prices in *S1* through 2030, but afterwards rapidly increased on a trajectory consistent with the growth of DAC. *S6* and *S7* reached prices of $~~5.90~~6.34/Mcf and $~~5.77~~6.20/Mcf, respectively, by 2050. The difference in price between *S6* and *S7* was within the tolerance of the model.

4. U.S. Macroeconomic Outcomes

While NEMS has rich detail about the energy system, a separate macroeconomic activity module (MAM) provides projections of economic drivers underpinning NEMS' energy supply, demand, and conversion modules. The MAM incorporates IHS Markit's (now S&P Global's) model of the U.S. economy, along with EIA's extensions of industrial output, employment, and models of regional economies. The S&P Global module is modified to include EIA's ~~assumptions on~~ key assumptions, such as world oil price, yielding a baseline trajectory of the economy. The baseline cannot appropriately respond to the wider economic changes in the net-zero scenarios, so such analysis is not included here. Within a NEMS scenario, feedback from the other NEMS modules includes:

- Production of energy, including coal, natural gas, petroleum, biomass, and other fuels;
- Trade in energy, including net exports coal, petroleum, natural gas, and biofuels;
- Total and end-use demand for energy, including sales of electricity;
- Consumer spending on energy, disaggregated to fuel oil motor fuels, electricity, natural gas, and highway consumption of gasoline;
- Energy prices, including a price index for consumer prices and wholesale prices; and
- Industrial production indices for oil and gas extraction and coal mining.

Since the MAM does not track individual projects, GDP estimates do not include economic activity associated with specific export facilities and thus the impacts are approximate.

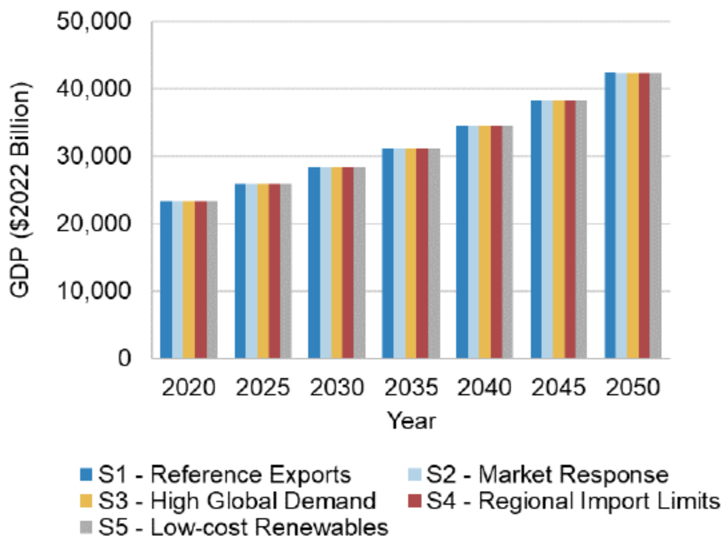


Figure 19. U.S. real GDP changes

GDP estimates in NEMS are only loosely coupled with the energy market representation and therefore there is a some uncertainty in the GDP metric. In addition, because NEMS is a domestic model, trade effects are not represented in as granular a level as domestic energy markets. One result is that in general modeled GDP growth is in general inversely proportional to the growth in natural gas prices, uncertainty increases as the forecast horizon increases. With those caveats, ~~As shown in~~ Figure 19, shows U.S. GDP growth across scenarios. The growth rate through 2045 remained essentially constant across all five scenarios, increasing at 1.9% annually. Higher natural gas exports ~~resulted in higher prices~~caused natural gas prices to rise by up to 33% in 2050, reducing economic activity in some sectors but increasing in others. The impact of increased LNG exports was positive on GDP by less than 0.1% across scenarios the through 2045. Accelerating natural gas prices in the last five years of the projection period in S2 reduced consumption ~~on~~ of other products and tended to slightly reduce the overall rate of economic growth relative to *S1*. Overall, GDP changes in 2050 relative to 2020 were within 0.3%, $42.4 in S1 vs $42.3 S2 – S5.~~across all five scenarios.~~

Commented [WS110]: A few points:
1. This data should be presented in numbers as well as visually.
2. We state that higher exports is positive on GDP until 2050, but S1 seems greater than S2 throughout the entire time series.
3. Does the last sentence mean we think that 0.3% of GDP is a small amount that doesn't warrant further discussion? 0.3% of 42 trillion is over 100 billion. Are we saying that incremental exports of 20 Bcf/d would reduce the size of the US economy by that amount? Over $5b per Bcf/d? If so that seems like a very consequential finding and one that should be explored in greater depth.
A few points:
1. This data should be presented in numbers as well as visually.
2. We state that higher exports is positive on GDP until 2050, but S1 seems greater than S2 throughout the entire time series.
3. Does the last sentence mean we think that 0.3% of GDP is a small amount that doesn't warrant further discussion? 0.3% of 42 trillion is over 100 billion. Are we saying that incremental exports of 20 Bcf/d would reduce the size of the US economy by that amount? Over $5b per Bcf/d? If so that seems like a very consequential finding and one that should be explored in greater depth.

Commented [UP111]: On page 36, we said that "increased LNG exports had a moderate effect on natural gas prices." Here we say "higher natural gas exports resulted in higher prices." Just flagging if this sounds inconsistent?G

Commented [DH112R111]: Edited to refer to the specific percentage (33%) instead of an ambiguous description

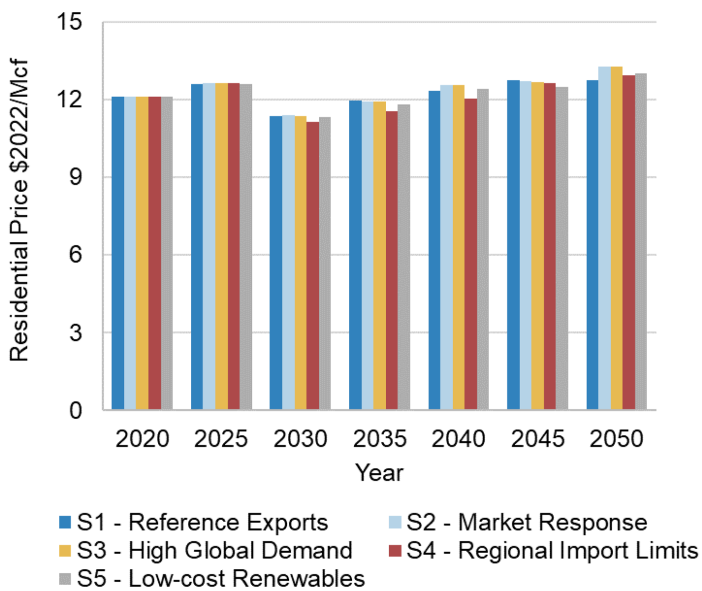


Figure 20. U.S. residential natural gas prices

Figure 20 shows the residential natural gas price in each of the five key scenarios. In 2050, natural gas prices in *S3* (when exports are the highest) were 4% higher than S1, when exports were the lowest. Overall, natural gas price differences between the scenarios were generally close to 1-2% across the scenarios.

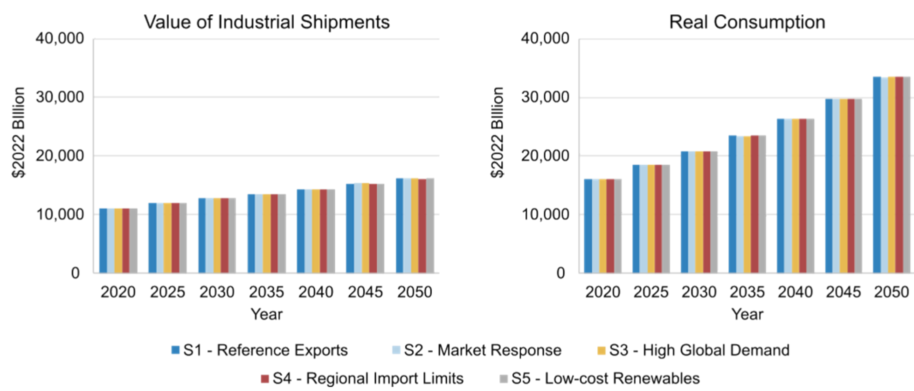


Figure 21. U.S. value of industrial shipments and real consumption

One component of GDP tracked by NEMS is the value of industrial shipments, shown in Figure 21. Industrial processes are sensitive to natural gas prices, which were generally higher than *S1*. However, increased production, processing, and transportation of natural gas requires additional equipment which tends to increase industrial shipments. Overall, NEMS showed a very slight increase in the value of industrial shipments in *S2* relative to *S1* of 0.2% in 2050. The value declined in S4 vs S1, reflecting lower natural gas production and exports.

The NEMS analysis shows LNG exports could benefit consumers through increased labor income and the return on capital expended on facilities to produce and export the commodity. Exports increased the value of the dollar, decreasing the cost of some imports. However, increased demand for natural gas, including exports, raised the price of natural gas and the costs of products that require natural gas as an input. This can be observed in the change in aggregate consumption which is another component of GDP. When energy prices rise, consumers must pay more for natural gas, but purchases of other goods decrease. Across all the scenarios, ~~this~~the~~is~~ effect on natural gas prices was small, and, while wealth transfers may occur between consumers as some groups benefit more than others through increased production, this was not reflected in the aggregate output of the model. Changes across all the scenarios were essentially flat. Overall, by 2050 consumption changes were less than 0.2%.

Commented [UP113]: Should this be LNG instead of NG? or does the NEMS analysis show benefits of all NG exports? We've been discussing LNG exports so far in the report so just checking?

Commented [DH114R113]: Yes apologies, this should be LNG. Edited.

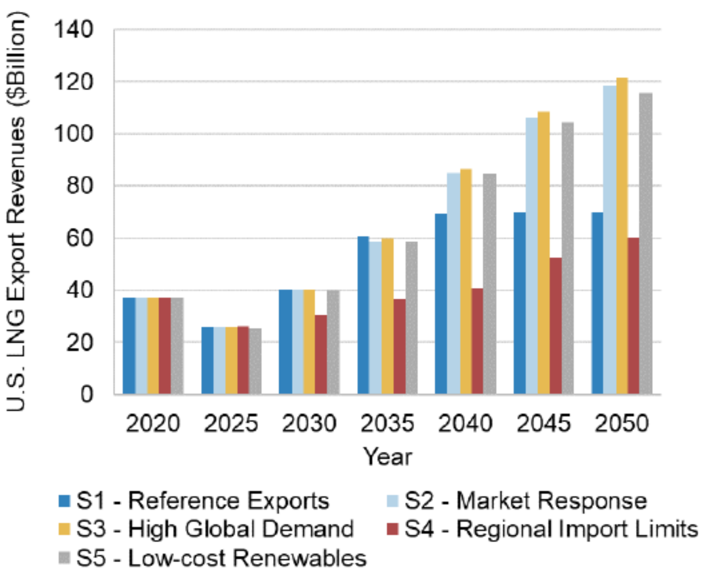


Figure 22. U.S. LNG export revenues

In a fully competitive market, the delivered price of LNG should be sufficient to fully accommodate the cost of production, liquefaction, and transportation of natural gas. Since much of this activity occurs domestically, it is a rough proxy for economic activity engendered by LNG exports. A representative price would be the price of imports to the EU. Figure 22 shows estimates of export revenues as the product of the LNG export volumes and the EU LNG price.

5. U.S. GHG Results

AEO2023-NEMS tracks CO_2 emissions from the combustion and use of fossil fuels. These CO_2 emissions did not change significantly ~~between~~ among scenarios in response to varying LNG export levels. Figure 23 plots CO_2 emissions from fossil fuels for *S1* through *S5*.

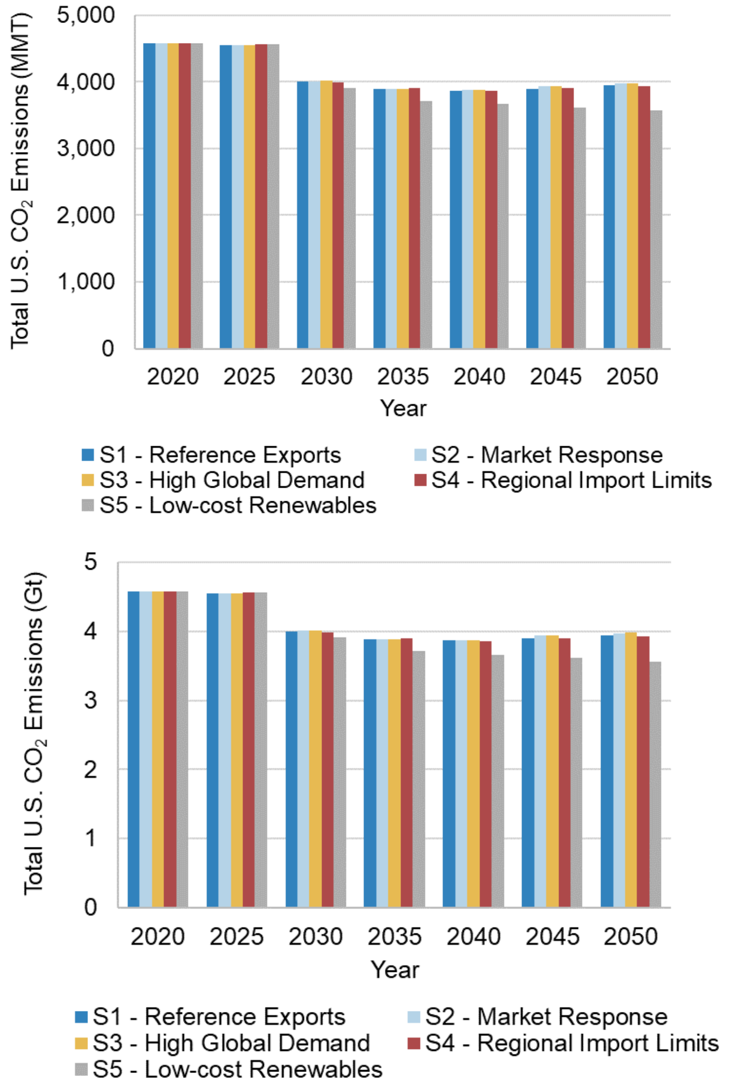


Figure 23. Total U.S. CO_2 emissions from fossil fuel combustion

From a starting point of 4.,580 GtMMT CO_2 emissions in the U.S. in 2020, the first four scenarios declined to between 3.,990 and 4.,020 GtMMT CO_2 in 2030 and followed a flatter trajectory to 39303.93-3.98980 GtMMT CO_2 in 2050. There was a weak connection between LNG exports and CO_2 emissions: cases with the highest exports (*S2* and *S3*) had slightly higher CO_2 emissions levels in 2050 of

~~3970~~ 3.97 and ~~3980~~ 3.98 ~~MMT~~Gt, respectively, whereas cases with lower exports (*S1* and *S4*) reported respective CO_2 emissions of ~~3040~~ 3.94 and 3.93~~030~~ ~~MMT~~Gt. The relationship was small, however, and accounted for only a 1% difference in emissions. The small differences between the first four scenarios were consistent with the relatively unchanged natural gas consumption volumes observed in Figure 16. *S5* was an outlier, continuing to decrease through 2030 (~~3910~~ 3.91 Gt~~MMT~~ CO_2) and reaching 3.57~~570~~ Gt~~MMT~~ CO_2 emissions by 2050. The lower emissions from *S5* were explained by the assumptions used for low renewable costs rather than by changes in LNG exports.

S6 and *S7* were modeled in FECM-NEMS, which endogenously calculated some additional emissions that AEO2023-NEMS is missing (most relevant being CH_4 leakage from natural gas production and processing infrastructure). To retain consistency between the two models, only the CO_2 emissions reported by FECM-NEMS were included in the analysis and used to define the net-zero GHG scenarios. The remaining non-CO_2 emissions (which still contributed to the overall net-zero GHG cap) were calculated endogenously within GCAM and used in FECM-NEMS as an exogenous input.

Figure 24 plots the CO_2 emissions and removals for *S6* and *S7*. Both scenarios had both lower emissions than *S1* and significant amounts of CO_2 removals, reaching net-zero by 2050.

Commented [WS115]: Should these be 3940 and 3930?

Commented [DH116R115]: Yes, thanks for catching that - updated to be 3.94 and 3.93 Gt CO2

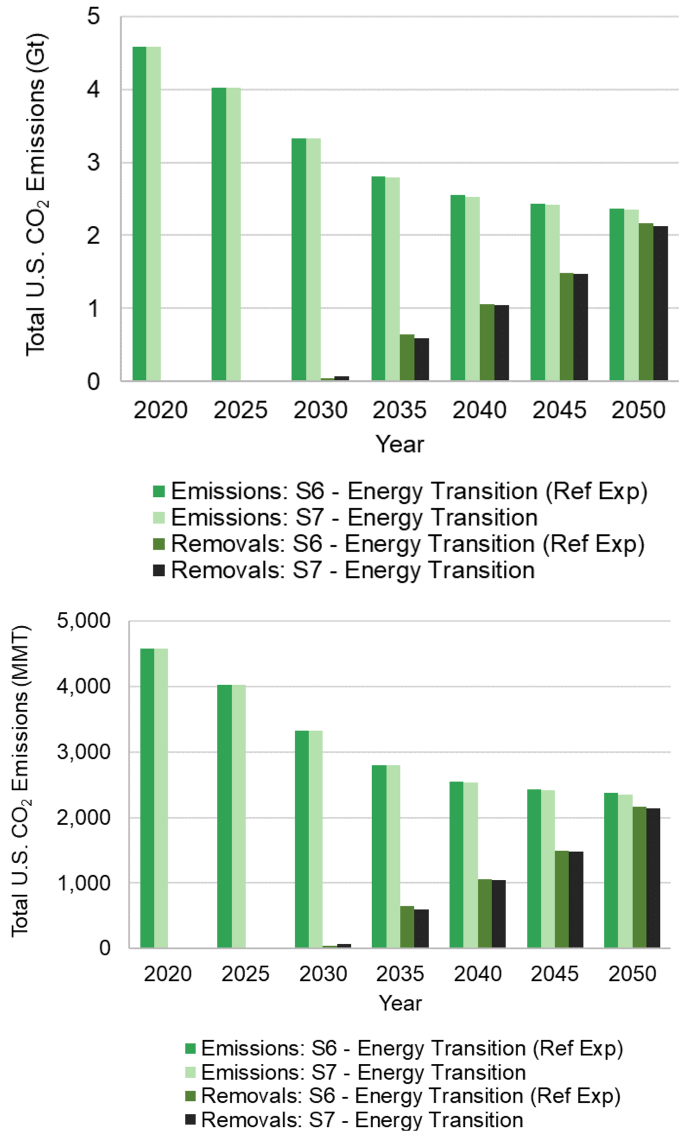


Figure 24. Total U.S. CO_2 emissions from fossil fuel combustion and removals, S6 and S7

CO_2 emissions from *S6* and *S7* began at 4.~~,~~58~~0~~ Gt~~MMT~~ and declined continuously through 2050, ending at 2.~~,~~37~~0~~ and 2.~~,~~35~~0~~ Gt~~MMT~~ CO_2, respectively. These declines were primarily driven by electrification of broad sections of the economy with a combination of renewables and CCS. The decline in emissions was accompanied by an increase in removals, which started growing rapidly in 2030 and eventually reached 2.~~,~~16~~0~~ Gt~~MMT~~ CO_2 for *S6* and 2.~~,~~13~~0~~ Gt~~MMT~~ CO_2 for *S7* in 2050. The majority of removals (87-89% by 2050) came from DAC, with the remainder coming from H_2 production with biomass and BECCS. The specific breakdown of removal technologies is explored in Section D of Appendix B. While the removals did not completely ~~cancel out~~counterbalance the 2.~~,~~35~~0~~-2.~~,~~37~~0~~ Gt~~MMT~~ of CO_2 emissions, the difference is ~~balanced out~~offset by the sum of the changes in land-use and non-CO_2 emissions calculated within GCAM and used as exogenous inputs, which were net negative.

Commented [PW117]: Added land-use

G. NETL Life Cycle Analysis

The goals of the LCA component of this project were twofold: first, to help contextualize how the other results of this study (i.e., NEMS and GCAM models) connect to past studies of U.S. natural gas and LNG operations and, second, to leverage the results of the other models to quantitatively represent the international global warming potential (GWP) consequences from changes in quantities of U.S. exported LNG.

In support of the first goal, the following work was completed:

- Assessed whether NEMS results suggested significant changes in domestic supply (and thus, resulting in potential future upstream GWP intensity or emissions changes~~)~~).
- Compared and aligned GCAM and NETL results to create a representation of the global natural gas supply chain that is consistent with existing NETL natural gas LCA studies.

Commented [AA118]: Delete or "that is"

In support of the second goal, the following work was completed:

- Developed a quantitative "market ~~effect~~ adjustment factor" that represents the consequences of additional export volumes of U.S. LNG, such as how additional available quantities of natural gas led to changes in the energy sectors of countries that purchase the LNG. These consequential effects were estimated by tracking differences in global GHG emissions and quantities of U.S. LNG exported from the GCAM model scenarios and assessed in comparison to existing NETL quantitative estimates of the upstream natural gas production.

In this project, the NEMS and GCAM models sought to represent economic and environmental changes associated with the defined changes in U.S. LNG exports. The GCAM model estimated global GHG emissions effects, including emissions associated with upstream natural gas. To compare the GCAM results with ~~past the~~ NETL life cycle analysis work used by DOE in support of natural gas and LNG export decisions, NETL assessed and aligned the emissions estimates per unit of gas produced and delivered to large end users (e.g., LNG export facilities) in the US of the ~~two~~ GCAM and NEMS models to the NETL life cycle GHG intensity for U.S. average natural gas production and delivery to large end users using the ratio of the NETL and GCAM results. Non-U.S ~~country~~region natural gas production and delivery GHG emissions intensity values were also adjusted to align with NETL life cycle GHG intensity values based on the ~~difference between the GCAM U.S. GHG emissions intensity for natural gas compared to each non-U.S. natural gas exporting countries GHG emissions intensity in GCAM~~same ratio of US values. This process was conducted for ~~each~~all years and regions reported by GCAM.

Commented [ST119]: Results were not aligned to the past NETL work on LNG exports. Work was aligned to the current NETL 2020 natutal gas upstream thru transmission to a large end user U.S. average GHG emissions per unit of natual gas delivered.

Commented [SM120R119]: Agreed, edited (slightly modified the suggested revision).

1. Assessment of NEMS Domestic Natural Gas Production by Region

The NEMS modeling focused on domestic changes that would be expected to occur in the seven scenarios modeled. NETL evaluated the regional sources of natural gas using outputs from NEMS to compare them to the mix of regions NETL uses in existing assessments of upstream natural gas emissions.

As shown in Appendix C, the NEMS results suggested only modest changes in the production mix by region and thus would not be expected to substantially change the domestic average GHG intensity per MJ of natural gas produced compared to previous analyses. As such, no regional adjustments were made to the U.S. results.

Commented [AA121]: Spell out if first time using this unit alone.

Commented [SM122R121]: Defined earlier, and added to glossary, thanks!

2. Comparison of GCAM and NETL Estimates of GHG Emissions of the Natural Gas ~~sector~~Sector

As discussed above, the GCAM model represents economic activity (and associated GHG emissions) by sectors and technologies, and their respective inputs and outputs, for regions, years, and scenarios. However, only a subset of these was relevant to the scope of the natural gas LCA-focused effort.

Only three sectors in the GCAM model include greenhouse gas emissions of the natural gas sector: *natural gas*, *gas pipeline*, and *other industrial energy use* (see Appendix C for more detail). Using the basis of process stages as represented in the NETL Natural Gas model, Figure 25 shows the relevant GCAM sectors that have associated CO_2 and non-CO_2 emissions. While the overall GCAM model has 16 species of GHG emissions, for the three sectors above relevant to the upstream natural gas sector, only emissions of CO_2, CH_4, and N_2O were represented.

As summarized in Figure 25, all stages of the NETL LCA are explicitly represented in GCAM except for Ocean Transport, which was included as part of other industrial energy use but could not be separated out for this analysis. As a result, the comparison in this report was focused on a comparison of emissions from production of natural gas in the U.S. through delivery to a large end user rather than LNG delivered around the world.

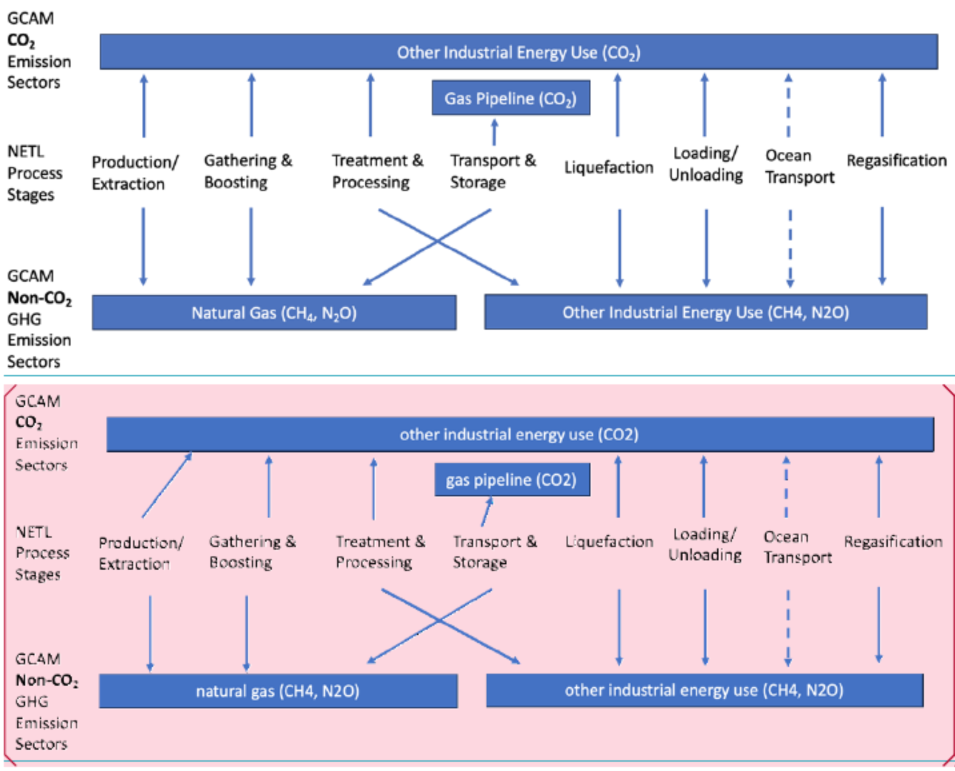


Figure 25. Mapping of NETL natural gas stages to GCAM sectors

Quantitative values of emissions intensities in the year 2020 of the various GCAM sectors for the "USA" region for the three natural gas-relevant sectors are listed and compared to NETL natural gas model results in Appendix C. Note, ~~that~~ in order to compare NETL and GCAM results, NETL model results were regenerated using LHV basis as shown below and differ from those published (as HHV by default) in the report.

Overall, the estimated upstream emissions for the USA in the GCAM model in the year 2020 for Scenario 1 were about 8.52 g CO_2e/MJ (on an IPCC AR6 100-year, LHV basis), which is slightly higher than those of the NETL model for the boundary of production through transmission to large end user (8.18 g CO_2e/MJ, LHV basis). Using the relationship between those estimates, emissions results in the three GCAM natural gas sectors were adjusted by a factor of 8.18/8.52, or 0.96 (a 4% reduction) to maintain consistency with past NETL studies of the natural gas sector. This adjustment factor was used for all regions and for all years in the model. Similar adjustment factors were found for IPCC AR6 20-year and IPCC AR5 100-year and 20-year bases (see Appendix C for further details). The results are similar whether using the adjusted or unadjusted values.

Commented [ST123]: Labels in "blue" boxes need capitalized.

Subscript the 2 and 4 in CO2, CH4, and N2O.

NETL Process Stage labels should be centered with the arrows.

Commented [SM124R123]: Fixed.

Commented [ST125]: The rest of the report uses "U.S." instead of "USA".

Commented [SM126R125]: Just referring to the actual GCAM model region name here

Commented [ST127]: See previous comment, this numeric values used need to be stated.

Commented [SM128R127]: Added

Commented [ST129]: Is the GCAM value consistent over the 35 year time horizon?

Is this the levelized average over 35 years that includes performance improvements within GCAM? Or is it the year 2020 value?

Are the values different for S7/S6 when climate pledges and net zero are considered? How did this effect the MAF calculation when considering temporal and economic variability?

Commented [ST130R129]: Need to state that the 8.52 is **the year 2020 GHG emissions intensity.**

Added to text - please confirm edit.

After reading the report, I don't think the value is levelized over 35 years. Unclear how GCAM GHG intensity per unit of LNG changes over time within the GCAM model (or NEMS).

Commented [SM131R129]: We apply the same adjustment factor through all the years, for all regions. This maintains the built-in methane mitigation curves in GCAM.

Commented [WS132]: If we used the GCAM estimate, how would that affect our GHG projections? Some will argue that we cherry picked a more favorable estimate, so it would be helpful to say that our conclusions are robust to that assumption.

Commented [SM133R132]: We show results using the raw and adjusted values in the report.

For context, in the GCAM results for *S1* in Year 2020, total global GHG emissions are approximately 53,000 Tg. The NETL adjustment post-processing of the GCAM model results on the IPCC AR6 100-year basis of the GCAM *gas pipeline* and *natural gas* sectors reduces emissions by about -7 and -35 Tg CO_2e, respectively, when considering those of S1 in the Year 2020. Post-processing adjustments of the GCAM model results of the *other industrial energy use* sector reduce emissions by about -10 Tg CO_2e when considering those of *S1* in the Year 2020. The adjustments for these three sectors needed to align with past NETL studies and have the cumulative effect of reducing estimated emissions from the GCAM model by about 0.2% (in *S1* in the Year 2020).

This same process was undertaken for different IPCC GWP values, and the resulting alignment tables and adjustment factors are provided in Appendix C.

3. Market Adjustment Factor Results

Market adjustment factors (MAF) quantitatively estimate the consequential effect on global emissions as a function of U.S. LNG exported based on the GCAM model results of this study. MAFs for *S2* were estimated versus a baseline of *S1*, while the MAF for *S7* was estimated versus a baseline of *S6* given the significantly different global economy modeled in these scenarios.

MAFs were calculated using the post-processed LHV NETL-adjusted GCAM results described previously as well as the unadjusted GCAM results (HHV results are shown in the Appendix). The MAF was calculated for each scenario by ~~aggregate~~ aggregating annual MAF values over the time horizon of the model (i.e., the MAF for *S2* versus *S1* was defined as the ~~total~~ cumulative difference in annually ~~-~~ estimated global emissions over the 35-year period divided by the ~~total~~ cumulative difference in annually estimated exported LNG over the ~~same~~ 35-year period).

All MAFs were found using a variety of IPCC Assessment Report GWP values over 20- and 100-year time horizons, and with the raw and post-processed NETL adjusted GCAM results. MAF results from the IPCC Sixth Assessment Report on a 100-year time horizon are presented here, ~~and~~ while results for other IPCC Assessment Reports and time horizons (and ~~all raw~~unadjusted GCAM results) are shown in Appendix C.

Table 4 shows the MAFs for *S2* (vs. *S1*), which varied from -5.34 to -5.35 g CO_2e/MJ on a 100-year time horizon (LHV basis~~).~~). Also included is a summary reminder of the differences in the modeled scenarios (e.g., where *S1* is the baseline and *S2* added an economic solution for LNG exports, making a direct comparison of the two appropriate).

Table 4. Market Adjustment Factors for S2 vs. S1 (IPCC AR6, 100 year)

Results (g CO_2e/ MJ, LHV)			
MAF Case	GCAM	GCAM with LHV NETL adjustment	Scenario Difference
S2* vs. *S1	-5.34	-5.35	Adds economic solution for LNG exports.

Table 5 shows market adjustment factors for *S7* vs. *S6*, both of which represented significantly different energy and economic investments in support of a low-carbon economy through climate policies. The *S7* ~~MF~~MAFs vary from -2.~~81~~ 95 to -3.01 on a 100-year time horizon (LHV).

Commented [ST134]: Why the italicized label? Not italicized in other parts of the report?

Commented [SM135R134]: Rest of report does have italicized Scenario references.

Commented [ST136]: All results need to be on a HHV basis to document what will actually be used by NETL when added to the attributional results.

I am okay with report comparing to GCAM in LHV, however, that is not the result that needs documented for use in future export analyses that include consequential market effects. This report needs to document the values that will be used in future work.

Commented [SM137R136]: Will add HHV values to Appendix.

Commented [ST138]: Add HHV results.

Table 5~~.~~ Market Adjustment Factors for S7 vs. S6 (IPCC AR6, 100 year)

Results (g CO_2e/ MJ, LHV)			
MAF Case	GCAM	GCAM with LHV NETL adjustment	Scenario Difference
S7* vs. *S6	-3.01	-2.95	S6 1.5°C pathway, economic solution for LNG exports

4. Interpretation of Global Market Adjustment Factor Results

On an IPCC AR6 100-year basis, for *S2-S1*, the MAF result was approximately -5.4 g CO_2e/MJ (LHV). For purposes of comparison, NETL estimated natural gas upstream emissions prior to delivery to a large domestic industrial end user (like an LNG terminal) are 8.18 g CO_2e/MJ (LHV), equivalent to 7.44 g CO_2e/MJ (HHV)~~).~~. The MAF ~~indicated~~ indicates that as U.S. LNG exports increased, the induced global market effects would result in an overall reduction in GHG emissions that is about ~~70~~65% of the estimated upstream emissions associated with production through delivery of the natural gas to a large industrial end user in the U.S.

Similarly, ~~The~~ the MAF result for *S7-S6* was about -3 g CO_2e/MJ (LHV)~~).~~. In a decarbonizing world, the overall reduction in emissions was ~~56~~36% of the estimated upstream emissions associated with production through delivery of the natural gas to a large industrial end user in the U.S.

As noted in Section C.1, NETL Natural Gas reports estimated life cycle GHG emissions associated with delivery of US LNG to a regasification facility in Europe to be 20 g CO_2e/MJ (IPCC AR6, 100 year, LHV basis) and 18.1 g CO_2e/MJ (HHV basis). Thus on a life cycle basis and considering cumulatively through 2050, the induced global market effects per unit of increased LNG exports are equivalent to an overall reduction in GHG emissions that is about: 27% of the estimated emissions associated with US LNG delivered to Europe under reference climate policy assumptions (LHV basis, 30% on HHV basis) and 15% of the estimated emissions associated with US LNG delivered to Europe under global decarbonization policy assumptions (LHV basis, 16% on HHV basis).

~~This is~~These results are consistent with the idea that as the broader findings of this study that the global economy decarbonizes, the induced global decarbonization benefit of increased U.S. LNG will be less. Overall, both of these results were consistent with the overall GCAM results that increased U.S. exports did not lead to increased global GHG emissions. Global changes in GHG emissions were constant to slightly negative as U.S. natural gas exports increased and global energy demand increased. The GHG reductions represented by the negative MAF were not so large that U.S. LNG should be regarded as a global climate reduction strategy but, at the same time, a negative MAF suggested that increased U.S. LNG exports could be compatible with global decarbonization efforts. A positive MAF would suggest U.S. LNG was leading to overall increased global emissions.

The results were aggregated in relation to estimated future volumes of exported LNG from the U.S. in the context of a global model. They represent overall expected effects and not those of individual shipments or authorizations of LNG. It is not possible to conclude that every MJ of exported LNG from domestic natural gas sources would directly lead to lower GHG emissions results when supplied around the world.

Commented [ST139]: Add HHV results.

Commented [TC140]: For the leadership briefing, Tim recalculated this interpretation as follows. Can you confirm these calculations and change the section to reflect this interpretation? (Tim also has the calculations in a comment below).

On a life cycle basis through 2050, the induced global market effects per unit of increased LNG exports are equivalent to an **overall reduction in GHG emissions** that is about:
27% of the estimated emissions associated with U.S. LNG delivered to Europe **under reference climate policy assumptions** (LHV basis, 24% on HHV basis)
15% of the estimated emissions associated with U.S. LNG delivered to Europe **under global decarbonization policy assumptions** (LHV basis, 15% on HHV basis)

Commented [ST141]: Reported as 7.44 previously in the report.

Commented [ST142]: Also report the result in LHV with the HHV result. (8.18 g CO2e/MJ, LHV basis)

Commented [ST143]: I calculate a 66% reduction. 70% is generous rounding.

Commented [WS144]: (b)(5)

(b)(5)

(b)(5)

Commented [ST145]: Results need to be also reported in context of delivered LNG to provide a more complete perspective on the actual magnitude of percent change in delivered LNG cargo.

Commented [ST146]: Add: result through delivered LNG.

E.g.

Commented [LBD147]: It's not completely clear to me why this comparison is made - it seems like there is a projected reduction in GHG emissions from S1 to S2, but it's small? A global reduction equal to 70% of

Commented [SM148R147]: We added the scope of delivered LNG to Europe, and reworded here - hopefully this is less confusing now.

Commented [ST149]: This paragraph needs to explain how -3 translates to a 56% reduction upstream NG emission profile to support the key insights.

~~V.~~VI. CONCLUSIONS

The purpose of this study was to examine the potential global and U.S. energy system and greenhouse gas (GHG) emissions implications of a wide range of economic levels of U.S. LNG exports. The study comprised three coordinated analyses: 1) **a Global Analysis** to explore a wide range of scenarios of U.S. LNG exports under alternative assumptions about future ~~socioeconomic~~ population and economic growth, regional preferences for domestically produced natural gas, pace of technological change in competing technologies (e.g., renewables), and countries' announced GHG emissions pledges and policies; 2) **a U.S. Domestic Analysis** of the implications of the various U.S. LNG export levels derived from the Global Analysis for the supply and demand of natural gas within the U.S. and the U.S. economy; and 3) **a Life Cycle Analysis** to examine the life cycle emissions implications of the various levels of U.S. LNG exports derived from the Domestic and Global analyses. A number of key insights from this study are summarized below. Table 6 ~~includes a~~provides a data summary of the ~~key~~ results across scenarios.

1. Across all modeled scenarios, U.S. LNG exports continue to grow beyond current operational export capacity (14.3 Bcf/day) through 2050. In addition, U.S. natural gas production ~~grow~~grows beyond current levels through 2050. Across all the scenarios, LNG exports range from 23-4~~9~~7 Bcf/day. The range of U.S. LNG exports from this study is consistent with the U.S. EIA's analysis (15-48 Bcf/day ~~)~~).[29] Compared to a scenario in which U.S. LNG exports follow the Reference Case from the AEO2023 (*S1*, growing to 27.3 Bcf/day by 2050), a scenario that assumes economically-driven LNG export levels (*S2*) results in significant growth in U.S. LNG exports to 47 Bcf/day by 2050. The availability of additional U.S. natural gas at competitive prices in the global natural gas market in the latter scenario (*S2*) results in a reduction in production, reduction in LNG exports, increase in LNG imports, and reduction in pipeline trade outside of the U.S.
2. Global natural gas consumption increases ~~only slightly (~~by <1 percent~~)~~ under a scenario with increased availability of U.S. natural gas in the global market that reflects economically-driven LNG export levels (*S2*) compared to the reference scenario (*S1*)~~, as the availability of additional U.S. natural gas in the global market does not materially affect the competitiveness of natural gas relative to other fuels globally~~. Instead, it results in a shift in the regional composition of natural gas production and trade. The majority of U.S. natural gas substitutes for other global sources of natural gas.
3. U.S. natural gas prices as measured at the Henry Hub increases modestly when comparing a scenario that reflects global market demand for exports (*S2*) to the reference scenario (*S1*). Across those scenarios, 2050 Henry Hub prices are projected to increase from $3.~~61~~88/Mcf to $~~4.74~~5.09/Mcf, both of which are less than the reference 2050 price expected in the most recent study DOE[6] commissioned on the economic impacts from U.S. LNG exports in 2018.
4. U.S. residential prices are projected to be 4% higher in 2050 when comparing a scenario that reflects global market demand for exports (*S2*) to the reference scenario (*S1*). In none of the scenarios did the change in residential prices exceed 4% and the percentage difference was generally ~~by~~ substantially less.
5. The value of industrial shipments remains essentially unchanged (increasing less than 0.1% by 2050) when comparing a scenario that reflects global market demand for exports (*S2*) to the

[29] U.S. EIA. (2023). Issues in Focus: Effects of Liquefied Natural Gas Exports on the U.S. Natural Gas. Available at: Markethttps://www.eia.gov/outlooks/aeo/IIF_LNG/

Commented [LBD150]: See comment above

Commented [UP151]: Shouldn't this be 49 Bcf/d based on S3 scenario (see page 21)?

Commented [IGC152R151]: Yes. Thanks.

Commented [UP153]: Here we're using 1-digit 27.3 Bcf/d versus 27.34 Bcf/d in earlier tables. I prefer 1-digit but we should be consistent with the decimal for the AEO 2023 forecast of LNG exports.

Commented [AA154]: Recommend adding clarifying language. Note description used early makes it clear that the reduction in production/export was from "other parts of the world." See:

Under *S2*, U.S. LNG exports grew to ~47 Bcf/day by 2050. In this scenario, the availability of additional U.S. natural gas in the global natural gas market at competitive prices resulted in a reduction in production and LNG exports from other parts of the world. The increased availability of U.S. LNG in the global market also resulted in higher LNG imports and reduced pipeline trade outside of the U.S.

Commented [IGC155R154]: The sentence includes "outside of the U.S." at the end.

Commented [LBD156]: Hard to describe as a "modest" increase, if in constant dollars. The increase is almost 1/3.

Commented [LBD157]: This point was not included in the summary of findings in the Ex Sum.

reference scenario *(S1)*. The impact of increased LNG exports on GDP is essentially flat, positive by less than 0.1% across scenarios through 2045 while all changes are within 0.3% in 2050.

6. Even though U.S. LNG exports continue to grow beyond existing and planned nameplate capacity across scenarios *S1* through *S5* to 23-4~~9~~7 Bcf/day by 2050, global and U.S. GHG emissions do not change appreciably. Global emissions in these scenarios range from 47.5-50.3 $GtCO_2e$ and U.S. emissions range from 4.3-4.6 $GtCO_2e$ across these scenarios.
7. The induced global market effects of a case that reflects ~~global market demand for exports (S2) compared to the reference case (S1)~~reference climate policies are equivalent to an overall reduction in GHG emissions of about ~~70~~30% of the estimated upstream emissions associated with production through delivery of the natural gas to ~~a large industrial end user (e.g., to~~ an LNG ~~export~~ regasification facility ~~) in the U.S~~in Europe. Such induced market effects in a case representing future global decarbonization policies are equivalent to a overall reduction of 16%.
8. When compared to the other scenarios, *S6* and *S7* – in which countries are assumed to achieve their GHG emissions pledges and pursue ambitious GHG mitigation policies consistent with limiting global warming to 1.5°C – are characterized by a global transition resulting in lower in natural gas, coal, and oil consumption without CCUS; higher deployment of gas, coal and biomass with CCUS, and renewables; higher deployment of carbon dioxide removal strategies; and lower overall energy consumption. While in scenario *S6*, in which U.S. LNG exports are limited to the values from the AEO2023 Reference case (by design) and grow to 27.~~3~~4 Bcf/day by 2050, *S7* assume economically-driven outcomes resulting in U.S. LNG exports growing to 34 Bcf/day by 2050. The higher growth in U.S. LNG exports in *S7* compared to *S6* is driven by increased global demand for natural gas with CCUS in the power and industrial sectors. Similar to the comparison between *S1* and *S2*, the availability of additional U.S. LNG in *S7* in the global natural gas market results in ~~a very small increase in natural gas consumption,~~a reduction in production, reduction in LNG exports, increase in LNG imports, and reduction in pipeline trade in the rest of the world compared to *S6*. In addition, global natural gas consumption increases by <1% under *S7* compared to *S6*. Furthermore, with the higher U.S. LNG exports in *S7* compared to *S6*, U.S. natural gas prices are essentially unchanged within modeling tolerance, reaching $~~5.90~~6.34/Mcf in *S6* and $6.20~~5.77~~/Mcf in *S7* by 2050.

Table 6. Key Results for U.S. and globe in 2050 across scenarios

Scenarios	U.S. LNG Exports (Bcf/d)	U.S. NG Henry Hub Price ($2022/Mcf)	US Net GHG Emissions ($GtCO_2e$)	Global Net GHG Emissions ($GtCO_2e$)
S1	27.3	$3.~~61~~88	4.5	4~~7.8~~7.7
S2-S5	23.1 – 48.7	$~~3.84~~4.12-$~~4.79~~5.15	4.3-4.6	47.5-50.3
S6-S7	27.3 – 33.6	$~~5.77~~6.20-$6.34~~5.90~~	0	17.1

67

Commented [WS158]: As noted above, this statement needs further explanation.

Commented [UP159]: Number check? 49?

Commented [LBD160]: It's not completely clear to me why this comparison is made - it seems like there is a projected reduction in GHG emissions from S1 to S2, but it's small? A global reduction equal to 70% of the LC emissions of one large industrial user? If that's correct, it might be clearer to just present the percentage reduction, or say that it was essentially the same level of emissions.

Commented [SM161R160]: We moved to using the "delivered LNG basis" that was added above.

Commented [ST162]: Consider splitting the conclusions into two parts: S1/S2 and S6/S7 to improve clarity.

Commented [IGC163R162]: This bullet focuses on S6-S7 only.

Commented [ST164]: Did we run another set of S6 and S7 results with and without CCUS? Where do these findings come from without CCUS?

Commented [IGC165R164]: As noted previously, all of our scenarios include both fossil fuel technologies w/ and w/o CCUS. The point of this statement is to compare S6 and S7 that have climate policy with other scenarios S1-S5 without climate policy. Compared to the scenarios *without* climate policy (S1-S5), the scenarios *with* climate policy (S6-S7) have lower fossil w/o CCUS.

Commented [UP166]: 2-digit here?

Commented [ST167]: Equivalent level of results are missing for S6/S7 as reported in Items #1 thru #7. MAF for S6/S7 is not discussed in the conclusion section, for example.

APPENDIX A: GLOBAL ANALYSIS AND DESCRIPTION OF GCAM

A. Additional detail about GCAM's energy system

The ~~GCAM's~~Global Change Analysis Model's (GCAM's)~~'s~~ energy system contains representations of fossil resources (coal, oil, gas), uranium, and renewable sources (wind, solar, geothermal, hydro, biomass, and traditional biomass) along with processes that transform these resources to final energy carriers (electricity generation, refining, hydrogen production, natural gas processing, and district heat) which are ultimately used to deliver goods and services demanded by end use sectors (residential buildings, commercial buildings, transportation, and industry). Each of the sectors in GCAM includes technological detail. For example, the electricity generation sector includes several different technology options to convert coal to electricity such as pulverized coal with and without carbon capture, utilization, and storage (CCUS), and coal integrated gasification combined cycle (IGCC) with and without CCUS. The full list of technologies in various sectors in GCAM is documented in the GCAM documentation page (http://jgcri.github.io/gcam-doc/).

In every sector within GCAM, individual technologies compete for market share based on the levelized cost of a technology. The cost of a technology in any period depends on (1) its exogenously specified non-energy cost, (2) its endogenously calculated fuel cost, and (3) any cost of emissions as determined by the climate policy. The first term, non-energy cost, represents capital, fixed and variable operating and maintenance (O&M) costs incurred over the lifetime of the equipment (except for fuel or electricity costs), expressed per unit of output. For example, the non-energy cost of coal-fired power plant is calculated as the sum of overnight capital cost (amortized using a capital recovery factor and converted to dollars per unit of energy output by applying a capacity factor), fixed and variable operations and maintenance costs. The second term, fuel or electricity cost, depends on the specified efficiency of the technology, which determines the amount of fuel or electricity required to produce each unit of output, as well as the cost of the fuel or electricity. The various data sources and assumptions are documented in the GCAM documentation page (http://jgcri.github.io/gcam-doc/). The prices of fossil fuels and uranium are calculated endogenously. Fossil fuel resource supply in GCAM is modeled using graded resource supply curves that represent increasing cost of extraction as cumulative extraction increases. Wind and rooftop PV technologies include resource costs that are also calculated from exogenous supply curves that represent marginal costs that increase with deployment, such as long-distance transmission line costs that would be required to produce power from remote wind resources. Utility-scale solar photovoltaic and concentrated solar power technologies are assumed to have constant marginal resource costs regardless of deployment levels.

In GCAM, technology choice is determined by market competition. The market share captured by a technology increases as its costs decline, but GCAM uses a logit model of market competition. This approach is designed to represent decision making among competing options when only some characteristics of the options can be observed and avoids a "winner take all" response.

For the purposes of this project, historical natural gas producer prices in the U.S. are calibrated to the Henry Hub prices from the EIA[30] and in Canada, they are calibrated to Alberta marker prices from the BP

[30] U.S. EIA (2023). Henry Hub Natural Gas Spot Price. Available at: https://www.eia.gov/dnav/ng/hist/rngwhhda.htm

Statistical Review.[31] For the rest of the world, natural gas producer prices in each GCAM region are based on the cost, insurance, and freight (CIF) prices from S&P (see Table A-1).[32] In a future model period, as demand changes, the change in regional producer prices from the historical calibrated values are calculated endogenously using regional supply curves that represent increasing cost of extraction as cumulative extraction increases.

Table A-1. Historical natural gas producer prices used for calibration in GCAM.

GCAM region	Natural gas producer prices (2022 $/MMBtu)
European Free Trade Association	1.61
Australia_NZ	1.89
Canada	2.45
Middle East	2.66
Africa_Northern	3.13
USA	3.17
Indonesia	3.61
South Asia	4.48
Southeast Asia	4.48
Central America and Caribbean	4.56
South America_Southern	4.56
Russia	5.76
Africa_Western	6.11
EU-12	8.61
EU-15	8.61
Europe_Non_EU	8.61
Africa_Eastern	9.48
Africa_Southern	9.48
China	11.08
India	11.08
Pakistan	11.08
Taiwan	11.97
Argentina	13.19
Brazil	13.19
Colombia	13.19
South America_Northern	13.19
Mexico	13.19
South Korea	13.37
Japan	13.43

[31] BP (2022). bp Statistical Review of World Energy. 71st edition. Available at: https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2022-full-report.pdf
[32] S&P Global (2023). S&P Global Commodity Insights. Historical and forecasted LNG prices data sheet.

B. Additional detail about scenario design

Table A-1. Detailed assumptions in the S4: Regional Import Limits scenario

Commented [IGC168]: Note to tech editor: Change numbering

Region Type	GCAM Regions	High-level target / sanction
Developed countries, natural gas importers with sufficient domestic resources	EU-12, EU-15, Europe_Eastern, Europe_Non_EU	Reduce gross imports to 90% by 2035 and zero by 2040
Developed countries, natural gas importers with low domestic natural gas resources	Japan, South Korea, Taiwan	Maintain current import dependence through 2050
Developing countries, natural gas importers	Brazil, China, India, Pakistan, Southeast Asia, Mexico, South Africa	Maintain current import dependence through 2050
Natural gas exporters	USA, Africa_Eastern, Africa_Northern, Africa_Southern, Africa_Western, Australia_NZ, Canada, Central America and Caribbean, Central Asia, European Free Trade Association, Indonesia, Middle East, South America_Southern, South America_Northern, South Asia, Colombia, Argentina	Reduce gross imports to 90% by 2035 and zero by 2040
Russia	Russia	Same as *S2*

C. Additional GCAM results

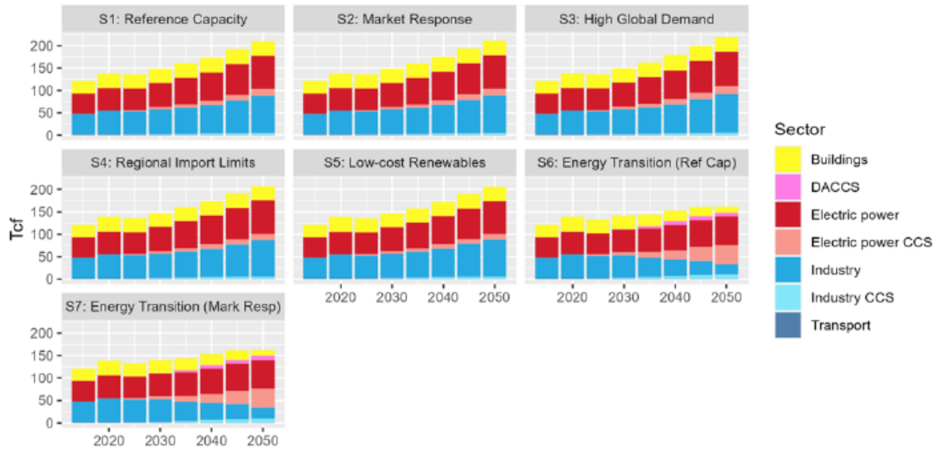


Figure A-1. Global natural gas consumption by sector across all scenarios. To convert from BCF/day to TCF/ yr and vice versa, the conversion factors are as follows: 1 TCF/yr = 2.74 Bcf/day and 1 BCF/day = 0.36 TCF/yr.

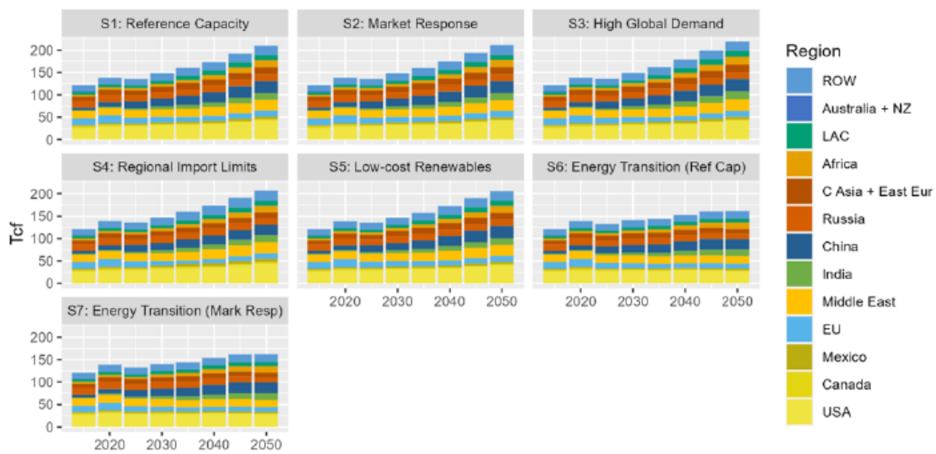


Figure A-2. Global natural gas consumption by region across all scenarios. To convert from BCF/day to TCF/ yr and vice versa, the conversion factors are as follows: 1 TCF/yr = 2.74 Bcf/day and 1 BCF/day = 0.36 TCF/yr.

Commented [UP169]: In the body of the report, we showed results in Bcf/d but in Appendix reverted back to Tcf making the comparisons of consumption and production not matching to the body of the report. LNG exports here are still shown as Bcf/d though so not consistent.

Commented [IGC170R169]: For the figures in main report, we need to stick with the same units for all panels so enhance readability. However, figures in the appendix follow more conventional untis (Tcf/yr for consumption and production; and Bcf/day for imports and exports). We have included data corresponding to all figures in the main section of the report in the corresponding units in Appendix D. To facilitate comparison between figures in the main report and this appendix, we have included conversion factors in the legends.

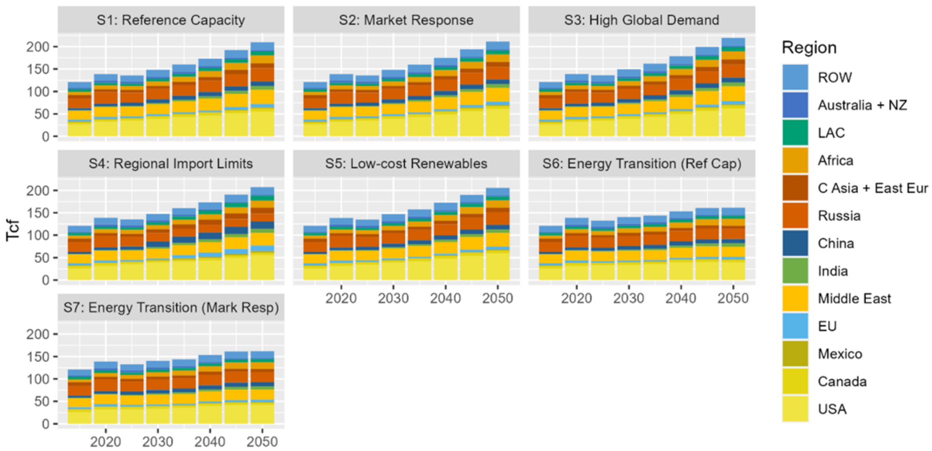


Figure A-3. Global natural gas production by region across all scenarios. *To convert from BCF/day to TCF/ yr and vice versa, the conversion factors are as follows: 1 TCF/yr = 2.74 Bcf/day and 1 BCF/day = 0.36 TCF/yr.*

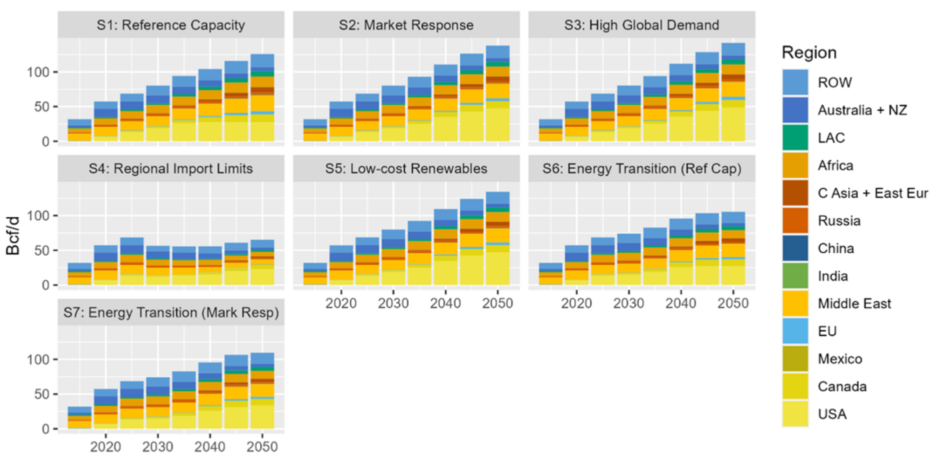


Figure A-4. Global LNG exports by region across all scenarios. *To convert from BCF/day to TCF/ yr and vice versa, the conversion factors are as follows: 1 TCF/yr = 2.74 Bcf/day and 1 BCF/day = 0.36 TCF/yr.*

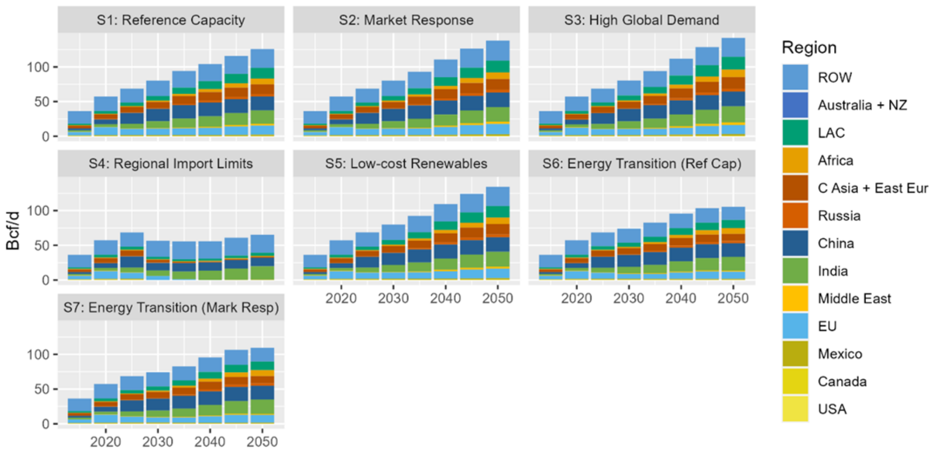


Figure A-5. Global LNG imports by region across all scenarios. To convert from BCF/day to TCF/ yr and vice versa, the conversion factors are as follows: 1 TCF/yr = 2.74 Bcf/day and 1 BCF/day = 0.36 TCF/yr.

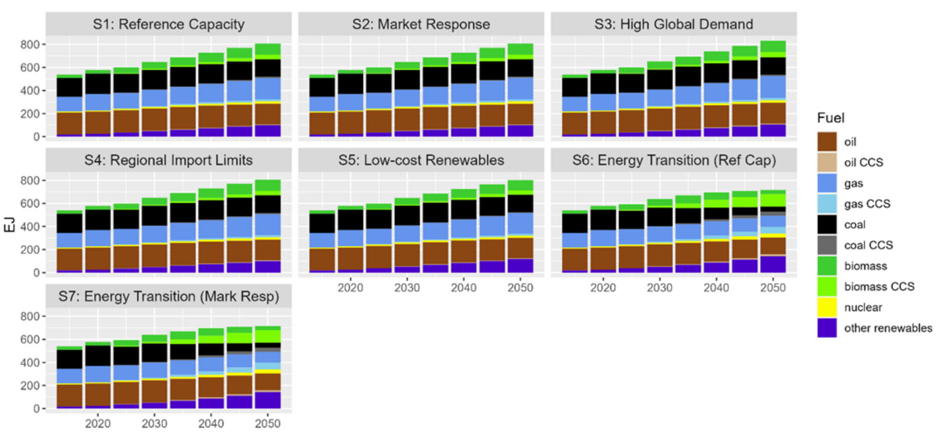


Figure A-6. Global primary energy consumption by fuel across all scenarios.

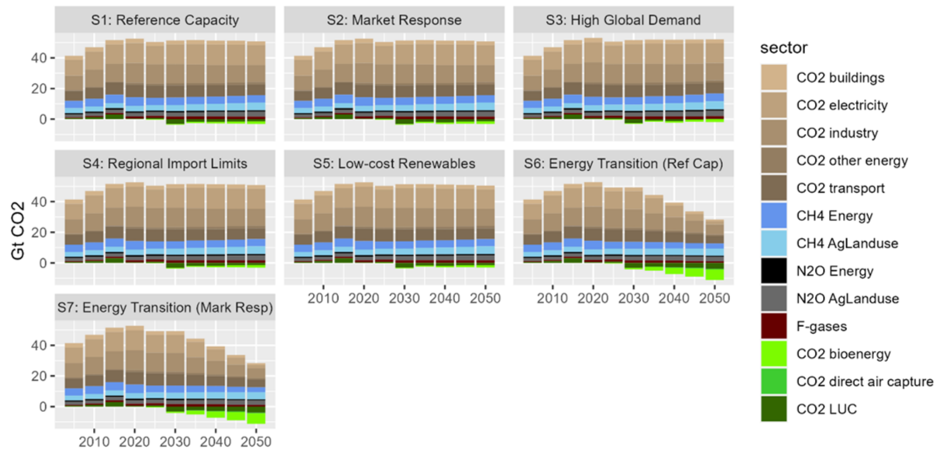


Figure A-7. Global GHG emissions by sector across all scenarios

APPENDIX B: U.S. ANALYSIS AND DESCRIPTION OF AEO2023-NEMS AND FECM-NEMS

A. Modeling U.S. LNG exports

AEO2023-NEMS and FECM-NEMS have two methods available to calculate LNG export capacity: endogenous and exogenous. There is a switch in the input files that can be toggled between the two methods before executing a run. *S1* ~~and *S6* iuse~~s the EIA AEO2023 reference case, which calculates LNG export capacity endogenously; *S2* through ~~*S6S56* and~~ *S7* are initialized with exogenous LNG export capacity, which use ~~exogenous~~ LNG export values from the GCAM model for each scenario. The LNG export capacity in *S6* is exogenously set to equal the capacity in *S1* and the EIA AEO2023 reference case. Both AEO2023-NEMS and FECM-NEMS follow a similar process with only minor differences in a small number of input values. In most cases (including all cases discussed in this report) LNG exports will equal LNG export capacity because the cost to construct capacity is so high that capacity will rarely be left unused once built. Therefore, the following description can be treated as an explanation for how AEO2023-NEMS and FECM-NEMS calculate LNG Export volumes.

The algorithm for calculating LNG export capacity endogenously has two steps. In the first step, AEO2023-NEMS considers LNG exports from existing or planned LNG export facilities. Beginning with Cheniere's Sabine Pass facility, which started exporting LNG in 2016, AEO2023-NEMS runs through a list of export facilities specified in an input file. This list is updated with each version of the AEO; AEO2023-NEMS includes existing and planned facilities expected to start or expand production by the end of 2025. For each facility, AEO2023-NEMS slowly increases production over the first few months to represent an export facility ramping up to full capacity.

The second step in the endogenous algorithm involves a prediction of future LNG exports. AEO2023-NEMS uses a set of exogenous values in an input file to specify how much demand Europe and Asia will have for LNG imports, as well as how much supply of non-U.S. LNG will exist on the market. Then, considering the volume of U.S. LNG exports at a given model year, AEO2023-NEMS calculates how the ratio of supply and demand changes over time. This ratio, together with the world oil price, is used to calculate the price at which international customers will purchase U.S. LNG. The purchase price algorithm is constructed in such a way that rises in the oil price, decreases or slowdowns in future LNG supply, or increases in future LNG demand will all increase the purchase price of LNG, and vice-versa. The influence that each factor has on LNG purchase price is controlled by several input parameters.

In addition to a purchase price, AEO2023-NEMS calculates the price at which U.S. LNG could be sold for. This "sale price" combines the natural gas Henry Hub price with various costs that represent the stages of preparing pipeline gas for LNG transport (including liquefaction, fuel consumption, shipping, and regasification). AEO2023-NEMS then compares the sale price to purchase prices at different destinations and determines a discounted net present value (NPV) of new LNG construction over the subsequent 20 years. Depending on the NPV, AEO2023-NEMS will decide to increase LNG export capacity by 0 to 600 Bcf/d. The increase in capacity takes effect after a four year "construction" period and brief "phase-in" period.

~~The algorithm in~~An input file is read by AEO2023-NEMS to define~~calculate~~ LNG export capacity exogenously ~~is far. simpler~~. A table in an input file lists LNG export capacity by year; these values are used by AEO2023-NEMS to set LNG exports for that year. In *S2* through *S~~6~~7*, various parameters,

Commented [UP171]: Is this sentence correct? Maybe was written pre-S7? I edited it but needs a check.

Commented [DH172R171]: The sentence was inaccurate - we've reworded it to clarify that S1 is endogenous and S2 through S7 are exogenous, even though the values from S6 equal S1.

Commented [UP173]: Sounds too informal for a description of a model. Maybe just stick to the facts versus saying it is hard or simple.

Commented [DH174R173]: Edited to remove informal language including LNG export volumes, are calculated by the GCAM model. The LNG export volumes are converted to the correct input format and adopted by AEO2023-NEMS as the exogenous LNG export capacity.

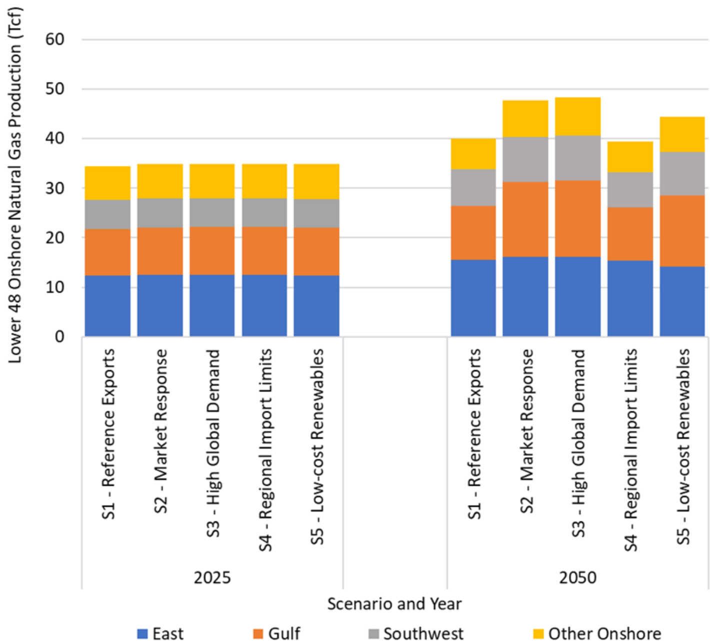
Commented [UP175]: S7?

Commented [DH176R175]: Apologies, S7 is correct

B. Additional detail on U.S. natural gas markets

1. Regional natural gas production

Figure B-1 and Figure B-2 plot onshore natural gas production by region for the first five scenarios and the net-zero scenarios, respectively, in 2025 and 2050. Offshore natural gas production comprises a small portion of the total (<4 % in all scenarios and years) and is omitted from these figures.


Lower 48 Onshore Natural Gas Production (Tcf)
60
50
40
30
20
10
0
S1 - Reference Exports
S2 - Market Response
S3 - High Global Demand
S4 - Regional Import Limits
S5 - Low-cost Renewables
2025
2050
Scenario and Year
East
Gulf
Southwest
Other Onshore

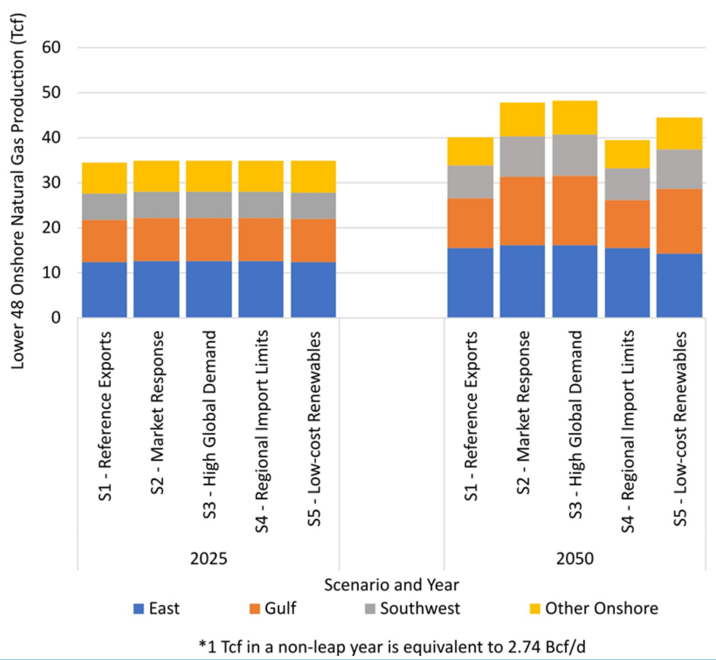
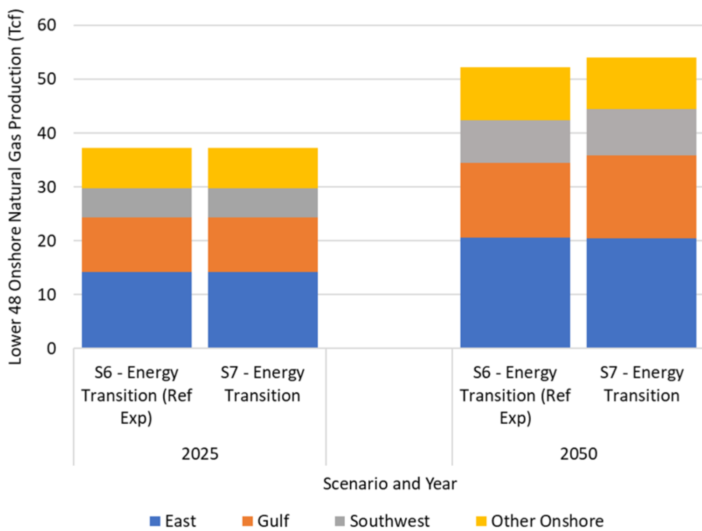
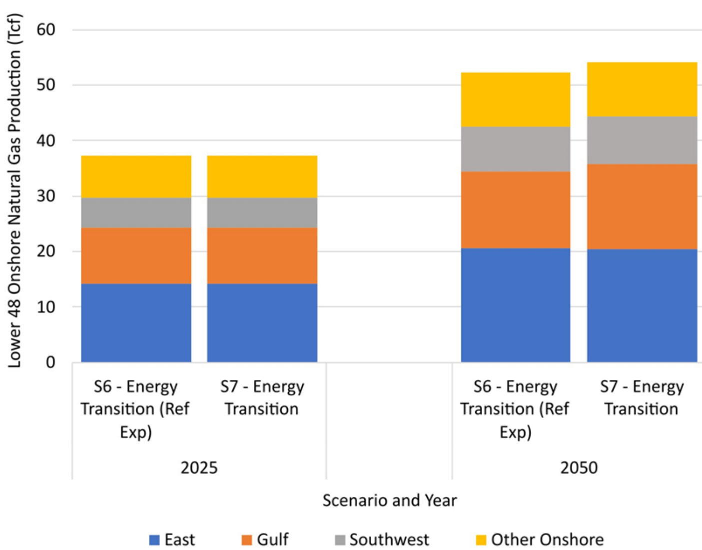


Figure B-1. U.S. Regional Natural gas production, S1 through S5

Onshore nNatural gas production experienced an upward trend across all scenarios by 2050, equaling or exceeding 39 Tcf. *S3* exhibited the highest production level at 48.3 Tcf, influenced by the global demand for natural gas. Expansion is primarily characterized by a significant increase in production in the Gulf region, subsequently followed by the Southwest and the East. Conversely, scenario *S4* sees the lowest natural gas production at 39 Tcf with least production growth in the Gulf region (1.4 Tcf from 2025 to 2050).





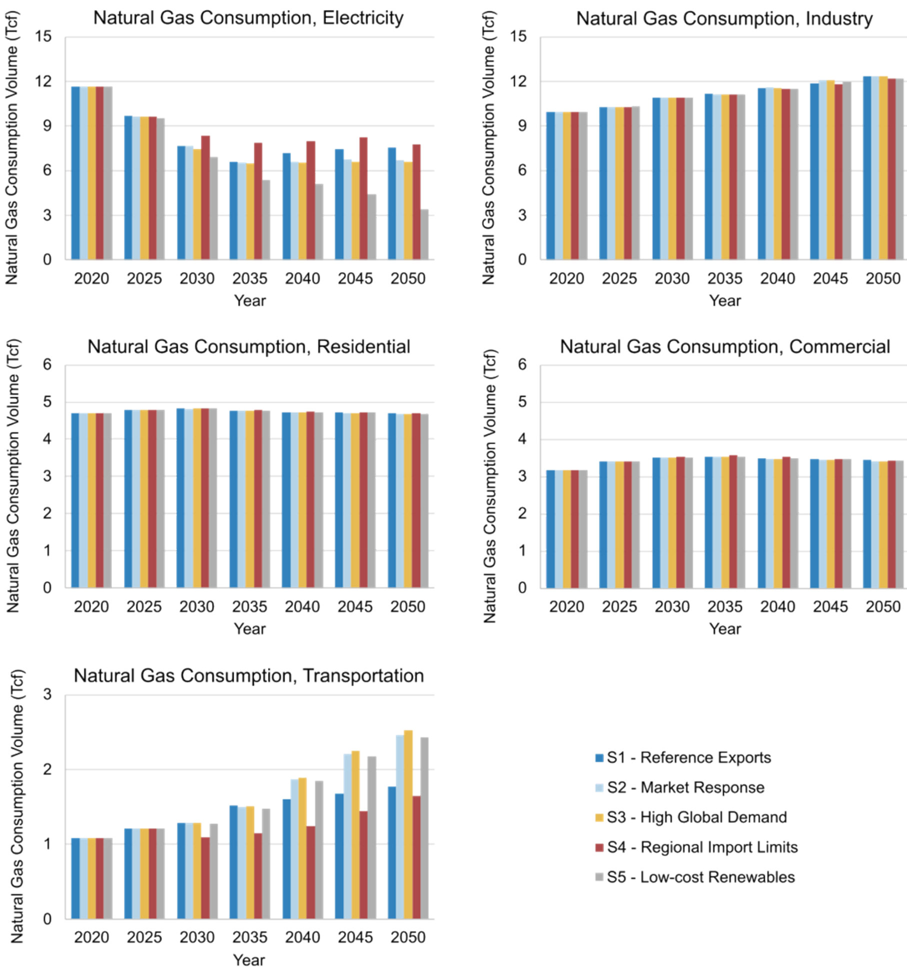
*1 Tcf in a non-leap year is equivalent to 2.74 Bcf/d

Figure B-2. U.S. regional natural gas production in S6 and S7

Similarly, oOnshore natural gas production grows significantly from 2025 to 2050 for both net-zero scenarios, rising from 37.3 Tcf in 2025 to 52.3 Tcf in *S6* and 54.1 Tcf in *S7*, respectively, by 2050. The large growth in natural gas production is primarily due to demand from DAC facilities, with only a small increase associated with elevated LNG exports in the *S7* scenario. Natural gas production rises in all regions, with the largest absolute increases coming from the East (6.4 Tcf in *S6* and 6.2 Tcf in *S7*) and Gulf (3.8 Tcf in *S6* and 5.23 Tcf in *S7*) regions and the largest increase by percentage coming from the Southwest (47% in *S6* and 58% in *S7*).

2. Natural gas consumption by economic sector

Figure B-3 plots natural gas consumption for electric power, industry, residential use, commercial use, and transportation over time for *S1* through *S5*. These sector-by-sector plots sum to equal the "Natural Gas Consumption" subplot displayed in Figure 16.


Natural Gas Consumption, Electricity
Natural Gas Consumption Volume (Tcf)
0
3
6
9
12
15
2020
2025
2030
2035
2040
2045
2050
Year
Natural Gas Consumption, Industry
Natural Gas Consumption Volume (Tcf)
Year
Natural Gas Consumption, Residential
Natural Gas Consumption Volume (Tcf)
0
1
2
3
4
5
6
Year
Natural Gas Consumption, Commercial
Natural Gas Consumption Volume (Tcf)
Year
Natural Gas Consumption, Transportation
Natural Gas Consumption Volume (Tcf)
0
1
2
3
Year
S1 - Reference Exports
S2 - Market Response
S3 - High Global Demand
S4 - Regional Import Limits
S5 - Low-cost Renewables

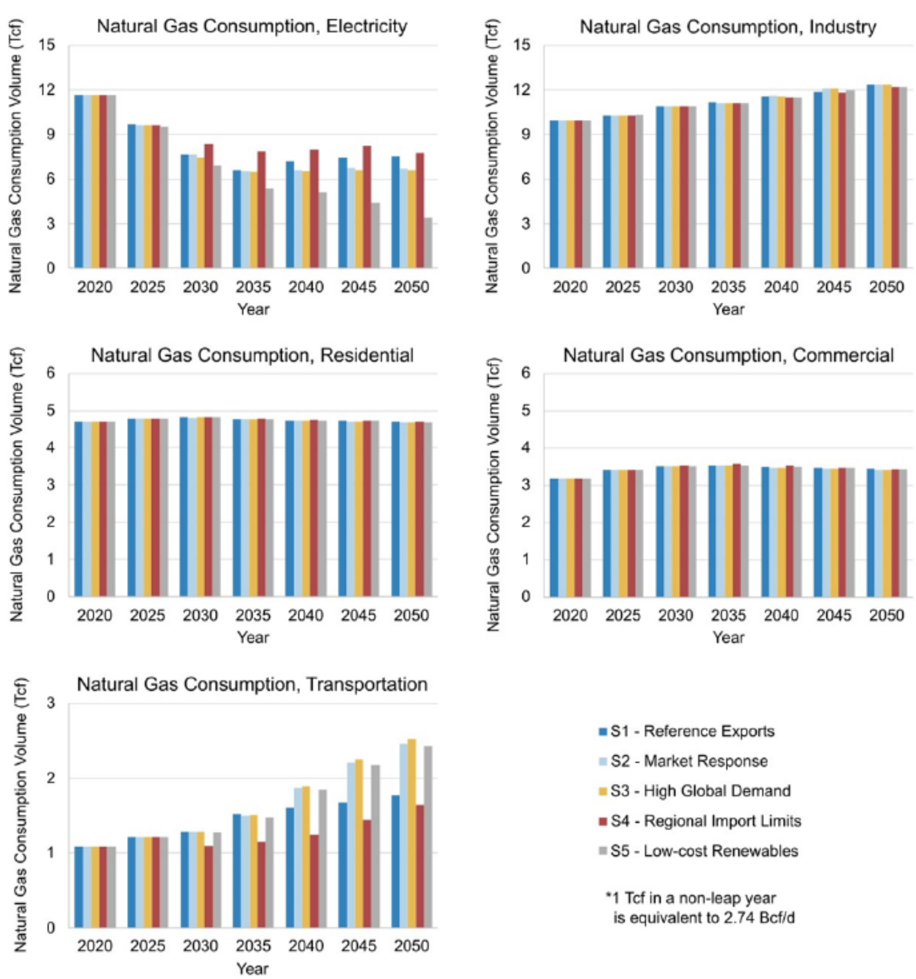


Figure B-3. U.S. natural gas consumption by sector, S1 through S5

Natural gas consumed for electricity was inversely correlated with LNG exports and natural gas prices for *S1-S4*. From a starting point of 11.6 Tcf in 2020, the first three scenarios drop to similar consumption volumes of 6.6,6.5, and -6.6 Tcf in 2035 before slightly increasing to 7.6 Tcf (*S1*) or plateauing at 6.7 and 6.6 Tcf (*S2* and *S3*, respectively) in 2050. The increased consumption of natural gas for electricity in *S1* can be explained as a response to price reductions caused by plateauing LNG exports, whereas high prices and exports in *S2* and *S3* lead to a flat consumption trend. *S4* – the scenario with the fewest exports and lowest prices through the first half of the model – exhibited the highest consumption for electricity in 2035 of 7.9 Tcf, which rises and falls slightly to a similar level to *S1* in 2050 (7.8 Tcf). *S5* is

Commented [UP177]: Hard to compare by sector data to the totals in the report as the report had the data in Bcf/d and in the Appendix we are now showing results in Tcf.

Commented [DH178R177]: Added a sentence to emphasize that this figure should be compared against Figure 16, and included a note about conversions from Tcf to Bcf/d. We will go through the report to improve unit consistency.

again an outlier here, reporting consistently lower natural gas consumption that hit a minimum of 3.4 Tcf in 2050. This trend is a consequence of its low renewable costs reducing the demand for natural gas in the electric sector.

Unlike for electricity, there was no significant difference between scenarios in the rate of natural gas consumption in the industrial, residential, or commercial sectors. Industrial natural gas consumption rises from 9.9 Tcf in 2020 to 12.2-12.4 Tcf in 2050 across the five scenarios; residential consumption remains relatively unchanged at 4.7 Tcf from 2020 to 2050 with some small variations; and commercial consumption rises and falls slightly from 3.2 Tcf in 2020 to 3.4 Tcf in 2050.

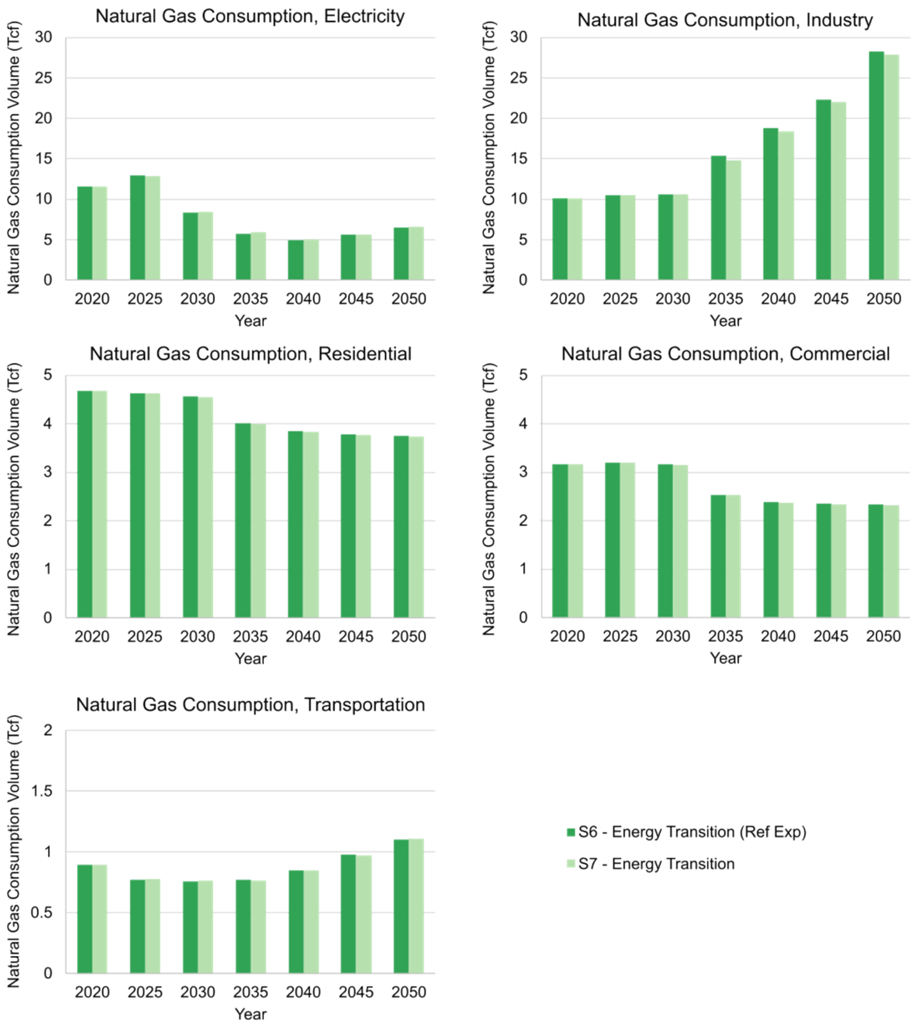
Natural gas consumed for transportation has a different response to changes in LNG exports, compared with the other consumptions sectors. The transportation category is dominated by pipeline fuel: natural gas consumed to power infrastructure underlying the natural gas supply chain, which includes LNG exports. Increases in natural gas consumption for transportation therefore correlate strongly with the quantity of LNG exports; *S3* exhibits the highest consumption in the transportation sector by 2050 (2.5 Tcf), followed by *S2* and *S5* (2.5 and 2.4 Tcf), *S1*, and finally *S4* (1.6 Tcf).

The sector-by-sector changes across the five scenarios end up cancelling each other out for *S1-S4*, leading to nearly identical total natural gas consumption values, as seen in Figure 16 in the main text. Only *S5*, thanks to its low renewable costs, exhibits a lower overall U.S. natural gas consumption trend.

~~Comparisons of *S1* through *S5* with *S6* and~~S ~~*S7* are complicated because of the many s~~ignificant changes to the energy economy (going from AEO2023-NEMS to FECM22-NEMS) that occur to satisfy the net-zero criteria make comparisons of *S1* through *S5* with *S6* and *S7* imprecise. Relative to *S1*, natural gas consumption values decline across most sectors in *S6* and *S7* but are substantially higher in the industry sector (where DAC consumption is categorized). Figure B-4 plots natural gas consumption for the net-zero cases on a sector-by-sector basis. The individual subplots are subsets of the "Natural Gas Consumption" subplot displayed in Figure 17.

Commented [UP179]: Do we want to say this like this-that it's complicated to go from AEO2023-NEMS to FECM22-NEMS? Again sounds too informal for a description of a model. All forecasting is complicated😉

Commented [DH180R179]: Reworded to make the statement more formal


Natural Gas Consumption, Electricity
Natural Gas Consumption, Industry
Natural Gas Consumption, Residential
Natural Gas Consumption, Commercial
Natural Gas Consumption, Transportation
Natural Gas Consumption Volume (Tcf)
Year
2020 2025 2030 2035 2040 2045 2050
S6 - Energy Transition (Ref Exp)
S7 - Energy Transition

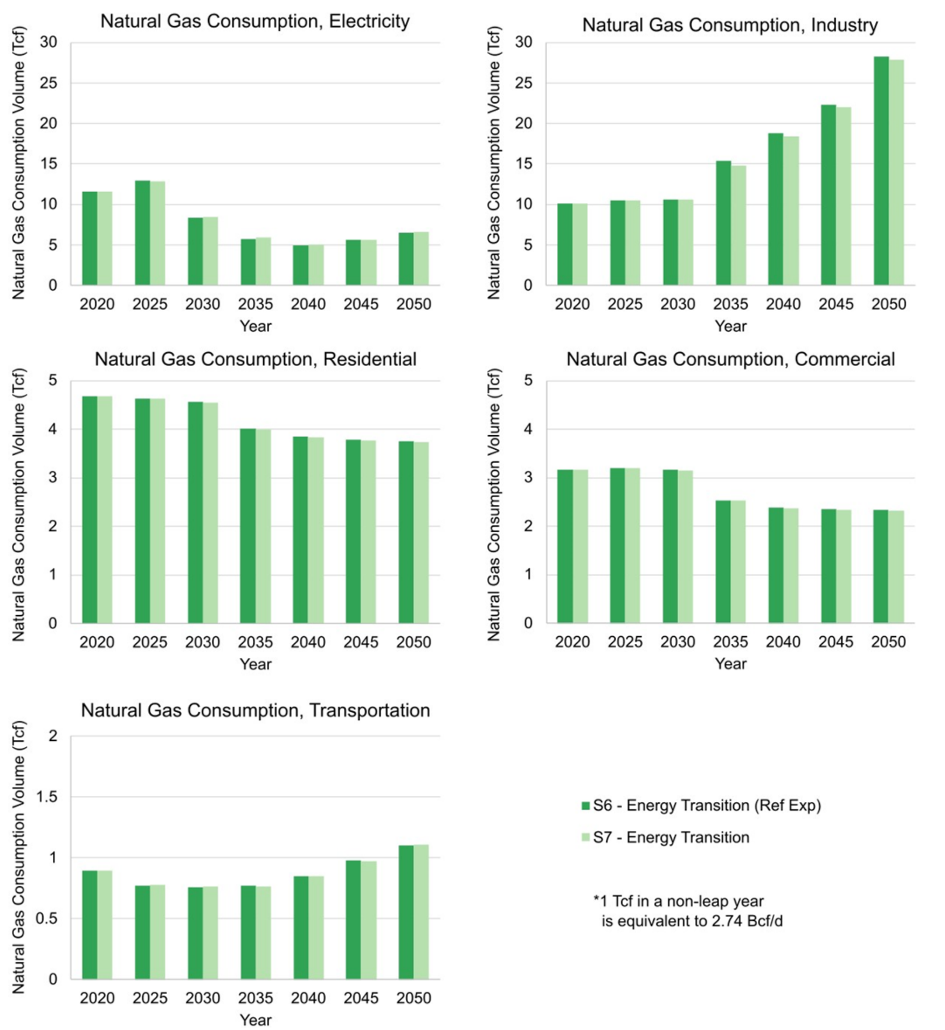


Figure B-4. U.S. natural gas consumption by sector, net-zero scenarios

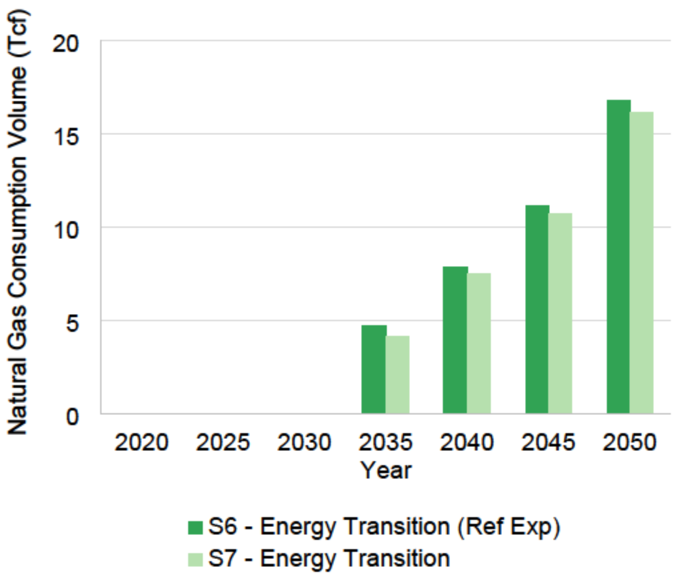
Differences in historical natural gas consumption and subsequent short-term effects cause a difference in natural gas consumption for electricity in 2020 and 2025 between *S6* and *S7* (from the FECM-NEMS model) and *S1* through *S5* (from the AEO2023-NEMS model). Similar differences in the historical data exist for all sector-specific consumption values. Volumes of natural gas consumed for electricity track closely between the two net-zero cases across most of the modeling years, ranging from 5.7 to 5.9 Tcf in 2035 for *S6* and *S7*, respectively, and rising in later years to 6.5 Tcf and 6.6 Tcf. *S6* reports a lower

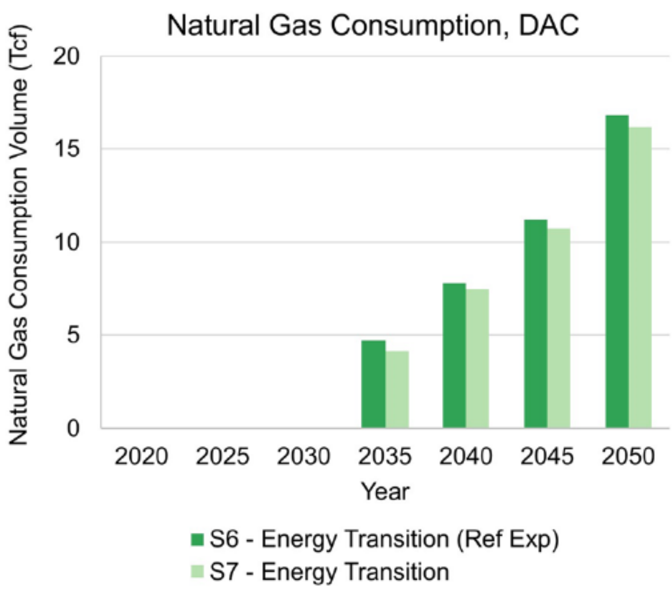
natural gas consumption value in 2050 than *S1* (7.6 Tcf), but the corresponding result for *S7* is fairly close to *S2* (6.7 Tcf).

Industry-sector natural gas consumption exhibits the largest change between S6 and S7 ~~and~~ relative to *S1* through *S5*, thanks to the strong influence of DAC. Whereas industry consumption of natural gas in *S1* and *S2* both increase from 9.9 Tcf to 12.3 Tcf ~~over the 50 model years~~from 2020-2050, the net-zero scenarios diverge after 2030 and grow rapidly to 28.2 and 27.8 Tcf for *S6* and *S7*, respectively, by 2050. The difference in consumption values is consistent with the natural gas consumption for DAC, which is plotted below in Figure B-5.

Residential- and commercial-sector natural gas consumption follow similar behavior. These values decrease in both net-zero scenarios across the model years 2020-2030 from 4.7 to 3.7 Tcf (residential) and from 3.2 to 2.3 Tcf (commercial). By comparison, both *S1* and *S2* have static or slightly increasing trends, with both reporting 4.7 Tcf in 2020 and 2050 for residential consumption and 3.2 to 3.4 Tcf from 2020 to 2050 for commercial consumption.

Transportation is the smallest of the five sectors in terms of natural gas consumption volumes, and calculation differences between AEO2023-NEMS and FECM-NEMS lead to large impacts on the consumption values. As a result, these values are not directly comparable between the three scenarios. *S6* and *S7* have nearly identical volumes of natural gas consumed for the transportation sector, varying from 0.9 Tcf in 2020 to 0.8 Tcf in 2035 and 1.1 Tcf in 2050. By comparison, *S1* and *S2* report consistently higher natural gas consumption for transportation across the model years, ranging from 1.1 Tcf in 2020 to 1.8 and 2.3 Tcf, respectively, in 2050.





*1 Tcf in a non-leap year is equivalent to 2.74 Bcf/d

Figure B-5. Natural gas consumed for DAC, net-zero scenarios

DAC is the main technology used by FECM-NEMS to meet the CO_2 cap and by 2050 is responsible for removing 1.930 GtMMT CO_2 per year in *S6* and 1.85850 GtMMT CO_2 per year in *S7*. A considerable amount of natural gas is consumed to support these levels of DAC: 16.8 Tcf and 16.2 Tcf in 2050 for *S6* and *S7*, respectively. More detail on CO_2 removal technologies incost assumptions for DAC in FECM-NEMS is given in the section below.

Commented [WS181]: Would be very helpful to state our assumptions regarding the cost of DAC over the 2035 to 2050 period.

In conclusion, even though four out of the five sectors exhibit decreases when comparing natural gas consumption in the net-zero scenarios to *S1* and *S2*, the strong increases in the industrial sector (mainly from increases in DAC) cause overall U.S. natural gas consumption to be significantly higher by 2050 in *S6* and *S7*. There is minimal difference between the *S6* and *S7* results, suggesting that the differences in LNG exports between the net-zero scenarios play a limited role in altering natural gas consumptions trends.

C. CO_2 removal technologies and carbon prices in FECM-NEMS

CO_2 removals in FECM-NEMS are driven by three technologies: production of hydrogen with sequestered biomass, BECCS, and DAC. Figure B-6 plots CO_2 removals for each technology and scenario by year.

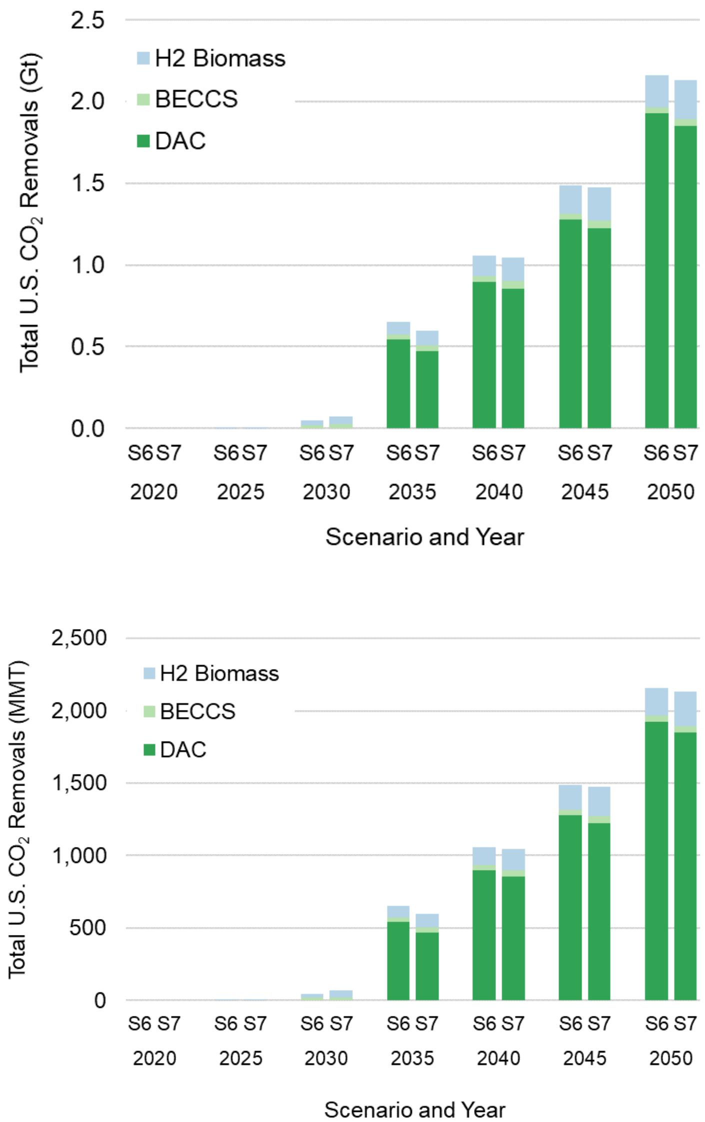


Figure B-6. U.S. CO_2 emissions and removals, net-zero scenarios

DAC is most widely used in both net-zero scenarios and scales up rapidly after 2030 to account for 1.93~~0~~ Gt~~MMT~~ CO_2 removed in *S6* and 1.85~~0~~ Gt~~MMT~~ CO_2 removed in *S7* (89% and 87% of total removals, respectively) by 2050. H_2 production with biomass and BECCS see significantly less adoption by 2050 in both scenarios; the former reaches 0.20200 (9% of total) and 0.24240 (11% of total) GtMMT CO_2 removed in *S6* and *S7*, respectively, whereas the later reaches approximately 0.04 40 MMTGt CO_2 removed in both scenarios (2% of total removals).

FECM-NEMS relies on two sets of DAC technology assumptions: "grid", and "NG only," derived from the literature using updated cost and performance data from FECM.[33] Both use natural gas to power the capture process; DAC grid offsets some of the natural gas demand by using electricityTable B-1 as well as lists the specific cost and technical assumptions underlying DAC in FECM-NEMS:the two DAC options.

Table B-1. DAC technology assumptions in FECM-NEMS

	Capex, $2022/ton	CRF	Capex, $2022/ton-year	Opex, $2022/ton-year	Electricity demand, kwhr/ton	Natural gas demand, MMBtu/ton
Grid	$1,451300	7.1%	$12512	$79.271	450	8.75
NG Only	$1,674500	7.1%	$144129	$93.383.6	0	9.27

FECM-NEMS relies on two sets of DAC technology assumptions: "grid", and "NG only," derived from the literature using updated cost and performance data from FECM.[34] Both use natural gas to power the capture process; DAC-grid offsets some of the natural gas demand by using electricity. Both technologies follow a learning curve that reduces the capital cost of deployment over time, and both use a capital recovery factor of 7.1%.

The effect of DAC on natural gas markets in *S6* and *S7* can be seen in the rapid growth of total natural gas consumption and subsequent rise in natural gas prices (Figure 18) in the main text. By 2050, natural gas consumption equals 16.8 Tcf and 16.2 Tcf for *S6*, and *S7*, respectively, reaching natural gas prices of $5.906.34 2022/Mcf and $5.776.20 2022/Mcf ($2022).

FECM-NEMS models the deployment of carbon removal technologies by determining a CO_2 price that represents the market equilibrium cost to capture and abate CO_2 emissions. FECM-NEMS adjusts the CO_2 price in accordance with the imposed carbon cap to ensure that the correct number of CO_2 emissions are abated each year. End-use prices are then adjusted by the product of the unsequestered carbon content of the fuel and the implied carbon price to reflect the carbon penalty of combustion. Residential natural gas prices, reflecting the implied carbon penalty, are $34.97/Mcf and $35.24/Mcf in *S6* and *S7*, respectively, by 2050.

[33] National Academies of Sciences, Engineering, and Medicine. (2019). Negative Emissions Technologies and Reliable Sequestration: A Research Agenda. Washington, DC: The National Academies Press. https://doi.org/10.17226/25259.

[34] National Academies of Sciences, Engineering, and Medicine. (2019). Negative Emissions Technologies and Reliable Sequestration: A Research Agenda. Washington, DC: The National Academies Press. https://doi.org/10.17226/25259.

Commented [DH182]: @Peter Whitman Hi Pete, I updated the $ year for the prices here and reworded some things. Is there anything else we can add to the description here?

Appendix C: Supporting LCA Analysis

A. NEMS and NETL LCA model comparison

The NEMS modeling done in this project focused on domestic changes that would be expected to occur in the seven scenarios modeled. NETL reviewed the NEMS data to evaluate if the regional production mix of natural gas would be expected to change over time. If the NEMS results suggested that production would be expected to shift significantly from the current mix of regions, and especially if to distinctly higher or lower intensity regions, then adjustments would be recommended to the assumed GHG intensity for U.S. natural gas in the results.

For *S1 - S7*, NEMS modeled data of dry natural gas production of "Production by OGSM District" was mapped to a state and then to an NETL natural gas model region as shown in Table C-1. Note that several "states" are offshore regions. OGSM is the Oil and Gas Supply Module in NEMS.

Commented [UP183]: What's OGSM? Needs to also be included under Acronyms/Abbreviations Table.

Commented [PW184R183]: Added to table

Table C-1. Matching NEMS (OGMP States) to NETL states and subsequently regions

Production by OGSM District	State	Region
Alabama, North	Alabama	Southeast
Alabama, South	Alabama	Southeast
Arizona	Arizona	Southwest
Arkansas	Arkansas	Southeast
California	California	Pacific
Colorado	Colorado	Rocky Mountain
Connecticut	Connecticut	Northeast
Delaware	Delaware	Northeast
~~**Washington, D.C.**~~	~~Washington~~	~~Pacific~~
Florida	Florida	Southeast
Georgia	Georgia	Southeast
Idaho	Idaho	Rocky Mountain
Illinois	Illinois	Midwest
Indiana	Indiana	Midwest
Iowa	Iowa	Midwest
Kansas	Kansas	Midwest
Kentucky	Kentucky	Southeast
Louisiana, North	Louisiana	Southeast
Louisiana, South	Louisiana	Southeast
Maryland	Maryland	Northeast
Massachusetts	Massachusetts	Northeast
Michigan	Michigan	Midwest
Minnesota	Minnesota	Midwest
Mississippi, North	Mississippi	Southeast
Mississippi, South	Mississippi	Southeast
Missouri	Missouri	Midwest

Commented [ST185]: Washington, D.C. is not a match for the State of Washington.

Are these intended to align OMGP States to NETL States?

Production by OGSM District	State	Region
Montana	Montana	Rocky Mountain
Nebraska	Nebraska	Midwest
Nevada	Nevada	Rocky Mountain
New Hampshire ~~New Hampshire~~	New Hampshire~~New York~~	Northeast
New Jersey	New Jersey	Northeast
New Mexico, East	New Mexico	Southwest
New Mexico, West	New Mexico	Southwest
New York	New York	Northeast
North Carolina	North Carolina	Southeast
North Dakota	North Dakota	Midwest
Ohio	Ohio	Midwest
Oklahoma	Oklahoma	Southwest
Oregon	Oregon	Pacific
Pennsylvania	Pennsylvania	Northeast
Rhode Island	Rhode Island	Northeast
South Carolina	South Carolina	Southeast
South Dakota	South Dakota	Midwest
Tennessee	Tennessee	Southeast
Texas RRC 1	Texas	Southwest
Texas RRC 2	Texas	Southwest
Texas RRC 3	Texas	Southwest
Texas RRC 4	Texas	Southwest
Texas RRC 5	Texas	Southwest
Texas RRC 6	Texas	Southwest
Texas RRC 7B	Texas	Southwest
Texas RRC 7C	Texas	Southwest
Texas RRC 8	Texas	Southwest
Texas RRC 8A	Texas	Southwest
Texas RRC 9	Texas	Southwest
Texas RRC 10	Texas	Southwest
Utah	Utah	Rocky Mountain
Virginia	Virginia	Northeast
Washington	Washington	Pacific
West Virginia	West Virginia	Northeast
Wisconsin	Wisconsin	Midwest
Wyoming	Wyoming	Rocky Mountain
~~**North Atlantic State Offshore**~~	~~North Carolina~~	~~Southeast~~
~~**South Atlantic State Offshore**~~	~~South Carolina~~	~~Southeast~~
Alabama State Offshore	Alabama	Southeast
Louisiana State Offshore	Louisiana	Southeast

Commented [ST186]: Should this be NH to NH?

Commented [ST187]: Would this be north of the mason dixon line?

Commented [ST188]: Should all "offshore" align to an NETL off-shore profile instead of and end-use/consumption region?

Production by OGSM District	State	Region
Texas State Offshore	Texas	Southwest
California State Offshore	California	Pacific
North Atlantic Federal Offshore	North Carolina	Southeast
Mid Atlantic Federal Offshore	Federal Offshore - GoM	Southeast
South Atlantic Federal Offshore	South Carolina	Southeast
Eastern GOM Federal Offshore	Federal Offshore - GoM	Southeast
Central GOM Federal Offshore	Federal Offshore - GoM	Southeast
Western GOM Federal Offshore	Federal Offshore - GoM	Southeast
California Federal Offshore	California	Pacific
Northern Pacific Federal Offshore	Federal Offshore - GoM	Southeast
Alaska Federal Offshore	Federal Offshore - GoM	Southeast

This classification enables the aggregation of dry production data (excluding extraction losses) by region for each respective year, as summarized with every 10 years of data in Table C-2.

Commented [ST189]: Why every 10 years of data when the raw data is provided on an annual basis from NEMS?

Commented [SM190R189]: The model uses annual data this is just to avoid cluttering the document, is why as an example every 10 years of data is included.

Table C-2 Regional dry production (trillion cubic feet) between 2020 and 2050, S1

Commented [ST191]: How much variability in dry production volume is considered significant? Northeast is a 55% increase. 60% decrease in Midwest.

Region	2020	2030	2040	2050
Midwest	3.273.26778	2.822.82406	2.412.40796	2.092.094116
Northeast	9.549.540964	11.1411.14082	13.0313.03394	14.0814.08478
Pacific	0.160.163061	0.290.285247	0.300.296763	0.280.280681
Rocky Mountain	3.333.328845	2.902.899944	2.802.796355	2.692.687115
Southeast	4.594.587738	6.086.084166	6.656.64734	5.725.720366
Southwest	12.2812.2792	13.3713.3737	15.2815.27886	16.6516.65195

From this aggregated data, the production ratio is share is calculated by dividing the region-specific production by the total U.S. production for each year and is summarized in Table C-3.

Table C-3 Regional NG dry production ratioshares, S1

Commented [ST192]: No discussion of Table C-3.

Ratio compared to what?

I think these are annual percentages. Column sums to 100%.

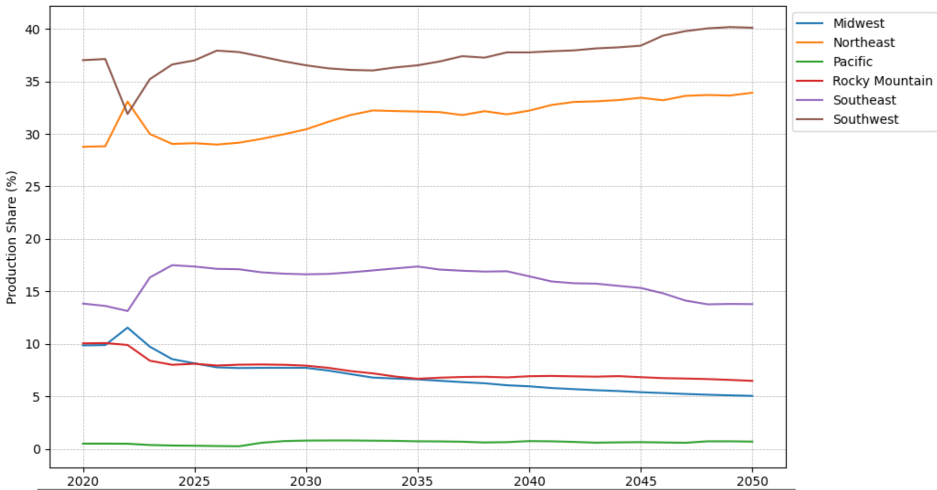
Caption needs better clarity.

Commented [SM193R192]: As a proportion of total US production. Additional text provided above Table C-3 for clarity.

Commented [ST194]: Why 2041 results?

Region	2020	2030	2040	20412050
Midwest	0.0999.85	0.0777.71	0.0605.95	0.0505.79
Northeast	0.28828.77	0.30430.43	0.32232.21	0.33932.75
Pacific	0.0050.49	0.0080.78	0.0070.73	0.0070.71
Rocky Mountain	0.10010.04	0.0797.92	0.0696.91	0.0656.94
Southeast	0.13813.83	0.16616.62	0.16416.43	0.13815.94
Southwest	0.37037.02	0.36536.53	0.37837.76	0.40137.87

Figure C-1 shows the percent of natural gas dry production for each region of *S1* as compared to total production in each year between 2020 and 2050. The same process was done for the other scenarios.



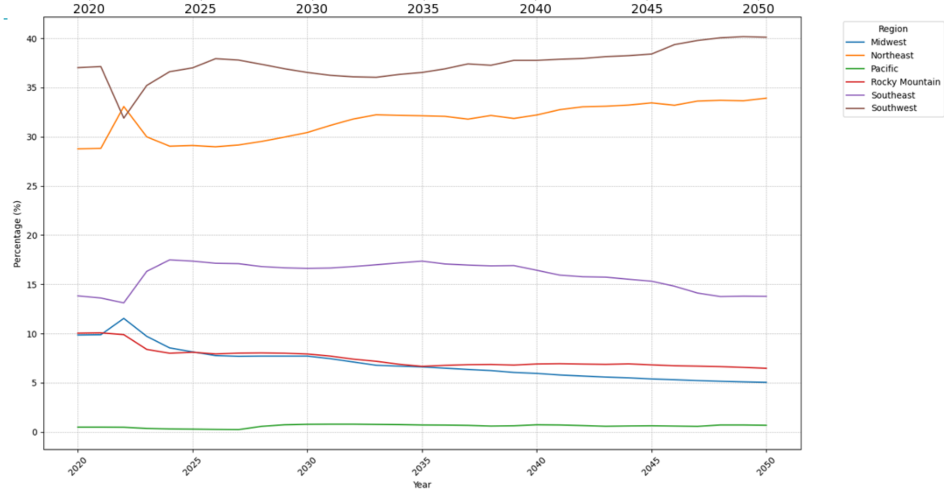


Figure C-1. Dry NG production percentage time-series for each region

The regional production shares estimated based on NEMS data are disaggregated to a techno-basin level based on the proportion of regional NG production shares in the 2020 NETL NG report [cite]. Based on the 2020 NETL NG report, Table C-4 provides the techno-basin to region mapping details and Table C-5 reports the GHG emissions intensity results for NG production from all techno-basins, for the production through transmission network life cycle boundary, using US average transmission network data. ~~This percentage can be multiplied with the 2020 GHG intensity values for each region from the NETL Natural Gas report[16] (shown in Table C-4) to estimate future GHG intensity results, as described in this mathematical representation:~~

$$GHG_{Midwest,2021} = GHG_{Midwest,2020} \times dry\ production\ ratio_{Midwest,\ 2021}$$

~~and finding the weighted US average GHG intensity across regions.~~

Table C-4. Techno-basin to Region Mapping

Techno-basin	Region
Alaska Offshore	Pacific
Anadarko Conventional	Southwest
Anadarko Shale	Southwest
Anadarko Tight	Southwest
Appalachian Shale	Northeast
Arkla Conventional	Southeast
Arkla Shale	Southeast
Arkla Tight	Southeast
Arkoma Conventional	Southwest
Arkoma Shale	Southwest
East Texas Conventional	Southwest
East Texas Shale	Southwest
East Texas Tight	Southwest
Fort Worth Shale	Southwest
GoM Offshore	Southeast
Green River Conventional	Rocky Mountain
Green River Tight	Rocky Mountain
Gulf Conventional	Southwest
Gulf Shale	Southwest
Gulf Tight	Southwest
Permian Conventional	Southwest
Permian Shale	Southwest
Piceance Tight	Rocky Mountain
San Juan CBM	Southwest
San Juan Shale	Southwest
South Oklahoma Shale	Southwest
Strawn Shale	Southwest
Uinta Conventional	Rocky Mountain
Uinta Tight	Rocky Mountain

Table C-5. GHG Emissions Intensity by Techno-basin, Production through Transmission network boundary using U.S. average transmission data (g CO_2e/MJ, IPCC AR6 100-yr GWP)

Commented [ST195]: Hanging text??? Old text???

Commented [ST196]: GHG Emissions Intensity

Commented [ST197]: There should be a space between the measurement unit and the descriptor of what was measured/reported.

E.g., g CO2e (with the 2 subscripted)

Commented [ST198]: How were the regional profiles converted to a single Weighted Average GHG Emissions Intensity value?

Techno-basin	GHG Emissions Intensity ($g\ CO_2e/MJ$)
Alaska Offshore	6.99E+00
Anadarko Conv	1.62E+01
Anadarko Shale	9.68E+00
Anadarko Tight	1.17E+01
Appalachian Shale	6.41E+00
Arkla Conv	6.40E+00
Arkla Shale	6.39E+00
Arkla Tight	1.16E+01
Arkoma Conv	1.54E+01
Arkoma Shale	1.22E+01
East Texas Conv	7.70E+00
East Texas Shale	8.01E+00
East Texas Tight	7.74E+00
Fort Worth Shale	1.32E+01
GoM Offshore	6.20E+00
Green River Conv	1.28E+01
Green River Tight	1.32E+01
Gulf Conv	8.51E+00
Gulf Shale	7.44E+00
Gulf Tight	9.38E+00
Permian Conv	9.61E+00
Permian Shale	1.03E+01
Piceance Tight	8.55E+00
San Juan CBM	1.77E+01
San Juan Shale	2.72E+01
South Oklahoma Shale	8.64E+00
Strawn Shale	1.34E+01
Uinta Conv	3.44E+01
Uinta Tight	1.84E+01

Note: The GHG emissions intensity results are provided on a per MJ NG delivered, LHV basis. Results from the 2020 NETL NG report were converted from HHV to LHV basis for this work.

Table C-4. Regional GHG Intensities (gCO_2e($g\ CO_2e$/MJ) from 2020 NETL Natural Gas Report

Region	GHG (gCO_2e ($g\ CO_2e$/MJ)
Midwest	8.44
Northeast	6.23
Pacific	11.3
Rocky Mountain	10.01
Southeast	9.02
Southwest	8.80

Commented [ST199]: GHG Emissions Intensity

Commented [ST200]: There should be a space between the measurement unit and the descriptor of what was measured/reported.

E.g., g CO2e (with the 2 subscripted)

Commented [ST201]: How were the regional profiles converted to a single Weighted Average GHG Emissions Intensity value?

Commented [ST202]: GHG Emissions Intensity

Overall, Figure C-2 suggests that the NEMS-modeled changes in domestic NG production by region across the scenarios are not expected to significantly affect the projected domestic GHG emissions intensities of natural gas production.

~~Overall, Figure C-2 suggests that the NEMS-modeled changes in domestic production by region across the scenarios are not expected to have a significant effect on the GHG intensity of domestic production (given the 2020 data on GHG intensity by region) if only the trend in "dry production" (based on delivery shares) is considered.~~

Commented [ST203]: NEMS includes endogenous learning. How much did the GHG emissions intensity of natural gas by region change in the model?

Should be different for S1 set versus S6/S7 set of model runs.

Commented [HK204]: Figure C-2 provides the variation in GHG emissions intensity as a function of changing regional NG production shares. It uses a constant set of techno-basin emission factors from the 2020 NG report (provided in Table C-5) and applies it across a range of production mixes over 30 years.

Commented [ST205]: NEMS includes endogenous learning. How much did the GHG emissions intensity of natural gas by region change in the model?

Should be different for S1 set versus S6/S7 set of model runs.

Commented [ST206]: This is a large caveat! The analysis should consider both dry production and GHG emissions intensity differences by year.

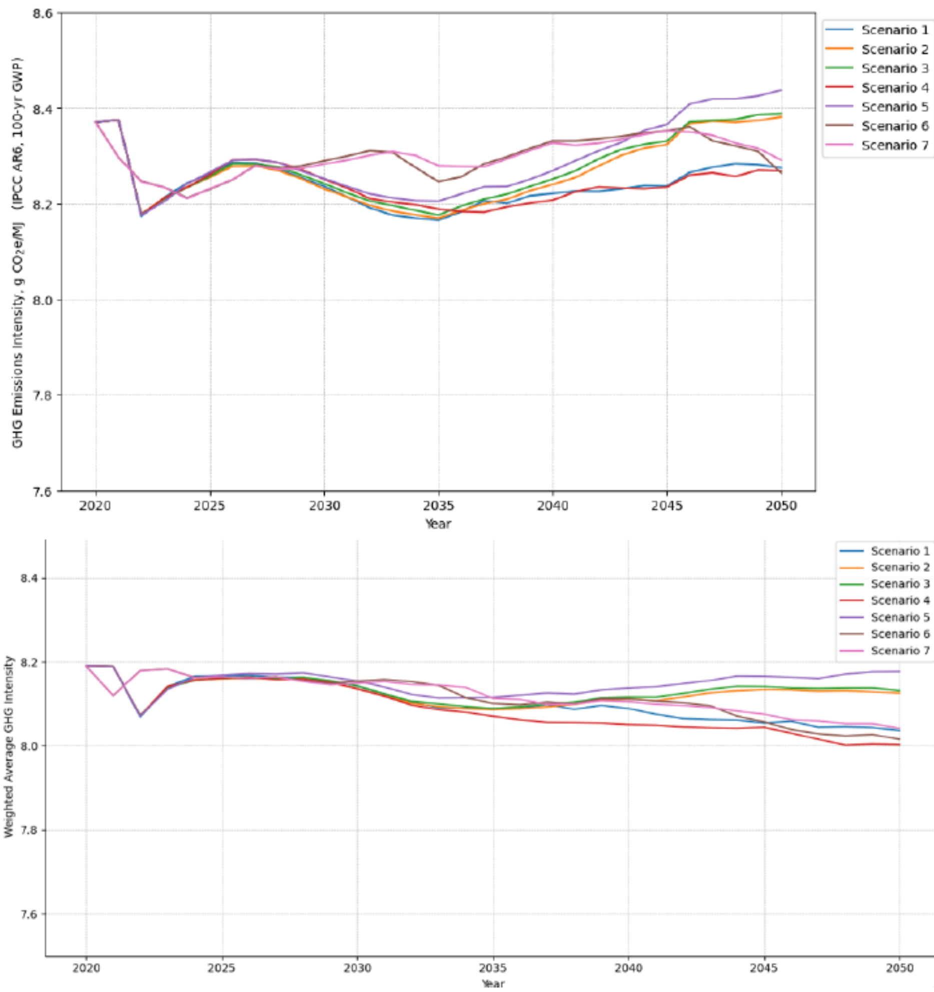


Figure C-2. Estimated U.S. Average GHG Intensity (g CO_2e/MJ) (S1 through S7), Production through Transmission (2020 - 2050)

B. Global Change Assessment Model – data inputs to LCA

~~The GCAM model is an input-output based model primarily represented by sectors and technologies and their respective inputs and outputs for particular years and scenarios.~~ Across all years and scenarios, GCAM has 105 discrete sectors, 377 discrete technologies, and many sector-technology pairs that can

Commented [ST207]: Y axis, add "Emissions" and units and GWP version to label; U.S. Weighted Average GHG Emissions Intensity, g CO2e/MJ (IPCC AR6 100-yr GWP)

Commented [ST208]: Why does S4 have a steeper and lower GHG emissions intensity per unit of gas produced in 2050 than S6 or S7?

Commented [ST209]: Quantitative data discussion is needed to justify why the change is "not significant" and that domestic market effects can be ignored.

The data and conclusion show that a change occurs. Southwest (permian) gas increase. Permian is high GHG intense gas. Why is this not a market effect that needs to be considered?

GCAM shows a reduction in GHGs from exports.

NEMS shows an increase in GHGs from exports.

The scale/magnitude of the GCAM results are -5 and -3 g CO2e/MJ.

What is the equivalent sum over 35 years for the change between S2 and S1, and S7 and S6? The 2050 value change appears very small.

I think the conclusion that domestic changes are less significant compared to non-US global changes is valid.

However, I am concerned about saying there is "no" domestic market effect which is the outcome when we choose to not include domestic market effects in the analysis.

We need to better defend and message this outcome, particularly when the NEMS data shows increases in GHG intense regions to meet future LNG export demand.

NETL - please provide more rationale and alternative concluding remarks/findings with respect to domestic market effects.

Commented [SM210R209]: From previous discussions, agreed that the graph shows negligible effects given the compressed y-axis.

vary depending on the model configuration. However, only a subset of these factors is relevant to this analysis (i.e., with a focus on the natural gas sector).

Results provided by PNNL for the various Scenarios (1-7) and years modeled were provided as described in Table C-5, and were processed accordingly.

Table C-5. Provided set of GCAM Data Documentation

File	Data Represented
co2_em_tech_2023.06.22	Provides data showing CO_2 emissions in megatons per year (~~MtCO_2~~Mt CO_2/yr) for various sectors, energy sources or "technology" for 6 different scenarios across each of 37 regions.
non_co2_em_tech_2023.06.22	Provides data showing non-CO_2 emissions in Gigagrams (Gg) equivalent to metric kilotons or 1,000 metric tons, for various sectors, energy sources or "technology" and 6 different scenarios across each of 37 regions.
inputs.by.tech_2023.06.22	Provides detailed information about energy consumption and capacity in different regions and sectors along with specific technologies and years. ~~It can be used to analyze and understand the energy landscape, make projections, and assess the impact of various factors on energy consumption and capacity (sub-sector is not applicable in this dataset).~~
outputs.by.tech_2023.06.22	Reports the energy production within the various regions, by sectors, (sub-sector is not applicable in this dataset) along with specific technologies and years.
Columns	**Description**
scenario	~~S~~scenario or context for which the data is provided such as "S1: ~~Existing Capacity~~, Reference Exports" which suggests that the data corresponds to the existing capacity or infrastructure in the region.
Region	This column specifies the geo-political region under consideration.
Sector	This column categorizes the different sectors or areas of activity for which carbon dioxide emissions are being measured, e.g., "agricultural energy use", "cement", "air_CO_2", etc.
sub-sector	Within each sector, there may be further divisions or subcategories to specify the specific aspect of the sector being measured, e.g., "mobile", "stationary," etc., indicating different types of energy use within a single sector.
technology	This column identifies the specific technology or energy source being utilized within the subsector. For example, "refined liquids" and "biomass~~"~~".
year	The specific year or time period for which the CO_2 emissions values are provided, this ranges from 2015 to 2050.
value	~~corresponding~~ Corresponding carbon dioxide emissions values for the given combination of scenario, region, sector, subsector, technology, and year. The values represent the estimated or projected amount of CO_2 emissions in megatons per year in this specific file as depicted in the "Units" column (not mentioned separately in this table).
ghg	Refers to the greenhouse gas that is being emitted. It identifies the specific type of gas responsible for the emissions, e.g., CH_4, N_2O, HFC125, C_2F_6, etc.

Commented [ST211]: Odd phrasing. The other "Data Represented" descriptions do not explain "how" to use the data set.

Commented [ST212]: Capitalization of column heading names seems to vary in this table. Intentional?

Commented [ST213]: The label for S1 and S2 were changed after the submission of this report. Capacity was changed " Exports".

S1: Reference Exports

S6 Energy Transition (Ref Exp)

Ref Exp = Reference Exports

Commented [ST214]: Subscript

input, output	Additional details or characteristics about the technology or process. ~~It helps to differentiate between different aspects or variations within a specific technology. Examples in the datasets include "elect_td_ind" (electricity transmission and distribution for industrial use) and "H2 wholesale dispensing" (hydrogen wholesale dispensing).~~
output	Additional details or characteristics about the technology or process.

Commented [ST215]: Is this the column heading or column response?

C. GCAM and NETL emissions intensity comparison

As noted in the main report, only three sectors of the GCAM model have information relevant to the upstream natural gas supply chain. The GCAM *gas pipeline* and *natural gas* sectors are assumed to wholly incorporate natural gas-relevant emissions, and so total emissions are extracted from GCAM model output result files.

However, the *other industrial energy use* sector contains a diverse set of activities ~~that are connected to overall gross domestic product (GDP) of each region, making it relatively difficult to~~without explicitly ~~identify~~ representing emissions related to natural gas. GCAM incorporates a variety of data sources to represent activity in this sector. Relevant to natural gas activities for this sector, 2015 IEA data on energy use by oil and gas production activities used by the GCAM modeling team were provided and utilized to apportion GHG emissions associated with natural gas activity, as in Table C-6. The provided data (not shown) details what percent of energy use in the sector was from the IEA energy flows (e.g., 25% of total sectoral energy use in a region from Extraction and Gathering and Boosting). As 99.5% of GHG emissions in the *other industrial energy use* sector are CO_2, only the IEA data source was used and only CO_2 data for that sector was adjusted.

Table C-6. LCA Stage Cross-Mapping

NETL LCA stage	IEA energy flow	GCAM sector – energy & CO_2
Extract	Oil and G	~~other~~ Other ~~industrial~~ Industrial ~~energy~~ Energy ~~use~~Use

ion	as Extraction	
Gathering and Boosting	Oil and Gas Extraction	Other Industrial Energy Use~~other industrial energy use~~
Processing	Gasworks	Other Industrial Energy Use~~other industrial energy use~~
Domest	Pipeli	~~gas~~ Gas ~~pipeline~~Pipeline

icPipelineTransport[1]	neTransport	
Liquefaction	Liquefaction (LNG)/Regasific	Other Industrial Energy Useother industrial energy use

	ationPlants	
OceanTransport	InternationalMarineBunkers ~~[2]~~	~~trn~~Trn_shipping_intl ~~[2]~~
Regasific	Liquefact	Other Industrial Energy Use~~other industrial energy use~~

ation	ion (LNG)/Regasification Plants	
Pipeline Transport (a	Pipeline Transport	Gas Pipeline~~gas pipeline~~

tdestination) ~~1~~		

~~This~~ The IEA data is aggregated into oil and gas activities such as "Extraction, Gathering and Boosting", "Processing", and "Liquefaction and Regasification". However, a challenge is that the IEA data represent aggregated activities of extraction of both oil and gas resources~~, which were variously allocated for the natural gas products.~~. Given the lack of data on liquefaction and regasification in the 2015 IEA data (including for the U.S.), emissions from those activities are excluded from the analysis, consistent with the focus on upstream natural gas effects.

Commented [ST216]: What does this mean? Unclear.

The emissions intensity cells in Table C-7 show the underlying equation used to generate values on an AR6-100 basis, where the numerator is the total emissions from the GCAM model for the USA region for Scenario *S1* for the year 2020 for each of the three greenhouse gases (if available), normalized by the total production of U.S. natural gas and oil from the GCAM model in 2020 (32.46 EJ and 22.46 EJ, respectively). Units of emissions intensity follow those internal to the GCAM model, which are Tg CO_2 equivalent per Exajoule, which conveniently are equal to g CO_2e/MJ, the same units as used in the NETL model. Thus, the bottom rows in Table C-7show comparisons to those of the NETL model.

As implemented, this adjustment factor of 0.96 is directly applied to GHG emissions in all regions of the model for the *natural gas* and *gas pipeline* sectors as they wholly related to natural gas activities. By linearly scaling all regional values in this way, ~~The~~ the existing and diverse methane mitigation trends for each region in the underlying GCAM emissions ~~data~~ factors for the *natural gas* sector ~~was~~ were preserved by using this adjustment method.

Commented [ST217]: How was it preserved?

Does the MAF change every year (model time step) due to endogenous learning in the model?

For the *other industrial energy use* sector, the adjustment is complicated by the fact that the sector includes many activities beyond natural gas. If the adjustment factor were wholly applied to the GHG emissions of the sector, then the total emissions in GCAM would be reduced for both natural gas and non-natural gas activities. A compromise was made to estimate the total needed reductions in emissions associated with only natural gas activity for each region, and to reduce the emissions of the other industrial energy use sector by that amount. While this does not achieve a full alignment of these associated emissions (i.e., it does not lead to a 4% reduction in emissions intensity for the other industrial energy use sector), it avoids the outcome where that sector's emissions are reduced for all of the other activities.

These adjustments to emissions from all regions, all scenarios, and all years were applied to existing GCAM model results (i.e., the GCAM model was not re-run or scenarios optimized based on these adjustments).

Table C-7. GCAM Emissions Intensities for Sectors (S1, 2020, USA region, AR6-100 basis)

			Estimated GCAM Emissions Intensity (LHV) (Tg CO_2e / EJ, g CO_2e / MJ) [IPCC AR6 100 yr]		
GCAM Sector	**NETL LCA Stage**	**Comments/Potential mapping inaccuracy**	**CO_2**	**CH_4**	**N_2O**
gas pipeline	Transmission and Storage	Have assumed this fully represents the Transmission sector equivalent to the NETL NG model.	38.0/32.5 = 1.17	-	-
natural gas	Production + Gathering & Boosting + Processing	From discussions with GCAM team, this sector represents all other natural gas related activities, thus the mapping to all other NETL stages other than transmission.	-	139.0/32.5 = 4.28	.015/32.5 = 4.5 E-4
other industrial energy use (technology = gas or gas cogen)[a]	**For 2015**, Extraction, Gathering & Boosting	Estimates from IEA energy shares. For technology = gas or gas cogen, all GHG emissions allocated to the natural gas product. For technology = refined liquids or refined liquids cogen, GHG emissions are allocated to the natural gas and crude oil products on an energy (EJ) produced basis from GCAM output data.	92.9/32.5 = 2.86	-	-
other industrial energy use (technology = refined liquids and refined liquids cogen)[a]			11/(32.5+22.5) = 0.2	-	-
other industrial energy use (electricity)[a]			-	-	-
Total GCAM by gas (LHV)			= 1.17 + 2.86 + .2 = 4.23	4.28	4.5 E-4
Total GCAM (LHV)			8.52		
Subtotal from NETL Model, Processing through Transmission boundary – LHV basis			8.18		

Adjustment factor (LHV)	8.18/8.52 = 0.96

Using the same detailed approach, Tables C-8 through C-10 more succinctly summarize the provided GCAM values and adjustments identified for the IPCC AR values.

Table C-8. GCAM Emissions Intensities for Sectors (S1, 2020, USA region, AR6-20 basis)

	Estimated GCAM Emissions Intensity (Tg CO_2e / EJ, g CO_2e / MJ) [IPCC AR6 20 yr]		
GCAM Sector	CO_2	CH_4	N_2O
gas pipeline	1.17	-	-
natural gas	-	11.86	4.5 E-4
other industrial energy use (technology = gas or gas cogen)	2.86	-	-
other industrial energy use (technology = refined liquids and refined liquids cogen)	0.2	-	-
Total GCAM by gas (LHV)	= 1.17 + 2.86 + .2 = 4.23	11.86	4.5 E-4
Total GCAM (LHV)	16.1		
NETL (LHV basis)	13.8		
Adjustment Factor (LHV)	0.86		

Table C-9. GCAM Emissions Intensities for Sectors (S1, 2020, USA region, AR5-100 basis)

	Estimated GCAM Emissions Intensity (Tg CO_2e / EJ, g CO_2e / MJ) [IPCC AR5 100 yr]		
GCAM Sector	CO_2	CH_4	N_2O
gas pipeline	1.17	-	-
natural gas	-	5.18	4.9 E-4
other industrial energy use (technology = gas or gas cogen)	2.86	-	-

other industrial energy use (technology = refined liquids and refined liquids cogen)	0.2	-	-
Total GCAM by gas (LHV)	= 1.17 + 2.86 + .2 = 4.23	5.18	4.9 E-4
Total GCAM (LHV)	9.41		
NETL (LHV basis)	8.84		
Adjustment Factor (LHV)	0.94		

Table C-10. GCAM Emissions Intensities for Sectors (S1, 2020, USA region, AR5-20 basis)

	Estimated GCAM Emissions Intensity (Tg CO_2e / EJ, g CO_2e / MJ) [IPCC AR5 20 yr]		
GCAM Sector	**CO_2**	**CH_4**	**N_2O**
gas pipeline	1.17	-	-
natural gas	-	12.36	4.4 E-4
other industrial energy use (technology = gas or gas cogen)	2.86	-	-
other industrial energy use (technology = refined liquids and refined liquids cogen)	0.2	-	-
Total GCAM by gas (LHV)	= 1.17 + 2.86 + .2 = 4.23	12.36	4.4 E-4
Total GCAM (LHV)	16.6		
NETL (LHV basis)	14.2		
Adjustment Factor (LHV)	0.86		

Table C-11 shows the GWP of key greenhouse gases which were used in conjunction with the emissions factors to derive the overall life cycle greenhouse gas intensity.

Table C-11. GWP Values ~~used~~ Used in this ~~analysis~~Analysis (Source: IPCC)

Greenhouse Gas	AR5-100 (with ccf)	AR5-20 (with ccf)	AR6-100	AR6-20
CH_4 (fossil)	36	86	29.8	82.5
CH_4 ~~CH4~~ (non-fossil)	34	84	27.2	80.8
N_2O (fossil)	298	268	273	273
N_2O ~~N2O~~ (non-fossil)	298	268	273	273
HFC125	3691	6207	3740	6740
HFC134a	1549	3789	1530	4140
HFC143a	5508	7064	5810	7840
HFC23	13856	11005	14600	12400
HFC32	817	2502	771	2690
SF_6	26087	17783	24300	18200
HFC245fa	1032	2992	962	3170
HFC365mfc	966	2724	914	2920
C_2F_6	12340	8344	12400	8940
CF_4	7349	4954	7380	5300
HFC43	1952	4403	1600	3960
HFC152a	167	524	164	591
HFC227ea	3860	3860	3600	5850
HFC236fa	8998	9810	8690	7450

Note that unlike the natural gas system-specific emission comparisons and adjustments discussed above which focus on CO_2, CH_4, and N_2O, GCAM estimates emissions of sixteen GHGs and all are included in this study.

1. Market Adjustment Factors for other IPCC GWP Values

Table C-12 shows all MAF results for Scenario 2.

Table C-12. NETL-adjusted MAF results for S2

Results (g CO_2e/ MJ, LHV basis)					
MAF Case	AR5, 100 with ccf	AR5, 20 with ccf	AR6-100	AR6-20	Scenario Difference
***S2* vs. *S1* - unadjusted**	-5.85	-9.17	-5.34	-8.86	Adds economic solution for LNG exports.
***S2* vs. *S1* - adjusted**	-5.86	-9.12	-5.35	-8.74	

Table C-13 shows all MAF results for *Scenario 7*.

Table C-13 NETL-adjusted MAF results for S7

Results (g CO_2e/ MJ, LHV basis)					
MAF Case	AR5, 100 with ccf	AR5, 20	AR6-100	AR6-20	Scenario Difference
***S7* vs. *S6* - unadjusted**	-3.54	-7.54	-3.01	-7.25	S6 1.5°C pathway, economic solution for LNG exports
***S7* vs. *S6* - adjusted**	-3.44	-7.26	-2.95	-6.61	

Table C-14 shows the underlying annual CO_2e emissions and US LNG export volumes used in the MAF calculations above for the AR6-100 case (LHV, with NETL adjustments). Cumulative MAF values are calculated by finding the cumulative sum of delta values from 2015 to the current year for both LNG export volumes and global GHG emissions, and the cumulative values for 2050 match those shown above in the report.

Commented [ST218]: What does "with adjustments mean?

Table C-14. Annual US Export Volumes of ~~US~~ LNG ~~and~~, NETL-Adjusted Global CO_2 Emissions (IPCC AR6, 100-yr GWP ~~100 basis~~) and Annual Market Adjustment Factors

Scenario	Year	US LNG S1 (EJ)	Global CO_2e S1 (Tg)	US LNG S2 (EJ)	Global CO2e S2 (Tg)	Delta CO2e (Tg)	Delta US LNG (EJ)	Annual MAF	Cumulative MAF
S2	2015	0.02	49,656.39	0.02	49,656.39	0.00	0.00	NA	NA
S2	2016	0.54	50,410.51	0.54	50,410.51	0.00	0.00	NA	NA
S2	2017	1.06	51,164.63	1.06	51,164.63	0.00	0.00	NA	NA
S2	2018	1.58	51,918.75	1.58	51,918.75	0.00	0.00	NA	NA
S2	2019	2.10	52,672.87	2.10	52,672.87	0.00	0.00	NA	NA
S2	2020	2.62	53,426.99	2.62	53,426.99	0.00	0.00	NA	NA
S2	2021	3.09	52,816.08	3.09	52,816.08	0.00	0.00	NA	NA
S2	2022	3.55	52,205.17	3.55	52,205.17	0.00	0.00	NA	NA
S2	2023	4.02	51,594.26	4.02	51,594.26	0.00	0.00	NA	NA
S2	2024	4.49	50,983.35	4.49	50,983.35	0.00	0.00	NA	NA
S2	2025	4.96	50,372.43	4.96	50,372.43	0.00	0.00	NA	NA
S2	2026	5.37	50,692.94	5.37	50,692.94	0.00	0.00	NA	NA
S2	2027	5.78	51,013.45	5.78	51,013.45	0.00	0.00	NA	NA

Commented [ST219]: Break this table by Scenario.

Add to S2, S3, S4, and S5 a column showing the change in GHG Emissions by year compared to the S1 (the reference scenario).

Same comment for S7 with S6 comparison by year.

S2	202 8	6.19	51,333.96	6.19	51,333.96	0.00	0.00	NA	NA
S2	202 9	6.60	51,654.47	6.60	51,654.47	0.00	0.00	NA	NA
S2	203 0	7.01	51,974.98	7.01	51,974.98	0.00	0.00	NA	NA
S2	203 1	7.54	51,974.45	7.46	51,975.00	0.54	-0.08	-6.63	-6.63
S2	203 2	8.07	51,973.92	7.91	51,975.01	1.09	-0.16	-6.63	-6.63
S2	203 3	8.60	51,973.39	8.36	51,975.02	1.63	-0.25	-6.63	-6.63
S2	203 4	9.13	51,972.85	8.81	51,975.03	2.18	-0.33	-6.63	-6.63
S2	203 5	9.66	51,972.32	9.25	51,975.04	2.72	-0.41	-6.63	-6.63
S2	203 6	9.77	51,862.93	10.00	51,862.21	-0.73	0.23	-3.15	-7.43
S2	203 7	9.87	51,753.55	10.74	51,749.37	-4.18	0.87	-4.79	-25.14
S2	203 8	9.97	51,644.16	11.48	51,636.53	-7.63	1.51	-5.04	-3.15
S2	203 9	10.07	51,534.78	12.22	51,523.70	-11.08	2.15	-5.14	-4.37
S2	204 0	10.17	51,425.39	12.96	51,410.86	-14.53	2.79	-5.20	-4.73
S2	204 1	10.17	51,339.60	13.56	51,323.22	-16.38	3.39	-4.83	-4.77
S2	204 2	10.17	51,253.81	14.16	51,235.58	-18.23	3.99	-4.57	-4.71
S2	204 3	10.17	51,168.03	14.75	51,147.94	-20.09	4.58	-4.38	-4.63
S2	204 4	10.17	51,082.24	15.35	51,060.30	-21.94	5.18	-4.24	-4.54

S2	2045	10.17	50,996.45	15.95	50,972.66	-23.79	5.78	-4.12	-4.46
S2	2046	10.17	50,853.84	16.27	50,824.21	-29.63	6.10	-4.86	-4.53
S2	2047	10.17	50,711.23	16.60	50,675.76	-35.47	6.43	-5.52	-4.68
S2	2048	10.17	50,568.62	16.92	50,527.31	-41.31	6.75	-6.12	-4.88
S2	2049	10.17	50,426.01	17.25	50,378.85	-47.16	7.08	-6.66	-5.11
S2	2050	10.17	50,283.40	17.57	50,230.40	-53.00	7.40	-7.16	-5.35
Scenario	**Year**	**US LNG - S6 (EJ)**	**Global CO2e - S6 (Tg)**	**US LNG - S7 (EJ)**	**Global CO2e - S7 (Tg)**	**Delta CO2e (Tg)**	**Delta US LNG (EJ)**	**Annual MAF**	**Cumulative MAF**
S7	2015	0.02	49656.39	0.02	49656.39	0.00	0.00	NA	NA
S7	2016	0.54	50410.92	0.54	50410.92	0.00	0.00	NA	NA
S7	2017	1.06	51165.45	1.06	51165.45	0.00	0.00	NA	NA
S7	2018	1.58	51919.97	1.58	51919.97	0.00	0.00	NA	NA
S7	2019	2.10	52674.50	2.10	52674.50	0.00	0.00	NA	NA
S7	2020	2.62	53429.03	2.62	53429.03	0.00	0.00	NA	NA
S7	2021	3.09	52542.09	3.09	52542.09	0.00	0.00	NA	NA
S7	2022	3.55	51655.16	3.55	51655.16	0.00	0.00	NA	NA
S7	2023	4.02	50768.22	4.02	50768.22	0.00	0.00	NA	NA
S7	2024	4.49	49881.28	4.49	49881.28	0.00	0.00	NA	NA

S7	2025	4.96	48994.35	4.96	48994.35	0.00	0.00	NA	NA
S7	2026	5.07	49084.34	5.07	49084.34	0.00	0.00	NA	NA
S7	2027	5.17	49174.33	5.17	49174.33	0.00	0.00	NA	NA
S7	2028	5.28	49264.33	5.28	49264.33	0.00	0.00	NA	NA
S7	2029	5.38	49354.32	5.38	49354.32	0.00	0.00	NA	NA
S7	2030	5.49	49444.31	5.49	49444.31	0.00	0.00	NA	NA
S7	2031	5.78	48082.73	5.78	48082.74	0.00	0.00	404.93	423.34
S7	2032	6.07	46721.16	6.07	46721.16	0.00	0.00	401.86	409.02
S7	2033	6.37	45359.58	6.37	45359.58	0.00	0.00	400.84	404.93
S7	2034	6.66	43998.00	6.66	43998.00	0.00	0.00	400.33	403.09
S7	2035	6.95	42636.42	6.95	42636.42	0.00	0.00	400.02	402.06
S7	2036	7.48	41287.64	7.48	41287.64	0.00	0.00	282.77	371.75
S7	2037	8.01	39938.86	8.01	39938.86	0.00	0.00	170.52	330.27
S7	2038	8.54	38590.08	8.54	38590.08	0.00	0.00	62.94	283.77
S7	2039	9.07	37241.30	9.07	37241.30	0.00	0.00	-40.25	234.92
S7	2040	9.60	35892.52	9.60	35892.52	0.00	0.00	-139.31	185.02
S7	2041	9.71	34455.49	10.01	34454.66	-0.83	0.30	-2.76	-2.72

S7	2042	9.83	33018.45	10.43	33016.79	-1.66	0.60	-2.76	-2.75		
S7	2043	9.94	31581.41	10.84	31578.93	-2.49	0.90	-2.76	-2.75		
S7	2044	10.06	30144.38	11.26	30141.06	-3.32	1.20	-2.76	-2.76		
S7	2045	10.17	28707.34	11.67	28703.20	-4.14	1.50	-2.76	-2.76		
S7	2046	10.17	27334.61	11.84	27329.82	-4.79	1.67	-2.87	-2.79		
S7	2047	10.17	25961.87	12.00	25956.45	-5.43	1.83	-2.96	-2.83		
S7	2048	10.17	24589.14	12.17	24583.07	-6.07	2.00	-3.04	-2.87		
S7	2049	10.17	23216.41	12.33	23209.69	-6.71	2.16	-3.11	-2.91		
S7	2050	10.17	21843.67	12.50	21836.32	-7.35	2.33	-3.16	-2.95		

Commented [ST220]: I expected to find the index of country GHG emissions intensity to show the relative differences before and after adjustment.

I also expected to see more detail on "what" changed within each countries energy portfolio as a result of increased US LNG exports.

There is a larger "report" decision that will need to be made regarding additional transparency needed to support the conclusions.

This would be more in-line with the expectations described in the August 17, 2023 email to Scott/Matt from Tim.

NO ACTION REQUIRED AT THIS TIME UNTIL FURTHE REPORT WIDE GUIDANCE ON TRANSPARNCY/LEVEL OF DETAIL PROVIDED

APPENDIX D: TABULATED VALUES FROM FIGURES

Table D-1. U.S. LNG exports across the scenarios, tabulated by year (Figure 3)

Scenario	Unit	2015	2020	2025	2030	2035	2040	2045	2050
S1: Reference Exports	Bcf/d	0.05	7.03	13.33	18.85	25.98	27.33	27.33	27.33
S2: Market Response	Bcf/d	0.05	7.03	13.33	18.85	24.87	34.84	42.86	47.23
S3: High Global Demand	Bcf/d	0.05	7.03	13.33	18.84	25.22	35.47	43.91	48.74
S4: Regional Import Limits	Bcf/d	0.05	7.03	13.33	12.15	13.26	15.22	19.81	23.06
S5: Low-cost Renewables	Bcf/d	0.05	7.03	13.33	18.85	24.94	34.89	42.69	47.18
S6: Energy Transition (Ref Exp)	Bcf/d	0.05	7.03	13.33	14.75	18.68	25.79	27.33	27.33
S7: Energy Transition	Bcf/d	0.05	7.03	13.33	14.75	18.68	25.79	31.37	33.59
S1 - S1	Bcf/d	0	0	0	0	0	0	0	0
S2 - S1	Bcf/d	0	0	0	0	-1.1	7.51	15.52	19.9
S3 - S1	Bcf/d	0	0	0	-0.01	-0.75	8.14	16.58	21.41
S4 - S1	Bcf/d	0	0	0	-6.71	-12.71	-12.11	-7.53	-4.27
S5 - S1	Bcf/d	0	0	0	0	-1.04	7.56	15.35	19.84
S6 - S1	Bcf/d	0	0	0	-4.1	-7.29	-1.54	0	0
S7 - S1	Bcf/d	0	0	0	-4.1	-7.29	-1.54	4.03	6.25
S1 - S1	%	0	0	0	0	0	0	0	0
S2 - S1	%	0	0	0	0	-4.2	27.5	56.8	72.8
S3 - S1	%	0	0	0	0	-2.9	29.8	60.6	78.3
S4 - S1	%	0	0	0	-35.6	-48.9	-44.3	-27.5	-15.6
S5 - S1	%	0	0	0	0	-4	27.6	56.2	72.6
S6 - S1	%	0	0	0	-21.7	-28.1	-5.6	0	0
S7 - S1	%	0	0	0	-21.7	-28.1	-5.6	14.8	22.9

Table D-2. Natural gas consumption, production, and trade by region under S1 and S2 (Figure 4) and changes in natural gas consumption, production, and trade by region in S2 vs. S1 (Figure 5)

Scenario	Region	Unit	NG Volumes	2015	2020	2025	2030	2035	2040	2045	2050
S1: Reference exports	ROW	Bcf/d	Consumption	36.63	42.29	40.4	45.44	48.91	50.95	53.93	55.91
S1: Reference exports	Australia + NZ	Bcf/d	Consumption	3.85	0.79	0.31	0.43	0.38	0.51	0.76	1.11
S1: Reference exports	LAC	Bcf/d	Consumption	16.2	17.55	16.48	19.77	23.42	26.72	30.13	33.06
S1: Reference exports	Africa	Bcf/d	Consumption	12.32	14.45	14.21	17.09	21.45	26.78	33.49	41.44
S1: Reference exports	C Asia + East Eur	Bcf/d	Consumption	23.97	28.95	30.4	32.56	35.76	39.02	42.05	44.38

S1: Reference exports	Russia	Bcf/d	Consumption	41.18	45.82	35.98	39.62	39.94	39.92	39.91	39.81
S1: Reference exports	China	Bcf/d	Consumption	17.41	27.43	41.41	47.78	55.34	61.76	68.74	73.96
S1: Reference exports	India	Bcf/d	Consumption	5.07	7.96	11.89	17.19	22.88	28.35	34.63	41.12
S1: Reference exports	Middle East	Bcf/d	Consumption	44.96	46.53	46.04	47.58	51.74	56.93	63.16	67.9
S1: Reference exports	EU	Bcf/d	Consumption	40.32	48.18	35.83	33.46	29.99	28.83	32.7	36.46
S1: Reference exports	Mexico	Bcf/d	Consumption	6.91	8.28	8.06	9.36	10.7	12.08	13.4	14.74
S1: Reference exports	Canada	Bcf/d	Consumption	10.91	11.44	7.98	8.3	7.89	7.46	6.82	5.98
S1: Reference exports	USA	Bcf/d	Consumption	71.81	80.43	82.48	87.93	90.3	95.39	106.72	119
S1: Reference exports		**Bcf/d**	**Total**	**331.53**	**380.11**	**371.45**	**406.51**	**438.72**	**474.7**	**526.45**	**574.88**
S1: Reference exports	ROW	Bcf/d	Production	36.73	41.02	37.93	43.12	45.75	46.59	47.87	48.66
S1: Reference exports	Australia + NZ	Bcf/d	Production	6.84	12.71	12.21	12.11	11.09	9.61	7.82	6.59
S1: Reference exports	LAC	Bcf/d	Production	16.56	15.44	13.76	15.88	17.84	19.94	22.71	25.42
S1: Reference exports	Africa	Bcf/d	Production	18.43	23.83	24.67	27.6	31.5	36.6	42.46	48.39
S1: Reference exports	C Asia + East Eur	Bcf/d	Production	23.23	17.31	17.56	18.75	20.56	23.38	26.73	30.13
S1: Reference exports	Russia	Bcf/d	Production	58.04	70.26	59.82	63.01	63.57	67.82	74.16	80.12
S1: Reference exports	China	Bcf/d	Production	12.49	16.74	19.82	22.5	24.88	26.36	27.6	28.26
S1: Reference exports	India	Bcf/d	Production	2.89	4.02	4.91	7.13	9.9	13.37	17.64	22.27
S1: Reference exports	Middle East	Bcf/d	Production	55	59.51	58.6	60.95	66.4	73	81.24	87.94
S1: Reference exports	EU	Bcf/d	Production	11.72	13.69	10.05	10.19	9.82	10.22	15.81	20.86
S1: Reference exports	Mexico	Bcf/d	Production	3.8	3.21	2.55	3.35	3.91	4.48	5.36	6.46
S1: Reference exports	Canada	Bcf/d	Production	15.4	15.11	14.05	14.59	15.24	16.86	18.23	18.12
S1: Reference exports	USA	Bcf/d	Production	70.47	87.25	95.51	107.34	118.25	126.46	138.82	151.65

S1: Reference exports		**Bcf/d**	**Total**	**331.61**	**380.11**	**371.45**	**406.51**	**438.72**	**474.69**	**526.45**	**574.88**
S1: Reference exports	ROW	Bcf/d	LNG exports	8.59	10.56	11.11	13.82	15.57	16.43	18.02	19.15
S1: Reference exports	Australia + NZ	Bcf/d	LNG exports	3.02	11.93	11.9	11.69	10.72	9.11	7.07	5.66
S1: Reference exports	LAC	Bcf/d	LNG exports	1.82	1.83	2.2	2.67	3.51	4.71	6.27	7.61
S1: Reference exports	Africa	Bcf/d	LNG exports	5.56	9.09	10.65	11.58	12.46	13.6	14.77	15.28
S1: Reference exports	C Asia + East Eur	Bcf/d	LNG exports	0.02	0.06	0.17	0.42	1.07	2.52	4.88	7.51
S1: Reference exports	Russia	Bcf/d	LNG exports	1.64	3.05	3.82	3.9	3.67	3.34	3.25	3.47
S1: Reference exports	China	Bcf/d	LNG exports	0	0	0	0.01	0.02	0.06	0.11	0.15
S1: Reference exports	India	Bcf/d	LNG exports	0.05	0.01	0.01	0.04	0.09	0.2	0.41	0.64
S1: Reference exports	Middle East	Bcf/d	LNG exports	10.41	13.4	13.05	14	15.75	17.71	20.44	22.91
S1: Reference exports	EU	Bcf/d	LNG exports	0.71	0.37	0.46	0.63	0.87	1.68	3.17	4.5
S1: Reference exports	Mexico	Bcf/d	LNG exports	0	0	0	0.01	0.03	0.09	0.2	0.34
S1: Reference exports	Canada	Bcf/d	LNG exports	0	0.01	2.01	2.65	4.39	7.38	10.05	11.15
S1: Reference exports	USA	Bcf/d	LNG exports	0.05	7.03	13.33	18.85	25.98	27.33	27.33	27.33
S1: Reference exports		**Bcf/d**	**Total**	**0**	**57.34**	**68.72**	**80.27**	**94.13**	**104.15**	**115.98**	**125.71**
S1: Reference exports	ROW	Bcf/d	LNG imports	18.06	20.88	20.26	22.28	23.89	24.6	25.95	26.95
S1: Reference exports	Australia + NZ	Bcf/d	LNG imports	0.03	0.01	0	0	0	0	0.01	0.18
S1: Reference exports	LAC	Bcf/d	LNG imports	2.26	3.94	4.92	6.56	9.09	11.49	13.69	15.24
S1: Reference exports	Africa	Bcf/d	LNG imports	0.67	0.97	1.16	1.95	3.14	4.32	6.08	8.44
S1: Reference exports	C Asia + East Eur	Bcf/d	LNG imports	3.91	6.4	7.97	9.15	11.15	12.55	13.61	14.19
S1: Reference exports	Russia	Bcf/d	LNG imports	0	0.82	0.68	0.81	1.82	2.62	3.13	3.33
S1: Reference exports	China	Bcf/d	LNG imports	2.62	6.98	15.66	17.75	19.34	19.68	19.85	19.88

S1: Reference exports	India	Bcf/d	LNG imports	2.24	3.95	7	10.1	13.08	15.18	17.39	19.5
S1: Reference exports	Middle East	Bcf/d	LNG imports	0.37	0.43	0.48	0.63	1.07	1.54	2.13	2.52
S1: Reference exports	EU	Bcf/d	LNG imports	4.98	11.32	8.86	9.21	9.65	10.24	12.01	13.18
S1: Reference exports	Mexico	Bcf/d	LNG imports	0.73	1.15	1.34	1.44	1.57	1.64	1.77	1.95
S1: Reference exports	Canada	Bcf/d	LNG imports	0.18	0.21	0.15	0.15	0.14	0.19	0.25	0.26
S1: Reference exports	USA	Bcf/d	LNG imports	0.27	0.26	0.26	0.23	0.18	0.1	0.1	0.1
S1: Reference exports		**Bcf/d**	**Total**	**36.32**	**57.34**	**68.72**	**80.27**	**94.13**	**104.15**	**115.98**	**125.71**
S1: Reference exports	ROW	Bcf/d	Pipeline exports	10.37	10.05	7.51	7.05	6.05	4.62	2.67	1.52
S1: Reference exports	Australia + NZ	Bcf/d	Pipeline exports	0	0	0	0	0	0	0	0
S1: Reference exports	LAC	Bcf/d	Pipeline exports	2.15	2.11	1.82	1.79	1.6	1.36	1.22	1.23
S1: Reference exports	Africa	Bcf/d	Pipeline exports	1.36	1.42	1.13	1.23	1.58	2.35	3.38	4.8
S1: Reference exports	C Asia + East Eur	Bcf/d	Pipeline exports	7.81	0.07	0.05	0.05	0.04	0.03	0.01	0.01
S1: Reference exports	Russia	Bcf/d	Pipeline exports	14.83	23.46	21.67	21.37	23.15	29.3	37.12	43.78
S1: Reference exports	China	Bcf/d	Pipeline exports	0	0	0	0	0	0	0	0
S1: Reference exports	India	Bcf/d	Pipeline exports	0	0	0	0	0	0	0	0
S1: Reference exports	Middle East	Bcf/d	Pipeline exports	0.03	0.03	0.02	0.03	0.03	0.04	0.06	0.09
S1: Reference exports	EU	Bcf/d	Pipeline exports	2.36	2.21	1.61	1.49	1.25	0.92	0.49	0.27
S1: Reference exports	Mexico	Bcf/d	Pipeline exports	0.01	0.01	0	0.01	0.05	0.15	0.35	0.56
S1: Reference exports	Canada	Bcf/d	Pipeline exports	5.97	6.23	5.87	5.51	4.76	3.97	3.3	2.81
S1: Reference exports	USA	Bcf/d	Pipeline exports	5.17	8.53	8.53	8.53	8.53	8.52	8.53	8.53
S1: Reference exports		**Bcf/d**	**Total**	**50.07**	**54.11**	**48.21**	**47.06**	**47.04**	**51.26**	**57.14**	**63.59**
S1: Reference exports	ROW	Bcf/d	Pipeline imports	1.01	1	0.83	0.91	0.88	0.8	0.8	0.98

S1: Reference exports	Australia + NZ	Bcf/d	Pipeline imports	0	0	0	0	0	0	0	0
S1: Reference exports	LAC	Bcf/d	Pipeline imports	2.15	2.11	1.82	1.79	1.6	1.36	1.22	1.23
S1: Reference exports	Africa	Bcf/d	Pipeline imports	0.14	0.15	0.16	0.35	0.84	1.81	3.11	4.68
S1: Reference exports	C Asia + East Eur	Bcf/d	Pipeline imports	5.58	5.37	5.09	5.13	5.17	5.64	6.61	7.59
S1: Reference exports	Russia	Bcf/d	Pipeline imports	1.11	1.25	0.97	1.08	1.37	2.12	3	3.62
S1: Reference exports	China	Bcf/d	Pipeline imports	2.29	3.7	5.93	7.54	11.14	15.78	21.4	25.97
S1: Reference exports	India	Bcf/d	Pipeline imports	0	0	0	0	0	0	0	0
S1: Reference exports	Middle East	Bcf/d	Pipeline imports	0.05	0.02	0.03	0.03	0.06	0.14	0.29	0.45
S1: Reference exports	EU	Bcf/d	Pipeline imports	26.7	25.74	18.99	16.18	12.65	10.96	8.54	7.18
S1: Reference exports	Mexico	Bcf/d	Pipeline imports	2.39	3.93	4.18	4.6	5.29	6.2	6.81	7.23
S1: Reference exports	Canada	Bcf/d	Pipeline imports	2.06	2.35	1.66	1.72	1.66	1.75	1.7	1.56
S1: Reference exports	USA	Bcf/d	Pipeline imports	7.74	8.48	8.56	7.73	6.38	4.7	3.67	3.11
S1: Reference exports		**Bcf/d**	**Total**	**51.21**	**54.11**	**48.21**	**47.06**	**47.04**	**51.27**	**57.14**	**63.59**
S2: Market Response	ROW	Bcf/d	Consumption	36.63	42.29	40.4	45.44	48.76	51.9	55.46	57.76
S2: Market Response	Australia + NZ	Bcf/d	Consumption	3.85	0.79	0.31	0.43	0.37	0.52	0.78	1.13
S2: Market Response	LAC	Bcf/d	Consumption	16.2	17.55	16.48	19.77	23.34	27.29	30.97	33.98
S2: Market Response	Africa	Bcf/d	Consumption	12.32	14.45	14.21	17.09	21.44	26.94	33.87	42
S2: Market Response	C Asia + East Eur	Bcf/d	Consumption	23.97	28.95	30.4	32.56	35.69	39.41	42.46	44.78
S2: Market Response	Russia	Bcf/d	Consumption	41.18	45.82	35.98	39.62	39.93	39.98	39.98	39.88
S2: Market Response	China	Bcf/d	Consumption	17.41	27.43	41.41	47.78	55.04	62.68	69.41	74.51
S2: Market Response	India	Bcf/d	Consumption	5.07	7.96	11.89	17.19	22.78	28.94	35.5	42.11
S2: Market Response	Middle East	Bcf/d	Consumption	44.96	46.53	46.04	47.58	51.75	56.89	63.14	67.95

S2: Market Response	EU	Bcf/d	Consumption	40.32	48.18	35.83	33.46	29.54	30.59	34.25	37.95
S2: Market Response	Mexico	Bcf/d	Consumption	6.91	8.28	8.06	9.36	10.7	12.08	13.42	14.76
S2: Market Response	Canada	Bcf/d	Consumption	10.91	11.44	7.98	8.3	7.9	7.47	6.92	6.11
S2: Market Response	USA	Bcf/d	Consumption	71.81	80.43	82.48	87.93	90.36	94.97	105.54	115.78
S2: Market Response		**Bcf/d**	**Total**	**331.53**	**380.11**	**371.45**	**406.51**	**437.59**	**479.66**	**531.68**	**578.69**
S2: Market Response	ROW	Bcf/d	Production	36.73	41.02	37.93	43.12	45.71	46.36	47.03	47.63
S2: Market Response	Australia + NZ	Bcf/d	Production	6.84	12.71	12.21	12.11	11.09	9.58	7.65	6.24
S2: Market Response	LAC	Bcf/d	Production	16.56	15.44	13.76	15.88	17.88	19.55	21.78	24.2
S2: Market Response	Africa	Bcf/d	Production	18.43	23.83	24.67	27.6	31.53	36.13	41.24	46.78
S2: Market Response	C Asia + East Eur	Bcf/d	Production	23.23	17.31	17.56	18.75	20.59	23.12	25.9	28.85
S2: Market Response	Russia	Bcf/d	Production	58.04	70.26	59.82	63.01	63.59	67.37	72.53	77.91
S2: Market Response	China	Bcf/d	Production	12.49	16.74	19.82	22.5	24.83	26.5	27.57	28.17
S2: Market Response	India	Bcf/d	Production	2.89	4.02	4.91	7.13	9.92	13.25	17.23	21.64
S2: Market Response	Middle East	Bcf/d	Production	55	59.51	58.6	60.95	66.41	72.45	79.54	85.59
S2: Market Response	EU	Bcf/d	Production	11.72	13.69	10.05	10.19	9.67	10.83	15.39	19.98
S2: Market Response	Mexico	Bcf/d	Production	3.8	3.21	2.55	3.35	3.91	4.48	5.31	6.4
S2: Market Response	Canada	Bcf/d	Production	15.4	15.11	14.05	14.59	15.23	16.78	17.78	17.52
S2: Market Response	USA	Bcf/d	Production	70.47	87.25	95.51	107.34	117.24	133.28	152.75	167.78
S2: Market Response		**Bcf/d**	**Total**	**331.61**	**380.11**	**371.45**	**406.51**	**437.59**	**479.66**	**531.68**	**578.69**
S2: Market Response	ROW	Bcf/d	LNG exports	8.59	10.56	11.11	13.82	15.59	16.26	17.28	18.13
S2: Market Response	Australia + NZ	Bcf/d	LNG exports	3.02	11.93	11.9	11.69	10.72	9.06	6.88	5.32
S2: Market Response	LAC	Bcf/d	LNG exports	1.82	1.83	2.2	2.67	3.5	4.63	5.9	7.03

S2: Market Response	Africa	Bcf/d	LNG exports	5.56	9.09	10.65	11.58	12.46	13.43	14.04	14.24
S2: Market Response	C Asia + East Eur	Bcf/d	LNG exports	0.02	0.06	0.17	0.42	1.07	2.45	4.37	6.58
S2: Market Response	Russia	Bcf/d	LNG exports	1.64	3.05	3.82	3.9	3.67	3.3	3.07	3.14
S2: Market Response	China	Bcf/d	LNG exports	0	0	0	0.01	0.02	0.05	0.09	0.13
S2: Market Response	India	Bcf/d	LNG exports	0.05	0.01	0.01	0.04	0.09	0.19	0.36	0.55
S2: Market Response	Middle East	Bcf/d	LNG exports	10.41	13.4	13.05	14	15.71	17.51	19.25	21.03
S2: Market Response	EU	Bcf/d	LNG exports	0.71	0.37	0.46	0.63	0.87	1.6	2.79	3.93
S2: Market Response	Mexico	Bcf/d	LNG exports	0	0	0	0.01	0.03	0.08	0.17	0.29
S2: Market Response	Canada	Bcf/d	LNG exports	0	0.01	2.01	2.65	4.38	7.26	9.47	10.36
S2: Market Response	USA	Bcf/d	LNG exports	0.05	7.03	13.33	18.85	24.87	34.84	42.86	47.23
S2: Market Response		**Bcf/d**	**Total**	**0**	**57.34**	**68.72**	**80.27**	**92.98**	**110.68**	**126.53**	**137.96**
S2: Market Response	ROW	Bcf/d	LNG imports	18.06	20.88	20.26	22.28	23.73	25.6	27.58	28.82
S2: Market Response	Australia + NZ	Bcf/d	LNG imports	0.03	0.01	0	0	0	0	0.01	0.21
S2: Market Response	LAC	Bcf/d	LNG imports	2.26	3.94	4.92	6.56	8.96	12.38	15.09	16.82
S2: Market Response	Africa	Bcf/d	LNG imports	0.67	0.97	1.16	1.95	3.09	4.78	6.95	9.58
S2: Market Response	C Asia + East Eur	Bcf/d	LNG imports	3.91	6.4	7.97	9.15	11.01	13.37	14.88	15.6
S2: Market Response	Russia	Bcf/d	LNG imports	0	0.82	0.68	0.81	1.76	2.97	3.72	3.98
S2: Market Response	China	Bcf/d	LNG imports	2.62	6.98	15.66	17.75	19.14	20.33	20.86	21.03
S2: Market Response	India	Bcf/d	LNG imports	2.24	3.95	7	10.1	12.94	15.88	18.63	21.02
S2: Market Response	Middle East	Bcf/d	LNG imports	0.37	0.43	0.48	0.63	1.03	1.87	2.67	3.1
S2: Market Response	EU	Bcf/d	LNG imports	4.98	11.32	8.86	9.21	9.44	11.34	13.61	14.99
S2: Market Response	Mexico	Bcf/d	LNG imports	0.73	1.15	1.34	1.44	1.56	1.77	2.02	2.27

S2: Market Response	Canada	Bcf/d	LNG imports	0.18	0.21	0.15	0.15	0.14	0.25	0.35	0.37
S2: Market Response	USA	Bcf/d	LNG imports	0.27	0.26	0.26	0.23	0.17	0.15	0.16	0.17
S2: Market Response		**Bcf/d**	**Total**	**36.32**	**57.34**	**68.72**	**80.27**	**92.98**	**110.68**	**126.53**	**137.96**
S2: Market Response	ROW	Bcf/d	Pipeline exports	10.37	10.05	7.51	7.05	5.97	4.59	2.65	1.5
S2: Market Response	Australia + NZ	Bcf/d	Pipeline exports	0	0	0	0	0	0	0	0
S2: Market Response	LAC	Bcf/d	Pipeline exports	2.15	2.11	1.82	1.79	1.61	1.3	1.12	1.1
S2: Market Response	Africa	Bcf/d	Pipeline exports	1.36	1.42	1.13	1.23	1.58	2.25	3.18	4.52
S2: Market Response	C Asia + East Eur	Bcf/d	Pipeline exports	7.81	0.07	0.05	0.05	0.04	0.03	0.01	0.01
S2: Market Response	Russia	Bcf/d	Pipeline exports	14.83	23.46	21.67	21.37	23.14	29.04	35.93	42.16
S2: Market Response	China	Bcf/d	Pipeline exports	0	0	0	0	0	0	0	0
S2: Market Response	India	Bcf/d	Pipeline exports	0	0	0	0	0	0	0	0
S2: Market Response	Middle East	Bcf/d	Pipeline exports	0.03	0.03	0.02	0.03	0.03	0.04	0.06	0.08
S2: Market Response	EU	Bcf/d	Pipeline exports	2.36	2.21	1.61	1.49	1.23	0.92	0.48	0.25
S2: Market Response	Mexico	Bcf/d	Pipeline exports	0.01	0.01	0	0.01	0.05	0.15	0.35	0.58
S2: Market Response	Canada	Bcf/d	Pipeline exports	5.97	6.23	5.87	5.51	4.76	3.99	3.36	2.9
S2: Market Response	USA	Bcf/d	Pipeline exports	5.17	8.53	8.53	8.53	8.53	8.53	8.53	8.53
S2: Market Response		**Bcf/d**	**Total**	**50.07**	**54.11**	**48.21**	**47.06**	**46.94**	**50.82**	**55.66**	**61.63**
S2: Market Response	ROW	Bcf/d	Pipeline imports	1.01	1	0.83	0.91	0.88	0.8	0.78	0.93
S2: Market Response	Australia + NZ	Bcf/d	Pipeline imports	0	0	0	0	0	0	0	0
S2: Market Response	LAC	Bcf/d	Pipeline imports	2.15	2.11	1.82	1.79	1.61	1.3	1.12	1.1
S2: Market Response	Africa	Bcf/d	Pipeline imports	0.14	0.15	0.16	0.35	0.86	1.71	2.9	4.41
S2: Market Response	C Asia + East Eur	Bcf/d	Pipeline imports	5.58	5.37	5.09	5.13	5.2	5.4	6.06	6.92

S2: Market Response	Russia	Bcf/d	Pipeline imports	1.11	1.25	0.97	1.08	1.38	1.98	2.73	3.29
S2: Market Response	China	Bcf/d	Pipeline imports	2.29	3.7	5.93	7.54	11.09	15.91	21.06	25.44
S2: Market Response	India	Bcf/d	Pipeline imports	0	0	0	0	0	0	0	0
S2: Market Response	Middle East	Bcf/d	Pipeline imports	0.05	0.02	0.03	0.03	0.06	0.12	0.24	0.37
S2: Market Response	EU	Bcf/d	Pipeline imports	26.7	25.74	18.99	16.18	12.53	10.94	8.53	7.16
S2: Market Response	Mexico	Bcf/d	Pipeline imports	2.39	3.93	4.18	4.6	5.32	6.07	6.6	6.94
S2: Market Response	Canada	Bcf/d	Pipeline imports	2.06	2.35	1.66	1.72	1.67	1.69	1.62	1.47
S2: Market Response	USA	Bcf/d	Pipeline imports	7.74	8.48	8.56	7.73	6.35	4.91	4.02	3.59
S2: Market Response		**Bcf/d**	**Total**	**51.21**	**54.11**	**48.21**	**47.06**	**46.94**	**50.82**	**55.66**	**61.63**
S2 - S1	ROW	Bcf/d	Consumption	0	0	0	0	-0.14	0.95	1.53	1.84
S2 - S1	Australia + NZ	Bcf/d	Consumption	0	0	0	0	0	0.01	0.02	0.02
S2 - S1	LAC	Bcf/d	Consumption	0	0	0	0	-0.08	0.57	0.84	0.93
S2 - S1	Africa	Bcf/d	Consumption	0	0	0	0	-0.02	0.16	0.37	0.56
S2 - S1	C Asia + East Eur	Bcf/d	Consumption	0	0	0	0	-0.08	0.4	0.41	0.4
S2 - S1	Russia	Bcf/d	Consumption	0	0	0	0	-0.02	0.07	0.07	0.07
S2 - S1	China	Bcf/d	Consumption	0	0	0	0	-0.3	0.92	0.67	0.55
S2 - S1	India	Bcf/d	Consumption	0	0	0	0	-0.11	0.59	0.87	0.98
S2 - S1	Middle East	Bcf/d	Consumption	0	0	0	0	0.01	-0.04	-0.02	0.04
S2 - S1	EU	Bcf/d	Consumption	0	0	0	0	-0.46	1.75	1.56	1.49
S2 - S1	Mexico	Bcf/d	Consumption	0	0	0	0	0	-0.01	0.02	0.02
S2 - S1	Canada	Bcf/d	Consumption	0	0	0	0	0	0.01	0.1	0.13
S2 - S1	USA	Bcf/d	Consumption	0	0	0	0	0.06	-0.43	-1.19	-3.22

S2 - S1		**Bcf/d**	**Total**	**0**	**0**	**0**	**0**	**-1.13**	**4.96**	**5.24**	**3.82**
S2 - S1	ROW	Bcf/d	Production	0	0	0	0	-0.05	-0.23	-0.85	-1.03
S2 - S1	Australia + NZ	Bcf/d	Production	0	0	0	0	0	-0.03	-0.17	-0.35
S2 - S1	LAC	Bcf/d	Production	0	0	0	0	0.05	-0.39	-0.93	-1.22
S2 - S1	Africa	Bcf/d	Production	0	0	0	0	0.02	-0.47	-1.22	-1.61
S2 - S1	C Asia + East Eur	Bcf/d	Production	0	0	0	0	0.03	-0.26	-0.83	-1.28
S2 - S1	Russia	Bcf/d	Production	0	0	0	0	0.02	-0.44	-1.63	-2.22
S2 - S1	China	Bcf/d	Production	0	0	0	0	-0.05	0.14	-0.03	-0.09
S2 - S1	India	Bcf/d	Production	0	0	0	0	0.03	-0.12	-0.41	-0.63
S2 - S1	Middle East	Bcf/d	Production	0	0	0	0	0.01	-0.55	-1.7	-2.35
S2 - S1	EU	Bcf/d	Production	0	0	0	0	-0.15	0.61	-0.42	-0.88
S2 - S1	Mexico	Bcf/d	Production	0	0	0	0	0	-0.01	-0.05	-0.05
S2 - S1	Canada	Bcf/d	Production	0	0	0	0	-0.01	-0.09	-0.45	-0.6
S2 - S1	USA	Bcf/d	Production	0	0	0	0	-1.01	6.82	13.93	16.13
S2 - S1		**Bcf/d**	**Total**	**0**	**0**	**0**	**0**	**-1.13**	**4.97**	**5.24**	**3.82**
S2 - S1	ROW	Bcf/d	LNG exports	0	0	0	0	0.02	-0.16	-0.75	-1.02
S2 - S1	Australia + NZ	Bcf/d	LNG exports	0	0	0	0	0	-0.04	-0.18	-0.34
S2 - S1	LAC	Bcf/d	LNG exports	0	0	0	0	-0.01	-0.08	-0.37	-0.57
S2 - S1	Africa	Bcf/d	LNG exports	0	0	0	0	-0.01	-0.17	-0.72	-1.03
S2 - S1	C Asia + East Eur	Bcf/d	LNG exports	0	0	0	0	0	-0.08	-0.51	-0.93
S2 - S1	Russia	Bcf/d	LNG exports	0	0	0	0	0	-0.03	-0.19	-0.34
S2 - S1	China	Bcf/d	LNG exports	0	0	0	0	0	0	-0.02	-0.03

S2 - S1	India	Bcf/d	LNG exports	0	0	0	0	0	-0.01	-0.05	-0.09
S2 - S1	Middle East	Bcf/d	LNG exports	0	0	0	0	-0.04	-0.2	-1.19	-1.88
S2 - S1	EU	Bcf/d	LNG exports	0	0	0	0	0	-0.07	-0.38	-0.56
S2 - S1	Mexico	Bcf/d	LNG exports	0	0	0	0	0	-0.01	-0.03	-0.05
S2 - S1	Canada	Bcf/d	LNG exports	0	0	0	0	-0.01	-0.12	-0.58	-0.79
S2 - S1	USA	Bcf/d	LNG exports	0	0	0	0	-1.1	7.51	15.52	19.9
S2 - S1		**Bcf/d**	**Total**	**0**	**0**	**0**	**0**	**-1.15**	**6.53**	**10.55**	**12.25**
S2 - S1	ROW	Bcf/d	LNG imports	0	0	0	0	-0.16	0.99	1.62	1.87
S2 - S1	Australia + NZ	Bcf/d	LNG imports	0	0	0	0	0	0	0.01	0.03
S2 - S1	LAC	Bcf/d	LNG imports	0	0	0	0	-0.13	0.89	1.39	1.57
S2 - S1	Africa	Bcf/d	LNG imports	0	0	0	0	-0.06	0.46	0.87	1.14
S2 - S1	C Asia + East Eur	Bcf/d	LNG imports	0	0	0	0	-0.14	0.83	1.27	1.42
S2 - S1	Russia	Bcf/d	LNG imports	0	0	0	0	-0.06	0.35	0.59	0.65
S2 - S1	China	Bcf/d	LNG imports	0	0	0	0	-0.2	0.65	1.02	1.15
S2 - S1	India	Bcf/d	LNG imports	0	0	0	0	-0.13	0.7	1.23	1.52
S2 - S1	Middle East	Bcf/d	LNG imports	0	0	0	0	-0.04	0.33	0.54	0.58
S2 - S1	EU	Bcf/d	LNG imports	0	0	0	0	-0.21	1.09	1.6	1.81
S2 - S1	Mexico	Bcf/d	LNG imports	0	0	0	0	-0.02	0.13	0.25	0.33
S2 - S1	Canada	Bcf/d	LNG imports	0	0	0	0	0	0.06	0.1	0.11
S2 - S1	USA	Bcf/d	LNG imports	0	0	0	0	-0.01	0.05	0.06	0.07
S2 - S1		**Bcf/d**	**Total**	**0**	**0**	**0**	**0**	**-1.15**	**6.53**	**10.55**	**12.25**
S2 - S1	ROW	Bcf/d	Pipeline exports	0	0	0	0	-0.08	-0.03	-0.02	-0.03

S2 - S1	Australia + NZ	Bcf/d	Pipeline exports	0	0	0	0	0	0	0	0
S2 - S1	LAC	Bcf/d	Pipeline exports	0	0	0	0	0.01	-0.06	-0.1	-0.12
S2 - S1	Africa	Bcf/d	Pipeline exports	0	0	0	0	0	-0.1	-0.2	-0.28
S2 - S1	C Asia + East Eur	Bcf/d	Pipeline exports	0	0	0	0	0	0	0	0
S2 - S1	Russia	Bcf/d	Pipeline exports	0	0	0	0	-0.01	-0.26	-1.2	-1.62
S2 - S1	China	Bcf/d	Pipeline exports	0	0	0	0	0	0	0	0
S2 - S1	India	Bcf/d	Pipeline exports	0	0	0	0	0	0	0	0
S2 - S1	Middle East	Bcf/d	Pipeline exports	0	0	0	0	0	0	0	-0.01
S2 - S1	EU	Bcf/d	Pipeline exports	0	0	0	0	-0.02	0	-0.01	-0.01
S2 - S1	Mexico	Bcf/d	Pipeline exports	0	0	0	0	0	0	0	0.02
S2 - S1	Canada	Bcf/d	Pipeline exports	0	0	0	0	0	0.02	0.06	0.09
S2 - S1	USA	Bcf/d	Pipeline exports	0	0	0	0	0	0	0	0
S2 - S1		**Bcf/d**	**Total**	**0**	**0**	**0**	**0**	**-0.1**	**-0.43**	**-1.49**	**-1.95**
S2 - S1	ROW	Bcf/d	Pipeline imports	0	0	0	0	0	-0.01	-0.02	-0.05
S2 - S1	Australia + NZ	Bcf/d	Pipeline imports	0	0	0	0	0	0	0	0
S2 - S1	LAC	Bcf/d	Pipeline imports	0	0	0	0	0.01	-0.06	-0.1	-0.12
S2 - S1	Africa	Bcf/d	Pipeline imports	0	0	0	0	0.01	-0.11	-0.2	-0.28
S2 - S1	C Asia + East Eur	Bcf/d	Pipeline imports	0	0	0	0	0.03	-0.24	-0.54	-0.67
S2 - S1	Russia	Bcf/d	Pipeline imports	0	0	0	0	0.01	-0.14	-0.27	-0.32
S2 - S1	China	Bcf/d	Pipeline imports	0	0	0	0	-0.06	0.13	-0.34	-0.53
S2 - S1	India	Bcf/d	Pipeline imports	0	0	0	0	0	0	0	0
S2 - S1	Middle East	Bcf/d	Pipeline imports	0	0	0	0	0	-0.02	-0.05	-0.08

S2 - S1	EU	Bcf/d	Pipeline imports	0	0	0	0	-0.12	-0.02	-0.01	-0.01
S2 - S1	Mexico	Bcf/d	Pipeline imports	0	0	0	0	0.02	-0.13	-0.21	-0.29
S2 - S1	Canada	Bcf/d	Pipeline imports	0	0	0	0	0	-0.06	-0.08	-0.09
S2 - S1	USA	Bcf/d	Pipeline imports	0	0	0	0	-0.03	0.21	0.35	0.48
S2 - S1		**Bcf/d**	**Total**	**0**	**0**	**0**	**0**	**-0.1**	**-0.44**	**-1.49**	**-1.95**
S2 - S1	ROW	%	Consumption	0	0	0	0	-0.29	1.87	2.83	3.3
S2 - S1	Australia + NZ	%	Consumption	0	0	0	0	-0.47	1.88	2.45	1.6
S2 - S1	LAC	%	Consumption	0	0	0	0	-0.34	2.13	2.77	2.8
S2 - S1	Africa	%	Consumption	0	0	0	0	-0.07	0.6	1.12	1.36
S2 - S1	C Asia + East Eur	%	Consumption	0	0	0	0	-0.21	1.02	0.98	0.9
S2 - S1	Russia	%	Consumption	0	0	0	0	-0.05	0.17	0.17	0.17
S2 - S1	China	%	Consumption	0	0	0	0	-0.54	1.5	0.97	0.75
S2 - S1	India	%	Consumption	0	0	0	0	-0.47	2.06	2.5	2.39
S2 - S1	Middle East	%	Consumption	0	0	0	0	0.02	-0.06	-0.03	0.06
S2 - S1	EU	%	Consumption	0	0	0	0	-1.52	6.08	4.77	4.1
S2 - S1	Mexico	%	Consumption	0	0	0	0	0.03	-0.05	0.17	0.12
S2 - S1	Canada	%	Consumption	0	0	0	0	0.05	0.11	1.42	2.19
S2 - S1	USA	%	Consumption	0	0	0	0	0.07	-0.45	-1.11	-2.71
S2 - S1		**%**	**Total**	**0**	**0**	**0**	**0**	**-3.82**	**16.87**	**19**	**17.03**
S2 - S1	ROW	%	Production	0	0	0	0	-0.1	-0.49	-1.77	-2.11
S2 - S1	Australia + NZ	%	Production	0	0	0	0	-0.04	-0.34	-2.2	-5.37
S2 - S1	LAC	%	Production	0	0	0	0	0.26	-1.96	-4.11	-4.79
S2 - S1	Africa	%	Production	0	0	0	0	0.08	-1.29	-2.87	-3.34
S2 - S1	C Asia + East Eur	%	Production	0	0	0	0	0.12	-1.12	-3.1	-4.26
S2 - S1	Russia	%	Production	0	0	0	0	0.02	-0.66	-2.2	-2.76
S2 - S1	China	%	Production	0	0	0	0	-0.18	0.54	-0.12	-0.31
S2 - S1	India	%	Production	0	0	0	0	0.26	-0.91	-2.35	-2.83
S2 - S1	Middle East	%	Production	0	0	0	0	0.01	-0.75	-2.09	-2.67

S2 - S1	EU	%	Production	0	0	0	0	-1.54	5.92	-2.64	-4.21
S2 - S1	Mexico	%	Production	0	0	0	0	-0.05	-0.18	-0.85	-0.85
S2 - S1	Canada	%	Production	0	0	0	0	-0.07	-0.51	-2.47	-3.3
S2 - S1	USA	%	Production	0	0	0	0	-0.85	5.39	10.03	10.63
S2 - S1		**%**	**Total**	**0**	**0**	**0**	**0**	**-2.09**	**3.64**	**-16.74**	**-26.16**
S2 - S1	ROW	%	LNG exports	0	0	0	0	0.14	-1	-4.15	-5.33
S2 - S1	Australia + NZ	%	LNG exports	0	0	0	0	-0.02	-0.47	-2.61	-6.07
S2 - S1	LAC	%	LNG exports	0	0	0	0	-0.24	-1.61	-5.96	-7.51
S2 - S1	Africa	%	LNG exports	0	0	0	0	-0.05	-1.27	-4.9	-6.77
S2 - S1	C Asia + East Eur	%	LNG exports	0	0	0	0	-0.46	-3.04	-10.47	-12.43
S2 - S1	Russia	%	LNG exports	0	0	0	0	0.02	-0.95	-5.7	-9.74
S2 - S1	China	%	LNG exports	0	0	0	0	0.2	-8.45	-16.08	-16.59
S2 - S1	India	%	LNG exports	0	0	0	0	0.16	-4.38	-12.25	-14.07
S2 - S1	Middle East	%	LNG exports	0	0	0	0	-0.23	-1.14	-5.83	-8.21
S2 - S1	EU	%	LNG exports	0	0	0	0	0.09	-4.42	-11.87	-12.53
S2 - S1	Mexico	%	LNG exports	0	0	0	0	0.03	-6.1	-14.35	-15.78
S2 - S1	Canada	%	LNG exports	0	0	0	0	-0.3	-1.63	-5.77	-7.1
S2 - S1	USA	%	LNG exports	0	0	0	0	-4.25	27.48	56.79	72.79
S2 - S1		**%**	**Total**	**0**	**0**	**0**	**0**	**-4.92**	**-6.98**	**-43.14**	**-49.33**
S2 - S1	ROW	%	LNG imports	0	0	0	0	-0.65	4.04	6.26	6.95
S2 - S1	Australia + NZ	%	LNG imports	0	0	0	0	-0.64	3.37	70.21	15.85
S2 - S1	LAC	%	LNG imports	0	0	0	0	-1.48	7.7	10.18	10.32
S2 - S1	Africa	%	LNG imports	0	0	0	0	-1.85	10.71	14.26	13.55
S2 - S1	C Asia + East Eur	%	LNG imports	0	0	0	0	-1.24	6.58	9.33	9.98
S2 - S1	Russia	%	LNG imports	0	0	0	0	-3.2	13.55	18.83	19.62
S2 - S1	China	%	LNG imports	0	0	0	0	-1.03	3.28	5.13	5.77
S2 - S1	India	%	LNG imports	0	0	0	0	-1.01	4.59	7.08	7.81
S2 - S1	Middle East	%	LNG imports	0	0	0	0	-3.4	21.78	25.32	22.96
S2 - S1	EU	%	LNG imports	0	0	0	0	-2.16	10.64	13.33	13.73
S2 - S1	Mexico	%	LNG imports	0	0	0	0	-1.21	7.78	14.18	16.8
S2 - S1	Canada	%	LNG imports	0	0	0	0	-0.55	31.63	41.39	42.83

S2 - S1	USA	%	LNG imports	0	0	0	0	-5.71	56.24	59.76	64.41
S2 - S1		**%**	**Total**	**0**	**0**	**0**	**0**	**-24.14**	**181.9**	**295.25**	**250.58**
S2 - S1	ROW	%	Pipeline exports	0	0	0	0	-1.28	-0.66	-0.93	-1.65
S2 - S1	Australia + NZ	%	Pipeline exports	0	0	0	0	0.05	-0.47	-1.41	-3.03
S2 - S1	LAC	%	Pipeline exports	0	0	0	0	0.61	-4.2	-8.18	-10.12
S2 - S1	Africa	%	Pipeline exports	0	0	0	0	0.07	-4.41	-6.05	-5.78
S2 - S1	C Asia + East Eur	%	Pipeline exports	0	0	0	0	-1.6	1.1	1.82	-0.02
S2 - S1	Russia	%	Pipeline exports	0	0	0	0	-0.05	-0.9	-3.23	-3.69
S2 - S1	China	%	Pipeline exports	0	0	0	0	2.5	-12.35	-15.31	-13.59
S2 - S1	India	%	Pipeline exports	0	0	0	0	2.25	-12.61	-15.36	-12.63
S2 - S1	Middle East	%	Pipeline exports	0	0	0	0	0.17	-4.45	-7.12	-8.16
S2 - S1	EU	%	Pipeline exports	0	0	0	0	-1.57	-0.46	-2.37	-3.96
S2 - S1	Mexico	%	Pipeline exports	0	0	0	0	-0.36	1.38	-0.44	3.13
S2 - S1	Canada	%	Pipeline exports	0	0	0	0	-0.02	0.56	1.67	3.14
S2 - S1	USA	%	Pipeline exports	0	0	0	0	0	0.05	0	0
S2 - S1		**%**	**Total**	**0**	**0**	**0**	**0**	**0.76**	**-37.41**	**-56.92**	**-56.36**
S2 - S1	ROW	%	Pipeline imports	0	0	0	0	0.34	-0.89	-2.63	-4.73
S2 - S1	Australia + NZ	%	Pipeline imports	0	0	0	0	-0.47	1.76	5.62	-8.96
S2 - S1	LAC	%	Pipeline imports	0	0	0	0	0.61	-4.2	-8.18	-10.12
S2 - S1	Africa	%	Pipeline imports	0	0	0	0	1.67	-5.81	-6.59	-5.94
S2 - S1	C Asia + East Eur	%	Pipeline imports	0	0	0	0	0.59	-4.29	-8.18	-8.81
S2 - S1	Russia	%	Pipeline imports	0	0	0	0	0.96	-6.5	-9.04	-8.93
S2 - S1	China	%	Pipeline imports	0	0	0	0	-0.5	0.84	-1.58	-2.05

S2 - S1	India	%	Pipeline imports	0	0	0	0	0.69	-1.85	-4.13	-5.15
S2 - S1	Middle East	%	Pipeline imports	0	0	0	0	2.49	-16.6	-18.59	-16.85
S2 - S1	EU	%	Pipeline imports	0	0	0	0	-0.92	-0.19	-0.14	-0.16
S2 - S1	Mexico	%	Pipeline imports	0	0	0	0	0.45	-2.11	-3.12	-4.02
S2 - S1	Canada	%	Pipeline imports	0	0	0	0	0.09	-3.43	-4.69	-5.58
S2 - S1	USA	%	Pipeline imports	0	0	0	0	-0.42	4.5	9.43	15.55
S2 - S1		**%**	**Total**	**0**	**0**	**0**	**0**	**5.6**	**-38.77**	**-51.84**	**-65.75**

Table D-3. Global primary energy consumption by fuel under S2 and S1 (Figure 6) and changes in S2 relative to S1

Scenario	**Fuel**	**Units**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
S1: Reference Exports	biomass	EJ	30.07	32.44	48.96	58.95	69.5	79.75	89.4	95.84
S1: Reference Exports	biomass CCS	EJ	0	0	5.66	9.4	13.7	20.24	29.79	39.58
S1: Reference Exports	coal	EJ	165.11	177.1	165.33	171.07	169.73	166.82	161.18	153.04
S1: Reference Exports	coal CCS	EJ	0	0	1.33	2.61	3.94	5.36	7.04	8.96
S1: Reference Exports	gas	EJ	126.84	141.53	133.91	142.14	148.85	157.25	171.51	184.76
S1: Reference Exports	gas CCS	EJ	0	0	3.39	6.49	9.74	12.7	15.18	17.7
S1: Reference Exports	nuclear	EJ	9.67	10.1	11.77	13.05	14.62	16.48	18.47	20.48
S1: Reference Exports	oil	EJ	189	192.82	192.8	193.97	193.85	191.61	185.81	179.87
S1: Reference Exports	oil CCS	EJ	0	0	1.13	2.41	3.86	4.9	5.4	5.97
S1: Reference Exports	other renewables	EJ	18.54	24.1	35.17	47.32	59.56	72.42	85.71	99.96
S1: Reference Exports	**Total**	**EJ**	**520.69**	**553.99**	**564.28**	**600.09**	**627.79**	**655.11**	**683.78**	**706.2**
S2: Market Response	biomass	EJ	30.07	32.44	48.96	58.95	69.66	79.06	88.77	95.48
S2: Market Response	biomass CCS	EJ	0	0	5.66	9.4	13.68	20.32	29.96	39.77
S2: Market Response	coal	EJ	165.11	177.1	165.33	171.07	169.88	166.22	160.57	152.42
S2: Market Response	coal CCS	EJ	0	0	1.33	2.61	3.93	5.37	7.04	8.95
S2: Market Response	gas	EJ	126.84	141.53	133.91	142.14	148.46	158.95	173.26	185.96
S2: Market Response	gas CCS	EJ	0	0	3.39	6.49	9.72	12.83	15.38	17.96
S2: Market Response	nuclear	EJ	9.67	10.1	11.77	13.05	14.62	16.47	18.45	20.45
S2: Market Response	oil	EJ	189	192.82	192.8	193.97	193.91	191.29	185.45	179.6

S2: Market Response	oil CCS	EJ	0	0	1.13	2.41	3.86	4.91	5.39	5.96
S2: Market Response	other renewables	EJ	18.54	24.1	35.17	47.32	59.57	72.34	85.59	99.86
S2: Market Response	**Total**	**EJ**	**509.16**	**545.65**	**550.49**	**588.46**	**617.63**	**648.7**	**681.09**	**710.93**
S2 - S1	biomass	EJ	0	0	0	0	0.16	-0.69	-0.63	-0.36
S2 - S1	biomass CCS	EJ	0	0	0	0	-0.02	0.08	0.17	0.19
S2 - S1	coal	EJ	0	0	0	0	0.15	-0.6	-0.61	-0.62
S2 - S1	coal CCS	EJ	0	0	0	0	-0.01	0.01	0	-0.01
S2 - S1	gas	EJ	0	0	0	0	-0.39	1.7	1.75	1.2
S2 - S1	gas CCS	EJ	0	0	0	0	-0.02	0.13	0.2	0.26
S2 - S1	nuclear	EJ	0	0	0	0	0	-0.01	-0.02	-0.03
S2 - S1	oil	EJ	0	0	0	0	0.06	-0.32	-0.36	-0.27
S2 - S1	oil CCS	EJ	0	0	0	0	0	0.01	-0.01	-0.01
S2 - S1	**Total**	**EJ**	**0**	**0**	**0**	**0**	**0.01**	**-0.08**	**-0.12**	**-0.1**
S2 - S1	biomass	%	0	0	0	0	0.00	-0.01	-0.01	0.00
S2 - S1	biomass CCS	%	0	0	0	0	0.00	0.00	0.01	0.00
S2 - S1	coal	%	0	0	0	0	0.00	0.00	0.00	0.00
S2 - S1	coal CCS	%	0	0	0	0	0.00	0.00	0.00	0.00
S2 - S1	gas	%	0	0	0	0	0.00	0.01	0.01	0.01
S2 - S1	gas CCS	%	0	0	0	0	0.00	0.01	0.01	0.01
S2 - S1	nuclear	%	0	0	0	0	0.00	0.00	0.00	0.00
S2 - S1	oil	%	0	0	0	0	0.00	0.00	0.00	0.00
S2 - S1	oil CCS	%	0	0	0	0	0.00	0.00	0.00	0.00
S2 - S1	**Total**	**%**	**0**	**0**	**0**	**0**	**0.00**	**0.00**	**0.00**	**0.00**

Table D-4. GHG emissions by sector under S2 and S1 (Figure 6) and changes in S2 relative to S1

Scenario	**Sector**	**Unit**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
S1: Reference Exports	CO2 buildings	Gt CO2e	2.84	2.92	2.56	2.63	2.63	2.61	2.59	2.54
S1: Reference Exports	CO2 electricity	Gt CO2e	12.64	13.02	12.06	12.81	13.26	13.46	13.39	13.04
S1: Reference Exports	CO2 industry	Gt CO2e	11.75	12.98	12.68	12.65	12.14	11.66	11.32	11.04
S1: Reference Exports	CO2 other energy	Gt CO2e	0.51	1.23	1.09	1.31	1.43	1.51	1.57	1.6
S1: Reference Exports	CO2 transport	Gt CO2e	7.89	8.24	8.06	7.87	7.58	7.31	7.16	7.04
S1: Reference Exports	CH4 Energy	Gt CO2e	5.43	5.6	4.71	4.85	4.84	4.73	4.78	4.8
S1: Reference Exports	CH4 AgLanduse	Gt CO2e	3.36	3.61	3.69	3.98	4.25	4.5	4.75	4.97

S1: Reference Exports	N2O Energy	Gt CO2e	0.96	0.97	0.93	0.96	0.92	0.86	0.87	0.88
S1: Reference Exports	N2O AgLanduse	Gt CO2e	2.17	2.32	2.48	2.65	2.79	2.93	3.1	3.28
S1: Reference Exports	F-gases	Gt CO2e	1.01	1.33	1.41	1.69	1.76	1.74	1.68	1.66
S1: Reference Exports	CO2 bioenergy	Gt CO2e	0	0	-0.34	-0.54	-0.74	-1	-1.33	-1.68
S1: Reference Exports	CO2 direct air capture	Gt CO2e	0	0	0	0	-0.01	-0.01	0	0
S1: Reference Exports	CO2 LUC	Gt CO2e	3.04	0.42	0.73	-3.08	-1.75	-1.79	-1.57	-1.42
S1: Reference Exports	**Total**	**Gt CO2e**	**51.6**	**52.64**	**50.06**	**47.78**	**49.1**	**48.51**	**48.31**	**47.75**
S2: Market Response	CO2 buildings	Gt CO2e	2.84	2.92	2.56	2.63	2.62	2.63	2.6	2.54
S2: Market Response	CO2 electricity	Gt CO2e	12.64	13.02	12.06	12.81	13.27	13.45	13.39	13.02
S2: Market Response	CO2 industry	Gt CO2e	11.75	12.98	12.68	12.65	12.14	11.66	11.32	11.04
S2: Market Response	CO2 other energy	Gt CO2e	0.51	1.23	1.09	1.31	1.43	1.51	1.57	1.6
S2: Market Response	CO2 transport	Gt CO2e	7.89	8.24	8.06	7.87	7.58	7.31	7.15	7.03
S2: Market Response	CH4 Energy	Gt CO2e	5.43	5.6	4.71	4.85	4.84	4.73	4.77	4.79
S2: Market Response	CH4 AgLanduse	Gt CO2e	3.36	3.61	3.69	3.98	4.25	4.49	4.74	4.97
S2: Market Response	N2O Energy	Gt CO2e	0.96	0.97	0.93	0.96	0.92	0.86	0.87	0.88
S2: Market Response	N2O AgLanduse	Gt CO2e	2.17	2.32	2.48	2.65	2.79	2.93	3.1	3.28
S2: Market Response	F-gases	Gt CO2e	1.01	1.33	1.41	1.69	1.76	1.74	1.68	1.67
S2: Market Response	CO2 bioenergy	Gt CO2e	0	0	-0.34	-0.54	-0.74	-1	-1.34	-1.69
S2: Market Response	CO2 direct air capture	Gt CO2e	0	0	0	0	-0.01	-0.01	0	0
S2: Market Response	CO2 LUC	Gt CO2e	3.04	0.42	0.73	-3.08	-1.72	-2.09	-1.61	-1.39
S2: Market Response	**Total**	**Gt CO2e**	**51.6**	**52.64**	**50.06**	**47.78**	**49.13**	**48.21**	**48.24**	**47.74**
S2 - S1	CO2 buildings	Gt CO2e	0	0	0	0	0	0.01	0.01	0.01
S2 - S1	CO2 electricity	Gt CO2e	0	0	0	0	0	-0.01	0	-0.02
S2 - S1	CO2 industry	Gt CO2e	0	0	0	0	0	0	0	-0.01
S2 - S1	CO2 other energy	Gt CO2e	0	0	0	0	0	0	0	0
S2 - S1	CO2 transport	Gt CO2e	0	0	0	0	0	0	-0.01	-0.01
S2 - S1	CH4 Energy	Gt CO2e	0	0	0	0	0	0	-0.01	-0.01
S2 - S1	CH4 AgLanduse	Gt CO2e	0	0	0	0	0	0	0	0
S2 - S1	N2O Energy	Gt CO2e	0	0	0	0	0	0	0	0
S2 - S1	N2O AgLanduse	Gt CO2e	0	0	0	0	0	0	0	0
S2 - S1	F-gases	Gt CO2e	0	0	0	0	0	0	0	0
S2 - S1	CO2 bioenergy	Gt CO2e	0	0	0	0	0	-0.01	-0.01	-0.01
S2 - S1	CO2 direct air capture	Gt CO2e	0	0	0	0	0	0	0	0

S2 - S1	CO2 LUC	Gt CO2e	0	0	0	0	0.03	-0.3	-0.04	0.03
S2 - S1	**Total**	**Gt CO2e**	**0**	**0**	**0**	**0**	**0.03**	**-0.31**	**-0.06**	**-0.02**
S2 - S1	CO2 buildings	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S2 - S1	CO2 electricity	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S2 - S1	CO2 industry	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S2 - S1	CO2 other energy	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S2 - S1	CO2 transport	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S2 - S1	CH4 Energy	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S2 - S1	CH4 AgLanduse	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S2 - S1	N2O Energy	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S2 - S1	N2O AgLanduse	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S2 - S1	F-gases	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S2 - S1	CO2 bioenergy	%	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01
S2 - S1	CO2 direct air capture	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S2 - S1	CO2 LUC	%	0.00	0.00	0.00	0.00	-0.02	0.17	0.03	-0.02
S2 - S1	**Total**	**%**	**0.00**	**0.00**	**0.00**	**0.00**	**-0.02**	**0.18**	**0.03**	**-0.02**

Table D-5. Global primary energy consumption by fuel under S6 and S7 (Figure 7) and changes in S7 relative to S6

Scenario	**Fuel**	**Units**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
S6: Energy Transition (Ref Exp)	biomass	EJ	30.06	32.44	49.56	60.69	69.95	65.82	52.85	35.59
S6: Energy Transition (Ref Exp)	biomass CCS	EJ	0	0	7.58	14.81	40.26	66.29	89.57	108.7
S6: Energy Transition (Ref Exp)	coal	EJ	165.11	177.09	159.14	161.43	133.25	103.67	70.56	44.43
S6: Energy Transition (Ref Exp)	coal CCS	EJ	0	0	1.7	3.45	8.16	16.42	26.45	35.07
S6: Energy Transition (Ref Exp)	gas	EJ	126.83	141.49	130.11	131.75	125.14	122.27	113.86	95.07
S6: Energy Transition (Ref Exp)	gas CCS	EJ	0	0	3.73	8.48	18.61	29.78	41.85	58.07
S6: Energy Transition (Ref Exp)	nuclear	EJ	9.67	10.1	11.98	13.55	16.43	21.14	27.44	34.96
S6: Energy Transition (Ref Exp)	oil	EJ	189	192.9	191.77	192.33	184.43	174.89	161.68	144.79

S6: Energy Transition (Ref Exp)	oil CCS	EJ	0	0	1.26	2.78	6.09	8.92	11.77	16.07
S6: Energy Transition (Ref Exp)	other renewables	EJ	18.54	24.1	36.56	49.97	67.18	87.31	112.36	142.92
S6: Energy Transition (Ref Exp)	**Total**	**EJ**	**539.21**	**578.12**	**593.39**	**639.24**	**669.5**	**696.51**	**708.39**	**715.67**
S7: Energy Transition	biomass	EJ	30.06	32.44	49.56	60.69	69.95	65.82	52.71	35.54
S7: Energy Transition	biomass CCS	EJ	0	0	7.58	14.81	40.26	66.29	89.62	108.7
S7: Energy Transition	coal	EJ	165.11	177.09	159.14	161.43	133.25	103.67	70.47	44.39
S7: Energy Transition	coal CCS	EJ	0	0	1.7	3.45	8.16	16.42	26.44	35.03
S7: Energy Transition	gas	EJ	126.83	141.49	130.11	131.76	125.14	122.27	114.19	95.24
S7: Energy Transition	gas CCS	EJ	0	0	3.73	8.48	18.61	29.78	42.08	58.41
S7: Energy Transition	nuclear	EJ	9.67	10.1	11.98	13.55	16.43	21.14	27.43	34.94
S7: Energy Transition	oil	EJ	189	192.9	191.77	192.33	184.43	174.89	161.59	144.71
S7: Energy Transition	oil CCS	EJ	0	0	1.26	2.78	6.09	8.92	11.75	16.04
S7: Energy Transition	other renewables	EJ	18.54	24.1	36.56	49.97	67.18	87.31	112.33	142.87
S7: Energy Transition	**Total**	**EJ**	**539.21**	**578.12**	**593.39**	**639.25**	**669.5**	**696.51**	**708.61**	**715.87**
S7 - S6	biomass	EJ	0	0	0	0	0	0	-0.13	-0.06
S7 - S6	biomass CCS	EJ	0	0	0	0	0	0	0.05	0
S7 - S6	coal	EJ	0	0	0	0	0	0	-0.09	-0.04
S7 - S6	coal CCS	EJ	0	0	0	0	0	0	-0.01	-0.05
S7 - S6	gas	EJ	0	0	0	0	0	0	0.34	0.17
S7 - S6	gas CCS	EJ	0	0	0	0	0	0	0.23	0.34
S7 - S6	nuclear	EJ	0	0	0	0	0	0	-0.01	-0.03
S7 - S6	oil	EJ	0	0	0	0	0	0	-0.1	-0.08
S7 - S6	oil CCS	EJ	0	0	0	0	0	0	-0.01	-0.03
S7 - S6	other renewables	EJ	0	0	0	0	0	0	-0.03	-0.05
S7 - S6	**Total**	**EJ**	**0**	**0**	**0**	**0**	**0**	**0**	**0.24**	**0.17**
S7 - S6	biomass	%	0	0	0	0	0	0	-0.002	-0.002
S7 - S6	biomass CCS	%	0	0	0	0	0	0	0.001	0.000
S7 - S6	coal	%	0	0	0	0	0	0	-0.001	-0.001
S7 - S6	coal CCS	%	0	0	0	0	0	0	0.000	-0.001

S7 - S6	gas	%	0	0	0	0	0	0	0.003	0.002
S7 - S6	gas CCS	%	0	0	0	0	0	0	0.005	0.006
S7 - S6	nuclear	%	0	0	0	0	0	0	0.000	-0.001
S7 - S6	oil	%	0	0	0	0	0	0	-0.001	-0.001
S7 - S6	oil CCS	%	0	0	0	0	0	0	-0.001	-0.002
S7 - S6	other renewables	%	0	0	0	0	0	0	0.000	0.000
S7 - S6	**Total**	**%**	**0**	**0**	**0**	**0**	**0**	**0**	**0.000**	**0.000**

Table D-6. GHG emissions by sector under S7 and S6 (Figure 7) and changes in S7 relative to S6

Scenario	**Sector**	**Unit**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
S6: Energy Transition (Ref Exp)	CO2 buildings	Gt CO2e	2.84	2.92	2.46	2.47	2.09	1.94	1.67	1.12
S6: Energy Transition (Ref Exp)	CO2 electricity	Gt CO2e	12.64	13.02	11.54	11.81	10.02	7.56	4.53	2.16
S6: Energy Transition (Ref Exp)	CO2 industry	Gt CO2e	11.75	12.98	12.46	12.27	10.42	8.83	7.58	6.47
S6: Energy Transition (Ref Exp)	CO2 other energy	Gt CO2e	0.51	1.23	1.06	1.27	1.11	1.08	1.04	0.95
S6: Energy Transition (Ref Exp)	CO2 transport	Gt CO2e	7.89	8.24	7.99	7.74	7.11	6.51	5.9	5
S6: Energy Transition (Ref Exp)	CH4 Energy	Gt CO2e	5.43	5.6	4.55	4.65	4.32	4	3.56	3.25
S6: Energy Transition (Ref Exp)	CH4 AgLanduse	Gt CO2e	3.36	3.61	3.68	3.95	4.14	4.33	4.51	4.69
S6: Energy Transition (Ref Exp)	N2O Energy	Gt CO2e	0.96	0.97	0.9	0.92	0.82	0.74	0.66	0.59
S6: Energy Transition (Ref Exp)	N2O AgLanduse	Gt CO2e	2.17	2.32	2.43	2.59	2.74	2.86	2.96	3.03
S6: Energy Transition (Ref Exp)	F-gases	Gt CO2e	1.01	1.33	1.37	1.62	1.58	1.5	1.23	1.07
S6: Energy Transition (Ref Exp)	CO2 bioenergy	Gt CO2e	0	0	-0.46	-0.9	-2.46	-4.02	-5.35	-6.81
S6: Energy Transition (Ref Exp)	CO2 direct air capture	Gt CO2e	0	0	0	-0.04	-0.28	-0.42	-0.44	-0.47
S6: Energy Transition (Ref Exp)	CO2 LUC	Gt CO2e	3.04	0.56	0.82	-3.26	-2.38	-2.84	-3.12	-3.92
S6: Energy Transition (Ref Exp)	**Total**	**Gt CO2e**	**51.6**	**52.78**	**48.8**	**45.09**	**39.23**	**32.07**	**24.73**	**17.13**
S7: Energy Transition	CO2 buildings	Gt CO2e	2.84	2.92	2.46	2.47	2.09	1.94	1.68	1.12

S7: Energy Transition	CO2 electricity	Gt CO2e	12.64	13.02	11.54	11.81	10.02	7.56	4.53	2.16
S7: Energy Transition	CO2 industry	Gt CO2e	11.75	12.98	12.46	12.27	10.42	8.83	7.58	6.47
S7: Energy Transition	CO2 other energy	Gt CO2e	0.51	1.23	1.06	1.27	1.11	1.08	1.04	0.95
S7: Energy Transition	CO2 transport	Gt CO2e	7.89	8.24	7.99	7.74	7.11	6.51	5.9	5
S7: Energy Transition	CH4 Energy	Gt CO2e	5.43	5.6	4.55	4.65	4.32	4	3.56	3.24
S7: Energy Transition	CH4 AgLanduse	Gt CO2e	3.36	3.61	3.68	3.95	4.14	4.33	4.51	4.69
S7: Energy Transition	N2O Energy	Gt CO2e	0.96	0.97	0.9	0.92	0.82	0.74	0.66	0.59
S7: Energy Transition	N2O AgLanduse	Gt CO2e	2.17	2.32	2.43	2.59	2.74	2.86	2.96	3.03
S7: Energy Transition	F-gases	Gt CO2e	1.01	1.33	1.37	1.62	1.58	1.5	1.23	1.07
S7: Energy Transition	CO2 bioenergy	Gt CO2e	0	0	-0.46	-0.9	-2.46	-4.02	-5.36	-6.81
S7: Energy Transition	CO2 direct air capture	Gt CO2e	0	0	0	-0.04	-0.28	-0.42	-0.44	-0.47
S7: Energy Transition	CO2 LUC	Gt CO2e	3.04	0.56	0.82	-3.26	-2.38	-2.84	-3.13	-3.92
S7: Energy Transition	**Total**	**Gt CO2e**	**51.6**	**52.78**	**48.8**	**45.09**	**39.23**	**32.07**	**24.72**	**17.12**
Delta S7 - S6	CO2 buildings	Gt CO2e	0	0	0	0	0	0	0	0
Delta S7 - S6	CO2 electricity	Gt CO2e	0	0	0	0	0	0	0	0
Delta S7 - S6	CO2 industry	Gt CO2e	0	0	0	0	0	0	0	0
Delta S7 - S6	CO2 other energy	Gt CO2e	0	0	0	0	0	0	0	0
Delta S7 - S6	CO2 transport	Gt CO2e	0	0	0	0	0	0	0	0
Delta S7 - S6	CH4 Energy	Gt CO2e	0	0	0	0	0	0	0	-0.01
Delta S7 - S6	CH4 AgLanduse	Gt CO2e	0	0	0	0	0	0	0	0
Delta S7 - S6	N2O Energy	Gt CO2e	0	0	0	0	0	0	0	0
Delta S7 - S6	N2O AgLanduse	Gt CO2e	0	0	0	0	0	0	0	0

Delta S7 - S6	F-gases	Gt CO2e	0	0	0	0	0	0	0	0
Delta S7 - S6	CO2 bioenergy	Gt CO2e	0	0	0	0	0	0	0	0
Delta S7 - S6	CO2 direct air capture	Gt CO2e	0	0	0	0	0	0	0	0
Delta S7 - S6	CO2 LUC	Gt CO2e	0	0	0	0	0	0	-0.01	0
Delta S7 - S6	**Total**	**Gt CO2e**	**0**	**0**	**0**	**0**	**0**	**0**	**-0.01**	**-0.01**
Delta S7 - S6	CO2 buildings	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Delta S7 - S6	CO2 electricity	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Delta S7 - S6	CO2 industry	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Delta S7 - S6	CO2 other energy	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Delta S7 - S6	CO2 transport	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Delta S7 - S6	CH4 Energy	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Delta S7 - S6	CH4 AgLanduse	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Delta S7 - S6	N2O Energy	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Delta S7 - S6	N2O AgLanduse	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Delta S7 - S6	F-gases	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Delta S7 - S6	CO2 bioenergy	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Delta S7 - S6	CO2 direct air capture	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Delta S7 - S6	CO2 LUC	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Delta S7 - S6	**Total**	**%**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Table D-7. Changes in global primary energy consumption under S6 and S7 relative to S1 and S2 respectively (Figure 8)

Scenario	**Fuel**	**Units**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
S6 - S1	biomass	EJ	0	0	0.6	1.73	0.46	-13.94	-36.55	-60.25
S6 - S1	biomass CCS	EJ	0	0	1.92	5.41	26.55	46.05	59.78	69.12
S6 - S1	coal	EJ	0	-0.01	-6.19	-9.64	-36.48	-63.15	-90.63	-108.6
S6 - S1	coal CCS	EJ	0	0	0.38	0.84	4.22	11.06	19.41	26.11
S6 - S1	gas	EJ	0	-0.05	-3.8	-10.39	-23.71	-34.98	-57.65	-89.7
S6 - S1	gas CCS	EJ	0	0	0.34	1.99	8.87	17.07	26.67	40.37
S6 - S1	nuclear	EJ	0	0	0.21	0.49	1.81	4.66	8.97	14.48
S6 - S1	oil	EJ	0	0.07	-1.02	-1.63	-9.42	-16.72	-24.13	-35.08
S6 - S1	oil CCS	EJ	0	0	0.13	0.38	2.23	4.01	6.37	10.1
S6 - S1	other renewables	EJ	0	0	1.39	2.64	7.62	14.89	26.65	42.95
S6 - S1	**Total**	**EJ**	**0**	**0.01**	**-6.04**	**-8.18**	**-17.85**	**-31.05**	**-61.11**	**-90.51**

S7 - S2	biomass	EJ	0	0	0.6	1.73	0.3	-13.24	-36.06	-59.95
S7 - S2	biomass CCS	EJ	0	0	1.92	5.41	26.57	45.97	59.66	68.94
S7 - S2	coal	EJ	0	-0.01	-6.19	-9.64	-36.63	-62.55	-90.1	-108
S7 - S2	coal CCS	EJ	0	0	0.38	0.84	4.22	11.05	19.4	26.08
S7 - S2	gas	EJ	0	-0.05	-3.8	-10.39	-23.32	-36.68	-59.07	-90.72
S7 - S2	gas CCS	EJ	0	0	0.34	1.99	8.9	16.94	26.7	40.46
S7 - S2	nuclear	EJ	0	0	0.21	0.49	1.81	4.67	8.98	14.49
S7 - S2	oil	EJ	0	0.07	-1.02	-1.63	-9.48	-16.4	-23.86	-34.89
S7 - S2	oil CCS	EJ	0	0	0.13	0.38	2.23	4	6.36	10.09
S7 - S2	other renewables	EJ	0	0	1.39	2.64	7.61	14.97	26.74	43.01
S7 - S2	**Total**	**EJ**	**0**	**0.01**	**-6.04**	**-8.18**	**-17.79**	**-31.27**	**-61.25**	**-90.52**
S6 - S1	biomass	%	0.00	0.00	1.23	2.93	0.66	-17.48	-40.88	-62.87
S6 - S1	biomass CCS	%	0.00	0.00	33.92	57.55	193.80	227.52	200.67	174.63
S6 - S1	coal	%	0.00	-0.01	-3.74	-5.64	-21.49	-37.86	-56.23	-70.97
S6 - S1	coal CCS	%	0.00	0.00	28.57	32.18	107.11	206.34	275.71	291.41
S6 - S1	gas	%	0.00	-0.04	-2.84	-7.31	-15.93	-22.24	-33.61	-48.55
S6 - S1	gas CCS	%	0.00	0.00	10.03	30.66	91.07	134.41	175.69	228.08
S6 - S1	nuclear	%	0.00	0.00	1.78	3.75	12.38	28.28	48.57	70.70
S6 - S1	oil	%	0.00	0.04	-0.53	-0.84	-4.86	-8.73	-12.99	-19.50
S6 - S1	oil CCS	%	0.00	0.00	11.50	15.77	57.77	81.84	117.96	169.18
S6 - S1	other renewables	%	0.00	0.00	3.95	5.58	12.79	20.56	31.09	42.97
S6 - S1	**Total**	**%**	**0.00**	**0.00**	**-1.07**	**-1.36**	**-2.84**	**-4.74**	**-8.94**	**-12.82**
S7 - S2	biomass	%	0.00	0.00	1.23	2.93	0.43	-16.75	-40.62	-62.79
S7 - S2	biomass CCS	%	0.00	0.00	33.92	57.55	194.23	226.23	199.13	173.35
S7 - S2	coal	%	0.00	-0.01	-3.74	-5.64	-21.56	-37.63	-56.11	-70.88
S7 - S2	coal CCS	%	0.00	0.00	28.57	32.18	107.38	205.77	275.57	291.40
S7 - S2	gas	%	0.00	-0.04	-2.84	-7.31	-15.71	-23.08	-34.09	-48.78
S7 - S2	gas CCS	%	0.00	0.00	10.03	30.66	91.56	132.03	173.60	225.28
S7 - S2	nuclear	%	0.00	0.00	1.78	3.75	12.38	28.35	48.67	70.86
S7 - S2	oil	%	0.00	0.04	-0.53	-0.84	-4.89	-8.57	-12.87	-19.43
S7 - S2	oil CCS	%	0.00	0.00	11.50	15.77	57.77	81.47	118.00	169.30
S7 - S2	other renewables	%	0.00	0.00	3.95	5.58	12.77	20.69	31.24	43.07
S7 - S2	**Total**	**%**	**0.00**	**0.00**	**-1.10**	**-1.39**	**-2.88**	**-4.82**	**-8.99**	**-12.73**

Table D-8. Changes in global GHG emissions by sector under S6 and S7 relative to S1 and S2 respectively (Figure 8)

Scenario	Sector	Units	2015	2020	2025	2030	2035	2040	2045	2050
S6 - S1	CO2 buildings	Gt CO2e	0	0	-0.1	-0.16	-0.54	-0.67	-0.91	-1.42
S6 - S1	CO2 electricity	Gt CO2e	0	0	-0.52	-1	-3.25	-5.9	-8.86	-10.88

S6 - S1	CO2 industry	Gt CO2e	0	0	-0.22	-0.38	-1.71	-2.83	-3.75	-4.57
S6 - S1	CO2 other energy	Gt CO2e	0	0	-0.03	-0.05	-0.32	-0.43	-0.53	-0.65
S6 - S1	CO2 transport	Gt CO2e	0	0	-0.08	-0.13	-0.47	-0.8	-1.26	-2.03
S6 - S1	CH4 Energy	Gt CO2e	0	0	-0.16	-0.2	-0.52	-0.73	-1.21	-1.55
S6 - S1	CH4 AgLanduse	Gt CO2e	0	0	-0.01	-0.02	-0.11	-0.17	-0.24	-0.28
S6 - S1	N2O Energy	Gt CO2e	0	0	-0.03	-0.03	-0.1	-0.12	-0.21	-0.29
S6 - S1	N2O AgLanduse	Gt CO2e	0	0	-0.05	-0.06	-0.05	-0.06	-0.14	-0.25
S6 - S1	F-gases	Gt CO2e	0	0	-0.04	-0.07	-0.18	-0.23	-0.45	-0.59
S6 - S1	CO2 bioenergy	Gt CO2e	0	0	-0.12	-0.36	-1.71	-3.02	-4.02	-5.12
S6 - S1	CO2 direct air capture	Gt CO2e	0	0	0	-0.03	-0.27	-0.41	-0.44	-0.47
S6 - S1	CO2 LUC	Gt CO2e	0	0.14	0.09	-0.17	-0.62	-1.05	-1.55	-2.5
S6 - S1	**Total**	**Gt CO2e**	**0**	**0.14**	**-1.27**	**-2.66**	**-9.85**	**-16.4**	**-23.6**	**-30.6**
S7 - S2	CO2 buildings	Gt CO2e	0	0	-0.1	-0.16	-0.53	-0.68	-0.92	-1.43
S7 - S2	CO2 electricity	Gt CO2e	0	0	-0.52	-1	-3.25	-5.89	-8.85	-10.86
S7 - S2	CO2 industry	Gt CO2e	0	0	-0.22	-0.38	-1.71	-2.83	-3.74	-4.56
S7 - S2	CO2 other energy	Gt CO2e	0	0	-0.03	-0.05	-0.32	-0.43	-0.53	-0.65
S7 - S2	CO2 transport	Gt CO2e	0	0	-0.08	-0.13	-0.47	-0.8	-1.25	-2.03
S7 - S2	CH4 Energy	Gt CO2e	0	0	-0.16	-0.2	-0.52	-0.72	-1.21	-1.54
S7 - S2	CH4 AgLanduse	Gt CO2e	0	0	-0.01	-0.02	-0.11	-0.17	-0.24	-0.28
S7 - S2	N2O Energy	Gt CO2e	0	0	-0.03	-0.03	-0.1	-0.12	-0.21	-0.29
S7 - S2	N2O AgLanduse	Gt CO2e	0	0	-0.05	-0.06	-0.05	-0.06	-0.14	-0.25
S7 - S2	F-gases	Gt CO2e	0	0	-0.04	-0.07	-0.18	-0.24	-0.45	-0.6
S7 - S2	CO2 bioenergy	Gt CO2e	0	0	-0.12	-0.36	-1.72	-3.01	-4.01	-5.11
S7 - S2	CO2 direct air capture	Gt CO2e	0	0	0	-0.03	-0.27	-0.41	-0.44	-0.47
S7 - S2	CO2 LUC	Gt CO2e	0	0.14	0.09	-0.17	-0.66	-0.75	-1.52	-2.53
S7 - S2	**Total**	**Gt CO2e**	**0**	**0.14**	**-1.27**	**-2.66**	**-9.89**	**-16.1**	**-23.5**	**-30.6**
S6 - S1	CO2 buildings	%	0	0	-3.91	-6.08	-20.5	-25.7	-35.1	-55.91
S6 - S1	CO2 electricity	%	0	0	-4.31	-7.81	-24.5	-43.8	-66.2	-83.44
S6 - S1	CO2 industry	%	0	0	-1.74	-3	-14.1	-24.3	-33.1	-41.39
S6 - S1	CO2 other energy	%	0	0	-2.75	-3.82	-22.4	-28.5	-33.8	-40.63
S6 - S1	CO2 transport	%	0	0	-0.99	-1.65	-6.2	-10.9	-17.6	-28.84

S6 - S1	CH4 Energy	%	0	0	-3.4	-4.12	-10.7	-15.4	-25.3	-32.29
S6 - S1	CH4 AgLanduse	%	0	0	-0.27	-0.5	-2.59	-3.78	-5.05	-5.634
S6 - S1	N2O Energy	%	0	0	-3.23	-3.13	-10.9	-14	-24.1	-32.95
S6 - S1	N2O AgLanduse	%	0	0	-2.02	-2.26	-1.79	-2.05	-4.52	-7.622
S6 - S1	F-gases	%	0	0	-2.84	-4.14	-10.2	-13.2	-26.8	-35.54
S6 - S1	CO2 bioenergy	%	0	0	35.3	66.7	231	302	302	304.8
S6 - S1	CO2 direct air capture	%	0	0	0	0	2700	4100	0	0
S6 - S1	CO2 LUC	%	0	33.3	12.3	5.52	35.4	58.7	98.7	176.1
S6 - S1	**Total**	**%**	**0**	**0.27**	**-2.54**	**-5.57**	**-20.1**	**-33.8**	**-48.8**	**-64.08**
S7 - S2	CO2 buildings	%	0	0	-3.91	-6.08	-20.2	-25.9	-35.4	-56.3
S7 - S2	CO2 electricity	%	0	0	-4.31	-7.81	-24.5	-43.8	-66.1	-83.41
S7 - S2	CO2 industry	%	0	0	-1.74	-3	-14.1	-24.3	-33	-41.3
S7 - S2	CO2 other energy	%	0	0	-2.75	-3.82	-22.4	-28.5	-33.8	-40.63
S7 - S2	CO2 transport	%	0	0	-0.99	-1.65	-6.2	-10.9	-17.5	-28.88
S7 - S2	CH4 Energy	%	0	0	-3.4	-4.12	-10.7	-15.2	-25.4	-32.15
S7 - S2	CH4 AgLanduse	%	0	0	-0.27	-0.5	-2.59	-3.79	-5.06	-5.634
S7 - S2	N2O Energy	%	0	0	-3.23	-3.13	-10.9	-14	-24.1	-32.95
S7 - S2	N2O AgLanduse	%	0	0	-2.02	-2.26	-1.79	-2.05	-4.52	-7.622
S7 - S2	F-gases	%	0	0	-2.84	-4.14	-10.2	-13.8	-26.8	-35.93
S7 - S2	CO2 bioenergy	%	0	0	35.3	66.7	232	301	299	302.4
S7 - S2	CO2 direct air capture	%	0	0	0	0	2700	4100	0	0
S7 - S2	CO2 LUC	%	0	33.3	12.3	5.52	38.4	35.9	94.4	182
S7 - S2	**Total**	**%**	**0**	**0.27**	**-2.54**	**-5.57**	**-20.1**	**-33.4**	**-48.7**	**-64.1**

Table D-9. CDR deployment by type in S6 and S7 and changes in S7 relative to S6 (Figure 9)

Scenario	Sector	Units	2015	2020	2025	2030	2035	2040	2045	2050
S6: Energy Transition (Ref Exp)	BECCS	Gt CO2	0	0	0.46	0.9	2.46	4.02	5.35	6.81
S6: Energy Transition (Ref Exp)	DAC	Gt CO2	0	0	0	0.04	0.28	0.42	0.44	0.47
S6: Energy Transition (Ref Exp)	Afforestation	Gt CO2e	1.38	1.54	1.5	3.99	3.38	3.37	3.43	4.06
S6: Energy Transition (Ref Exp)	**Total**	**Gt CO2e**	**1.38**	**1.54**	**1.96**	**4.93**	**6.12**	**7.81**	**9.22**	**11.3**
S7: Energy Transition	BECCS	Gt CO2	0	0	0.46	0.9	2.46	4.02	5.36	6.81
S7: Energy Transition	DAC	Gt CO2	0	0	0	0.04	0.28	0.42	0.44	0.47
S7: Energy Transition	Afforestation	Gt CO2e	1.38	1.54	1.5	3.99	3.38	3.37	3.44	4.06
S7: Energy Transition	**Total**	**Gt CO2e**	**1.38**	**1.54**	**1.96**	**4.93**	**6.12**	**7.81**	**9.24**	**11.3**
S7 - S6	BECCS	Gt CO2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S7 - S6	DAC	Gt CO2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S7 - S6	Afforestation	Gt CO2e	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S7 - S6	**Total**	**Gt CO2e**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
S7 - S6	BECCS	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S7 - S6	DAC	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S7 - S6	Afforestation	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S7 - S6	**Total**	**%**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Table D-10. Natural gas consumption, production, consumption, and trade by region under S6 and S7 (Figure 10) and changes in S7 relative to S6 (Figure 12)

Scenario	Region	Unit	NG Volumes	2020	2025	2030	2035	2040	2045	2050
S6: Energy Transition (Ref Exp)	ROW	Bcf/d	Consumption	42.29	39.95	42.56	42.59	44	46.19	45.43
S6: Energy Transition (Ref Exp)	Australia + NZ	Bcf/d	Consumption	0.79	0.33	0.49	0.34	0.44	0.63	0.91
S6: Energy Transition (Ref Exp)	LAC	Bcf/d	Consumption	17.55	16.52	19.24	20.64	22.58	23.55	24.91
S6: Energy Transition (Ref Exp)	Africa	Bcf/d	Consumption	14.45	14.23	16.98	20.22	25.07	31.92	38.76
S6: Energy Transition (Ref Exp)	C Asia + East Eur	Bcf/d	Consumption	28.94	30.46	32.45	32.35	32.44	30.5	28.2
S6: Energy Transition (Ref Exp)	Russia	Bcf/d	Consumption	45.82	36.03	39.59	39.92	39.43	36.08	33.1
S6: Energy Transition (Ref Exp)	China	Bcf/d	Consumption	27.43	41.73	46.57	52.25	59.32	66.21	64.93
S6: Energy Transition (Ref Exp)	India	Bcf/d	Consumption	7.96	11.56	16.4	21.55	27.64	34.62	40.31

S6: Energy Transition (Ref Exp)	Middle East	Bcf/d	Consumption	46.41	45.15	47.15	46.26	46.8	47.07	45.5
S6: Energy Transition (Ref Exp)	EU	Bcf/d	Consumption	48.18	35	28.79	24.88	26.86	29.64	28.38
S6: Energy Transition (Ref Exp)	Mexico	Bcf/d	Consumption	8.28	8.19	9.5	9.81	9.99	10.28	10.83
S6: Energy Transition (Ref Exp)	Canada	Bcf/d	Consumption	11.44	8.25	8.26	6.72	5.99	5.53	4.98
S6: Energy Transition (Ref Exp)	USA	Bcf/d	Consumption	80.45	75.28	76.47	76.36	79.45	77.9	75.67
S6: Energy Transition (Ref Exp)	_	**Bcf/d**	**Total**	**380**	**362.69**	**384.44**	**393.88**	**420.01**	**440.11**	**441.92**
S7: Energy Transition	ROW	Bcf/d	Consumption	42.29	39.95	42.56	42.59	44	46.65	45.95
S7: Energy Transition	Australia + NZ	Bcf/d	Consumption	0.79	0.33	0.49	0.34	0.44	0.64	0.92
S7: Energy Transition	LAC	Bcf/d	Consumption	17.55	16.52	19.24	20.64	22.58	23.78	25.2
S7: Energy Transition	Africa	Bcf/d	Consumption	14.45	14.23	16.98	20.22	25.07	32.01	38.94
S7: Energy Transition	C Asia + East Eur	Bcf/d	Consumption	28.94	30.46	32.45	32.35	32.44	30.57	28.27
S7: Energy Transition	Russia	Bcf/d	Consumption	45.82	36.03	39.59	39.92	39.43	36.09	33.12
S7: Energy Transition	China	Bcf/d	Consumption	27.43	41.73	46.57	52.25	59.32	66.39	65.02
S7: Energy Transition	India	Bcf/d	Consumption	7.96	11.56	16.4	21.55	27.64	34.86	40.59
S7: Energy Transition	Middle East	Bcf/d	Consumption	46.41	45.15	47.15	46.26	46.8	47.06	45.5
S7: Energy Transition	EU	Bcf/d	Consumption	48.18	35	28.79	24.88	26.86	30.04	28.53
S7: Energy Transition	Mexico	Bcf/d	Consumption	8.28	8.19	9.5	9.81	9.99	10.28	10.84
S7: Energy Transition	Canada	Bcf/d	Consumption	11.44	8.25	8.26	6.72	5.99	5.54	5
S7: Energy Transition	USA	Bcf/d	Consumption	80.45	75.28	76.47	76.36	79.45	77.73	75.42
S7: Energy Transition		**Bcf/d**	**Total**	**380**	**362.69**	**384.44**	**393.88**	**420.01**	**441.64**	**443.29**
S6: Energy Transition (Ref Exp)	ROW	Bcf/d	Production	41.02	37.63	40.92	41.75	42.28	43.38	43.46
S6: Energy Transition (Ref Exp)	Australia + NZ	Bcf/d	Production	12.71	12.21	12.09	10.84	9.16	7.08	5.31

S6: Energy Transition (Ref Exp)	LAC	Bcf/d	Production	15.44	13.65	15.64	16.05	16.86	17.9	19.08
S6: Energy Transition (Ref Exp)	Africa	Bcf/d	Production	23.83	24.62	27.17	29.58	33.29	38.2	42.33
S6: Energy Transition (Ref Exp)	C Asia + East Eur	Bcf/d	Production	17.31	17.51	18.71	18.64	19.21	19.55	19.79
S6: Energy Transition (Ref Exp)	Russia	Bcf/d	Production	70.26	59.65	62.68	61.92	64.03	65.28	61.94
S6: Energy Transition (Ref Exp)	China	Bcf/d	Production	16.74	19.7	22.17	23.72	25.2	26.33	24.8
S6: Energy Transition (Ref Exp)	India	Bcf/d	Production	4.02	4.75	7.01	9.46	12.66	17	20.74
S6: Energy Transition (Ref Exp)	Middle East	Bcf/d	Production	59.39	57.77	59.86	59.95	61.7	63.69	63.1
S6: Energy Transition (Ref Exp)	EU	Bcf/d	Production	13.69	9.87	8.52	7.91	9.03	13.03	14.42
S6: Energy Transition (Ref Exp)	Mexico	Bcf/d	Production	3.21	2.39	3.14	3.2	3.3	3.52	3.96
S6: Energy Transition (Ref Exp)	Canada	Bcf/d	Production	15.11	14.11	14.29	13.94	14.97	15.66	15.04
S6: Energy Transition (Ref Exp)	USA	Bcf/d	Production	87.26	88.83	92.25	96.9	108.31	109.49	107.95
S6: Energy Transition (Ref Exp)		**Bcf/d**	**Total**	**379.99**	**362.69**	**384.45**	**393.86**	**420**	**440.11**	**441.92**
S7: Energy Transition	ROW	Bcf/d	Production	41.02	37.63	40.92	41.75	42.28	43.14	43
S7: Energy Transition	Australia + NZ	Bcf/d	Production	12.71	12.21	12.09	10.84	9.16	7.05	5.21
S7: Energy Transition	LAC	Bcf/d	Production	15.44	13.65	15.64	16.05	16.86	17.71	18.72
S7: Energy Transition	Africa	Bcf/d	Production	23.83	24.62	27.17	29.58	33.29	37.81	41.66
S7: Energy Transition	C Asia + East Eur	Bcf/d	Production	17.31	17.51	18.71	18.64	19.21	19.4	19.44
S7: Energy Transition	Russia	Bcf/d	Production	70.26	59.65	62.68	61.92	64.03	64.96	61.24
S7: Energy Transition	China	Bcf/d	Production	16.74	19.7	22.17	23.72	25.2	26.3	24.74
S7: Energy Transition	India	Bcf/d	Production	4.02	4.75	7.01	9.46	12.66	16.8	20.38
S7: Energy Transition	Middle East	Bcf/d	Production	59.39	57.77	59.86	59.95	61.7	63.27	62.29
S7: Energy Transition	EU	Bcf/d	Production	13.69	9.87	8.52	7.91	9.03	12.87	13.99

S7: Energy Transition	Mexico	Bcf/d	Production	3.21	2.39	3.14	3.2	3.3	3.5	3.93
S7: Energy Transition	Canada	Bcf/d	Production	15.11	14.11	14.29	13.94	14.97	15.55	14.81
S7: Energy Transition	USA	Bcf/d	Production	87.26	88.83	92.25	96.9	108.31	113.29	113.87
S7: Energy Transition		**Bcf/d**	**Total**	**379.99**	**362.69**	**384.45**	**393.86**	**420**	**441.65**	**443.28**
S6: Energy Transition (Ref Exp)	ROW	Bcf/d	LNG exports	10.56	11.06	13.52	15.16	15.5	16.15	16.3
S6: Energy Transition (Ref Exp)	Australia + NZ	Bcf/d	LNG exports	11.93	11.88	11.61	10.51	8.72	6.46	4.55
S6: Energy Transition (Ref Exp)	LAC	Bcf/d	LNG exports	1.83	2.17	2.46	3.06	4.03	5.2	5.93
S6: Energy Transition (Ref Exp)	Africa	Bcf/d	LNG exports	9.09	10.61	11.28	11.59	12.1	12.3	11.73
S6: Energy Transition (Ref Exp)	C Asia + East Eur	Bcf/d	LNG exports	0.06	0.16	0.33	0.81	1.94	3.6	5.03
S6: Energy Transition (Ref Exp)	Russia	Bcf/d	LNG exports	3.05	3.81	3.89	3.56	3.09	2.72	2.5
S6: Energy Transition (Ref Exp)	China	Bcf/d	LNG exports	0	0	0	0.02	0.04	0.07	0.09
S6: Energy Transition (Ref Exp)	India	Bcf/d	LNG exports	0.01	0.01	0.04	0.07	0.15	0.27	0.37
S6: Energy Transition (Ref Exp)	Middle East	Bcf/d	LNG exports	13.4	13.05	13.27	14.4	16.11	18.04	19.03
S6: Energy Transition (Ref Exp)	EU	Bcf/d	LNG exports	0.37	0.47	0.61	0.75	1.29	2.21	3.07
S6: Energy Transition (Ref Exp)	Mexico	Bcf/d	LNG exports	0	0	0.01	0.02	0.07	0.14	0.22
S6: Energy Transition (Ref Exp)	Canada	Bcf/d	LNG exports	0.01	2.01	2.42	4.08	6.85	9.01	9.49
S6: Energy Transition (Ref Exp)	USA	Bcf/d	LNG exports	7.03	13.33	14.75	18.68	25.79	27.33	27.33
S6: Energy Transition (Ref Exp)		**Bcf/d**	**Total**	**57.34**	**68.56**	**74.19**	**82.71**	**95.68**	**103.5**	**105.64**
S7: Energy Transition	ROW	Bcf/d	LNG exports	10.56	11.06	13.52	15.16	15.5	15.97	15.92
S7: Energy Transition	Australia + NZ	Bcf/d	LNG exports	11.93	11.88	11.61	10.51	8.72	6.42	4.46
S7: Energy Transition	LAC	Bcf/d	LNG exports	1.83	2.17	2.46	3.06	4.03	5.1	5.73
S7: Energy Transition	Africa	Bcf/d	LNG exports	9.09	10.61	11.28	11.59	12.1	12.14	11.4

S7: Energy Transition	C Asia + East Eur	Bcf/d	LNG exports	0.06	0.16	0.33	0.81	1.94	3.49	4.73
S7: Energy Transition	Russia	Bcf/d	LNG exports	3.05	3.81	3.89	3.56	3.09	2.68	2.4
S7: Energy Transition	China	Bcf/d	LNG exports	0	0	0	0.02	0.04	0.07	0.09
S7: Energy Transition	India	Bcf/d	LNG exports	0.01	0.01	0.04	0.07	0.15	0.26	0.34
S7: Energy Transition	Middle East	Bcf/d	LNG exports	13.4	13.05	13.27	14.4	16.11	17.77	18.37
S7: Energy Transition	EU	Bcf/d	LNG exports	0.37	0.47	0.61	0.75	1.29	2.14	2.87
S7: Energy Transition	Mexico	Bcf/d	LNG exports	0	0	0.01	0.02	0.07	0.14	0.2
S7: Energy Transition	Canada	Bcf/d	LNG exports	0.01	2.01	2.42	4.08	6.85	8.89	9.25
S7: Energy Transition	USA	Bcf/d	LNG exports	7.03	13.33	14.75	18.68	25.79	31.37	33.59
S7: Energy Transition		**Bcf/d**	**Total**	**57.34**	**68.56**	**74.19**	**82.71**	**95.68**	**106.44**	**109.35**
S6: Energy Transition (Ref Exp)	ROW	Bcf/d	LNG imports	20.88	19.92	20.38	20.28	20.94	20.86	18.94
S6: Energy Transition (Ref Exp)	Australia + NZ	Bcf/d	LNG imports	0.01	0	0	0	0	0.01	0.15
S6: Energy Transition (Ref Exp)	LAC	Bcf/d	LNG imports	3.94	5.05	6.06	7.64	9.75	10.85	11.76
S6: Energy Transition (Ref Exp)	Africa	Bcf/d	LNG imports	0.97	1.17	1.83	2.84	4.4	6.26	8.21
S6: Energy Transition (Ref Exp)	C Asia + East Eur	Bcf/d	LNG imports	6.4	8.07	8.92	9.85	10.96	10.75	10.25
S6: Energy Transition (Ref Exp)	Russia	Bcf/d	LNG imports	0.82	0.68	0.81	1.82	3	3.33	3.37
S6: Energy Transition (Ref Exp)	China	Bcf/d	LNG imports	6.98	16.04	17.19	18.43	19.58	19.91	19.61
S6: Energy Transition (Ref Exp)	India	Bcf/d	LNG imports	3.94	6.83	9.43	12.16	15.13	17.89	19.95
S6: Energy Transition (Ref Exp)	Middle East	Bcf/d	LNG imports	0.43	0.43	0.54	0.7	1.18	1.36	1.38
S6: Energy Transition (Ref Exp)	EU	Bcf/d	LNG imports	11.32	8.65	7.28	7.37	9.19	10.77	10.46
S6: Energy Transition (Ref Exp)	Mexico	Bcf/d	LNG imports	1.15	1.35	1.4	1.36	1.31	1.27	1.31
S6: Energy Transition (Ref Exp)	Canada	Bcf/d	LNG imports	0.21	0.15	0.15	0.12	0.13	0.17	0.19

S6: Energy Transition (Ref Exp)	USA	Bcf/d	LNG imports	0.26	0.24	0.18	0.14	0.12	0.08	0.08
S6: Energy Transition (Ref Exp)		**Bcf/d**	**Total**	**57.31**	**68.58**	**74.17**	**82.71**	**95.69**	**103.51**	**105.66**
S7: Energy Transition	ROW	Bcf/d	LNG imports	20.88	19.92	20.38	20.28	20.94	21.37	19.55
S7: Energy Transition	Australia + NZ	Bcf/d	LNG imports	0.01	0	0	0	0	0.01	0.17
S7: Energy Transition	LAC	Bcf/d	LNG imports	3.94	5.05	6.06	7.64	9.75	11.18	12.21
S7: Energy Transition	Africa	Bcf/d	LNG imports	0.97	1.17	1.83	2.84	4.4	6.59	8.74
S7: Energy Transition	C Asia + East Eur	Bcf/d	LNG imports	6.4	8.07	8.92	9.85	10.96	10.92	10.44
S7: Energy Transition	Russia	Bcf/d	LNG imports	0.82	0.68	0.81	1.82	3	3.45	3.51
S7: Energy Transition	China	Bcf/d	LNG imports	6.98	16.04	17.19	18.43	19.58	20.23	19.95
S7: Energy Transition	India	Bcf/d	LNG imports	3.94	6.83	9.43	12.16	15.13	18.31	20.55
S7: Energy Transition	Middle East	Bcf/d	LNG imports	0.43	0.43	0.54	0.7	1.18	1.52	1.54
S7: Energy Transition	EU	Bcf/d	LNG imports	11.32	8.65	7.28	7.37	9.19	11.26	11.01
S7: Energy Transition	Mexico	Bcf/d	LNG imports	1.15	1.35	1.4	1.36	1.31	1.31	1.36
S7: Energy Transition	Canada	Bcf/d	LNG imports	0.21	0.15	0.15	0.12	0.13	0.19	0.22
S7: Energy Transition	USA	Bcf/d	LNG imports	0.26	0.24	0.18	0.14	0.12	0.1	0.09
S7: Energy Transition		**Bcf/d**	**Total**	**57.31**	**68.58**	**74.17**	**82.71**	**95.69**	**106.44**	**109.34**
S6: Energy Transition (Ref Exp)	ROW	Bcf/d	Pipeline exports	10.05	7.37	6.09	5.05	4.42	2.64	1.55
S6: Energy Transition (Ref Exp)	Australia + NZ	Bcf/d	Pipeline exports	0	0	0	0	0	0	0
S6: Energy Transition (Ref Exp)	LAC	Bcf/d	Pipeline exports	2.11	1.81	1.81	1.53	1.2	0.97	0.92
S6: Energy Transition (Ref Exp)	Africa	Bcf/d	Pipeline exports	1.42	1.11	1.11	1.44	2.31	3.73	5.77
S6: Energy Transition (Ref Exp)	C Asia + East Eur	Bcf/d	Pipeline exports	0.07	0.05	0.04	0.03	0.03	0.01	0.01
S6: Energy Transition (Ref Exp)	Russia	Bcf/d	Pipeline exports	23.46	21.46	21.08	21.63	26.42	32.12	32.15

S6: Energy Transition (Ref Exp)	China	Bcf/d	Pipeline exports	0	0	0	0	0	0	0
S6: Energy Transition (Ref Exp)	India	Bcf/d	Pipeline exports	0	0	0	0	0	0	0
S6: Energy Transition (Ref Exp)	Middle East	Bcf/d	Pipeline exports	0.03	0.02	0.02	0.03	0.05	0.08	0.12
S6: Energy Transition (Ref Exp)	EU	Bcf/d	Pipeline exports	2.21	1.58	1.26	1.03	0.89	0.46	0.23
S6: Energy Transition (Ref Exp)	Mexico	Bcf/d	Pipeline exports	0.01	0	0.01	0.03	0.08	0.17	0.29
S6: Energy Transition (Ref Exp)	Canada	Bcf/d	Pipeline exports	6.23	5.73	5.48	4.68	3.66	2.79	2.23
S6: Energy Transition (Ref Exp)	USA	Bcf/d	Pipeline exports	8.53	8.53	8.53	8.53	8.53	8.53	8.53
S6: Energy Transition (Ref Exp)	-	**Bcf/d**	**Total**	**54.12**	**47.66**	**45.43**	**43.98**	**47.59**	**51.5**	**51.8**
S7: Energy Transition	ROW	Bcf/d	Pipeline exports	10.05	7.37	6.09	5.05	4.42	2.62	1.53
S7: Energy Transition	Australia + NZ	Bcf/d	Pipeline exports	0	0	0	0	0	0	0
S7: Energy Transition	LAC	Bcf/d	Pipeline exports	2.11	1.81	1.81	1.53	1.2	0.95	0.88
S7: Energy Transition	Africa	Bcf/d	Pipeline exports	1.42	1.11	1.11	1.44	2.31	3.62	5.58
S7: Energy Transition	C Asia + East Eur	Bcf/d	Pipeline exports	0.07	0.05	0.04	0.03	0.03	0.01	0.01
S7: Energy Transition	Russia	Bcf/d	Pipeline exports	23.46	21.46	21.08	21.63	26.42	31.88	31.62
S7: Energy Transition	China	Bcf/d	Pipeline exports	0	0	0	0	0	0	0
S7: Energy Transition	India	Bcf/d	Pipeline exports	0	0	0	0	0	0	0
S7: Energy Transition	Middle East	Bcf/d	Pipeline exports	0.03	0.02	0.02	0.03	0.05	0.07	0.12
S7: Energy Transition	EU	Bcf/d	Pipeline exports	2.21	1.58	1.26	1.03	0.89	0.46	0.23
S7: Energy Transition	Mexico	Bcf/d	Pipeline exports	0.01	0	0.01	0.03	0.08	0.17	0.28
S7: Energy Transition	Canada	Bcf/d	Pipeline exports	6.23	5.73	5.48	4.68	3.66	2.79	2.23
S7: Energy Transition	USA	Bcf/d	Pipeline exports	8.53	8.53	8.53	8.53	8.53	8.53	8.53
S7: Energy Transition		**Bcf/d**	**Total**	**54.12**	**47.66**	**45.43**	**43.98**	**47.59**	**51.1**	**51.01**

S6: Energy Transition (Ref Exp)	ROW	Bcf/d	Pipeline imports	1	0.82	0.86	0.77	0.7	0.74	0.88
S6: Energy Transition (Ref Exp)	Australia + NZ	Bcf/d	Pipeline imports	0	0	0	0	0	0	0
S6: Energy Transition (Ref Exp)	LAC	Bcf/d	Pipeline imports	2.11	1.81	1.81	1.53	1.2	0.97	0.92
S6: Energy Transition (Ref Exp)	Africa	Bcf/d	Pipeline imports	0.15	0.16	0.37	0.84	1.8	3.48	5.73
S6: Energy Transition (Ref Exp)	C Asia + East Eur	Bcf/d	Pipeline imports	5.37	5.09	5.19	4.7	4.24	3.82	3.2
S6: Energy Transition (Ref Exp)	Russia	Bcf/d	Pipeline imports	1.25	0.97	1.08	1.36	1.9	2.3	2.44
S6: Energy Transition (Ref Exp)	China	Bcf/d	Pipeline imports	3.7	5.99	7.21	10.12	14.58	20.04	20.62
S6: Energy Transition (Ref Exp)	India	Bcf/d	Pipeline imports	0	0	0	0	0	0	0
S6: Energy Transition (Ref Exp)	Middle East	Bcf/d	Pipeline imports	0.02	0.03	0.03	0.04	0.08	0.14	0.18
S6: Energy Transition (Ref Exp)	EU	Bcf/d	Pipeline imports	25.74	18.52	14.86	11.38	10.82	8.52	6.8
S6: Energy Transition (Ref Exp)	Mexico	Bcf/d	Pipeline imports	3.93	4.45	4.98	5.29	5.53	5.81	6.08
S6: Energy Transition (Ref Exp)	Canada	Bcf/d	Pipeline imports	2.35	1.73	1.72	1.42	1.4	1.5	1.47
S6: Energy Transition (Ref Exp)	USA	Bcf/d	Pipeline imports	8.48	8.07	7.32	6.52	5.34	4.19	3.51
S6: Energy Transition (Ref Exp)	-	**Bcf/d**	**Total**	**54.1**	**47.64**	**45.43**	**43.97**	**47.59**	**51.51**	**51.83**
S7: Energy Transition	ROW	Bcf/d	Pipeline imports	1	0.82	0.86	0.77	0.7	0.73	0.85
S7: Energy Transition	Australia + NZ	Bcf/d	Pipeline imports	0	0	0	0	0	0	0
S7: Energy Transition	LAC	Bcf/d	Pipeline imports	2.11	1.81	1.81	1.53	1.2	0.95	0.88
S7: Energy Transition	Africa	Bcf/d	Pipeline imports	0.15	0.16	0.37	0.84	1.8	3.38	5.53
S7: Energy Transition	C Asia + East Eur	Bcf/d	Pipeline imports	5.37	5.09	5.19	4.7	4.24	3.76	3.13
S7: Energy Transition	Russia	Bcf/d	Pipeline imports	1.25	0.97	1.08	1.36	1.9	2.25	2.38
S7: Energy Transition	China	Bcf/d	Pipeline imports	3.7	5.99	7.21	10.12	14.58	19.92	20.41
S7: Energy Transition	India	Bcf/d	Pipeline imports	0	0	0	0	0	0	0

S7: Energy Transition	Middle East	Bcf/d	Pipeline imports	0.02	0.03	0.03	0.04	0.08	0.13	0.16
S7: Energy Transition	EU	Bcf/d	Pipeline imports	25.74	18.52	14.86	11.38	10.82	8.51	6.62
S7: Energy Transition	Mexico	Bcf/d	Pipeline imports	3.93	4.45	4.98	5.29	5.53	5.77	6.03
S7: Energy Transition	Canada	Bcf/d	Pipeline imports	2.35	1.73	1.72	1.42	1.4	1.48	1.44
S7: Energy Transition	USA	Bcf/d	Pipeline imports	8.48	8.07	7.32	6.52	5.34	4.24	3.57
S7: Energy Transition		**Bcf/d**	**Total**	**54.1**	**47.64**	**45.43**	**43.97**	**47.59**	**51.12**	**51**
S7 - S6	ROW	Bcf/d	Consumption	0	0	0	0	0	0.45	0.52
S7 - S6	Australia + NZ	Bcf/d	Consumption	0	0	0	0	0	0.01	0.01
S7 - S6	LAC	Bcf/d	Consumption	0	0	0	0	0	0.23	0.29
S7 - S6	Africa	Bcf/d	Consumption	0	0	0	0	0	0.1	0.18
S7 - S6	C Asia + East Eur	Bcf/d	Consumption	0	0	0	0	0	0.07	0.07
S7 - S6	Russia	Bcf/d	Consumption	0	0	0	0	0	0.02	0.01
S7 - S6	China	Bcf/d	Consumption	0	0	0	0	0	0.18	0.09
S7 - S6	India	Bcf/d	Consumption	0	0	0	0	0	0.23	0.27
S7 - S6	Middle East	Bcf/d	Consumption	0	0	0	0	0	-0.01	-0.01
S7 - S6	EU	Bcf/d	Consumption	0	0	0	0	0	0.39	0.15
S7 - S6	Mexico	Bcf/d	Consumption	0	0	0	0	0	0	0.01
S7 - S6	Canada	Bcf/d	Consumption	0	0	0	0	0	0.01	0.01
S7 - S6	USA	Bcf/d	Consumption	0	0	0	0	0	-0.17	-0.25
S7 - S6	_	**Bcf/d**	**Total**	**0**	**0**	**0**	**0**	**0**	**1.53**	**1.37**
S7 - S6	ROW	Bcf/d	Production	0	0	0	0	0	-0.24	-0.47
S7 - S6	Australia + NZ	Bcf/d	Production	0	0	0	0	0	-0.03	-0.1

S7 - S6	LAC	Bcf/d	Production	0	0	0	0	0	-0.19	-0.36
S7 - S6	Africa	Bcf/d	Production	0	0	0	0	0	-0.39	-0.67
S7 - S6	C Asia + East Eur	Bcf/d	Production	0	0	0	0	0	-0.15	-0.35
S7 - S6	Russia	Bcf/d	Production	0	0	0	0	0	-0.32	-0.7
S7 - S6	China	Bcf/d	Production	0	0	0	0	0	-0.03	-0.05
S7 - S6	India	Bcf/d	Production	0	0	0	0	0	-0.2	-0.35
S7 - S6	Middle East	Bcf/d	Production	0	0	0	0	0	-0.42	-0.81
S7 - S6	EU	Bcf/d	Production	0	0	0	0	0	-0.16	-0.43
S7 - S6	Mexico	Bcf/d	Production	0	0	0	0	0	-0.01	-0.03
S7 - S6	Canada	Bcf/d	Production	0	0	0	0	0	-0.12	-0.23
S7 - S6	USA	Bcf/d	Production	0	0	0	0	0	3.79	5.92
S7 - S6		**Bcf/d**	**Total**	**0**	**0**	**0**	**0**	**0**	**1.53**	**1.37**
S7 - S6	ROW	Bcf/d	LNG exports	0	0	0	0	0	-0.18	-0.39
S7 - S6	Australia + NZ	Bcf/d	LNG exports	0	0	0	0	0	-0.04	-0.1
S7 - S6	LAC	Bcf/d	LNG exports	0	0	0	0	0	-0.09	-0.21
S7 - S6	Africa	Bcf/d	LNG exports	0	0	0	0	0	-0.16	-0.33
S7 - S6	C Asia + East Eur	Bcf/d	LNG exports	0	0	0	0	0	-0.11	-0.3
S7 - S6	Russia	Bcf/d	LNG exports	0	0	0	0	0	-0.04	-0.1
S7 - S6	China	Bcf/d	LNG exports	0	0	0	0	0	0	-0.01
S7 - S6	India	Bcf/d	LNG exports	0	0	0	0	0	-0.01	-0.02
S7 - S6	Middle East	Bcf/d	LNG exports	0	0	0	0	0	-0.27	-0.65
S7 - S6	EU	Bcf/d	LNG exports	0	0	0	0	0	-0.07	-0.19

S7 - S6	Mexico	Bcf/d	LNG exports	0	0	0	0	0	-0.01	-0.02
S7 - S6	Canada	Bcf/d	LNG exports	0	0	0	0	0	-0.13	-0.25
S7 - S6	USA	Bcf/d	LNG exports	0	0	0	0	0	4.03	6.25
S7 - S6		**Bcf/d**	**Total**	**0**	**0**	**0**	**0**	**0**	**2.92**	**3.69**
S7 - S6	ROW	Bcf/d	LNG imports	0	0	0	0	0	0.51	0.61
S7 - S6	Australia + NZ	Bcf/d	LNG imports	0	0	0	0	0	0	0.02
S7 - S6	LAC	Bcf/d	LNG imports	0	0	0	0	0	0.33	0.45
S7 - S6	Africa	Bcf/d	LNG imports	0	0	0	0	0	0.33	0.53
S7 - S6	C Asia + East Eur	Bcf/d	LNG imports	0	0	0	0	0	0.18	0.18
S7 - S6	Russia	Bcf/d	LNG imports	0	0	0	0	0	0.12	0.14
S7 - S6	China	Bcf/d	LNG imports	0	0	0	0	0	0.32	0.34
S7 - S6	India	Bcf/d	LNG imports	0	0	0	0	0	0.42	0.6
S7 - S6	Middle East	Bcf/d	LNG imports	0	0	0	0	0	0.16	0.16
S7 - S6	EU	Bcf/d	LNG imports	0	0	0	0	0	0.5	0.56
S7 - S6	Mexico	Bcf/d	LNG imports	0	0	0	0	0	0.04	0.06
S7 - S6	Canada	Bcf/d	LNG imports	0	0	0	0	0	0.02	0.03
S7 - S6	USA	Bcf/d	LNG imports	0	0	0	0	0	0.02	0.01
S7 - S6		**Bcf/d**	**Total**	**0**	**0**	**0**	**0**	**0**	**2.92**	**3.69**
S7 - S6	ROW	Bcf/d	Pipeline exports	0	0	0	0	0	-0.02	-0.02
S7 - S6	Australia + NZ	Bcf/d	Pipeline exports	0	0	0	0	0	0	0
S7 - S6	LAC	Bcf/d	Pipeline exports	0	0	0	0	0	-0.02	-0.04
S7 - S6	Africa	Bcf/d	Pipeline exports	0	0	0	0	0	-0.11	-0.19

S7 - S6	C Asia + East Eur	Bcf/d	Pipeline exports	0	0	0	0	0	0	0
S7 - S6	Russia	Bcf/d	Pipeline exports	0	0	0	0	0	-0.24	-0.53
S7 - S6	China	Bcf/d	Pipeline exports	0	0	0	0	0	0	0
S7 - S6	India	Bcf/d	Pipeline exports	0	0	0	0	0	0	0
S7 - S6	Middle East	Bcf/d	Pipeline exports	0	0	0	0	0	0	-0.01
S7 - S6	EU	Bcf/d	Pipeline exports	0	0	0	0	0	0	0
S7 - S6	Mexico	Bcf/d	Pipeline exports	0	0	0	0	0	0	-0.01
S7 - S6	Canada	Bcf/d	Pipeline exports	0	0	0	0	0	0	0
S7 - S6	USA	Bcf/d	Pipeline exports	0	0	0	0	0	0	0
S7 - S6		**Bcf/d**	**Total**	**0**	**0**	**0**	**0**	**0**	**-0.38**	**-0.8**
S7 - S6	ROW	Bcf/d	Pipeline imports	0	0	0	0	0	-0.01	-0.03
S7 - S6	Australia + NZ	Bcf/d	Pipeline imports	0	0	0	0	0	0	0
S7 - S6	LAC	Bcf/d	Pipeline imports	0	0	0	0	0	-0.02	-0.04
S7 - S6	Africa	Bcf/d	Pipeline imports	0	0	0	0	0	-0.11	-0.19
S7 - S6	C Asia + East Eur	Bcf/d	Pipeline imports	0	0	0	0	0	-0.06	-0.07
S7 - S6	Russia	Bcf/d	Pipeline imports	0	0	0	0	0	-0.05	-0.07
S7 - S6	China	Bcf/d	Pipeline imports	0	0	0	0	0	-0.12	-0.21
S7 - S6	India	Bcf/d	Pipeline imports	0	0	0	0	0	0	0
S7 - S6	Middle East	Bcf/d	Pipeline imports	0	0	0	0	0	-0.01	-0.01
S7 - S6	EU	Bcf/d	Pipeline imports	0	0	0	0	0	-0.01	-0.18
S7 - S6	Mexico	Bcf/d	Pipeline imports	0	0	0	0	0	-0.03	-0.04
S7 - S6	Canada	Bcf/d	Pipeline imports	0	0	0	0	0	-0.02	-0.03

S7 - S6	USA	Bcf/d	Pipeline imports	0	0	0	0	0	0.06	0.07
S7 - S6		**Bcf/d**	**Total**	**0**	**0**	**0**	**0**	**0**	**-0.38**	**-0.8**
S7 - S6	ROW	%	Consumption	0	0	0	0	0	0.98	1.14
S7 - S6	Australia + NZ	%	Consumption	0	0	0	0	0	1.77	1.61
S7 - S6	LAC	%	Consumption	0	0	0	0	0	0.99	1.18
S7 - S6	Africa	%	Consumption	0	0	0	0	0	0.31	0.47
S7 - S6	C Asia + East Eur	%	Consumption	0	0	0	0	0	0.24	0.24
S7 - S6	Russia	%	Consumption	0	0	0	0	0	0.05	0.05
S7 - S6	China	%	Consumption	0	0	0	0	0	0.27	0.14
S7 - S6	India	%	Consumption	0	0	0	0	0	0.67	0.68
S7 - S6	Middle East	%	Consumption	0	0	0	0	0	-0.01	-0.01
S7 - S6	EU	%	Consumption	0	0	0	0	0	1.33	0.52
S7 - S6	Mexico	%	Consumption	0	0	0	0	0	0	0.08
S7 - S6	Canada	%	Consumption	0	0	0	0	0	0.18	0.28
S7 - S6	USA	%	Consumption	0	0	0	0	0	-0.22	-0.33
S7 - S6		**%**	**Total**	**0**	**0**	**0**	**0**	**0**	**6.58**	**6.03**
S7 - S6	ROW	%	Production	0	0	0	0	0	-0.55	-1.08
S7 - S6	Australia + NZ	%	Production	0	0	0	0	0	-0.43	-1.88
S7 - S6	LAC	%	Production	0	0	0	0	0	-1.06	-1.89
S7 - S6	Africa	%	Production	0	0	0	0	0	-1.02	-1.58
S7 - S6	C Asia + East Eur	%	Production	0	0	0	0	0	-0.79	-1.79
S7 - S6	Russia	%	Production	0	0	0	0	0	-0.49	-1.13
S7 - S6	China	%	Production	0	0	0	0	0	-0.12	-0.21
S7 - S6	India	%	Production	0	0	0	0	0	-1.15	-1.7
S7 - S6	Middle East	%	Production	0	0	0	0	0	-0.66	-1.29
S7 - S6	EU	%	Production	0	0	0	0	0	-1.26	-2.96
S7 - S6	Mexico	%	Production	0	0	0	0	0	-0.32	-0.69
S7 - S6	Canada	%	Production	0	0	0	0	0	-0.75	-1.54
S7 - S6	USA	%	Production	0	0	0	0	0	3.47	5.48
S7 - S6		**%**	**Total**	**0**	**0**	**0**	**0**	**0**	**-5.14**	**-12.24**
S7 - S6	ROW	%	LNG exports	0	0	0	0	0	-1.14	-2.37

S7 - S6	Australia + NZ	%	LNG exports	0	0	0	0	0	-0.65	-2.12
S7 - S6	LAC	%	LNG exports	0	0	0	0	0	-1.81	-3.52
S7 - S6	Africa	%	LNG exports	0	0	0	0	0	-1.32	-2.8
S7 - S6	C Asia + East Eur	%	LNG exports	0	0	0	0	0	-3.04	-5.99
S7 - S6	Russia	%	LNG exports	0	0	0	0	0	-1.38	-4.11
S7 - S6	China	%	LNG exports	0	0	0	0	0	-6.48	-8.66
S7 - S6	India	%	LNG exports	0	0	0	0	0	-3.69	-6.53
S7 - S6	Middle East	%	LNG exports	0	0	0	0	0	-1.49	-3.43
S7 - S6	EU	%	LNG exports	0	0	0	0	0	-3.01	-6.22
S7 - S6	Mexico	%	LNG exports	0	0	0	0	0	-4.8	-7.91
S7 - S6	Canada	%	LNG exports	0	0	0	0	0	-1.41	-2.6
S7 - S6	USA	%	LNG exports	0	0	0	0	0	14.76	22.87
S7 - S6		**%**	**Total**	**0**	**0**	**0**	**0**	**0**	**-15.45**	**-33.37**
S7 - S6	ROW	%	LNG imports	0	0	0	0	0	2.42	3.2
S7 - S6	Australia + NZ	%	LNG imports	0	0	0	0	0	2.49	11.73
S7 - S6	LAC	%	LNG imports	0	0	0	0	0	3.04	3.79
S7 - S6	Africa	%	LNG imports	0	0	0	0	0	5.19	6.42
S7 - S6	C Asia + East Eur	%	LNG imports	0	0	0	0	0	1.65	1.8
S7 - S6	Russia	%	LNG imports	0	0	0	0	0	3.48	4.22
S7 - S6	China	%	LNG imports	0	0	0	0	0	1.61	1.74
S7 - S6	India	%	LNG imports	0	0	0	0	0	2.34	3.03
S7 - S6	Middle East	%	LNG imports	0	0	0	0	0	11.5	11.86
S7 - S6	EU	%	LNG imports	0	0	0	0	0	4.61	5.33
S7 - S6	Mexico	%	LNG imports	0	0	0	0	0	2.8	4.39
S7 - S6	Canada	%	LNG imports	0	0	0	0	0	14.16	15.65
S7 - S6	USA	%	LNG imports	0	0	0	0	0	20.21	17.02
S7 - S6		**%**	**Total**	**0**	**0**	**0**	**0**	**0**	**75.51**	**90.16**
S7 - S6	ROW	%	Pipeline exports	0	0	0	0	0	-0.65	-1.58
S7 - S6	Australia + NZ	%	Pipeline exports	0	0	0	0	0	-0.61	-2.03
S7 - S6	LAC	%	Pipeline exports	0	0	0	0	0	-2	-3.93

S7 - S6	Africa	%	Pipeline exports	0	0	0	0	0	-2.85	-3.32
S7 - S6	C Asia + East Eur	%	Pipeline exports	0	0	0	0	0	0.56	0.6
S7 - S6	Russia	%	Pipeline exports	0	0	0	0	0	-0.73	-1.66
S7 - S6	China	%	Pipeline exports	0	0	0	0	0	-7.94	-9.38
S7 - S6	India	%	Pipeline exports	0	0	0	0	0	-7.94	-9.28
S7 - S6	Middle East	%	Pipeline exports	0	0	0	0	0	-3.24	-4.39
S7 - S6	EU	%	Pipeline exports	0	0	0	0	0	-0.66	-1.62
S7 - S6	Mexico	%	Pipeline exports	0	0	0	0	0	-1.05	-1.83
S7 - S6	Canada	%	Pipeline exports	0	0	0	0	0	0.06	0.1
S7 - S6	USA	%	Pipeline exports	0	0	0	0	0	0	0
S7 - S6	-	**%**	**Total**	**0**	**0**	**0**	**0**	**0**	**-27.06**	**-38.34**
S7 - S6	ROW	%	Pipeline imports	0	0	0	0	0	-1.75	-3.55
S7 - S6	Australia + NZ	%	Pipeline imports	0	0	0	0	0	1.73	-7.8
S7 - S6	LAC	%	Pipeline imports	0	0	0	0	0	-2	-3.93
S7 - S6	Africa	%	Pipeline imports	0	0	0	0	0	-3.05	-3.4
S7 - S6	C Asia + East Eur	%	Pipeline imports	0	0	0	0	0	-1.52	-2.07
S7 - S6	Russia	%	Pipeline imports	0	0	0	0	0	-2.22	-2.76
S7 - S6	China	%	Pipeline imports	0	0	0	0	0	-0.58	-1.01
S7 - S6	India	%	Pipeline imports	0	0	0	0	0	-2.08	-3.14
S7 - S6	Middle East	%	Pipeline imports	0	0	0	0	0	-8.29	-8.39
S7 - S6	EU	%	Pipeline imports	0	0	0	0	0	-0.09	-2.62
S7 - S6	Mexico	%	Pipeline imports	0	0	0	0	0	-0.57	-0.73

S7 - S6	Canada	%	Pipeline imports	0	0	0	0	0	-1.48	-1.91
S7 - S6	USA	%	Pipeline imports	0	0	0	0	0	1.32	1.98
S7 - S6		%	Total	0	0	0	0	0	-20.58	-39.33

Table D-11. Changes in natural gas consumption, production, and trade by region: S6 vs S1 and S7 vs S2 (Figure 11)

Commented [IGC221]: Missing. Checking on it.

Scenario	Region	Unit	NG Volumes	2020	2025	2030	2035	2040	2045	2050
S6 - S1	ROW	Bcf/d	Consumption	0	-0.45	-2.88	-6.32	-6.95	-7.74	-10.48
S6 - S1	Australia + NZ	Bcf/d	Consumption	0	0.02	0.06	-0.04	-0.07	-0.13	-0.2
S6 - S1	LAC	Bcf/d	Consumption	0	0.04	-0.53	-2.78	-4.14	-6.58	-8.15
S6 - S1	Africa	Bcf/d	Consumption	0	0.02	-0.11	-1.23	-1.71	-1.57	-2.68
S6 - S1	C Asia + East Eur	Bcf/d	Consumption	-0.01	0.06	-0.11	-3.41	-6.58	-11.55	-16.18
S6 - S1	Russia	Bcf/d	Consumption	0	0.05	-0.03	-0.02	-0.49	-3.83	-6.71
S6 - S1	China	Bcf/d	Consumption	0	0.32	-1.21	-3.09	-2.44	-2.53	-9.03
S6 - S1	India	Bcf/d	Consumption	0	-0.33	-0.79	-1.33	-0.71	-0.01	-0.81
S6 - S1	Middle East	Bcf/d	Consumption	-0.12	-0.89	-0.43	-5.48	-10.13	-16.09	-22.4
S6 - S1	EU	Bcf/d	Consumption	0	-0.83	-4.67	-5.11	-1.97	-3.06	-8.08
S6 - S1	Mexico	Bcf/d	Consumption	0	0.13	0.14	-0.89	-2.09	-3.12	-3.91
S6 - S1	Canada	Bcf/d	Consumption	0	0.27	-0.04	-1.17	-1.47	-1.29	-1
S6 - S1	USA	Bcf/d	Consumption	0.02	-7.2	-11.46	-13.94	-15.94	-28.82	-43.33
S6 - S1		Bcf/d	Total	-0.11	-8.76	-22.07	-44.84	-54.69	-86.34	-132.96
S6 - S1	ROW	Bcf/d	Production	0	-0.3	-2.2	-4	-4.31	-4.49	-5.2
S6 - S1	Australia + NZ	Bcf/d	Production	0	0	-0.02	-0.25	-0.45	-0.74	-1.28
S6 - S1	LAC	Bcf/d	Production	0	-0.11	-0.24	-1.79	-3.08	-4.81	-6.34
S6 - S1	Africa	Bcf/d	Production	0	-0.05	-0.43	-1.92	-3.31	-4.26	-6.06
S6 - S1	C Asia + East Eur	Bcf/d	Production	0	-0.05	-0.04	-1.92	-4.17	-7.18	-10.34
S6 - S1	Russia	Bcf/d	Production	0	-0.17	-0.33	-1.65	-3.79	-8.88	-18.18
S6 - S1	China	Bcf/d	Production	0	-0.12	-0.33	-1.16	-1.16	-1.27	-3.46
S6 - S1	India	Bcf/d	Production	0	-0.16	-0.12	-0.44	-0.71	-0.64	-1.53
S6 - S1	Middle East	Bcf/d	Production	-0.12	-0.83	-1.09	-6.45	-11.3	-17.55	-24.84
S6 - S1	EU	Bcf/d	Production	0	-0.18	-1.67	-1.91	-1.19	-2.78	-6.44
S6 - S1	Mexico	Bcf/d	Production	0	-0.16	-0.21	-0.71	-1.18	-1.84	-2.5
S6 - S1	Canada	Bcf/d	Production	0	0.06	-0.3	-1.3	-1.89	-2.57	-3.08
S6 - S1	USA	Bcf/d	Production	0.01	-6.68	-15.09	-21.35	-18.15	-29.33	-43.7
S6 - S1		Bcf/d	Total	-0.12	-8.76	-22.06	-44.86	-54.69	-86.34	-132.96
S6 - S1	ROW	Bcf/d	LNG exports	0	-0.05	-0.3	-0.41	-0.93	-1.87	-2.85
S6 - S1	Australia + NZ	Bcf/d	LNG exports	0	-0.02	-0.08	-0.21	-0.39	-0.61	-1.11

S6 - S1	LAC	Bcf/d	LNG exports	0	-0.03	-0.21	-0.45	-0.68	-1.07	-1.68
S6 - S1	Africa	Bcf/d	LNG exports	0	-0.04	-0.3	-0.87	-1.5	-2.47	-3.55
S6 - S1	C Asia + East Eur	Bcf/d	LNG exports	0	-0.01	-0.09	-0.26	-0.58	-1.28	-2.48
S6 - S1	Russia	Bcf/d	LNG exports	0	-0.01	-0.01	-0.11	-0.25	-0.53	-0.97
S6 - S1	China	Bcf/d	LNG exports	0	0	-0.01	0	-0.02	-0.04	-0.06
S6 - S1	India	Bcf/d	LNG exports	0	0	0	-0.02	-0.05	-0.14	-0.27
S6 - S1	Middle East	Bcf/d	LNG exports	0	0	-0.73	-1.35	-1.6	-2.4	-3.88
S6 - S1	EU	Bcf/d	LNG exports	0	0.01	-0.02	-0.12	-0.39	-0.96	-1.43
S6 - S1	Mexico	Bcf/d	LNG exports	0	0	0	-0.01	-0.02	-0.06	-0.12
S6 - S1	Canada	Bcf/d	LNG exports	0	0	-0.23	-0.31	-0.53	-1.04	-1.66
S6 - S1	USA	Bcf/d	LNG exports	0	0	-4.1	-7.3	-1.54	0	0
S6 - S1		**Bcf/d**	**Total**	**0**	**-0.16**	**-6.08**	**-11.42**	**-8.47**	**-12.48**	**-20.07**
S6 - S1	ROW	Bcf/d	LNG imports	0	-0.34	-1.9	-3.61	-3.66	-5.09	-8.01
S6 - S1	Australia + NZ	Bcf/d	LNG imports	0	0	0	0	0	0	-0.03
S6 - S1	LAC	Bcf/d	LNG imports	0	0.13	-0.5	-1.45	-1.74	-2.84	-3.48
S6 - S1	Africa	Bcf/d	LNG imports	0	0.01	-0.12	-0.3	0.08	0.18	-0.23
S6 - S1	C Asia + East Eur	Bcf/d	LNG imports	0	0.1	-0.23	-1.3	-1.59	-2.86	-3.94
S6 - S1	Russia	Bcf/d	LNG imports	0	0	0	0	0.38	0.2	0.04
S6 - S1	China	Bcf/d	LNG imports	0	0.38	-0.56	-0.91	-0.1	0.06	-0.27
S6 - S1	India	Bcf/d	LNG imports	-0.01	-0.17	-0.67	-0.92	-0.05	0.5	0.45
S6 - S1	Middle East	Bcf/d	LNG imports	0	-0.05	-0.09	-0.37	-0.36	-0.77	-1.14
S6 - S1	EU	Bcf/d	LNG imports	0	-0.21	-1.93	-2.28	-1.05	-1.24	-2.72
S6 - S1	Mexico	Bcf/d	LNG imports	0	0.01	-0.04	-0.21	-0.33	-0.5	-0.64
S6 - S1	Canada	Bcf/d	LNG imports	0	0	0	-0.02	-0.06	-0.08	-0.07
S6 - S1	USA	Bcf/d	LNG imports	0	-0.02	-0.05	-0.04	0.02	-0.02	-0.02
S6 - S1		**Bcf/d**	**Total**	**-0.03**	**-0.14**	**-6.1**	**-11.42**	**-8.46**	**-12.47**	**-20.05**
S6 - S1	ROW	Bcf/d	Pipeline exports	0	-0.14	-0.96	-1	-0.2	-0.03	0.03
S6 - S1	Australia + NZ	Bcf/d	Pipeline exports	0	0	0	0	0	0	0
S6 - S1	LAC	Bcf/d	Pipeline exports	0	-0.01	0.02	-0.07	-0.16	-0.25	-0.31
S6 - S1	Africa	Bcf/d	Pipeline exports	0	-0.02	-0.12	-0.14	-0.04	0.35	0.97
S6 - S1	C Asia + East Eur	Bcf/d	Pipeline exports	0	0	-0.01	-0.01	0	0	0
S6 - S1	Russia	Bcf/d	Pipeline exports	0	-0.21	-0.29	-1.52	-2.88	-5	-11.63
S6 - S1	China	Bcf/d	Pipeline exports	0	0	0	0	0	0	0
S6 - S1	India	Bcf/d	Pipeline exports	0	0	0	0	0	0	0
S6 - S1	Middle East	Bcf/d	Pipeline exports	0	0	-0.01	0	0.01	0.02	0.03
S6 - S1	EU	Bcf/d	Pipeline exports	0	-0.03	-0.23	-0.22	-0.03	-0.03	-0.04
S6 - S1	Mexico	Bcf/d	Pipeline exports	0	0	0	-0.02	-0.07	-0.18	-0.27
S6 - S1	Canada	Bcf/d	Pipeline exports	0	-0.14	-0.03	-0.08	-0.31	-0.51	-0.58

S6 - S1	USA	Bcf/d	Pipeline exports	0	0	0	0	0.01	0	0
S6 - S1		**Bcf/d**	**Total**	**0.01**	**-0.55**	**-1.63**	**-3.06**	**-3.67**	**-5.64**	**-11.79**
S6 - S1	ROW	Bcf/d	Pipeline imports	0	-0.01	-0.05	-0.11	-0.1	-0.06	-0.1
S6 - S1	Australia + NZ	Bcf/d	Pipeline imports	0	0	0	0	0	0	0
S6 - S1	LAC	Bcf/d	Pipeline imports	0	-0.01	0.02	-0.07	-0.16	-0.25	-0.31
S6 - S1	Africa	Bcf/d	Pipeline imports	0	0	0.02	0	-0.01	0.37	1.05
S6 - S1	C Asia + East Eur	Bcf/d	Pipeline imports	0	0	0.06	-0.47	-1.4	-2.79	-4.39
S6 - S1	Russia	Bcf/d	Pipeline imports	0	0	0	-0.01	-0.22	-0.7	-1.18
S6 - S1	China	Bcf/d	Pipeline imports	0	0.06	-0.33	-1.02	-1.2	-1.36	-5.35
S6 - S1	India	Bcf/d	Pipeline imports	0	0	0	0	0	0	0
S6 - S1	Middle East	Bcf/d	Pipeline imports	0	0	0	-0.02	-0.06	-0.15	-0.27
S6 - S1	EU	Bcf/d	Pipeline imports	0	-0.47	-1.32	-1.27	-0.14	-0.02	-0.38
S6 - S1	Mexico	Bcf/d	Pipeline imports	0	0.27	0.38	0	-0.67	-1	-1.15
S6 - S1	Canada	Bcf/d	Pipeline imports	0	0.07	0	-0.24	-0.35	-0.2	-0.09
S6 - S1	USA	Bcf/d	Pipeline imports	0	-0.49	-0.41	0.14	0.64	0.52	0.4
S6 - S1		**Bcf/d**	**Total**	**-0.01**	**-0.57**	**-1.63**	**-3.07**	**-3.68**	**-5.63**	**-11.76**
S7 - S2	ROW	Bcf/d	Consumption	0	-0.45	-2.88	-6.17	-7.9	-8.81	-11.81
S7 - S2	Australia + NZ	Bcf/d	Consumption	0	0.02	0.06	-0.03	-0.08	-0.14	-0.21
S7 - S2	LAC	Bcf/d	Consumption	0	0.04	-0.53	-2.7	-4.71	-7.19	-8.78
S7 - S2	Africa	Bcf/d	Consumption	0	0.02	-0.11	-1.22	-1.87	-1.86	-3.06
S7 - S2	C Asia + East Eur	Bcf/d	Consumption	-0.01	0.06	-0.11	-3.34	-6.97	-11.89	-16.51
S7 - S2	Russia	Bcf/d	Consumption	0	0.05	-0.03	-0.01	-0.55	-3.89	-6.76
S7 - S2	China	Bcf/d	Consumption	0	0.32	-1.21	-2.79	-3.36	-3.02	-9.49
S7 - S2	India	Bcf/d	Consumption	0	-0.33	-0.79	-1.23	-1.3	-0.64	-1.52
S7 - S2	Middle East	Bcf/d	Consumption	-0.12	-0.89	-0.43	-5.49	-10.09	-16.08	-22.45
S7 - S2	EU	Bcf/d	Consumption	0	-0.83	-4.67	-4.66	-3.73	-4.21	-9.42
S7 - S2	Mexico	Bcf/d	Consumption	0	0.13	0.14	-0.89	-2.09	-3.14	-3.92
S7 - S2	Canada	Bcf/d	Consumption	0	0.27	-0.04	-1.18	-1.48	-1.38	-1.11
S7 - S2	USA	Bcf/d	Consumption	0.02	-7.2	-11.46	-14	-15.52	-27.81	-40.36
S7 - S2		**Bcf/d**	**Total**	**-0.11**	**-8.76**	**-22.07**	**-43.71**	**-59.65**	**-90.04**	**-135.4**
S7 - S2	ROW	Bcf/d	Production	0	-0.3	-2.2	-3.96	-4.08	-3.89	-4.63
S7 - S2	Australia + NZ	Bcf/d	Production	0	0	-0.02	-0.25	-0.42	-0.6	-1.03
S7 - S2	LAC	Bcf/d	Production	0	-0.11	-0.24	-1.83	-2.69	-4.07	-5.48
S7 - S2	Africa	Bcf/d	Production	0	-0.05	-0.43	-1.95	-2.84	-3.43	-5.12
S7 - S2	C Asia + East Eur	Bcf/d	Production	0	-0.05	-0.04	-1.95	-3.91	-6.5	-9.41
S7 - S2	Russia	Bcf/d	Production	0	-0.17	-0.33	-1.67	-3.34	-7.57	-16.67
S7 - S2	China	Bcf/d	Production	0	-0.12	-0.33	-1.11	-1.3	-1.27	-3.43
S7 - S2	India	Bcf/d	Production	0	-0.16	-0.12	-0.46	-0.59	-0.43	-1.26

S7 - S2	Middle East	Bcf/d	Production	-0.12	-0.83	-1.09	-6.46	-10.75	-16.27	-23.3
S7 - S2	EU	Bcf/d	Production	0	-0.18	-1.67	-1.76	-1.8	-2.52	-5.99
S7 - S2	Mexico	Bcf/d	Production	0	-0.16	-0.21	-0.71	-1.18	-1.81	-2.47
S7 - S2	Canada	Bcf/d	Production	0	0.06	-0.3	-1.29	-1.81	-2.23	-2.71
S7 - S2	USA	Bcf/d	Production	0.01	-6.68	-15.09	-20.34	-24.97	-39.46	-53.91
S7 - S2		**Bcf/d**	**Total**	**-0.12**	**-8.76**	**-22.06**	**-43.73**	**-59.66**	**-90.03**	**-135.41**
S7 - S2	ROW	Bcf/d	LNG exports	0	-0.05	-0.3	-0.43	-0.76	-1.31	-2.21
S7 - S2	Australia + NZ	Bcf/d	LNG exports	0	-0.02	-0.08	-0.21	-0.34	-0.46	-0.86
S7 - S2	LAC	Bcf/d	LNG exports	0	-0.03	-0.21	-0.44	-0.6	-0.8	-1.3
S7 - S2	Africa	Bcf/d	LNG exports	0	-0.04	-0.3	-0.87	-1.33	-1.9	-2.84
S7 - S2	C Asia + East Eur	Bcf/d	LNG exports	0	-0.01	-0.09	-0.26	-0.51	-0.88	-1.85
S7 - S2	Russia	Bcf/d	LNG exports	0	-0.01	-0.01	-0.11	-0.21	-0.39	-0.74
S7 - S2	China	Bcf/d	LNG exports	0	0	-0.01	0	-0.01	-0.02	-0.04
S7 - S2	India	Bcf/d	LNG exports	0	0	0	-0.02	-0.04	-0.1	-0.21
S7 - S2	Middle East	Bcf/d	LNG exports	0	0	-0.73	-1.31	-1.4	-1.48	-2.66
S7 - S2	EU	Bcf/d	LNG exports	0	0.01	-0.02	-0.12	-0.31	-0.65	-1.06
S7 - S2	Mexico	Bcf/d	LNG exports	0	0	0	-0.01	-0.01	-0.03	-0.09
S7 - S2	Canada	Bcf/d	LNG exports	0	0	-0.23	-0.3	-0.41	-0.58	-1.11
S7 - S2	USA	Bcf/d	LNG exports	0	0	-4.1	-6.19	-9.05	-11.49	-13.64
S7 - S2		**Bcf/d**	**Total**	**0**	**-0.16**	**-6.08**	**-10.27**	**-15**	**-20.09**	**-28.61**
S7 - S2	ROW	Bcf/d	LNG imports	0	-0.34	-1.9	-3.45	-4.66	-6.21	-9.27
S7 - S2	Australia + NZ	Bcf/d	LNG imports	0	0	0	0	0	0	-0.04
S7 - S2	LAC	Bcf/d	LNG imports	0	0.13	-0.5	-1.32	-2.63	-3.91	-4.61
S7 - S2	Africa	Bcf/d	LNG imports	0	0.01	-0.12	-0.25	-0.38	-0.36	-0.84
S7 - S2	C Asia + East Eur	Bcf/d	LNG imports	0	0.1	-0.23	-1.16	-2.41	-3.96	-5.16
S7 - S2	Russia	Bcf/d	LNG imports	0	0	0	0.06	0.03	-0.27	-0.47
S7 - S2	China	Bcf/d	LNG imports	0	0.38	-0.56	-0.71	-0.75	-0.63	-1.08
S7 - S2	India	Bcf/d	LNG imports	-0.01	-0.17	-0.67	-0.78	-0.75	-0.32	-0.47
S7 - S2	Middle East	Bcf/d	LNG imports	0	-0.05	-0.09	-0.33	-0.69	-1.15	-1.56
S7 - S2	EU	Bcf/d	LNG imports	0	-0.21	-1.93	-2.07	-2.15	-2.35	-3.98
S7 - S2	Mexico	Bcf/d	LNG imports	0	0.01	-0.04	-0.2	-0.46	-0.71	-0.91
S7 - S2	Canada	Bcf/d	LNG imports	0	0	0	-0.02	-0.12	-0.16	-0.15
S7 - S2	USA	Bcf/d	LNG imports	0	-0.02	-0.05	-0.03	-0.03	-0.06	-0.08
S7 - S2		**Bcf/d**	**Total**	**-0.03**	**-0.14**	**-6.1**	**-10.27**	**-14.99**	**-20.09**	**-28.62**
S7 - S2	ROW	Bcf/d	Pipeline exports	0	-0.14	-0.96	-0.92	-0.17	-0.03	0.03
S7 - S2	Australia + NZ	Bcf/d	Pipeline exports	0	0	0	0	0	0	0
S7 - S2	LAC	Bcf/d	Pipeline exports	0	-0.01	0.02	-0.08	-0.1	-0.17	-0.22
S7 - S2	Africa	Bcf/d	Pipeline exports	0	-0.02	-0.12	-0.14	0.06	0.44	1.06
S7 - S2	C Asia + East Eur	Bcf/d	Pipeline exports	0	0	-0.01	-0.01	0	0	0
S7 - S2	Russia	Bcf/d	Pipeline exports	0	-0.21	-0.29	-1.51	-2.62	-4.05	-10.54

S7 - S2	China	Bcf/d	Pipeline exports	0	0	0	0	0	0	0
S7 - S2	India	Bcf/d	Pipeline exports	0	0	0	0	0	0	0
S7 - S2	Middle East	Bcf/d	Pipeline exports	0	0	-0.01	0	0.01	0.01	0.04
S7 - S2	EU	Bcf/d	Pipeline exports	0	-0.03	-0.23	-0.2	-0.03	-0.02	-0.02
S7 - S2	Mexico	Bcf/d	Pipeline exports	0	0	0	-0.02	-0.07	-0.18	-0.3
S7 - S2	Canada	Bcf/d	Pipeline exports	0	-0.14	-0.03	-0.08	-0.33	-0.57	-0.67
S7 - S2	USA	Bcf/d	Pipeline exports	0	0	0	0	0	0	0
S7 - S2		**Bcf/d**	**Total**	**0.01**	**-0.55**	**-1.63**	**-2.96**	**-3.23**	**-4.56**	**-10.62**
S7 - S2	ROW	Bcf/d	Pipeline imports	0	-0.01	-0.05	-0.11	-0.1	-0.05	-0.08
S7 - S2	Australia + NZ	Bcf/d	Pipeline imports	0	0	0	0	0	0	0
S7 - S2	LAC	Bcf/d	Pipeline imports	0	-0.01	0.02	-0.08	-0.1	-0.17	-0.22
S7 - S2	Africa	Bcf/d	Pipeline imports	0	0	0.02	-0.02	0.09	0.48	1.12
S7 - S2	C Asia + East Eur	Bcf/d	Pipeline imports	0	0	0.06	-0.5	-1.16	-2.3	-3.79
S7 - S2	Russia	Bcf/d	Pipeline imports	0	0	0	-0.02	-0.08	-0.48	-0.91
S7 - S2	China	Bcf/d	Pipeline imports	0	0.06	-0.33	-0.97	-1.33	-1.14	-5.03
S7 - S2	India	Bcf/d	Pipeline imports	0	0	0	0	0	0	0
S7 - S2	Middle East	Bcf/d	Pipeline imports	0	0	0	-0.02	-0.04	-0.11	-0.21
S7 - S2	EU	Bcf/d	Pipeline imports	0	-0.47	-1.32	-1.15	-0.12	-0.02	-0.54
S7 - S2	Mexico	Bcf/d	Pipeline imports	0	0.27	0.38	-0.03	-0.54	-0.83	-0.91
S7 - S2	Canada	Bcf/d	Pipeline imports	0	0.07	0	-0.25	-0.29	-0.14	-0.03
S7 - S2	USA	Bcf/d	Pipeline imports	0	-0.49	-0.41	0.17	0.43	0.22	-0.02
S7 - S2		**Bcf/d**	**Total**	**-0.01**	**-0.57**	**-1.63**	**-2.97**	**-3.23**	**-4.54**	**-10.63**
S6 - S1	ROW	%	Consumption	0.00	-1.11	-6.34	-12.92	-13.64	-14.35	-18.74
S6 - S1	Australia + NZ	%	Consumption	0.00	6.45	13.95	-10.53	-13.73	-17.11	-18.02
S6 - S1	LAC	%	Consumption	0.00	0.24	-2.68	-11.87	-15.49	-21.84	-24.65
S6 - S1	Africa	%	Consumption	0.00	0.14	-0.64	-5.73	-6.39	-4.69	-6.47
S6 - S1	C Asia + East Eur	%	Consumption	-0.03	0.20	-0.34	-9.54	-16.86	-27.47	-36.46
S6 - S1	Russia	%	Consumption	0.00	0.14	-0.08	-0.05	-1.23	-9.60	-16.86
S6 - S1	China	%	Consumption	0.00	0.77	-2.53	-5.58	-3.95	-3.68	-12.21
S6 - S1	India	%	Consumption	0.00	-2.78	-4.60	-5.81	-2.50	-0.03	-1.97
S6 - S1	Middle East	%	Consumption	-0.26	-1.93	-0.90	-10.59	-17.79	-25.47	-32.99
S6 - S1	EU	%	Consumption	0.00	-2.32	-13.96	-17.04	-6.83	-9.36	-22.16
S6 - S1	Mexico	%	Consumption	0.00	1.61	1.50	-8.32	-17.30	-23.28	-26.53
S6 - S1	Canada	%	Consumption	0.00	3.38	-0.48	-14.83	-19.71	-18.91	-16.72
S6 - S1	USA	%	Consumption	0.02	-8.73	-13.03	-15.44	-16.71	-27.01	-36.41
S6 - S1		**%**	**Total**	**-0.03**	**-2.36**	**-5.43**	**-10.22**	**-11.52**	**-16.40**	**-23.13**

S6 - S1	ROW	%	Production	0.00	-0.79	-5.10	-8.74	-9.25	-9.38	-10.69
S6 - S1	Australia + NZ	%	Production	0.00	0.00	-0.17	-2.25	-4.68	-9.46	-19.42
S6 - S1	LAC	%	Production	0.00	-0.80	-1.51	-10.03	-15.45	-21.18	-24.94
S6 - S1	Africa	%	Production	0.00	-0.20	-1.56	-6.10	-9.04	-10.03	-12.52
S6 - S1	C Asia + East Eur	%	Production	0.00	-0.28	-0.21	-9.34	-17.84	-26.86	-34.32
S6 - S1	Russia	%	Production	0.00	-0.28	-0.52	-2.60	-5.59	-11.97	-22.69
S6 - S1	China	%	Production	0.00	-0.61	-1.47	-4.66	-4.40	-4.60	-12.24
S6 - S1	India	%	Production	0.00	-3.26	-1.68	-4.44	-5.31	-3.63	-6.87
S6 - S1	Middle East	%	Production	-0.20	-1.42	-1.79	-9.71	-15.48	-21.60	-28.25
S6 - S1	EU	%	Production	0.00	-1.79	-16.39	-19.45	-11.64	-17.58	-30.87
S6 - S1	Mexico	%	Production	0.00	-6.27	-6.27	-18.16	-26.34	-34.33	-38.70
S6 - S1	Canada	%	Production	0.00	0.43	-2.06	-8.53	-11.21	-14.10	-17.00
S6 - S1	USA	%	Production	0.01	-6.99	-14.06	-18.05	-14.35	-21.13	-28.82
S6 - S1		**%**	**Total**	**-0.03**	**-2.36**	**-5.43**	**-10.23**	**-11.52**	**-16.40**	**-23.13**
S6 - S1	ROW	%	LNG exports	0.00	-0.45	-2.17	-2.63	-5.66	-10.38	-14.88
S6 - S1	Australia + NZ	%	LNG exports	0.00	-0.17	-0.68	-1.96	-4.28	-8.63	-19.61
S6 - S1	LAC	%	LNG exports	0.00	-1.36	-7.87	-12.82	-14.44	-17.07	-22.08
S6 - S1	Africa	%	LNG exports	0.00	-0.38	-2.59	-6.98	-11.03	-16.72	-23.23
S6 - S1	C Asia + East Eur	%	LNG exports	0.00	-5.88	-21.43	-24.30	-23.02	-26.23	-33.02
S6 - S1	Russia	%	LNG exports	0.00	-0.26	-0.26	-3.00	-7.49	-16.31	-27.95
S6 - S1	China	%	LNG exports	0.00	0.00	-100.00	0.00	-33.33	-36.36	-40.00
S6 - S1	India	%	LNG exports	0.00	0.00	0.00	-22.22	-25.00	-34.15	-42.19
S6 - S1	Middle East	%	LNG exports	0.00	0.00	-5.21	-8.57	-9.03	-11.74	-16.94
S6 - S1	EU	%	LNG exports	0.00	2.17	-3.17	-13.79	-23.21	-30.28	-31.78
S6 - S1	Mexico	%	LNG exports	0.00	0.00	0.00	-33.33	-22.22	-30.00	-35.29
S6 - S1	Canada	%	LNG exports	0.00	0.00	-8.68	-7.06	-7.18	-10.35	-14.89
S6 - S1	USA	%	LNG exports	0.00	0.00	-21.75	-28.10	-5.63	0.00	0.00
S6 - S1		**%**	**Total**	**0.00**	**-0.23**	**-7.57**	**-12.13**	**-8.13**	**-10.76**	**-15.97**
S6 - S1	ROW	%	LNG imports	0.00	-1.68	-8.53	-15.11	-14.88	-19.61	-29.72
S6 - S1	Australia + NZ	%	LNG imports	0.00	0.00	0.00	0.00	0.00	0.00	-16.67
S6 - S1	LAC	%	LNG imports	0.00	2.64	-7.62	-15.95	-15.14	-20.75	-22.83
S6 - S1	Africa	%	LNG imports	0.00	0.86	-6.15	-9.55	1.85	2.96	-2.73
S6 - S1	C Asia + East Eur	%	LNG imports	0.00	1.25	-2.51	-11.66	-12.67	-21.01	-27.77
S6 - S1	Russia	%	LNG imports	0.00	0.00	0.00	0.00	14.50	6.39	1.20
S6 - S1	China	%	LNG imports	0.00	2.43	-3.15	-4.71	-0.51	0.30	-1.36
S6 - S1	India	%	LNG imports	-0.25	-2.43	-6.63	-7.03	-0.33	2.88	2.31
S6 - S1	Middle East	%	LNG imports	0.00	-10.42	-14.29	-34.58	-23.38	-36.15	-45.24
S6 - S1	EU	%	LNG imports	0.00	-2.37	-20.96	-23.63	-10.25	-10.32	-20.64
S6 - S1	Mexico	%	LNG imports	0.00	0.75	-2.78	-13.38	-20.12	-28.25	-32.82
S6 - S1	Canada	%	LNG imports	0.00	0.00	0.00	-14.29	-31.58	-32.00	-26.92
S6 - S1	USA	%	LNG imports	0.00	-7.69	-21.74	-22.22	20.00	-20.00	-20.00
S6 - S1		**%**	**Total**	**-0.05**	**-0.20**	**-7.60**	**-12.13**	**-8.12**	**-10.75**	**-15.95**

S6 - S1	ROW	%	Pipeline exports	0.00	-1.86	-13.62	-16.53	-4.33	-1.12	1.97
S6 - S1	Australia + NZ	%	Pipeline exports	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S6 - S1	LAC	%	Pipeline exports	0.00	-0.55	1.12	-4.38	-11.76	-20.49	-25.20
S6 - S1	Africa	%	Pipeline exports	0.00	-1.77	-9.76	-8.86	-1.70	10.36	20.21
S6 - S1	C Asia + East Eur	%	Pipeline exports	0.00	0.00	-20.00	-25.00	0.00	0.00	0.00
S6 - S1	Russia	%	Pipeline exports	0.00	-0.97	-1.36	-6.57	-9.83	-13.47	-26.56
S6 - S1	China	%	Pipeline exports	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S6 - S1	India	%	Pipeline exports	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S6 - S1	Middle East	%	Pipeline exports	0.00	0.00	-33.33	0.00	25.00	33.33	33.33
S6 - S1	EU	%	Pipeline exports	0.00	-1.86	-15.44	-17.60	-3.26	-6.12	-14.81
S6 - S1	Mexico	%	Pipeline exports	0.00	0.00	0.00	-40.00	-46.67	-51.43	-48.21
S6 - S1	Canada	%	Pipeline exports	0.00	-2.39	-0.54	-1.68	-7.81	-15.45	-20.64
S6 - S1	USA	%	Pipeline exports	0.00	0.00	0.00	0.00	0.12	0.00	0.00
S6 - S1		**%**	**Total**	**0.02**	**-1.14**	**-3.46**	**-6.51**	**-7.16**	**-9.87**	**-18.54**
S6 - S1	ROW	%	Pipeline imports	0.00	-1.20	-5.49	-12.50	-12.50	-7.50	-10.20
S6 - S1	Australia + NZ	%	Pipeline imports	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S6 - S1	LAC	%	Pipeline imports	0.00	-0.55	1.12	-4.38	-11.76	-20.49	-25.20
S6 - S1	Africa	%	Pipeline imports	0.00	0.00	5.71	0.00	-0.55	11.90	22.44
S6 - S1	C Asia + East Eur	%	Pipeline imports	0.00	0.00	1.17	-9.09	-24.82	-42.21	-57.84
S6 - S1	Russia	%	Pipeline imports	0.00	0.00	0.00	-0.73	-10.38	-23.33	-32.60
S6 - S1	China	%	Pipeline imports	0.00	1.01	-4.38	-9.16	-7.60	-6.36	-20.60
S6 - S1	India	%	Pipeline imports	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S6 - S1	Middle East	%	Pipeline imports	0.00	0.00	0.00	-33.33	-42.86	-51.72	-60.00
S6 - S1	EU	%	Pipeline imports	0.00	-2.47	-8.16	-10.04	-1.28	-0.23	-5.29
S6 - S1	Mexico	%	Pipeline imports	0.00	6.46	8.26	0.00	-10.81	-14.68	-15.91
S6 - S1	Canada	%	Pipeline imports	0.00	4.22	0.00	-14.46	-20.00	-11.76	-5.77
S6 - S1	USA	%	Pipeline imports	0.00	-5.72	-5.30	2.19	13.62	14.17	12.86
S6 - S1		**%**	**Total**	**-0.02**	**-1.18**	**-3.46**	**-6.53**	**-7.18**	**-9.85**	**-18.49**
S7 - S2	ROW	%	Consumption	0.00	-1.11	-6.34	-12.65	-15.22	-15.89	-20.45
S7 - S2	Australia + NZ	%	Consumption	0.00	6.45	13.95	-8.11	-15.38	-17.95	-18.58
S7 - S2	LAC	%	Consumption	0.00	0.24	-2.68	-11.57	-17.26	-23.22	-25.84
S7 - S2	Africa	%	Consumption	0.00	0.14	-0.64	-5.69	-6.94	-5.49	-7.29
S7 - S2	C Asia + East Eur	%	Consumption	-0.03	0.20	-0.34	-9.36	-17.69	-28.00	-36.87
S7 - S2	Russia	%	Consumption	0.00	0.14	-0.08	-0.03	-1.38	-9.73	-16.95

S7 - S2	China	%	Consumption	0.00	0.77	-2.53	-5.07	-5.36	-4.35	-12.74
S7 - S2	India	%	Consumption	0.00	-2.78	-4.60	-5.40	-4.49	-1.80	-3.61
S7 - S2	Middle East	%	Consumption	-0.26	-1.93	-0.90	-10.61	-17.74	-25.47	-33.04
S7 - S2	EU	%	Consumption	0.00	-2.32	-13.96	-15.78	-12.19	-12.29	-24.82
S7 - S2	Mexico	%	Consumption	0.00	1.61	1.50	-8.32	-17.30	-23.40	-26.56
S7 - S2	Canada	%	Consumption	0.00	3.38	-0.48	-14.94	-19.81	-19.94	-18.17
S7 - S2	USA	%	Consumption	0.02	-8.73	-13.03	-15.49	-16.34	-26.35	-34.86
S7 - S2		**%**	**Total**	**-0.03**	**-2.36**	**-5.43**	**-9.99**	**-12.44**	**-16.93**	**-23.40**
S7 - S2	ROW	%	Production	0.00	-0.79	-5.10	-8.66	-8.80	-8.27	-9.72
S7 - S2	Australia + NZ	%	Production	0.00	0.00	-0.17	-2.25	-4.38	-7.84	-16.51
S7 - S2	LAC	%	Production	0.00	-0.80	-1.51	-10.23	-13.76	-18.69	-22.64
S7 - S2	Africa	%	Production	0.00	-0.20	-1.56	-6.18	-7.86	-8.32	-10.94
S7 - S2	C Asia + East Eur	%	Production	0.00	-0.28	-0.21	-9.47	-16.91	-25.10	-32.62
S7 - S2	Russia	%	Production	0.00	-0.28	-0.52	-2.63	-4.96	-10.44	-21.40
S7 - S2	China	%	Production	0.00	-0.61	-1.47	-4.47	-4.91	-4.61	-12.18
S7 - S2	India	%	Production	0.00	-3.26	-1.68	-4.64	-4.45	-2.50	-5.82
S7 - S2	Middle East	%	Production	-0.20	-1.42	-1.79	-9.73	-14.84	-20.46	-27.22
S7 - S2	EU	%	Production	0.00	-1.79	-16.39	-18.20	-16.62	-16.37	-29.98
S7 - S2	Mexico	%	Production	0.00	-6.27	-6.27	-18.16	-26.34	-34.09	-38.59
S7 - S2	Canada	%	Production	0.00	0.43	-2.06	-8.47	-10.79	-12.54	-15.47
S7 - S2	USA	%	Production	0.01	-6.99	-14.06	-17.35	-18.73	-25.83	-32.13
S7 - S2		**%**	**Total**	**-0.03**	**-2.36**	**-5.43**	**-9.99**	**-12.44**	**-16.93**	**-23.40**
S7 - S2	ROW	%	LNG exports	0.00	-0.45	-2.17	-2.76	-4.67	-7.58	-12.19
S7 - S2	Australia + NZ	%	LNG exports	0.00	-0.17	-0.68	-1.96	-3.75	-6.69	-16.17
S7 - S2	LAC	%	LNG exports	0.00	-1.36	-7.87	-12.57	-12.96	-13.56	-18.49
S7 - S2	Africa	%	LNG exports	0.00	-0.38	-2.59	-6.98	-9.90	-13.53	-19.94
S7 - S2	C Asia + East Eur	%	LNG exports	0.00	-5.88	-21.43	-24.30	-20.82	-20.14	-28.12
S7 - S2	Russia	%	LNG exports	0.00	-0.26	-0.26	-3.00	-6.36	-12.70	-23.57
S7 - S2	China	%	LNG exports	0.00	0.00	-100.00	0.00	-20.00	-22.22	-30.77
S7 - S2	India	%	LNG exports	0.00	0.00	0.00	-22.22	-21.05	-27.78	-38.18
S7 - S2	Middle East	%	LNG exports	0.00	0.00	-5.21	-8.34	-8.00	-7.69	-12.65
S7 - S2	EU	%	LNG exports	0.00	2.17	-3.17	-13.79	-19.38	-23.30	-26.97
S7 - S2	Mexico	%	LNG exports	0.00	0.00	0.00	-33.33	-12.50	-17.65	-31.03
S7 - S2	Canada	%	LNG exports	0.00	0.00	-8.68	-6.85	-5.65	-6.12	-10.71
S7 - S2	USA	%	LNG exports	0.00	0.00	-21.75	-24.89	-25.98	-26.81	-28.88
S7 - S2		**%**	**Total**	**0.00**	**-0.23**	**-7.57**	**-11.05**	**-13.55**	**-15.88**	**-20.74**
S7 - S2	ROW	%	LNG imports	0.00	-1.68	-8.53	-14.54	-18.20	-22.52	-32.17
S7 - S2	Australia + NZ	%	LNG imports	0.00	0.00	0.00	0.00	0.00	0.00	-19.05
S7 - S2	LAC	%	LNG imports	0.00	2.64	-7.62	-14.73	-21.24	-25.91	-27.41
S7 - S2	Africa	%	LNG imports	0.00	0.86	-6.15	-8.09	-7.95	-5.18	-8.77
S7 - S2	C Asia + East Eur	%	LNG imports	0.00	1.25	-2.51	-10.54	-18.03	-26.61	-33.08
S7 - S2	Russia	%	LNG imports	0.00	0.00	0.00	3.41	1.01	-7.26	-11.81

S7 - S2	China	%	LNG imports	0.00	2.43	-3.15	-3.71	-3.69	-3.02	-5.14
S7 - S2	India	%	LNG imports	-0.25	-2.43	-6.63	-6.03	-4.72	-1.72	-2.24
S7 - S2	Middle East	%	LNG imports	0.00	-10.42	-14.29	-32.04	-36.90	-43.07	-50.32
S7 - S2	EU	%	LNG imports	0.00	-2.37	-20.96	-21.93	-18.96	-17.27	-26.55
S7 - S2	Mexico	%	LNG imports	0.00	0.75	-2.78	-12.82	-25.99	-35.15	-40.09
S7 - S2	Canada	%	LNG imports	0.00	0.00	0.00	-14.29	-48.00	-45.71	-40.54
S7 - S2	USA	%	LNG imports	0.00	-7.69	-21.74	-17.65	-20.00	-37.50	-47.06
S7 - S2		**%**	**Total**	**-0.05**	**-0.20**	**-7.60**	**-11.05**	**-13.54**	**-15.88**	**-20.75**
S7 - S2	ROW	%	Pipeline exports	0.00	-1.86	-13.62	-15.41	-3.70	-1.13	2.00
S7 - S2	Australia + NZ	%	Pipeline exports	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S7 - S2	LAC	%	Pipeline exports	0.00	-0.55	1.12	-4.97	-7.69	-15.18	-20.00
S7 - S2	Africa	%	Pipeline exports	0.00	-1.77	-9.76	-8.86	2.67	13.84	23.45
S7 - S2	C Asia + East Eur	%	Pipeline exports	0.00	0.00	-20.00	-25.00	0.00	0.00	0.00
S7 - S2	Russia	%	Pipeline exports	0.00	-0.97	-1.36	-6.53	-9.02	-11.27	-25.00
S7 - S2	China	%	Pipeline exports	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S7 - S2	India	%	Pipeline exports	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S7 - S2	Middle East	%	Pipeline exports	0.00	0.00	-33.33	0.00	25.00	16.67	50.00
S7 - S2	EU	%	Pipeline exports	0.00	-1.86	-15.44	-16.26	-3.26	-4.17	-8.00
S7 - S2	Mexico	%	Pipeline exports	0.00	0.00	0.00	-40.00	-46.67	-51.43	-51.72
S7 - S2	Canada	%	Pipeline exports	0.00	-2.39	-0.54	-1.68	-8.27	-16.96	-23.10
S7 - S2	USA	%	Pipeline exports	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S7 - S2		**%**	**Total**	**0.02**	**-1.14**	**-3.46**	**-6.31**	**-6.36**	**-8.19**	**-17.23**
S7 - S2	ROW	%	Pipeline imports	0.00	-1.20	-5.49	-12.50	-12.50	-6.41	-8.60
S7 - S2	Australia + NZ	%	Pipeline imports	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S7 - S2	LAC	%	Pipeline imports	0.00	-0.55	1.12	-4.97	-7.69	-15.18	-20.00
S7 - S2	Africa	%	Pipeline imports	0.00	0.00	5.71	-2.33	5.26	16.55	25.40
S7 - S2	C Asia + East Eur	%	Pipeline imports	0.00	0.00	1.17	-9.62	-21.48	-37.95	-54.77
S7 - S2	Russia	%	Pipeline imports	0.00	0.00	0.00	-1.45	-4.04	-17.58	-27.66
S7 - S2	China	%	Pipeline imports	0.00	1.01	-4.38	-8.75	-8.36	-5.41	-19.77
S7 - S2	India	%	Pipeline imports	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S7 - S2	Middle East	%	Pipeline imports	0.00	0.00	0.00	-33.33	-33.33	-45.83	-56.76
S7 - S2	EU	%	Pipeline imports	0.00	-2.47	-8.16	-9.18	-1.10	-0.23	-7.54
S7 - S2	Mexico	%	Pipeline imports	0.00	6.46	8.26	-0.56	-8.90	-12.58	-13.11
S7 - S2	Canada	%	Pipeline imports	0.00	4.22	0.00	-14.97	-17.16	-8.64	-2.04
S7 - S2	USA	%	Pipeline imports	0.00	-5.72	-5.30	2.68	8.76	5.47	-0.56

S7 - S2		%	Total	-0.02	-1.18	-3.46	-6.33	-6.36	-8.16	-17.25

Table D-12. Primary energy consumption by fuel in 2015 and under all scenarios in 2050 (Figure 13)

Scenario	Fuel	Units	2015	2050
S1: Reference Exports	biomass	EJ	30.07	95.84
S1: Reference Exports	biomass CCS	EJ	0	39.58
S1: Reference Exports	coal	EJ	165.11	153.04
S1: Reference Exports	coal CCS	EJ	0	8.96
S1: Reference Exports	gas	EJ	126.84	184.76
S1: Reference Exports	gas CCS	EJ	0	17.7
S1: Reference Exports	nuclear	EJ	9.67	20.48
S1: Reference Exports	oil	EJ	189	179.87
S1: Reference Exports	oil CCS	EJ	0	5.97
S1: Reference Exports	other renewables	EJ	18.54	99.96
S1: Reference Exports	**Total**	**EJ**	**539.23**	**806.16**
S2: Market Response	biomass	EJ	30.07	95.48
S2: Market Response	biomass CCS	EJ	0	39.77
S2: Market Response	coal	EJ	165.11	152.42
S2: Market Response	coal CCS	EJ	0	8.95
S2: Market Response	gas	EJ	126.84	185.96
S2: Market Response	gas CCS	EJ	0	17.96
S2: Market Response	nuclear	EJ	9.67	20.45
S2: Market Response	oil	EJ	189	179.6
S2: Market Response	oil CCS	EJ	0	5.96
S2: Market Response	other renewables	EJ	18.54	99.86
S2: Market Response	**Total**	**EJ**	**539.23**	**806.41**
S3: High Global Demand	biomass	EJ	30.07	100.36
S3: High Global Demand	biomass CCS	EJ	0	44.37
S3: High Global Demand	coal	EJ	165.11	151.31
S3: High Global Demand	coal CCS	EJ	0	10.39
S3: High Global Demand	gas	EJ	126.84	189.54
S3: High Global Demand	gas CCS	EJ	0	21.24
S3: High Global Demand	nuclear	EJ	9.67	21.48
S3: High Global Demand	oil	EJ	189	181.76
S3: High Global Demand	oil CCS	EJ	0	7.21
S3: High Global Demand	other renewables	EJ	18.54	104.99
S3: High Global Demand	**Total**	**EJ**	**539.23**	**832.65**
S4: Regional Import Limits	biomass	EJ	30.07	97.32
S4: Regional Import Limits	biomass CCS	EJ	0	39.07
S4: Regional Import Limits	coal	EJ	165.11	154.51
S4: Regional Import Limits	coal CCS	EJ	0	9.13

S4: Regional Import Limits	gas	EJ	126.83	182.31
S4: Regional Import Limits	gas CCS	EJ	0	17.73
S4: Regional Import Limits	nuclear	EJ	9.67	20.73
S4: Regional Import Limits	oil	EJ	189	179.54
S4: Regional Import Limits	oil CCS	EJ	0	5.93
S4: Regional Import Limits	other renewables	EJ	18.54	99.87
S4: Regional Import Limits	**Total**	**EJ**	**539.22**	**806.14**
S5: Low-cost Renewables	biomass	EJ	30.07	90.69
S5: Low-cost Renewables	biomass CCS	EJ	0	36.23
S5: Low-cost Renewables	coal	EJ	165.11	151.76
S5: Low-cost Renewables	coal CCS	EJ	0	7.88
S5: Low-cost Renewables	gas	EJ	126.84	179.4
S5: Low-cost Renewables	gas CCS	EJ	0	16.2
S5: Low-cost Renewables	nuclear	EJ	9.67	18.93
S5: Low-cost Renewables	oil	EJ	189	178.07
S5: Low-cost Renewables	oil CCS	EJ	0	4.89
S5: Low-cost Renewables	other renewables	EJ	18.54	117.95
S5: Low-cost Renewables	**Total**	**EJ**	**539.23**	**802**
S6: Energy Transition (Ref Exp)	biomass	EJ	30.06	35.59
S6: Energy Transition (Ref Exp)	biomass CCS	EJ	0	108.7
S6: Energy Transition (Ref Exp)	coal	EJ	165.11	44.43
S6: Energy Transition (Ref Exp)	coal CCS	EJ	0	35.07
S6: Energy Transition (Ref Exp)	gas	EJ	126.83	95.07
S6: Energy Transition (Ref Exp)	gas CCS	EJ	0	58.07
S6: Energy Transition (Ref Exp)	nuclear	EJ	9.67	34.96
S6: Energy Transition (Ref Exp)	oil	EJ	189	144.79
S6: Energy Transition (Ref Exp)	oil CCS	EJ	0	16.07
S6: Energy Transition (Ref Exp)	other renewables	EJ	18.54	142.92
S6: Energy Transition (Ref Exp)	**Total**	**EJ**	**539.21**	**715.67**
S7: Energy Transition	biomass	EJ	30.06	35.54
S7: Energy Transition	biomass CCS	EJ	0	108.7
S7: Energy Transition	coal	EJ	165.11	44.39
S7: Energy Transition	coal CCS	EJ	0	35.03
S7: Energy Transition	gas	EJ	126.83	95.24
S7: Energy Transition	gas CCS	EJ	0	58.41
S7: Energy Transition	nuclear	EJ	9.67	34.94
S7: Energy Transition	oil	EJ	189	144.71
S7: Energy Transition	oil CCS	EJ	0	16.04
S7: Energy Transition	other renewables	EJ	18.54	142.87
S7: Energy Transition	**Total**	**EJ**	**539.21**	**715.87**

Table D-13. GHG emissions by sector in 2015 and under all scenarios in 2050 (Figure 13)

Scenario	Sector	2015	2050
S1: Reference Exports	CO2 buildings	2.84	2.54
S1: Reference Exports	CO2 electricity	12.64	13.04
S1: Reference Exports	CO2 industry	11.75	11.04
S1: Reference Exports	CO2 other energy	0.51	1.60
S1: Reference Exports	CO2 transport	7.89	7.04
S1: Reference Exports	CH4 Energy	5.43	4.80
S1: Reference Exports	CH4 AgLanduse	3.36	4.97
S1: Reference Exports	N2O Energy	0.96	0.88
S1: Reference Exports	N2O AgLanduse	2.17	3.28
S1: Reference Exports	F-gases	1.01	1.66
S1: Reference Exports	CO2 bioenergy	0.00	-1.68
S1: Reference Exports	CO2 direct air capture	0.00	0.00
S1: Reference Exports	CO2 LUC	3.04	-1.42
S1: Reference Exports	**Total**	**51.58**	**47.74**
S2: Market Response	CO2 buildings	2.84	2.54
S2: Market Response	CO2 electricity	12.64	13.02
S2: Market Response	CO2 industry	11.75	11.04
S2: Market Response	CO2 other energy	0.51	1.60
S2: Market Response	CO2 transport	7.89	7.03
S2: Market Response	CH4 Energy	5.43	4.79
S2: Market Response	CH4 AgLanduse	3.36	4.97
S2: Market Response	N2O Energy	0.96	0.88
S2: Market Response	N2O AgLanduse	2.17	3.28
S2: Market Response	F-gases	1.01	1.67
S2: Market Response	CO2 bioenergy	0.00	-1.69
S2: Market Response	CO2 direct air capture	0.00	0.00
S2: Market Response	CO2 LUC	3.04	-1.39
S2: Market Response	**Total**	**51.58**	**47.72**
S3: High Global Demand	CO2 buildings	2.84	2.55
S3: High Global Demand	CO2 electricity	12.64	12.87
S3: High Global Demand	CO2 industry	11.75	11.27
S3: High Global Demand	CO2 other energy	0.51	1.63
S3: High Global Demand	CO2 transport	7.89	7.09
S3: High Global Demand	CH4 Energy	5.43	5.02
S3: High Global Demand	CH4 AgLanduse	3.36	5.34
S3: High Global Demand	N2O Energy	0.96	0.92
S3: High Global Demand	N2O AgLanduse	2.17	3.51
S3: High Global Demand	F-gases	1.01	1.76
S3: High Global Demand	CO2 bioenergy	0.00	-1.88
S3: High Global Demand	CO2 direct air capture	0.00	0.00

S3: High Global Demand	CO2 LUC	3.04	0.18
S3: High Global Demand	**Total**	**51.58**	**50.25**
S4: Regional Import Limits	CO2 buildings	2.84	2.44
S4: Regional Import Limits	CO2 electricity	12.64	13.13
S4: Regional Import Limits	CO2 industry	11.75	10.99
S4: Regional Import Limits	CO2 other energy	0.51	1.64
S4: Regional Import Limits	CO2 transport	7.89	7.05
S4: Regional Import Limits	CH4 Energy	5.43	4.75
S4: Regional Import Limits	CH4 AgLanduse	3.36	4.97
S4: Regional Import Limits	N2O Energy	0.96	0.88
S4: Regional Import Limits	N2O AgLanduse	2.17	3.28
S4: Regional Import Limits	F-gases	1.01	1.66
S4: Regional Import Limits	CO2 bioenergy	0.00	-1.65
S4: Regional Import Limits	CO2 direct air capture	0.00	0.00
S4: Regional Import Limits	CO2 LUC	3.04	-1.43
S4: Regional Import Limits	**Total**	**51.58**	**47.71**
S5: Low-cost Renewables	CO2 buildings	2.84	2.44
S5: Low-cost Renewables	CO2 electricity	12.64	12.78
S5: Low-cost Renewables	CO2 industry	11.75	11.08
S5: Low-cost Renewables	CO2 other energy	0.51	1.58
S5: Low-cost Renewables	CO2 transport	7.89	7.05
S5: Low-cost Renewables	CH4 Energy	5.43	4.74
S5: Low-cost Renewables	CH4 AgLanduse	3.36	4.99
S5: Low-cost Renewables	N2O Energy	0.96	0.87
S5: Low-cost Renewables	N2O AgLanduse	2.17	3.26
S5: Low-cost Renewables	F-gases	1.01	1.68
S5: Low-cost Renewables	CO2 bioenergy	0.00	-1.51
S5: Low-cost Renewables	CO2 direct air capture	0.00	0.00
S5: Low-cost Renewables	CO2 LUC	3.04	-1.50
S5: Low-cost Renewables	**Total**	**51.58**	**47.47**
S6: Energy Transition (Ref Exp)	CO2 buildings	2.84	1.12
S6: Energy Transition (Ref Exp)	CO2 electricity	12.64	2.16
S6: Energy Transition (Ref Exp)	CO2 industry	11.75	6.47
S6: Energy Transition (Ref Exp)	CO2 other energy	0.51	0.95
S6: Energy Transition (Ref Exp)	CO2 transport	7.89	5.00
S6: Energy Transition (Ref Exp)	CH4 Energy	5.43	3.25
S6: Energy Transition (Ref Exp)	CH4 AgLanduse	3.36	4.69
S6: Energy Transition (Ref Exp)	N2O Energy	0.96	0.59
S6: Energy Transition (Ref Exp)	N2O AgLanduse	2.17	3.03
S6: Energy Transition (Ref Exp)	F-gases	1.01	1.07
S6: Energy Transition (Ref Exp)	CO2 bioenergy	0.00	-6.81
S6: Energy Transition (Ref Exp)	CO2 direct air capture	0.00	-0.47
S6: Energy Transition (Ref Exp)	CO2 LUC	3.04	-3.92

S6: Energy Transition (Ref Exp)	Total	51.58	17.13
S7: Energy Transition	CO2 buildings	2.84	1.12
S7: Energy Transition	CO2 electricity	12.64	2.16
S7: Energy Transition	CO2 industry	11.75	6.47
S7: Energy Transition	CO2 other energy	0.51	0.95
S7: Energy Transition	CO2 transport	7.89	5.00
S7: Energy Transition	CH4 Energy	5.43	3.24
S7: Energy Transition	CH4 AgLanduse	3.36	4.69
S7: Energy Transition	N2O Energy	0.96	0.59
S7: Energy Transition	N2O AgLanduse	2.17	3.03
S7: Energy Transition	F-gases	1.01	1.07
S7: Energy Transition	CO2 bioenergy	0.00	-6.81
S7: Energy Transition	CO2 direct air capture	0.00	-0.47
S7: Energy Transition	CO2 LUC	3.04	-3.92
S7: Energy Transition	Total	51.58	17.12

Table D-1. U.S. GHG emissions and removals scenarios S6 and S7, by year (Figure 1)

Commented [IGC222]: NEMS tables start here and need to be renumbered.

CO_2 Emissions and Removals	Units	2020	2025	2030	2035	2040	2045	2050
Net CO_2 Emissions (Carbon Cap in FECM-NEMS)	Gt CO_2e	4.59	4.02	3.26	2.15	1.49	0.93	0.19
Sum of Remaining Emissions & Removals	Gt CO_2e	0.52	0.29	0.19	0.44	0.24	-0.07	-0.18

Table D-2. U.S. primary energy consumption, S1 through S5, tabulated by year (Figure 14)

Scenario	U.S. Primary Energy Consumption	Units	2020	2025	2030	2035	2040	2045	2050
S1: Reference Exports	Natural Gas	EJ	33.4	32.1	30.8	30.2	31.2	31.9	32.7
S1: Reference Exports	Coal	EJ	9.6	9.1	4.6	4.5	4.0	3.8	3.5
S1: Reference Exports	Petroleum / Other	EJ	44.4	47.3	46.1	44.8	43.8	44.3	45.2
S1: Reference Exports	Other Renewables	EJ	7.2	11.4	18.7	22.0	23.5	25.2	27.2
S1: Reference Exports	Biomass	EJ	3.1	3.2	3.2	3.2	3.2	3.3	3.4
S1: Reference Exports	**Total**	**EJ**	**97.7**	**103.1**	**103.4**	**104.7**	**105.8**	**108.4**	**111.9**
S2: Market Response	Natural Gas	EJ	33.4	32.1	30.8	30.1	30.9	32.0	32.4
S2: Market Response	Coal	EJ	9.6	9.2	4.7	4.6	4.2	4.1	3.9
S2: Market Response	Petroleum / Other	EJ	44.4	47.3	46.1	44.6	43.9	44.2	45.1
S2: Market Response	Other Renewables	EJ	7.2	11.4	18.7	22.1	24.4	26.2	28.6
S2: Market Response	Biomass	EJ	3.1	3.2	3.2	3.2	3.2	3.3	3.4

Scenario	U.S. Primary Energy Consumption	Units	2020	2025	2030	2035	2040	2045	2050
S2: Market Response	**Total**	**EJ**	**97.7**	**103.1**	**103.4**	**104.6**	**106.7**	**109.8**	**113.3**
S3: High Global Demand	Natural Gas	EJ	33.4	32.1	30.6	30.0	30.8	31.9	32.4
S3: High Global Demand	Coal	EJ	9.6	9.2	4.9	4.5	4.2	4.1	4.0
S3: High Global Demand	Petroleum / Other	EJ	44.4	47.3	46.1	44.6	44.0	44.5	45.3
S3: High Global Demand	Other Renewables	EJ	7.2	11.4	18.8	22.3	24.4	26.3	28.5
S3: High Global Demand	Biomass	EJ	3.1	3.2	3.2	3.2	3.2	3.3	3.4
S3: High Global Demand	**Total**	**EJ**	**97.7**	**103.1**	**103.5**	**104.8**	**106.8**	**110.0**	**113.5**
S4: Regional Import Limits	Natural Gas	EJ	33.4	32.1	31.4	31.2	31.7	32.5	32.6
S4: Regional Import Limits	Coal	EJ	9.6	9.2	4.2	4.2	3.7	3.6	3.4
S4: Regional Import Limits	Petroleum / Other	EJ	44.4	47.3	46.0	44.4	43.4	43.9	44.8
S4: Regional Import Limits	Other Renewables	EJ	7.2	11.4	18.2	20.6	22.7	24.3	27.2
S4: Regional Import Limits	Biomass	EJ	3.1	3.2	3.2	3.2	3.2	3.3	3.4
S4: Regional Import Limits	**Total**	**EJ**	**97.7**	**103.2**	**103.0**	**103.6**	**104.8**	**107.6**	**111.3**
S5: Low-cost Renewables	Natural Gas	EJ	33.4	32.0	30.0	28.7	29.2	29.3	28.6
S5: Low-cost Renewables	Coal	EJ	9.6	9.2	4.0	3.3	2.8	2.1	1.4
S5: Low-cost Renewables	Petroleum / Other	EJ	44.4	47.4	46.2	44.4	43.2	43.4	46.0
S5: Low-cost Renewables	Other Renewables	EJ	7.2	11.4	20.4	25.4	28.4	31.8	34.2
S5: Low-cost Renewables	Biomass	EJ	3.1	3.2	3.2	3.3	3.4	3.7	4.4
S5: Low-cost Renewables	**Total**	**EJ**	**97.7**	**103.2**	**103.8**	**105.2**	**107.0**	**110.2**	**114.6**
S2 – S1	Natural Gas	EJ	0.0	-0.1	0.0	-0.1	-0.3	0.1	-0.3
S2 – S1	Coal	EJ	0.0	0.1	0.1	0.1	0.2	0.3	0.4
S2 – S1	Petroleum / Other	EJ	0.0	0.0	0.0	-0.1	0.1	0.0	-0.1
S2 – S1	Other Renewables	EJ	0.0	0.0	0.0	0.1	0.9	1.0	1.4
S2 – S1	Biomass	EJ	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S2 – S1	**Total**	**EJ**	**0.0**	**0.0**	**0.0**	**-0.1**	**0.8**	**1.4**	**1.4**
S3 – S1	Natural Gas	EJ	0.0	0.0	-0.2	-0.2	-0.4	0.0	-0.3
S3 – S1	Coal	EJ	0.0	0.0	0.3	0.0	0.2	0.3	0.5
S3 – S1	Petroleum / Other	EJ	0.0	0.0	0.0	-0.1	0.2	0.2	0.1
S3 – S1	Other Renewables	EJ	0.0	0.0	0.0	0.3	0.9	1.1	1.3
S3 – S1	Biomass	EJ	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S3 – S1	**Total**	**EJ**	**0.0**	**0.0**	**0.1**	**0.1**	**0.9**	**1.6**	**1.6**
S4 – S1	Natural Gas	EJ	0.0	-0.1	0.6	1.0	0.5	0.6	-0.1
S4 – S1	Coal	EJ	0.0	0.1	-0.4	-0.3	-0.3	-0.2	-0.1

Scenario	U.S. Primary Energy Consumption	Units	2020	2025	2030	2035	2040	2045	2050
S4 – S1	Petroleum / Other	EJ	0.0	0.0	-0.1	-0.4	-0.4	-0.3	-0.4
S4 – S1	Other Renewables	EJ	0.0	0.0	-0.5	-1.4	-0.8	-0.8	0.0
S4 – S1	Biomass	EJ	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S4 – S1	**Total**	**EJ**	**0.0**	**0.0**	**-0.4**	**-1.1**	**-1.0**	**-0.8**	**-0.6**
S5 – S1	Natural Gas	EJ	0.0	-0.1	-0.8	-1.5	-2.1	-2.6	-4.0
S5 – S1	Coal	EJ	0.0	0.1	-0.6	-1.2	-1.2	-1.7	-2.1
S5 – S1	Petroleum / Other	EJ	0.0	0.1	0.2	-0.3	-0.6	-0.9	0.8
S5 – S1	Other Renewables	EJ	0.0	0.0	1.7	3.5	4.9	6.7	7.0
S5 – S1	Biomass	EJ	0.0	-0.1	0.0	0.1	0.1	0.4	1.0
S5 – S1	**Total**	**EJ**	**0.0**	**0.0**	**0.4**	**0.5**	**1.1**	**1.8**	**2.7**
S2 – S1	Natural Gas	% Difference	0.0	-0.2	0.0	-0.4	-1.1	0.3	-0.8
S2 – S1	Coal	% Difference	0.0	0.7	1.3	1.8	4.7	8.9	12.1
S2 – S1	Petroleum / Other	% Difference	0.0	0.0	0.0	-0.3	0.2	-0.1	-0.2
S2 – S1	Other Renewables	% Difference	0.0	0.0	-0.2	0.5	3.8	4.1	5.0
S2 – S1	Biomass	% Difference	0.0	0.0	0.0	0.0	-0.1	0.0	-0.1
S2 – S1	**Total**	**% Difference**	**0.0**	**0.0**	**0.0**	**-0.1**	**0.8**	**1.3**	**1.3**
S3 – S1	Natural Gas	% Difference	0.0	0.1	-0.6	-0.1	-0.1	-0.5	-0.1
S3 – S1	Coal	% Difference	0.0	-0.4	4.3	-1.1	0.2	0.3	2.3
S3 – S1	Petroleum / Other	% Difference	0.0	0.0	0.0	0.0	0.2	0.5	0.5
S3 – S1	Other Renewables	% Difference	0.0	0.0	0.4	1.1	0.1	0.3	-0.3
S3 – S1	Biomass	% Difference	0.0	0.0	0.2	0.1	0.1	0.1	0.0
S3 – S1	**Total**	**% Difference**	**0.0**	**0.0**	**0.1**	**0.1**	**0.1**	**0.2**	**0.2**
S4 – S1	Natural Gas	% Difference	0.0	-0.2	1.9	3.4	1.6	1.8	-0.3
S4 – S1	Coal	% Difference	0.0	0.9	-9.1	-7.5	-8.5	-4.8	-2.1
S4 – S1	Petroleum / Other	% Difference	0.0	0.0	-0.1	-0.8	-0.9	-0.8	-0.9
S4 – S1	Other Renewables	% Difference	0.0	0.0	-2.7	-6.2	-3.3	-3.3	-0.1
S4 – S1	Biomass	% Difference	0.0	0.0	0.1	0.2	-0.2	-0.2	-0.5
S4 – S1	**Total**	**% Difference**	**0.0**	**0.0**	**-0.4**	**-1.0**	**-1.0**	**-0.7**	**-0.5**
S5 – S1	Natural Gas	% Difference	0.0	-0.4	-2.7	-4.9	-6.6	-8.3	-12.3
S5 – S1	Coal	% Difference	0.0	0.7	-12.0	-25.9	-29.1	-44.9	-59.2
S5 – S1	Petroleum / Other	% Difference	0.0	0.3	0.4	-0.7	-1.4	-2.1	1.8
S5 – S1	Other Renewables	% Difference	0.0	0.4	8.8	15.7	20.8	26.5	25.7
S5 – S1	Biomass	% Difference	0.0	-2.5	0.1	1.6	3.5	12.8	28.9

Scenario	U.S. Primary Energy Consumption	Units	2020	2025	2030	2035	2040	2045	2050
S5 – S1	**Total**	**% Difference**	**0.0**	**0.0**	**0.4**	**0.5**	**1.1**	**1.7**	**2.4**

Table D-3. U.S. primary energy consumption, S6 and S7, by year (Figure 15)

Scenario	U.S. Primary Energy Consumption	Units	2020	2025	2030	2035	2040	2045	2050
S6: Energy Transition (Ref Exp)	Natural Gas	EJ	33.4	35.0	29.8	30.8	33.1	37.5	44.8
S6: Energy Transition (Ref Exp)	Coal	EJ	9.6	1.9	1.8	1.9	1.6	1.6	1.5
S6: Energy Transition (Ref Exp)	Petroleum / Other	EJ	44.5	47.7	44.5	40.1	37.6	36.6	36.2
S6: Energy Transition (Ref Exp)	Other Renewables	EJ	7.2	11.7	19.5	26.1	29.6	29.9	30.9
S6: Energy Transition (Ref Exp)	Biomass	EJ	3.2	3.7	4.6	5.9	6.7	7.5	8.1
S6: Energy Transition (Ref Exp)	**Total**	**EJ**	**97.8**	**99.9**	**100.3**	**104.8**	**108.7**	**113.0**	**121.5**
S7: Energy Transition	Natural Gas	EJ	33.4	34.9	30.0	30.3	32.8	37.1	44.4
S7: Energy Transition	Coal	EJ	9.6	1.9	2.1	1.9	1.9	1.9	1.6
S7: Energy Transition	Petroleum / Other	EJ	44.5	47.7	44.5	40.0	37.1	36.3	35.8
S7: Energy Transition	Other Renewables	EJ	7.2	11.7	19.0	25.9	29.4	29.5	30.5
S7: Energy Transition	Biomass	EJ	3.2	3.7	4.6	5.7	6.7	7.6	8.2
S7: Energy Transition	**Total**	**EJ**	**97.8**	**100.0**	**100.2**	**103.8**	**107.9**	**112.5**	**120.6**
S7 – S6	Natural Gas	EJ	0.0	0.0	0.1	-0.5	-0.4	-0.4	-0.4
S7 – S6	Coal	EJ	0.0	0.0	0.2	0.1	0.3	0.3	0.2
S7 – S6	Petroleum / Other	EJ	0.0	0.0	0.0	-0.2	-0.5	-0.2	-0.4
S7 – S6	Other Renewables	EJ	0.0	0.0	-0.6	-0.1	-0.2	-0.3	-0.4
S7 – S6	Biomass	EJ	0.0	0.0	0.1	-0.2	0.0	0.1	0.1
S7 – S6	**Total**	**EJ**	**0.0**	**0.0**	**-0.1**	**-1.0**	**-0.8**	**-0.5**	**-0.9**
S7 – S6	Natural Gas	% Difference	0.0	-0.1	0.5	-1.7	-1.1	-1.0	-0.9
S7 – S6	Coal	% Difference	0.0	1.9	11.9	3.5	16.3	21.0	10.7
S7 – S6	Petroleum / Other	% Difference	0.0	0.0	0.0	-0.5	-1.2	-0.7	-1.1
S7 – S6	Other Renewables	% Difference	0.0	0.0	-2.8	-0.6	-0.7	-1.1	-1.2
S7 – S6	Biomass	% Difference	0.0	0.8	1.3	-3.6	-0.6	1.5	1.5
S7 – S6	**Total**	**% Difference**	**0.0**	**0.0**	**-0.1**	**-1.0**	**-0.7**	**-0.4**	**-0.7**

Table D-4. Total U.S. natural gas production, consumption, and export volumes, S1 through S5, by year (Figure 16)

Scenario	Total U.S. Natural Gas Volumes	Units	2020	2025	2030	2035	2040	2045	2050
S1: Reference Exports	NG Production	Tcf	33.5	35.8	37.0	39.5	40.9	41.4	42.0
S2: Market Response	NG Production	Tcf	33.5	36.2	37.5	39.4	43.7	47.5	49.0
S3: High Global Demand	NG Production	Tcf	33.5	36.2	37.3	39.5	43.9	47.7	49.5
S4: Regional Import Limits	NG Production	Tcf	33.5	36.2	35.8	36.4	37.6	39.8	40.7
S5: Low-cost Renewables	NG Production	Tcf	33.5	36.1	36.8	38.2	42.3	45.0	45.7
S1: Reference Exports	NG Consumption	Tcf	30.5	29.4	28.2	27.6	28.5	29.2	29.8
S2: Market Response	NG Consumption	Tcf	30.5	29.3	28.2	27.5	28.2	29.2	29.6
S3: High Global Demand	NG Consumption	Tcf	30.5	29.3	28.0	27.4	28.2	29.1	29.6
S4: Regional Import Limits	NG Consumption	Tcf	30.5	29.3	28.7	28.5	29.0	29.7	29.8
S5: Low-cost Renewables	NG Consumption	Tcf	30.5	29.2	27.4	26.2	26.6	26.7	26.2
S1: Reference Exports	LNG Exports	Tcf	2.4	4.9	6.9	9.5	10.0	10.0	10.0
S2: Market Response	LNG Exports	Tcf	2.4	4.9	6.9	9.1	12.8	15.6	17.2
S3: High Global Demand	LNG Exports	Tcf	2.4	4.9	6.9	9.2	13.0	16.0	17.8
S4: Regional Import Limits	LNG Exports	Tcf	2.4	4.9	4.4	4.8	5.6	7.2	8.4
S5: Low-cost Renewables	LNG Exports	Tcf	2.4	4.9	6.9	9.1	12.8	15.6	17.2
S2 – S1	NG Production	Tcf	0.0	0.4	0.5	0.0	2.8	6.1	7.1
S3 – S1	NG Production	Tcf	0.0	0.4	0.3	0.1	3.1	6.3	7.6
S4 – S1	NG Production	Tcf	0.0	0.4	-1.3	-3.0	-3.3	-1.6	-1.3
S5 – S1	NG Production	Tcf	0.0	0.3	-0.2	-1.2	1.4	3.6	3.8
S2 – S1	NG Consumption	Tcf	0.0	-0.1	0.0	-0.1	-0.3	0.1	-0.2
S3 – S1	NG Consumption	Tcf	0.0	0.0	-0.2	-0.2	-0.4	0.0	-0.3
S4 – S1	NG Consumption	Tcf	0.0	-0.1	0.6	0.9	0.4	0.5	-0.1
S5 – S1	NG Consumption	Tcf	0.0	-0.1	-0.8	-1.3	-1.9	-2.4	-3.7
S2 – S1	LNG Exports	Tcf	0.0	0.0	0.0	-0.4	2.8	5.7	7.3
S3 – S1	LNG Exports	Tcf	0.0	0.0	0.0	-0.3	3.0	6.0	7.8
S4 – S1	LNG Exports	Tcf	0.0	0.0	-2.4	-4.6	-4.4	-2.8	-1.6
S5 – S1	LNG Exports	Tcf	0.0	0.0	0.0	-0.4	2.8	5.6	7.2
S2 – S1	NG Production	% Difference	0.0	1.1	1.3	-0.1	7.0	14.8	16.9
S3 – S1	NG Production	% Difference	0.0	1.1	0.9	0.1	7.5	15.3	18.1
S4 – S1	NG Production	% Difference	0.0	1.1	-3.4	-7.7	-8.0	-3.8	-3.1
S5 – S1	NG Production	% Difference	0.0	0.9	-0.6	-3.0	3.3	8.7	9.0

Scenario	Total U.S. Natural Gas Volumes	Units	2020	2025	2030	2035	2040	2045	2050
S2 – S1	NG Consumption	% Difference	0.0	-0.2	0.0	-0.4	-1.1	0.3	-0.8
S3 – S1	NG Consumption	% Difference	0.0	-0.1	-0.7	-0.6	-1.2	-0.2	-0.9
S4 – S1	NG Consumption	% Difference	0.0	-0.2	2.0	3.4	1.6	1.8	-0.3
S5 – S1	NG Consumption	% Difference	0.0	-0.4	-2.7	-4.9	-6.6	-8.3	-12.3
S2 – S1	LNG Exports	% Difference	0.0	0.0	0.0	-4.2	27.6	56.7	72.7
S3 – S1	LNG Exports	% Difference	0.0	0.0	0.0	-2.9	29.9	60.6	78.3
S4 – S1	LNG Exports	% Difference	0.0	0.0	-35.6	-48.9	-44.3	-27.6	-15.7
S5 – S1	LNG Exports	% Difference	0.0	0.0	0.0	-4.0	27.7	56.1	72.5

*1 Tcf in a non-leap year is equivalent to 2.74 Bcf/d

Table D-5. Total U.S. natural gas production, consumption, and export volumes, S6 and S7, by year (Figure 17)

Scenario	Total U.S. Natural Gas Volumes	Units	2020	2025	2030	2035	2040	2045	2050
S6: Energy Transition (Ref Exp)	NG Production	Tcf	34.1	38.5	35.1	37.6	42.6	47.4	54.7
S7: Energy Transition	NG Production	Tcf	34.1	38.5	35.3	37.1	42.3	48.6	56.5
S6: Energy Transition (Ref Exp)	NG Consumption	Tcf	30.5	32.0	27.4	28.4	30.8	35.0	41.9
S7: Energy Transition	NG Consumption	Tcf	30.5	31.9	27.5	27.9	30.5	34.7	41.5
S6: Energy Transition (Ref Exp)	LNG Exports	Tcf	2.4	4.9	5.4	6.8	9.4	10.0	10.0
S7: Energy Transition	LNG Exports	Tcf	2.4	4.9	5.4	6.8	9.4	11.4	12.3
S7 – S6	NG Production	Tcf	0.0	0.0	0.1	-0.4	-0.3	1.2	1.8
S7 – S6	NG Consumption	Tcf	0.0	0.0	0.1	-0.5	-0.3	-0.3	-0.3
S7 – S6	LNG Exports	Tcf	0.0	0.0	0.0	0.0	0.0	1.5	2.3
S7 – S6	NG Production	% Difference	0.0	-0.1	0.4	-1.1	-0.8	2.4	3.4
S7 – S6	NG Consumption	% Difference	0.0	-0.1	0.5	-1.7	-1.1	-0.9	-0.8
S7 – S6	LNG Exports	% Difference	0.0	0.0	0.0	0.0	0.0	14.8	22.9

*1 Tcf in a non-leap year is equivalent to 2.74 Bcf/d

Table D-6. U.S. natural gas Henry Hub price, S1 through S7, tabulated by year (Figure 18)

Scenario	Units	2020	2025	2030	2035	2040	2045	2050
S1: Reference Exports	$2022/Mcf	2.31	3.63	3.04	3.81	4.08	4.05	3.88
S2: Market Response	$2022/Mcf	2.31	3.70	3.09	3.77	4.50	4.61	5.09
S3: High Global Demand	$2022/Mcf	2.31	3.69	3.06	3.78	4.54	4.65	5.15
S4: Regional Import Limits	$2022/Mcf	2.31	3.68	2.63	3.03	3.52	3.73	4.12
S5: Low-cost Renewables	$2022/Mcf	2.31	3.68	3.00	3.65	4.38	4.41	4.67

Scenario	Units	2020	2025	2030	2035	2040	2045	2050
S2 – S1	$2022/Mcf	0.00	0.07	0.05	-0.04	0.42	0.56	1.22
S3 – S1	$2022/Mcf	0.00	0.07	0.02	-0.03	0.46	0.60	1.27
S4 – S1	$2022/Mcf	0.00	0.06	-0.41	-0.78	-0.56	-0.32	0.24
S5 – S1	$2022/Mcf	0.00	0.06	-0.04	-0.16	0.30	0.37	0.80
S2 – S1	% Difference	0.0	2.0	1.7	-1.1	10.4	13.9	31.4
S3 – S1	% Difference	0.0	1.9	0.5	-0.8	11.4	14.8	32.8
S4 – S1	% Difference	0.0	1.6	-13.5	-20.6	-13.6	-7.9	6.3
S5 – S1	% Difference	0.0	1.6	-1.2	-4.2	7.3	9.0	20.5
S6: Energy Transition (Ref Exp)	$2022/Mcf	2.35	3.80	3.36	4.42	4.67	5.46	6.34
S7: Energy Transition	$2022/Mcf	2.35	3.80	3.42	4.34	4.70	5.40	6.20
S7 – S6	$2022/Mcf	0.00	0.00	0.06	-0.08	0.03	-0.06	-0.14
S7 – S6	% Difference	0.0	0.0	1.8	-1.8	0.6	-1.1	-2.2

Table D-7. U.S. real GDP, S1 through S5, by year (Figure 19)

Scenario	Units	2020	2025	2030	2035	2040	2045	2050
S1: Reference Exports	$2022, Trillion	23.3	25.9	28.4	31.1	34.5	38.2	42.4
S2: Market Response	$2022, Trillion	23.3	25.9	28.4	31.1	34.5	38.3	42.3
S3: High Global Demand	$2022, Trillion	23.3	25.9	28.4	31.1	34.5	38.3	42.3
S4: Regional Import Limits	$2022, Trillion	23.3	25.9	28.4	31.1	34.4	38.2	42.3
S5: Low-cost Renewables	$2022, Trillion	23.3	25.9	28.4	31.1	34.4	38.3	42.3
S2 – S1	$2022, Trillion	0.0	0.0	0.0	0.0	0.0	0.0	-0.1
S3 – S1	$2022, Trillion	0.0	0.0	0.0	0.0	0.0	0.0	-0.1
S4 – S1	$2022, Trillion	0.0	0.0	0.0	0.0	0.0	0.0	-0.1
S5 – S1	$2022, Trillion	0.0	0.0	0.0	0.0	0.0	0.0	-0.1
S2 – S1	% Difference	0.0	0.0	0.0	0.0	0.0	0.1	-0.3
S3 – S1	% Difference	0.0	0.0	0.0	0.0	0.0	0.1	-0.2
S4 – S1	% Difference	0.0	0.0	0.0	0.0	-0.1	0.0	-0.2
S5 – S1	% Difference	0.0	-0.1	0.1	0.0	0.0	0.1	-0.2

Table D-8. U.S. residential natural gas prices, S1 through S5, by year (Figure 20)

Scenario	Units	2020	2025	2030	2035	2040	2045	2050
S1: Reference Exports	$2022/Mcf	12.09	12.58	11.37	11.96	12.33	12.75	12.74

Scenario	Units	2020	2025	2030	2035	2040	2045	2050
S2: Market Response	$2022/Mcf	12.09	12.65	11.41	11.93	12.56	12.69	13.28
S3: High Global Demand	$2022/Mcf	12.09	12.65	11.37	11.91	12.55	12.68	13.28
S4: Regional Import Limits	$2022/Mcf	12.09	12.65	11.12	11.53	12.04	12.64	12.92
S5: Low-cost Renewables	$2022/Mcf	12.09	12.58	11.33	11.83	12.41	12.48	13.00
S2 – S1	$2022/Mcf	0.00	0.06	0.04	-0.03	0.23	-0.06	0.54
S3 – S1	$2022/Mcf	0.00	0.06	-0.01	-0.05	0.23	-0.07	0.54
S4 – S1	$2022/Mcf	0.00	0.06	-0.25	-0.43	-0.29	-0.11	0.18
S5 – S1	$2022/Mcf	0.00	0.00	-0.05	-0.14	0.08	-0.28	0.26
S2 – S1	% Difference	0.0	0.5	0.3	-0.3	1.9	-0.5	4.2
S3 – S1	% Difference	0.0	0.5	-0.1	-0.4	1.8	-0.6	4.2
S4 – S1	% Difference	0.0	0.5	-2.2	-3.6	-2.3	-0.9	1.4
S5 – S1	% Difference	0.0	0.0	-0.4	-1.1	0.7	-2.2	2.0

Table D-9. U.S. value of industrial shipments and real consumption, S1 through S5, by year (Figure 21)

Scenario	Total U.S. Value~~Natural Gas Volumes~~	Units	2020	2025	2030	2035	2040	2045	2050
S1: Reference Exports	Industrial Shipments	$2022, Trillion	11.0	12.0	12.8	13.5	14.3	15.2	16.2
S2: Market Response	Industrial Shipments	$2022, Trillion	11.0	12.0	12.8	13.5	14.4	15.3	16.2
S3: High Global Demand	Industrial Shipments	$2022, Trillion	11.0	12.0	12.8	13.5	14.4	15.3	16.2
S4: Regional Import Limits	Industrial Shipments	$2022, Trillion	11.0	12.0	12.8	13.4	14.3	15.2	16.1
S5: Low-cost Renewables	Industrial Shipments	$2022, Trillion	11.0	12.0	12.8	13.5	14.3	15.3	16.2
S1: Reference Exports	Real Consumption	$2022, Trillion	16.0	18.5	20.8	23.4	26.4	29.8	33.5
S2: Market Response	Real Consumption	$2022, Trillion	16.0	18.4	20.8	23.4	26.4	29.8	33.5
S3: High Global Demand	Real Consumption	$2022, Trillion	16.0	18.4	20.8	23.4	26.4	29.8	33.5
S4: Regional Import Limits	Real Consumption	$2022, Trillion	16.0	18.5	20.8	23.5	26.4	29.8	33.5
S5: Low-cost Renewables	Real Consumption	$2022, Trillion	16.0	18.4	20.8	23.4	26.4	29.8	33.5
S2 – S1	Industrial Shipments	$2022, Trillion	0.0	0.0	0.0	0.0	0.0	0.1	0.0
S3 – S1	Industrial Shipments	$2022, Trillion	0.0	0.0	0.0	0.0	0.0	0.1	0.0
S4 – S1	Industrial Shipments	$2022, Trillion	0.0	0.0	0.0	0.0	-0.1	0.0	-0.1
S5 – S1	Industrial Shipments	$2022, Trillion	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S2 – S1	Real Consumption	$2022, Trillion	0.0	0.0	0.0	0.0	0.0	0.0	-0.1
S3 – S1	Real Consumption	$2022, Trillion	0.0	0.0	0.0	0.0	0.0	0.0	-0.1
S4 – S1	Real Consumption	$2022, Trillion	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Scenario	Total U.S. Value~~Natural Gas Volumes~~	Units	2020	2025	2030	2035	2040	2045	2050
S5 – S1	Real Consumption	$2022, Trillion	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S2 – S1	Industrial Shipments	% Difference	0.0	0.0	0.0	-0.1	0.3	0.7	0.1
S3 – S1	Industrial Shipments	% Difference	0.0	0.0	0.0	-0.1	0.3	0.7	0.2
S4 – S1	Industrial Shipments	% Difference	0.0	0.0	-0.1	-0.2	-0.4	-0.2	-0.4
S5 – S1	Industrial Shipments	% Difference	0.0	-0.1	0.1	-0.2	0.0	0.3	0.0
S2 – S1	Real Consumption	% Difference	0.0	0.0	0.0	0.0	0.0	0.1	-0.2
S3 – S1	Real Consumption	% Difference	0.0	0.0	0.0	0.0	0.0	0.1	-0.2
S4 – S1	Real Consumption	% Difference	0.0	0.0	0.0	0.1	-0.1	0.0	-0.1
S5 – S1	Real Consumption	% Difference	0.0	-0.1	0.1	0.0	0.0	0.1	-0.1

Table D-10. U.S. LNG export revenues, S1 through S5, by year (Figure 22)

Scenario	Units	2020	2025	2030	2035	2040	2045	2050
S1: Reference Exports	$2022, Billion	37.1	25.6	40.3	60.8	69.2	69.8	69.9
S2: Market Response	$2022, Billion	37.1	25.6	40.3	58.8	84.9	106.3	118.3
S3: High Global Demand	$2022, Billion	37.1	25.6	40.5	59.7	86.3	108.4	121.5
S4: Regional Import Limits	$2022, Billion	37.1	26.0	30.6	36.4	40.8	52.2	60.1
S5: Low-cost Renewables	$2022, Billion	37.0	25.5	40.2	58.7	84.5	104.5	115.7
S2 – S1	$2022, Billion	0.0	0.0	0.0	-2.0	15.7	36.6	48.4
S3 – S1	$2022, Billion	-0.1	0.0	0.2	-1.1	17.1	38.6	51.6
S4 – S1	$2022, Billion	0.0	0.4	-9.7	-24.3	-28.4	-17.5	-9.8
S5 – S1	$2022, Billion	-0.1	-0.1	-0.2	-2.1	15.3	34.7	45.8
S2 – S1	% Difference	0.0	0.0	0.0	-3.3	22.6	52.4	69.3
S3 – S1	% Difference	-0.2	0.0	0.5	-1.7	24.7	55.4	73.8
S4 – S1	% Difference	0.0	1.5	-24.0	-40.0	-41.1	-25.1	-14.0
S5 – S1	% Difference	-0.3	-0.4	-0.4	-3.4	22.0	49.8	65.5

Table D-11. Total U.S. CO_2 emissions from fossil fuel combustion, S1 through S5, by year (Figure 23)

Scenario	Units	2020	2025	2030	2035	2040	2045	2050
S1: Reference Exports	Gt CO_2	4.58	4.55	4.00	3.89	3.87	3.89	3.94
S2: Market Response	Gt CO_2	4.58	4.56	4.01	3.89	3.87	3.94	3.97
S3: High Global Demand	Gt CO_2	4.58	4.55	4.02	3.89	3.88	3.94	3.98

Scenario	Units	2020	2025	2030	2035	2040	2045	2050
S4: Regional Import Limits	Gt CO_2	4.58	4.56	3.99	3.90	3.86	3.90	3.93
S5: Low-cost Renewables	Gt CO_2	4.58	4.56	3.91	3.71	3.67	3.62	3.57
S2 – S1	Gt CO_2	0.00	0.00	0.00	0.00	0.00	0.04	0.03
S3 – S1	Gt CO_2	0.00	0.00	0.01	0.00	0.01	0.04	0.04
S4 – S1	Gt CO_2	0.00	0.00	-0.02	0.01	-0.01	0.01	-0.02
S5 – S1	Gt CO_2	0.00	0.01	-0.09	-0.18	-0.21	-0.28	-0.38
S2 – S1	% Difference	0.0	0.0	0.1	0.0	0.0	1.1	0.7
S3 – S1	% Difference	0.0	0.0	0.3	-0.1	0.1	1.1	0.9
S4 – S1	% Difference	0.0	0.1	-0.4	0.3	-0.3	0.3	-0.4
S5 – S1	% Difference	0.0	0.1	-2.3	-4.6	-5.3	-7.1	-9.6

Table D-12. U.S. CO_2 emissions, fossil fuel combustion and removals, S6 and S7, by year (Figure 24)

Scenario	CO_2 Emissions and Removals	Units	2020	2025	2030	2035	2040	2045	2050
S6: Energy Transition (Ref Exp)	Emissions	Gt CO_2	4.58	4.03	3.32	2.80	2.55	2.43	2.37
S7: Energy Transition	Emissions	Gt CO_2	4.58	4.02	3.33	2.80	2.53	2.41	2.35
S6: Energy Transition (Ref Exp)	Removals	Gt CO_2	0.00	0.00	0.05	0.65	1.06	1.49	2.16
S7: Energy Transition	Removals	Gt CO_2	0.00	0.00	0.07	0.60	1.04	1.48	2.13
S7 – S6	Emissions	Gt CO_2	0.00	-0.01	0.01	-0.01	-0.02	-0.02	-0.02
S7 – S6	Removals	Gt CO_2	0.00	0.00	0.02	-0.05	-0.01	-0.01	-0.03
S7 – S6	Emissions	% Difference	0.0	-0.1	0.2	-0.3	-0.8	-0.7	-1.0
S7 – S6	Removals	% Difference	0.0	-1.0	52.1	-8.3	-1.3	-0.7	-1.2

Table D-13. U.S. regional onshore natural gas production, S1 through S5, by year (Figure B-1)

Scenario	Natural Gas Volumes~~U.S. Primary Energy Consumption~~	Units	2020	2025	2030	2035	2040	2045	2050
S1: Reference Exports	East	Tcf	12.0	12.3	13.1	14.3	14.6	15.1	15.5
S1: Reference Exports	Gulf Coast	Tcf	7.0	9.5	9.2	10.5	11.2	11.0	11.0
S1: Reference Exports	Southwest	Tcf	5.1	5.8	6.0	6.4	6.8	7.1	7.4
S1: Reference Exports	Other Onshore	Tcf	8.2	6.9	6.9	6.5	6.6	6.4	6.3
S1: Reference Exports	**Total**	**Tcf**	**32.4**	**34.5**	**35.3**	**37.7**	**39.3**	**39.6**	**40.1**
S2: Market Response	East	Tcf	12.0	12.5	13.3	14.4	15.2	15.7	16.1

Scenario	Natural Gas VolumesU.S. Primary Energy Consumption	Units	2020	2025	2030	2035	2040	2045	2050
S2: Market Response	Gulf Coast	Tcf	7.0	9.6	9.4	10.3	12.6	14.3	15.1
S2: Market Response	Southwest	Tcf	5.1	5.8	6.1	6.4	7.3	8.3	9.1
S2: Market Response	Other Onshore	Tcf	8.2	7.0	7.0	6.6	7.0	7.4	7.5
S2: Market Response	**Total**	**Tcf**	**32.4**	**34.9**	**35.7**	**37.7**	**42.1**	**45.7**	**47.8**
S3: High Global Demand	East	Tcf	12.0	12.5	13.2	14.4	15.1	15.7	16.1
S3: High Global Demand	Gulf Coast	Tcf	7.0	9.6	9.4	10.4	12.8	14.5	15.4
S3: High Global Demand	Southwest	Tcf	5.1	5.8	6.1	6.4	7.3	8.3	9.2
S3: High Global Demand	Other Onshore	Tcf	8.2	7.0	7.0	6.6	7.1	7.4	7.6
S3: High Global Demand	**Total**	**Tcf**	**32.4**	**34.9**	**35.6**	**37.8**	**42.3**	**45.9**	**48.3**
S4: Regional Import Limits	East	Tcf	12.0	12.5	12.7	13.6	14.1	14.7	15.4
S4: Regional Import Limits	Gulf Coast	Tcf	7.0	9.7	8.8	8.9	9.5	10.3	10.6
S4: Regional Import Limits	Southwest	Tcf	5.1	5.8	5.8	5.9	6.1	6.8	7.2
S4: Regional Import Limits	Other Onshore	Tcf	8.2	7.0	6.8	6.3	6.3	6.3	6.1
S4: Regional Import Limits	**Total**	**Tcf**	**32.4**	**34.9**	**34.0**	**34.7**	**36.0**	**38.1**	**39.3**
S5: Low-cost Renewables	East	Tcf	12.0	12.4	12.8	13.6	14.3	14.4	14.2
S5: Low-cost Renewables	Gulf Coast	Tcf	7.0	9.6	9.3	10.1	12.3	13.6	14.4
S5: Low-cost Renewables	Southwest	Tcf	5.1	5.8	6.0	6.4	7.2	8.1	8.7
S5: Low-cost Renewables	Other Onshore	Tcf	8.2	7.0	6.9	6.5	6.9	7.1	7.2
S5: Low-cost Renewables	**Total**	**Tcf**	**32.4**	**34.8**	**35.1**	**36.5**	**40.7**	**43.2**	**44.4**
S2 – S1	East	Tcf	0.0	0.2	0.2	0.0	0.5	0.6	0.6
S2 – S1	Gulf Coast	Tcf	0.0	0.1	0.2	-0.2	1.3	3.3	4.2
S2 – S1	Southwest	Tcf	0.0	0.0	0.0	0.0	0.5	1.2	1.7
S2 – S1	Other Onshore	Tcf	0.0	0.1	0.1	0.1	0.4	1.0	1.2
S2 – S1	**Total**	**Tcf**	**0.0**	**0.4**	**0.5**	**-0.1**	**2.8**	**6.0**	**7.7**
S3 – S1	East	Tcf	0.0	0.2	0.1	0.0	0.5	0.5	0.7
S3 – S1	Gulf Coast	Tcf	0.0	0.1	0.2	-0.1	1.5	3.5	4.4
S3 – S1	Southwest	Tcf	0.0	0.0	0.0	0.0	0.6	1.2	1.7
S3 – S1	Other Onshore	Tcf	0.0	0.1	0.1	0.1	0.5	1.0	1.3
S3 – S1	**Total**	**Tcf**	**0.0**	**0.4**	**0.3**	**0.1**	**3.1**	**6.3**	**8.2**
S4 – S1	East	Tcf	0.0	0.2	-0.4	-0.7	-0.6	-0.4	0.0
S4 – S1	Gulf Coast	Tcf	0.0	0.2	-0.4	-1.5	-1.7	-0.6	-0.3
S4 – S1	Southwest	Tcf	0.0	0.0	-0.3	-0.6	-0.6	-0.3	-0.2

Scenario	Natural Gas VolumesU.S. Primary Energy Consumption	Units	2020	2025	2030	2035	2040	2045	2050
S4 – S1	Other Onshore	Tcf	0.0	0.0	-0.2	-0.2	-0.3	-0.2	-0.2
S4 – S1	**Total**	**Tcf**	**0.0**	**0.4**	**-1.3**	**-3.0**	**-3.2**	**-1.5**	**-0.7**
S5 – S1	East	Tcf	0.0	0.1	-0.3	-0.8	-0.4	-0.7	-1.3
S5 – S1	Gulf Coast	Tcf	0.0	0.1	0.1	-0.3	1.1	2.6	3.5
S5 – S1	Southwest	Tcf	0.0	0.0	0.0	-0.1	0.4	1.0	1.3
S5 – S1	Other Onshore	Tcf	0.0	0.1	0.0	0.0	0.3	0.7	0.9
S5 – S1	**Total**	**Tcf**	**0.0**	**0.3**	**-0.2**	**-1.2**	**1.4**	**3.6**	**4.4**
S2 – S1	East	% Difference	0.0	1.8	1.5	0.2	3.7	3.9	4.0
S2 – S1	Gulf Coast	% Difference	0.0	1.0	1.8	-1.6	11.8	30.1	38.1
S2 – S1	Southwest	% Difference	0.0	0.2	0.4	-0.1	7.9	16.6	22.3
S2 – S1	Other Onshore	% Difference	0.0	0.8	1.2	1.4	6.7	15.3	19.8
S2 – S1	**Total**	**% Difference**	**0.0**	**1.1**	**1.3**	**-0.1**	**7.2**	**15.2**	**19.2**
S3 – S1	East	% Difference	0.0	1.7	0.4	0.2	3.4	3.5	4.3
S3 – S1	Gulf Coast	% Difference	0.0	1.4	2.0	-0.7	13.3	32.0	40.5
S3 – S1	Southwest	% Difference	0.0	0.2	0.2	-0.2	8.3	17.1	23.6
S3 – S1	Other Onshore	% Difference	0.0	0.8	1.1	1.7	7.6	15.8	21.1
S3 – S1	**Total**	**% Difference**	**0.0**	**1.2**	**0.9**	**0.1**	**7.8**	**15.8**	**20.4**
S4 – S1	East	% Difference	0.0	1.4	-3.1	-5.1	-3.8	-2.8	-0.1
S4 – S1	Gulf Coast	% Difference	0.0	2.4	-4.6	-14.6	-15.5	-5.9	-3.0
S4 – S1	Southwest	% Difference	0.0	0.0	-4.3	-8.7	-9.3	-4.0	-3.0
S4 – S1	Other Onshore	% Difference	0.0	0.2	-2.3	-2.7	-4.7	-2.4	-2.7
S4 – S1	**Total**	**% Difference**	**0.0**	**1.2**	**-3.6**	**-8.0**	**-8.3**	**-3.8**	**-1.8**
S5 – S1	East	% Difference	0.0	0.7	-2.1	-5.5	-2.6	-4.8	-8.3
S5 – S1	Gulf Coast	% Difference	0.0	1.4	1.1	-3.3	9.5	23.9	31.5
S5 – S1	Southwest	% Difference	0.0	0.3	-0.2	-1.2	6.1	14.2	16.9
S5 – S1	Other Onshore	% Difference	0.0	1.1	0.0	0.3	4.5	10.6	14.9
S5 – S1	**Total**	**% Difference**	**0.0**	**0.9**	**-0.5**	**-3.2**	**3.5**	**9.0**	**10.9**

*1 Tcf in a non-leap year is equivalent to 2.74 Bcf/d

Table D-14. U.S. regional onshore natural gas production, S6 and S7, by year (Figure B-2)

Scenario	~~U.S. Primary Energy Consumption~~Natural Gas Volumes	Units	2020	2025	2030	2035	2040	2045	2050
S6: Energy Transition (Ref Exp)	East	Tcf	12.5	14.2	12.7	13.7	15.0	17.4	20.6
S6: Energy Transition (Ref Exp)	Gulf Coast	Tcf	6.8	10.1	8.5	9.2	11.6	12.2	13.9
S6: Energy Transition (Ref Exp)	Southwest	Tcf	5.5	5.4	5.4	5.7	6.3	7.1	8.0
S6: Energy Transition (Ref Exp)	Other Onshore	Tcf	8.1	7.5	6.9	6.9	7.5	8.6	9.8
S6: Energy Transition (Ref Exp)	**Total**	**Tcf**	**33.0**	**37.3**	**33.5**	**35.5**	**40.3**	**45.2**	**52.3**
S7: Energy Transition	East	Tcf	12.5	14.2	12.7	13.6	15.0	17.3	20.4
S7: Energy Transition	Gulf Coast	Tcf	6.8	10.2	8.6	9.0	11.3	13.1	15.4
S7: Energy Transition	Southwest	Tcf	5.5	5.4	5.4	5.6	6.3	7.2	8.6
S7: Energy Transition	Other Onshore	Tcf	8.1	7.5	6.9	6.9	7.5	8.7	9.7
S7: Energy Transition	**Total**	**Tcf**	**33.0**	**37.3**	**33.6**	**35.1**	**40.0**	**46.3**	**54.1**
S7 – S6	East	Tcf	0.0	0.0	0.0	-0.1	0.1	-0.1	-0.2
S7 – S6	Gulf Coast	Tcf	0.0	0.0	0.1	-0.2	-0.3	1.0	1.5
S7 – S6	Southwest	Tcf	0.0	0.0	0.0	0.0	0.0	0.2	0.6
S7 – S6	Other Onshore	Tcf	0.0	0.0	0.0	-0.1	0.0	0.1	-0.1
S7 – S6	**Total**	**Tcf**	**0.0**	**0.0**	**0.1**	**-0.4**	**-0.3**	**1.1**	**1.8**
S7 – S6	East	% Difference	0.0	-0.3	0.3	-0.8	0.4	-0.4	-0.9
S7 – S6	Gulf Coast	% Difference	0.0	0.1	1.0	-2.0	-2.7	8.0	10.8
S7 – S6	Southwest	% Difference	0.0	0.0	0.1	-0.5	-0.2	2.2	7.6
S7 – S6	Other Onshore	% Difference	0.0	0.0	-0.1	-1.1	-0.7	0.8	-1.2
S7 – S6	**Total**	**% Difference**	**0.0**	**-0.1**	**0.4**	**-1.1**	**-0.7**	**2.5**	**3.4**

*1 Tcf in a non-leap year is equivalent to 2.74 Bcf/d

Table D-15. U.S. natural gas consumption by sector, S1 through S5, by year (Figure B-3)

Scenario	~~U.S. Primary Energy Consumption~~Natural Gas Volumes	Units	2020	2025	2030	2035	2040	2045	2050
S1: Reference Exports	Electricity	Tcf	11.6	9.7	7.7	6.6	7.2	7.5	7.6
S2: Market Response	Electricity	Tcf	11.6	9.6	7.7	6.6	6.6	6.8	6.7
S3: High Global Demand	Electricity	Tcf	11.6	9.6	7.5	6.5	6.5	6.6	6.6
S4: Regional Import Limits	Electricity	Tcf	11.6	9.6	8.3	7.9	8.0	8.2	7.8
S5: Low-cost Renewables	Electricity	Tcf	11.6	9.5	6.9	5.4	5.1	4.4	3.4
S1: Reference Exports	Industry	Tcf	9.9	10.3	10.9	11.1	11.5	11.8	12.3
S2: Market Response	Industry	Tcf	9.9	10.3	10.9	11.1	11.6	12.1	12.3

Scenario	~~U.S. Primary Energy Consumption~~Natural Gas Volumes	Units	2020	2025	2030	2035	2040	2045	2050
S3: High Global Demand	Industry	Tcf	9.9	10.3	10.9	11.1	11.6	12.1	12.4
S4: Regional Import Limits	Industry	Tcf	9.9	10.3	10.9	11.1	11.5	11.8	12.2
S5: Low-cost Renewables	Industry	Tcf	9.9	10.3	10.9	11.1	11.5	12.0	12.2
S1: Reference Exports	Residential	Tcf	4.7	4.8	4.8	4.8	4.7	4.7	4.7
S2: Market Response	Residential	Tcf	4.7	4.8	4.8	4.8	4.7	4.7	4.7
S3: High Global Demand	Residential	Tcf	4.7	4.8	4.8	4.8	4.7	4.7	4.7
S4: Regional Import Limits	Residential	Tcf	4.7	4.8	4.8	4.8	4.7	4.7	4.7
S5: Low-cost Renewables	Residential	Tcf	4.7	4.8	4.8	4.8	4.7	4.7	4.7
S1: Reference Exports	Commercial	Tcf	3.2	3.4	3.5	3.5	3.5	3.5	3.4
S2: Market Response	Commercial	Tcf	3.2	3.4	3.5	3.5	3.5	3.5	3.4
S3: High Global Demand	Commercial	Tcf	3.2	3.4	3.5	3.5	3.5	3.5	3.4
S4: Regional Import Limits	Commercial	Tcf	3.2	3.4	3.5	3.6	3.5	3.5	3.4
S5: Low-cost Renewables	Commercial	Tcf	3.2	3.4	3.5	3.5	3.5	3.5	3.4
S1: Reference Exports	Transportation	Tcf	1.1	1.2	1.3	1.5	1.6	1.7	1.8
S2: Market Response	Transportation	Tcf	1.1	1.2	1.3	1.5	1.9	2.2	2.5
S3: High Global Demand	Transportation	Tcf	1.1	1.2	1.3	1.5	1.9	2.2	2.5
S4: Regional Import Limits	Transportation	Tcf	1.1	1.2	1.1	1.1	1.2	1.4	1.6
S5: Low-cost Renewables	Transportation	Tcf	1.1	1.2	1.3	1.5	1.8	2.2	2.4
S1: Reference Exports	**Total**	**Tcf**	**30.5**	**29.4**	**28.2**	**27.6**	**28.5**	**29.2**	**29.8**
S2: Market Response	**Total**	**Tcf**	**30.5**	**29.3**	**28.2**	**27.5**	**28.2**	**29.2**	**29.6**
S3: High Global Demand	**Total**	**Tcf**	**30.5**	**29.3**	**28.0**	**27.4**	**28.2**	**29.1**	**29.6**
S4: Regional Import Limits	**Total**	**Tcf**	**30.5**	**29.3**	**28.7**	**28.5**	**29.0**	**29.7**	**29.8**
S5: Low-cost Renewables	**Total**	**Tcf**	**30.5**	**29.2**	**27.4**	**26.2**	**26.6**	**26.7**	**26.2**
S2 – S1	Electricity	Tcf	0.0	-0.1	0.0	-0.1	-0.6	-0.7	-0.9
S3 – S1	Electricity	Tcf	0.0	0.0	-0.2	-0.1	-0.6	-0.9	-1.0
S4 – S1	Electricity	Tcf	0.0	-0.1	0.7	1.2	0.8	0.8	0.2
S5 – S1	Electricity	Tcf	0.0	-0.2	-0.8	-1.3	-2.1	-3.0	-4.2
S2 – S1	Industry	Tcf	0.0	0.0	0.0	0.0	0.0	0.3	0.0
S3 – S1	Industry	Tcf	0.0	0.0	0.0	0.0	0.0	0.3	0.0
S4 – S1	Industry	Tcf	0.0	0.0	0.0	0.0	-0.1	0.0	-0.1
S5 – S1	Industry	Tcf	0.0	0.1	0.0	0.0	0.0	0.1	-0.1
S2 – S1	Residential	Tcf	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Scenario	~~U.S. Primary Energy Consumption~~Natural Gas Volumes	Units	2020	2025	2030	2035	2040	2045	2050
S3 – S1	Residential	Tcf	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S4 – S1	Residential	Tcf	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S5 – S1	Residential	Tcf	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S2 – S1	Commercial	Tcf	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S3 – S1	Commercial	Tcf	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S4 – S1	Commercial	Tcf	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S5 – S1	Commercial	Tcf	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S2 – S1	Transportation	Tcf	0.0	0.0	0.0	0.0	0.3	0.5	0.7
S3 – S1	Transportation	Tcf	0.0	0.0	0.0	0.0	0.3	0.6	0.7
S4 – S1	Transportation	Tcf	0.0	0.0	-0.2	-0.4	-0.4	-0.2	-0.1
S5 – S1	Transportation	Tcf	0.0	0.0	0.0	0.0	0.2	0.5	0.7
S2 – S1	**Total**	**Tcf**	**0.0**	**-0.1**	**0.0**	**-0.1**	**-0.3**	**0.1**	**-0.2**
S3 – S1	**Total**	**Tcf**	**0.0**	**0.0**	**-0.2**	**-0.2**	**-0.4**	**0.0**	**-0.3**
S4 – S1	**Total**	**Tcf**	**0.0**	**-0.1**	**0.6**	**0.9**	**0.4**	**0.5**	**-0.1**
S5 – S1	**Total**	**Tcf**	**0.0**	**-0.1**	**-0.8**	**-1.3**	**-1.9**	**-2.4**	**-3.7**
S2 – S1	Electricity	% Difference	0.0	-0.5	-0.2	-1.3	-8.3	-9.1	-11.5
S3 – S1	Electricity	% Difference	0.0	-0.3	-2.5	-2.1	-9.0	-11.4	-13.0
S4 – S1	Electricity	% Difference	0.0	-0.6	8.8	18.6	11.4	10.4	2.6
S5 – S1	Electricity	% Difference	0.0	-1.8	-9.9	-19.3	-29.0	-40.8	-55.0
S2 – S1	Industry	% Difference	0.0	0.1	0.1	-0.1	0.4	2.1	0.1
S3 – S1	Industry	% Difference	0.0	0.1	0.1	-0.1	0.3	2.2	0.2
S4 – S1	Industry	% Difference	0.0	0.1	0.2	0.0	-0.5	-0.4	-1.1
S5 – S1	Industry	% Difference	0.0	0.6	0.0	-0.3	-0.4	1.0	-1.0
S2 – S1	Residential	% Difference	0.0	-0.1	-0.1	0.1	-0.2	-0.2	-0.6
S3 – S1	Residential	% Difference	0.0	-0.1	0.0	0.1	-0.2	-0.1	-0.6
S4 – S1	Residential	% Difference	0.0	-0.1	0.3	0.6	0.4	0.1	-0.1
S5 – S1	Residential	% Difference	0.0	0.0	0.0	0.2	-0.1	0.0	-0.4
S2 – S1	Commercial	% Difference	0.0	-0.1	-0.1	0.1	-0.5	-0.5	-1.3
S3 – S1	Commercial	% Difference	0.0	-0.1	0.0	0.2	-0.5	-0.4	-1.3
S4 – S1	Commercial	% Difference	0.0	-0.1	0.6	1.2	0.8	0.2	-0.4
S5 – S1	Commercial	% Difference	0.0	0.0	0.0	0.3	-0.1	0.1	-0.6
S2 – S1	Transportation	% Difference	0.0	-0.2	0.2	-1.9	16.0	31.9	38.7

Scenario	~~U.S. Primary Energy Consumption~~Natural Gas Volumes	Units	2020	2025	2030	2035	2040	2045	2050
S3 – S1	Transportation	% Difference	0.0	-0.1	0.2	-1.1	17.5	33.9	42.2
S4 – S1	Transportation	% Difference	0.0	-0.1	-14.6	-24.6	-22.5	-13.6	-7.3
S5 – S1	Transportation	% Difference	0.0	-0.4	-0.9	-2.9	14.7	29.6	36.6
S2 – S1	**Total**	**% Difference**	**0.0**	**-0.2**	**0.0**	**-0.4**	**-1.1**	**0.3**	**-0.8**
S3 – S1	**Total**	**% Difference**	**0.0**	**-0.1**	**-0.7**	**-0.6**	**-1.2**	**-0.2**	**-0.9**
S4 – S1	**Total**	**% Difference**	**0.0**	**-0.2**	**2.0**	**3.4**	**1.6**	**1.8**	**-0.3**
S5 – S1	**Total**	**% Difference**	**0.0**	**-0.4**	**-2.7**	**-4.9**	**-6.6**	**-8.3**	**-12.3**

*1 Tcf in a non-leap year is equivalent to 2.74 Bcf/d

Table D-16. U.S. sectoral natural gas consumption by sector, S6 and S7, by year (Figure B-4)

Scenario	~~U.S. Primary Energy Consumption~~Natural Gas Volumes	Units	2020	2025	2030	2035	2040	2045	2050
S6: Energy Transition (Ref Exp)	Electricity	Tcf	11.6	12.9	8.3	5.7	5.0	5.7	6.5
S7: Energy Transition	Electricity	Tcf	11.6	12.8	8.5	5.9	5.0	5.7	6.6
S6: Energy Transition (Ref Exp)	Industry	Tcf	10.1	10.5	10.6	15.4	18.8	22.3	28.2
S7: Energy Transition	Industry	Tcf	10.1	10.5	10.6	14.7	18.4	22.0	27.8
S6: Energy Transition (Ref Exp)	Residential	Tcf	4.7	4.6	4.6	4.0	3.8	3.8	3.7
S7: Energy Transition	Residential	Tcf	4.7	4.6	4.5	4.0	3.8	3.8	3.7
S6: Energy Transition (Ref Exp)	Commercial	Tcf	3.2	3.2	3.2	2.5	2.4	2.3	2.3
S7: Energy Transition	Commercial	Tcf	3.2	3.2	3.1	2.5	2.4	2.3	2.3
S6: Energy Transition (Ref Exp)	Transportation	Tcf	0.9	0.8	0.8	0.8	0.9	1.0	1.1
S7: Energy Transition	Transportation	Tcf	0.9	0.8	0.8	0.8	0.8	1.0	1.1
S6: Energy Transition (Ref Exp)	**Total**	**Tcf**	**30.5**	**32.0**	**27.4**	**28.4**	**30.8**	**35.0**	**41.9**
S7: Energy Transition	**Total**	**Tcf**	**30.5**	**31.9**	**27.5**	**27.9**	**30.5**	**34.7**	**41.5**
S7 – S6	Electricity	Tcf	0.0	0.0	0.2	0.2	0.1	0.0	0.1
S7 – S6	Industry	Tcf	0.0	0.0	0.0	-0.6	-0.4	-0.3	-0.4
S7 – S6	Residential	Tcf	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S7 – S6	Commercial	Tcf	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S7 – S6	Transportation	Tcf	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S7 – S6	**Total**	**Tcf**	**0.0**	**0.0**	**0.1**	**-0.5**	**-0.3**	**-0.3**	**-0.3**
S7 – S6	Electricity	% Difference	0.0	-0.4	2.0	3.1	1.4	-0.1	1.4
S7 – S6	Industry	% Difference	0.0	0.0	0.1	-4.1	-2.0	-1.3	-1.4
S7 – S6	Residential	% Difference	0.0	0.0	-0.4	-0.1	-0.3	-0.2	-0.3

Scenario	~~U.S. Primary Energy Consumption~~Natural Gas Volumes	Units	2020	2025	2030	2035	2040	2045	2050
S7 – S6	Commercial	% Difference	0.0	0.0	-0.5	-0.4	-0.5	-0.5	-0.4
S7 – S6	Transportation	% Difference	0.0	0.4	0.1	-1.1	-0.3	-0.7	0.3
S7 – S6	**Total**	**% Difference**	**0.0**	**-0.1**	**0.5**	**-1.7**	**-1.1**	**-0.9**	**-0.8**

*1 Tcf in a non-leap year is equivalent to 2.74 Bcf/d

Table D-17. U.S. ~~regional~~ natural gas consumption for DAC, S6 and S7, by year (Figure B-5)

Scenario	Units	2020	2025	2030	2035	2040	2045	2050
S6: Energy Transition (Ref Exp)	Tcf	0.0	0.0	0.0	4.7	7.8	11.2	16.8
S7: Energy Transition	Tcf	0.0	0.0	0.0	4.1	7.5	10.7	16.2
S7 – S6	Tcf	0.0	0.0	0.0	-0.6	-0.4	-0.5	-0.7
S7 – S6	% Difference	0.0	0.0	0.0	-13.0	-4.5	-4.1	-4.0

*1 Tcf in a non-leap year is equivalent to 2.74 Bcf/dTable D-1

Table D-18. U.S. CO_2 removals by technology, S6 and S7, by year (Figure B-6)

Scenario	~~U.S. Primary Energy Consumption~~CO_2 Removals	Units	2020	2025	2030	2035	2040	2045	2050
S6: Energy Transition (Ref Exp)	H_2 Biomass	Gt CO_2	0.00	0.00	0.03	0.08	0.12	0.17	0.20
S6: Energy Transition (Ref Exp)	BECCS	Gt CO_2	0.00	0.00	0.02	0.03	0.04	0.04	0.04
S6: Energy Transition (Ref Exp)	DAC	Gt CO_2	0.00	0.00	0.00	0.54	0.90	1.28	1.93
S6: Energy Transition (Ref Exp)	**Total**	Gt CO_2	**0.00**	**0.00**	**0.05**	**0.65**	**1.06**	**1.49**	**2.16**
S7: Energy Transition	H_2 Biomass	Gt CO_2	0.00	0.00	0.05	0.09	0.14	0.21	0.24
S7: Energy Transition	BECCS	Gt CO_2	0.00	0.00	0.02	0.04	0.04	0.04	0.04
S7: Energy Transition	DAC	Gt CO_2	0.00	0.00	0.00	0.47	0.86	1.23	1.85
S7: Energy Transition	**Total**	Gt CO_2	**0.00**	**0.00**	**0.07**	**0.60**	**1.04**	**1.48**	**2.13**
S7 – S6	H_2 Biomass	Gt CO_2	0.00	0.00	0.02	0.01	0.02	0.03	0.04
S7 – S6	BECCS	Gt CO_2	0.00	0.00	0.00	0.00	0.01	0.01	0.01
S7 – S6	DAC	Gt CO_2	0.00	0.00	0.00	-0.07	-0.04	-0.05	-0.08
S7 – S6	**Total**	Gt CO_2	**0.00**	**0.00**	**0.02**	**-0.05**	**-0.01**	**-0.01**	**-0.03**
S7 – S6	H_2 Biomass	% Difference	0.0	-1.0	79.1	19.1	15.5	20.4	21.6
S7 – S6	BECCS	% Difference	0.0	0.0	15.0	5.5	18.7	18.4	18.8
S7 – S6	DAC	% Difference	0.0	0.0	0.0	-13.0	-4.5	-4.1	-4.0
S7 – S6	**Total**	**% Difference**	**0.0**	**-1.0**	**52.1**	**-8.3**	**-1.3**	**-0.7**	**-1.2**

ENERGY, ECONOMIC, AND ENVIRONMENTAL ASSESSMENT OF U.S. LNG EXPORTS

FINAL REVIEW DRAFT September 5, 2023

Prepared for:

Office of Resource Sustainability
U.S. Department of Energy — Fossil Energy and Carbon Management

Prepared by:

OnLocation, Inc.
501 Church St NE, Suite 300
Vienna, VA 22180

Joint Global Change Research Institute
Pacific Northwest National Laboratory
5825 University Research Ct
College Park, MD 20740

National Energy Technology Laboratory
Department of Energy
3610 Collins Ferry Road
Morgantown, WV 26505

Table of Contents

I. Executive Summary 1
II. Background on LNG Export Studies Commissioned by Department of Energy....5
III. Introduction 7
A. Project Background....7
B. Purpose of Study....7
C. Organization of the Report 9
IV. Scenarios, Methodology, and Key Assumptions 10
A. GCAM Model and Global Scenarios Design 10
B. NEMS Models and Analysis Methodology 14
1. AEO2023-NEMS 14
2. FECM-NEMS....14
3. Harmonizing GCAM and NEMS....15
C. NETL Life Cycle Analysis Model Methodology 16
1. Past NETL Natural Gas Life Cycle Reports....17
2. Market Adjustment Factors....20
V. Results....21
A. U.S. LNG exports....21
B. Global Natural Gas Consumption, Production, and Trade Under Scenarios *S1* And *S2*....22
C. Global Primary Energy Consumption by Fuel and GHG Emissions by Sector Under *S6* And *S7*....25
D. Global Natural Gas Consumption, Production, and Trade Under Scenarios *S6* and *S7*....28
E. Global Primary Energy Consumption and GHG Emissions Across All Scenarios....32
F. NEMS Analysis: Implications for U.S. Energy Systems....33
1. Energy Impacts 33
2. Natural Gas Production and Consumption Impacts 34
3. Natural Gas Henry Hub Prices Impacts....37
4. U.S. Macroeconomic Outcomes 38
5. U.S. GHG Results....42
G. NETL Life Cycle Analysis....43
1. Assessment of NEMS Domestic Natural Gas Production by Region....44
2. Comparison of GCAM and NETL Estimates of GHG Emissions of the Natural Gas sector 44
3. Market Adjustment Factor Results....46
4. Interpretation of Market Adjustment Factor Results....47

VI. Conclusions 47
Appendix A: Global Analysis and Description of GCAM.....50
A. Additional detail about GCAM's energy system 50
B. Additional detail about scenario design 51
C. Additional GCAM results.....52
Appendix B: U.S. Analysis and Description of AEO2023-NEMS and FECM-NEMS 56
A. Modeling U.S. LNG exports.....56
B. Additional detail on U.S. natural gas markets 57
1. Regional natural gas production.....57
2. Natural gas consumption by economic sector.....58
C. CO_2 removal technologies and carbon prices in FECM-NEMS.....63
Appendix C: Supporting LCA Analysis 65
A. NEMS and NETL LCA model comparison 65
B. Global Change Assessment Model – data inputs to LCA 69
C. GCAM and NETL emissions intensity comparison 70
1. Market Adjustment Factors for other IPCC GWP Values.....75
Appendix D: Tabulated Values from Figures 83

List of Figures

Figure ES-1. U.S. LNG exports across the scenarios explored in this study. 4
Figure 1. U.S. GHG emissions and removals in the net-zero scenarios 16
Figure 2. Life cycle GHG emissions from the 2020 U.S. average Natural Gas supply chain, HHV basis.....19
Figure 3. U.S. LNG exports across the scenarios. 21
Figure 4 Natural gas consumption, production, and trade by region.....23
Figure 5. Changes in natural gas consumption, production, and trade by region in S2 vs. S1 24
Figure 6. Global primary energy consumption by fuel and GHG emissions by sector under S2 and S1.....25
Figure 7. Global primary energy consumption by fuel and GHG emissions by sector under S6 and S7.....26
Figure 8. Changes in global primary energy consumption and GHG emissions under S6 and S7.....27
Figure 9. CDR deployment by type and region in S6 and S7.....28
Figure 10. Natural gas consumption, production, consumption, and trade by region under S6 and S7....29
Figure 11. Changes in natural gas consumption, production, and trade by region: S6 vs S1 and S7 vs S2 30
Figure 12. Changes in natural gas markets in S7 vs. S6 31
Figure 13. Primary energy consumption by fuel and GHG emissions by sector under all scenarios.....32
Figure 14. U.S. primary energy consumption, S1 through S5.....33
Figure 15. U.S. primary energy consumption S6 and S7.....34
Figure 16. Total U.S. natural gas production, consumption, and export volumes over time, by scenario.35

Figure 17. Total U.S. natural gas production, consumption, and export volumes, net-zero scenarios 36
Figure 18. Total U.S. natural gas Henry Hub price by scenario ($2022) 37
Figure 19. U.S. real GDP changes 38
Figure 20. U.S. residential natural gas prices 39
Figure 21. U.S. value of industrial shipments and real consumption 40
Figure 22. U.S. LNG export revenues 41
Figure 23. Total U.S. CO_2 emissions from fossil fuel combustion 42
Figure 24. Total U.S. CO_2 emissions from fossil fuel combustion and removals, S6 and S7 43
Figure 25. Mapping of NETL natural gas stages to GCAM sectors 45

Appendix A Figures

Figure A-1. Global natural gas consumption by sector across all scenarios 52
Figure A-2. Global natural gas consumption by region across all scenarios 52
Figure A-3. Global natural gas production by region across all scenarios 53
Figure A-4. Global LNG exports by region across all scenarios 53
Figure A-5. Global LNG imports by region across all scenarios 54
Figure A-6. Global primary energy consumption by fuel across all scenarios 54
Figure A-7. Global GHG emissions by sector across all scenarios 55

Appendix B Figures

Figure B-1. U.S. Regional Natural gas production, S1 through S5 57
Figure B-2. U.S. regional natural gas production in S6 and S7 58
Figure B-3. U.S. natural gas consumption by sector, S1 through S5 59
Figure B-4. U.S. natural gas consumption by sector, net-zero scenarios 61
Figure B-5. Natural gas consumed for DAC, net-zero scenarios 62
Figure B-6. U.S. CO_2 emissions and removals, net-zero scenarios 63

Appendix C Figures

Figure C-1. Dry NG production percentage time-series for each region 68
Figure C-2. Estimated U.S. Average GHG Intensity (g CO_2e/MJ) (S1 through S7), ...69

List of Tables

Table 1. Previous Studies 5
Table 2. Scenario Descriptions 13
Table 3. Natural Gas and Liquefied Natural Gas Life Cycle Stages 17
Table 4. Market Adjustment Factors for S2 vs. S1 46
Table 5. Market Adjustment Factors for S7 vs. S6 46
Table 6. Key Results for U.S. and globe in 2050 across scenarios 49
Table A-1. Detailed assumptions in the S4: Regional Import Limits scenario 51
Table B-1. DAC technology assumptions in FECM-NEMS 64

Table C-1. Matching NEMS (OGMP States) to NETL states and subsequently regions..............................65
Table C-2 Regional dry production (trillion cubic feet) between 2020 and 2050, S1 67
Table C-3 Regional dry production ratio, S1 67
Table C-4. Regional GHG Intensities (g CO_2e/MJ) from 2020 NETL Natural Gas Report............................68
Table C-5. Provided set of GCAM Data Documentation 69
Table C-6. LCA Stage Cross-Mapping 71
Table C-7. GCAM Emissions Intensities for Sectors (S1, 2020, USA region, AR6-100 basis) 72
Table C-8. GCAM Emissions Intensities for Sectors (S1, 2020, USA region, AR6-20 basis) 73
Table C-9. GCAM Emissions Intensities for Sectors (S1, 2020, USA region, AR5-100 basis) 74
Table C-10. GCAM Emissions Intensities for Sectors (S1, 2020, USA region, AR5-20 basis) 74
Table C-11. GWP Values used in this analysis..75
Table C-12. NETL-adjusted MAF results for S2 75
Table C-13 NETL-adjusted MAF results for S7 76
Table C-14. Annual Export Volumes of US LNG and Adjusted Global CO_2 Emissions (IPCC AR6, 100-yr GWP)..76
Table D-1. U.S. GHG emissions and removals scenarios S6 and S7, by year (Figure 1) 83
Table D-2. U.S. primary energy consumption, S1 through S5, tabulated by year (Figure 14) 83
Table D-3. U.S. primary energy consumption, S6 and S7, by year (Figure 15) 84
Table D-4. Total U.S. natural gas production, consumption, and export volumes, S1 through S5, by year (Figure 16) 85
Table D-5. Total U.S. natural gas production, consumption, and export volumes, S6 and S7, by year (Figure 17) 85
Table D-6. U.S. natural gas Henry Hub price, S1 through S7, tabulated by year (Figure 18)......................86
Table D-7. U.S. real GDP, S1 through S5, by year (Figure 19) 86
Table D-8. U.S. residential natural gas prices, S1 through S5, by year (Figure 20) 86
Table D-9. U.S. value of industrial shipments and real consumption, S1 through S5, by year (Figure 21).87
Table D-10. U.S. LNG export revenues, S1 through S5, by year (Figure 22) 87
Table D-11. Total U.S. CO_2 emissions from fossil fuel combustion, S1 through S5, by year (Figure 23).....87
Table D-12. U.S. CO_2 emissions, fossil fuel combustion and removals, S6 and S7, by year (Figure 24)......88
Table D-13. U.S. regional onshore natural gas production, S1 through S5, by year (Figure B-1) 88
Table D-14. U.S. regional onshore natural gas production, S6 and S7, by year (Figure B-2) 89
Table D-15. U.S. natural gas consumption by sector, S1 through S5, by year (Figure B-3) 89
Table D-16. U.S. sectoral natural gas consumption by sector, S6 and S7, by year (Figure B-4) 91
Table D-17. U.S. regional natural gas consumption for DAC, S6 and S7, by year (Figure B-5)....................91
Table D-18. U.S. CO_2 removals by technology, S6 and S7, by year (Figure B-6) 91

Acronyms and Abbreviations

AEO	Annual Energy Outlook
BECCS	Bioenergy with carbon capture and storage
Bcf	Billion cubic feet
BIL	Bipartisan Infrastructure Law
BP	British Petroleum
BTU	British Thermal Unit
CCS	Carbon capture and storage
CCUS	Carbon capture, utilization, and storage
CDR	Carbon dioxide removal
CH_4	Methane
CO_2	Carbon dioxide
DAC	Direct air capture
DOE	Department of Energy
EIA	Energy Information Administration
EJ	Exajoule (10^{18} joules)
EPA	Environmental Protection Agency
EU	European Union
FECM	Fossil Energy and Carbon Management
GHG	Greenhouse gas
GCAM	Global Change Analysis Model
GNGM	Global Natural Gas Model
Gt	Gigaton
GWP	Global warming potential
HMM	Hydrogen Market Module
IPCC	Intergovernmental Panel on Climate Change
ITC	Investment tax credit
IRA	Inflation Reduction Act
Kwhr	Kilowatt-hour

Commented [PW1]: Deleted CAFE, as per AA

LHV Lower heating value

LNG Liquefied natural gas

LULUCF Land use, land use change, and forestry

MAF Market Adjustment Factor

Mcf Million cubic feet

MJ Megajoule

MMT Million metric Tons

NERA NERA Economic Consulting

NEMS National Energy Modeling System

NETL National Energy Technology Laboratory

NGA Natural Gas Act

NGP Natural gas processing

NHTSA National Highway Traffic Safety Administration

NREL National Renewable Energy Laboratory

N2O Nitrous oxide

OGSM Oil and Gas Supply Module

OPEX Operating Expenses

PNNL Pacific Northwest National Laboratory

PTC Production tax credit

S&P Standard & Poor's

Tcf Trillion cubic feet

Tg Teragram (10^{12} grams)

I. Executive Summary

The Department of Energy (DOE) is responsible for authorizing exports of U.S. natural gas, including liquefied natural gas (LNG), to foreign countries pursuant to section 3 of the Natural Gas Act (NGA), 15 U.S.C. 717b. Under the NGA provisions, applications requesting authority for the import or export of natural gas, including LNG, from and to a nation with which there is in effect a free trade agreement (FTA) requiring national treatment for trade in natural gas, and/or the import of LNG from other international sources, are deemed consistent with the public interest and granted without modification or delay. For authorizations relating to those countries with which the United States does not have such an FTA, then pursuant to Section 3(a) of the NGA, DOE is required to grant a permit to export domestically produced natural gas unless it finds that such action is not consistent with the public interest.

To inform its public interest determination, since 2012, the Office of Fossil Energy and Carbon Management (DOE-FECM) and its predecessor, the Office of Fossil Energy, has commissioned five studies to assess the effects of different levels of LNG exports on the U.S. economy and energy markets. This sixth updated study, like the previous ones, will serves as an input to be considered in the evaluation of applications to export LNG from the United States under Section 3 of the NGA.

The purpose of this latest study is to examine the potential global and U.S. energy system and greenhouse gas (GHG) emissions implications of a wide range of economic levels of U.S. LNG exports. The study was comprised of three coordinated analyses: 1) **a Global Analysis** to explore a wide range of scenarios of U.S. LNG exports under alternative assumptions about future population and economic growth, regional preferences for domestically produced natural gas, pace of technological change in competing technologies (e.g. renewables), and countries' announced GHG emissions pledges and policies; 2) **a U.S. Domestic Analysis** of the implications of the various U.S. LNG export levels derived from the Global Analysis for the supply and demand of natural gas within the U.S. and the U.S. economy; and 3) **a Life Cycle Analysis** to examine the life cycle emissions implications of the various levels of U.S. LNG exports derived from the Domestic and Global analyses.

As part of the **Global Analysis,** DOE-FECM explored seven scenarios spanning a range of plausible U.S. LNG export outcomes by 2050 using the Pacific Northwest National Laboratory's Global Change Analysis Model (GCAM). GCAM is a model of global energy, economy, agriculture, land use, water, and climate systems with regional detail in 32 geopolitical regions. This includes major economies as single-country regions (e.g., U.S., Canada, China, India, Russia). The seven scenarios explored in this study are shown in Table ES-1.

Commented [TC2]: Let's add a paragraph on general limitations on modeling, consistent with the discussion at and following the leadership briefing. The Exec Summary should have a summary of caveats and the introduction should have a broader discussion.

Commented [TC3]: Global comments:
-The report needs an edit to improve consistency of voice.
-Make sure there is consistency in units. Consistent report units. GCAM uses EJ and NEMS is quads (quadrillion Btu). 1 quad = 1.-5506 EJ
a.There is a mix in the report currently.
i.Primary Energy: quads and EJ
ii.Gas production/Exports/Imports: Tcf and Bcf/day
iii.GHG emissions: Gigatonnes (metric tons), MMT (million metric tons)
iv.LCA/GHG: grams per megajoule
b.Recommend energy and mass be in metric units and volume (of gaseous natural gas) be reported in English units of cubic feet (industry standard convention).
-Move away from qualitative descriptions like "modest" or "small" and toward quantitative information with context for the reader to make a qualitative assessment.
-Include detailed data that can be used by the reader to understand figures in new appendices.
-In general, the report would benefit from more discussion of why the trends or results we are seeing are consistent with expectations. For example, making comments about US prices increasing in response to increased demand for natural gas.
-As we are developing responses to the IA and GC comments in separate documents, we should look to add context to this report.

Commented [LBD4]: I'm not familiar with "growth" as a noun modified by this word... if this is meant to mean both population growth and economic growth, suggest saying both. Or maybe it's just "economic growth"?

Commented [IGC5R4]: It refers to population and economic growth.

Table ES-1. Scenario Descriptions

Scenario	Description	U.S. LNG Export Volumes (Bcf/d)
***S1*: Reference Exports**	U.S. LNG exports follow Energy Information Administration's (EIA's) 2023 Annual Energy Outlook (AEO). Incorporates U.S. policy assumptions (including the 2022 Inflation Reduction Act). Assumes existing policies and measures, globally.	Grows to 27.3 Bcf/d by 2050
***S2*: Market Response**	Assumes policies consistent with *S1*, but U.S. LNG exports are determined by global market equilibrium.	GCAM Market Response
***S3*: High Global Demand**	Same assumptions as *S2*, U.S. LNG exports determined by global market equilibrium, but assumes higher population growth outside of the U.S.	
***S4*: Regional Import Limits**	Same assumptions as *S2*, U.S. LNG exports determined by global market equilibrium, but includes constraints on importing and exporting natural gas with a global focus to maximize use of domestic gas.	
***S5*: Low-cost Renewables**	Same assumptions as *S2*, U.S. LNG exports determined by global market equilibrium, but assumes lower capital costs for renewable energy technologies.	
***S6*: Energy Transition (Ref Exp)**	Assumes an emissions pathway consistent with a global temperature change of 1.5°C by end of century. Countries' emissions are constrained to announced GHG pledges, including the U.S. following a path to net-zero GHG emissions by 2050. NEMS follows CO_2 emissions constraint from GCAM. U.S. LNG exports are limited to the values from the AEO 2023 Reference scenario.	Grows to 27.3 Bcf/d by 2050
***S7*: Energy Transition**	Same emissions pathway assumptions as *S6*, but U.S. LNG exports are determined by global market equilibrium.	GCAM Market Response

Commented [UP6]: Do we have to show by 2 digits in 2050? EIA's TIE article for example rounds to just 1-digit showing 27.3 Bcf/d which prob is better. https://www.eia.gov/todayinenergy/detail.php?id=56600

Commented [PW7R6]: Revised, thank you.

Commented [UP8]: S6 has a different background color than the other sections of the table? Also on the third column why is GCAM Market Response "white background" for S2-S5 but then "blue" for S7?

All of the scenarios include representations of the 2022 Inflation Reduction Act (IRA) in the U.S. and existing emission policies in the rest of the world. The scenarios also include a constraint on Russian exports. The modeling and analysis for this report was completed by August 2023.

The **U.S. Domestic Analysis** was conducted using the National Energy Modeling System (NEMS). U.S. LNG exports (for all scenarios except *S1*) and CO_2 emissions (in scenarios *S6* and *S7*) used in NEMS were harmonized to values from GCAM. NEMS was then used to explore the implications of the seven global scenarios on domestic gas prices, the energy system, and the macro-economy within the U.S.

Finally, the **Life Cycle Analysis** of natural gas used for export was enhanced by comparing the results provided from the domestic and global analyses to previously completed National Energy Technology Laboratory (NETL) studies of the natural gas life cycle. GCAM results were assessed against existing DOE life cycle studies of natural gas and aligned to have the same GHG intensity for the purposes of consistency. The main results of this analysis were a series of estimated market adjustment factors that supplement the previous life cycle analyses and better represent the total global change in emissions per unit of U.S. LNG exported.

A number of key insights emerged from this study:

1. Across all modeled scenarios, U.S. LNG exports and U.S. natural gas production increase beyond current levels through 2050 (Figure ES-1). In these scenarios, U.S. LNG exports range from 23 to 49 Bcf/day. The range of U.S. LNG exports from this study is consistent with the U.S. EIA's analysis (15-48 Bcf/day).[1]
2. Global natural gas consumption increases by less than 1% under a scenario with increased availability of U.S. natural gas in the global market that reflects economically-driven LNG export levels (S2) compared to the reference scenario (S1). Most of the additional U.S. natural gas substitutes for other global sources of natural gas.
3. By 2050, U.S. natural gas prices as measured at the Henry Hub increase when comparing a scenario that reflects global market demand for exports (S2) to the reference scenario (S1). Across those scenarios, 2050 Henry Hub prices are projected to increase from $3.88/Mcf to $5.09/Mcf ($2022), both of which are less than the reference 2050 price expected in the most recent study commissioned on the economic impacts from U.S. LNG exports in 2018. While LNG export profiles were different, natural gas prices in S2 were comparable to the "Fast Builds Plus High LNG Price" scenario ($4.98/Mcf).
4. U.S. residential prices are projected to be 4% higher in 2050 when comparing a scenario that reflects global market demand for exports (S2) to the reference scenario (S1).
5. The value of industrial shipments remains essentially unchanged (increasing less than 0.1% by 2050) under a scenario that reflects global market demand for exports (S2) compared to the reference scenario (S1). The impact of increased LNG exports on GDP is essentially flat: positive by less than 0.1% across scenarios through 2045 while all changes are within 0.3% in 2050.
6. Global and U.S. GHG emissions do not change appreciably across the scenarios with current climate policy assumptions (S2 to S5) even though these scenarios vary widely in terms of U.S.

Commented [UP9]: Should "economically driven" have a hyphen or not? We seem to sometimes hyphenate it and sometimes not. I added hyphens but can be reversed.

Commented [IGC10R9]: I am OK with economically-driven, with the hyphen.

Commented [ZA11]: Is a 30% price increase modest?

Commented [LBD12]: Hard to describe as a "modest" increase, if in constant dollars. The increase is almost 1/3.

Commented [PW13R12]: Removed.

Commented [LBD14]: Suggest specify real or current dollars

Commented [PW15R14]: Added constant dollrs

Commented [AA16]: Just FYI for tech writer: Previous references were not italicized.

[1] U.S. EIA. (2023). Issues in Focus: Effects of Liquefied Natural Gas Exports on the U.S. Natural Gas. Available at: Markethttps://www.eia.gov/outlooks/aeo/IIF_LNG/

LNG export outcomes. In these scenarios, global net GHG emissions range from 47.5-50.3 GtCO2e and U.S. emissions range from 4.3-4.6 Gt CO_2e.

7. The induced global market effects per unit of increased U.S. LNG exports in a scenario that reflects global market demand for exports (S2) compared to the reference scenario (S1) are equivalent to an overall reduction in GHG emissions that is about 70% of the estimated upstream emissions associated with production through delivery of the natural gas through the transmission system in the U.S.
8. Relative to the other scenarios, the scenarios in which countries are assumed to achieve GHG emissions pledges and pursue ambitious GHG mitigation policies (S6 and S7) are characterized by lower energy consumption; lower fossil fuel consumption without carbon capture, utilization, and storage (CCUS); higher deployment of renewables and fossil fuels and biomass with CCUS; and higher deployment of carbon dioxide removal strategies.

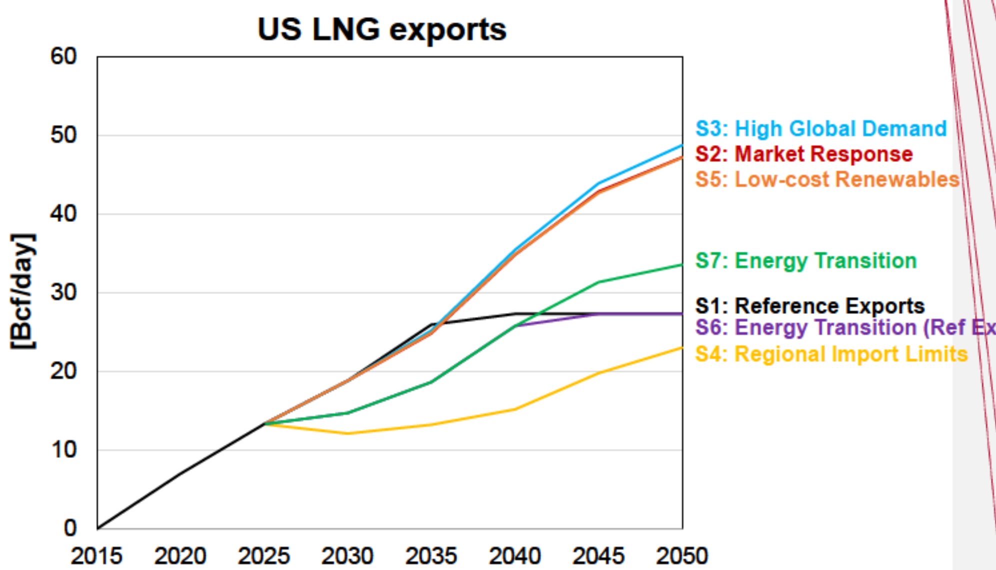


Figure ES-1. U.S. LNG exports across the scenarios explored in this study. Note that the U.S. LNG export outcomes for S2 and S5 were very close to each other.

Several considerations are required in interpreting this study and its results. Foremost, this study is not intended to serve as forecasts of U.S. LNG exports. Rather, it is an exercise in exploring alternative conditional "what-if" scenarios of future U.S. LNG exports and examining their implications for the global and U.S. energy and economic systems, and GHG emissions. Such scenario analysis is a well-established analytical approach for exploring complex relationships across a range of variables. In addition, the scenarios explored in this study are meant to span a range of plausible U.S. LNG export outcomes by 2050. However, they hinge on many assumptions about a wide range of domestic and international, and economic and non-economic factors such as future socioeconomic development, technology and resource availability, technological advancement, institutional change, etc. A full

Commented [WS17]: There is a notable difference in the way we present the data from our conclusions. When we reference GDP, gas consumption, and prices, we scale the effect against the global or national total, resulting in small percentage changes. When we talk about GHGs we scale the effect to units of gas exported. But the table in the appendix shows that the reduction in emissions between S2 and S1 is 50 million tons – or roughly 0.01% of global emissions. I recommend that we take a more consistent approach to characterizing the model results.

Commented [PW18R17]: This result is relevant to extending the LCA analysis, and results from a distinct methodolg.. LCA are always expressed per unit.

Suggest adding In order to enhance the LCA analysis of LNG exports.

Commented [WS19]: This sentence has way too many elements and needs to be re-written.

Commented [LBD20]: It's not completely clear to me why this comparison is made – it seems like there is a projected reduction in GHG emissions from S1 to S2, but it's small? A global reduction equal to 70% of the LC emissions of one large industrial user? If that's correct, it might be clearer to just present the percentage reduction, or say that it was essentially the same level of emissions.

Commented [ST21]: Did we run a non-CCUS S6 and S7 case?

What supports this finding?

Commented [IGC22R21]: All of our scenarios include both fossil fuel technologies w/ and w/o CCUS. The point of this statement is to compare S6 and S7 that have climate policy with other scenarios S1-S5 without climate policy. Compared to the scenarios *without* climate policy (S1-S5), the scenarios *with* climate policy (S6-S7) have lower fossil w/o CCUS.

Commented [IGC23]: I've copied this paragraph here – including an expanded discussion – from the Introduction. May need to rephrase some of the sentences here or simply delete this paragraph from the Intro section.

Commented [IGC24R23]: Update: I think we decided to keep in both places.

uncertainty analysis encompassing all of the above factors was beyond the scope of this study. This study does not attach probabilities to any of the scenarios and no inference about the likelihood of these scenarios occurring should be made. Finally, scenarios S6 and S7 that incorporate countries' climate pledges do not explicitly model the actual policy instruments and mechanisms that countries might adopt to meet their pledges – due to lack of sufficient literature on policies and regulations over the longer time horizon of focus in this study. Instead, these scenarios assume that countries achieve their pledges within their geographic boundaries through a combination of cost-effective strategies. The results from these scenarios described in this report could be different depending on the actual policies and mechanisms countries use to meet their pledges.

II. Background on LNG Export Studies Commissioned by Department of Energy

Since 2012, the Office of Fossil Energy and Carbon Management (DOE-FECM) and its predecessor, the Office of Fossil Energy, has commissioned five studies on the effects of increased LNG exports on the U.S. economy and energy markets. The previous studies of the impact of LNG exports are listed in Table 1.

Commented [UP25]: Table 1 should be moved back to below paragraph 1 where it is mentioned.

Commented [PW26R25]: Done

The EIA 2012 study examined four different levels of exports across four domestic natural gas supply scenarios for a total of 16 scenarios. Exports ranged from 6 to 12 Bcf/day with varying trajectories. The supply scenarios were: AEO2011 Reference, High Shale Estimated Ultimate Recovery (EUR), the Low Shale EUR, and High Economic Growth. Key results demonstrate that domestic natural gas markets balanced the increased exports through increased supply and prices and a reduction in demand for power generation and in the other sectors.

The NERA 2012 report used NERA's Global Natural Gas Model (GNGM) and NewERA energy-economy model to look at the domestic economic effects of LNG exports. Building upon the EIA 2012 study, the NERA 2012 report examined sixteen scenarios from the earlier study using different assumptions on natural gas supply and demand. The report additionally included scenarios examining the global demand for U.S. LNG exports and the macroeconomic impact of increased LNG exports on the economy.

The EIA 2014 study included updated export scenarios from 12 to 20 Bcf/day and domestic natural gas supply scenarios from AEO2014: the Low and High Oil and Gas Resource scenarios, High Economic Growth, and Accelerated Coal and Nuclear Retirements. Increased exports led to increased natural gas production and prices relative to respective base scenarios, as well as higher primary energy consumption and energy-related CO_2 emissions.

Table 1. Previous Studies

Report Name	Organization	Short Name
Effect of Increased Natural Gas Exports on Domestic Energy Markets[2]	EIA	EIA 2012
Effect of Increased Natural Gas Exports on Domestic Energy Markets[3]	NERA	NERA 2012
Effect of Increased Levels of Liquefied Natural Gas Exports on U.S. Energy Market[4]	EIA	EIA 2014

[2] U.S. EIA. (2012). Effects of Increased Natural Gas Exports on Domestic Energy Markets. Available at: https://energy.gov/sites/prod/files/2013/04/f0/fe_eia_lng.pdf

[3] NERA Economic Consulting. (2012). Macroeconomic Impacts of LNG Exports from the United States. Available at: https://energy.gov/sites/prod/files/2013/04/f0/nera_lng_report.pdf

[4] U.S. EIA. (2014). Effect of Increased Levels of Liquefied Natural Gas Exports on U.S. Energy Markets. Available at: https://www.eia.gov/analysis/requests/fe/pdf/lng.pdf

Report Name	Organization	Short Name
The Macroeconomic Impact of Increasing U.S. LNG Exports[5]	Baker Institute/ Oxford Economics	Baker 2018
Macroeconomic Outcomes of Market Determined Levels of U.S. LNG Exports[6]	NERA	NERA 2018

The Baker 2015 study examined U.S. LNG exports of 12 and 20 Bcf/day. Two models were used: an international natural gas model (from the Baker institute) and a global economic model from Oxford Economics. This study outlined the international conditions that could result in a market for over 20 Bcf/day of LNG exports and examined the impact on the U.S. economy of scenarios with 12 and 20 Bcf/day of LNG exports with low gas resource recovery, high gas resource recovery, and high natural gas demand.

The NERA 2018 study again used NERA's Global Natural Gas Model and the NewERA energy-economy model to look at the domestic economic effects of LNG exports. LNG exports were determined by the model for each scenario. The study included 54 different scenarios capturing a broad range of domestic and international gas supply and demand conditions, and probabilities on the likelihood of each of the 54 export scenarios. In general, high levels of LNG exports corresponded to high oil and gas supply but higher prices. Since approximately 80% of the exports resulted from increased production rather than decreased demand, the general economic impact was positive across the scenarios. The report concluded that the impact on energy-intensive industries was minimal while increased investment attributed to LNG exports raised GDP.

[5] Cooper, A., Kleiman, M., Livermore, S., & Medlock III, K. B. (2015). The Macroeconomic Impact of Increasing US LNG Exports. Available at:
https://energy.gov/sites/prod/files/2015/12/f27/20151113_macro_impact_of_lng_exports_0.pdf

[6] NERA Economic Consulting. (2018). Macroeconomic Outcomes of Market Determined Levels of U.S. LNG Exports. Available at:
https://www.energy.gov/sites/prod/files/2018/06/f52/Macroeconomic%20LNG%20Export%20Study%202018.pdf

III. INTRODUCTION

A. Project Background

The Department of Energy (DOE) is responsible for authorizing exports of natural gas, including LNG, to foreign countries pursuant to Section 3 of the Natural Gas Act (NGA), 15 U.S.C. 717b. Under the NGA , applications requesting authority for the import or export of natural gas, including LNG, from and to a nation with which there is in effect a free trade agreement (FTA) requiring national treatment for trade in natural gas, and/or the import of LNG from other international sources, are deemed consistent with the public interest and granted without modification or delay. For authorizations relating to those countries with which the United States does not have such an FTA ,and with which trade is not prohibited by the United States law or policy, Section 3(a) of the NGA requires DOE to grant a permit to export domestically produced natural gas unless it finds that such action is not consistent with the public interest.[7]

DOE has identified a range of factors that it evaluates when reviewing an application for LNG export authorization. Specifically, DOE's review of export applications has focused on: "(i) the domestic need for the natural gas proposed to be exported, (ii) whether the proposed exports pose a threat to the security of domestic natural gas supplies, (iii) whether the arrangement is consistent with DOE's policy of promoting market competition, and (iv) any other factors bearing on the public interest as determined by DOE, such as international and environmental impacts."[8]

To inform its public interest determination, since 2012, the Office of Fossil Energy and Carbon Management (DOE-FECM) and its predecessor, the Office of Fossil Energy, has commissioned five studies on the effects of increased LNG exports on the U.S. economy and energy markets. The studies examined the impacts of increasing demand, including exports, on the domestic natural gas market.

This updated study, similar to the previous studies, is intended to serve as a reference to be considered in the evaluation of applications to export LNG from the United States under Section 3 of the Natural Gas Act. DOE-FECM commissioned OnLocation, Inc., Pacific Northwest National Laboratory (PNNL), and the National Energy Technology Laboratory (NETL) to assess the economic level of U.S. LNG exports across seven scenarios representing a broad range of economic, environmental, and political scenarios, along with changes to global greenhouse gas emissions at differing levels of U.S. LNG exports. U.S. LNG export levels were found using a global equilibrium model and were then input into the domestic model to examine the market effects of increased LNG exports, including natural gas price and consumption across sectors and changes in U.S. greenhouse gas emissions. Finally, the incumbent life cycle analysis of U.S. LNG exports was expanded to incorporate market effects from the results of this study.

B. Purpose of Study

Since the NERA 2018 report was published, several events have altered the explicit and implicit assumptions underpinning the global and U.S. natural gas markets. These include: i) the issuance of

[7] Natural Gas Act. 15 U.S.C. 717b.

[8] Order Amending Long-Term Authorization to Export Liquefied Natural Gas to Non-Free Trade Agreement Nations at 43, Magnolia LLC, Docket 13-132-LNG (April 2022).

Commented [AA27]: Perhaps I missed it, but it would be nice to have a section on "limitations" or a disclaimer or a brief description of what this study did not/cannot do.

Commented [PW28R27]: Paragraph on limitations now last paragraph of Purpose of Study

Commented [ZA29]: Same

Commented [PW30R29]: See above

Commented [LBD31]: "input" seems awkward. "a reference"?

Commented [PW32R31]: Reference

Commented [UP33]: What's the incumbent life cycle analysis? Is that different than the Life Cycle Analysis described in the Executive Summary?

additional DOE LNG export authorizations, ii) the Russia-Ukraine war, iii) global and U.S. greenhouse gas policy developments, iv) technological change in production, transmission, storage, and end-use of natural gas, iv) and the passage of significant energy-related legislation in the U.S. (the Infrastructure Investment and Jobs Act[9] also known as the Bipartisan Infrastructure Law (BIL) and Inflation Reduction Act[10] (IRA)). This report updates previous analytical work in line with current laws and regulations, as well as economic and technology conditions using newly derived scenarios. The defined seven scenarios are:

***S1*: Reference Exports** (Reference scenario in which U.S. LNG exports follow the Reference case from the U.S. Energy Information Administration's 2023 Annual Energy Outlook (AEO))

***S2*: Market Response** (U.S. LNG exports determined by global market equilibrium)

***S3*: High Global Demand** (U.S. LNG exports determined by global market equilibrium, higher population growth outside of the U.S.)

***S4*: Regional Import Limits** (U.S. LNG exports determined by global market equilibrium, global focus on maximizing consumption of local energy sources)

***S5*: Low-cost Renewables** (U.S. LNG exports determined by global market equilibrium, lower costs for variable renewable energy technologies)

***S6*: Energy Transition (Ref Exp)** (U.S. LNG exports are limited to the values from the AEO 2023 Reference case, countries achieve emissions pledges and pursue ambitious GHG mitigation policies consistent with limiting global warming to 1.5°C, U.S. emissions to net-zero by 2050)

***S7*: Energy Transition** (U.S. LNG exports determined by global market equilibrium, countries achieve emissions pledges and pursue ambitious GHG mitigation policies consistent with limiting global warming to 1.5°C, U.S. emissions to net-zero by 2050)

These scenarios are described in more detail in Section 1.A.

Several considerations are required in interpreting this study and its results. Foremost, this study is not intended to serve as forecasts of U.S. LNG exports. Rather, it is an exercise in exploring alternative conditional "what-if" scenarios of future U.S. LNG exports and examining their implications for the global and U.S. energy and economic systems, and GHG emissions. Such scenario analysis is a well-established analytical approach for exploring complex relationships across a range of variables. In addition, the scenarios explored in this study are meant to span a range of plausible U.S. LNG export outcomes by 2050. However, they hinge on many assumptions about a wide range of domestic and international, and economic and non-economic factors such as future socioeconomic development, technology and resource availability, technological advancement, institutional change, etc. A full uncertainty analysis encompassing all of the above factors was beyond the scope of this study. This study does not attach probabilities to any of the scenarios and no inference about the likelihood of these scenarios occurring should be made. Finally, scenarios S6 and S7 that incorporate countries'

Commented [UP34]: Should we say "regional energy sources" as in the bolded heading? Local seems like in-country ng source is available versus in the region.

Commented [IGC35R34]: In the way this scenario is implemented in GCAM, each GCAM region - many of which are individual countries - is incentivized to maximize production within their geographic boundaries (through constraints on imports). Hence, "locally" is probably better. But thoughts welcome.

Commented [IGC36]: Should we delete this section since it appears in the Exec summary as well (per Tom's comment).

Commented [PW37R36]: Best in both.

Commented [AA38]: Should this be advancement?

Commented [TC39]: Expand this discussion consistent with the discussion during and after the leadership briefing about the general considerations evaluating and interpreting model results.

Commented [IGC40R39]: I've expanded this discussion to include the points raised during the briefing as suggested.

[9] Infrastructure Investment and Jobs Act, Pub. L. 117-58, (November 15, 2021), https://www.congress.gov/117/plaws/publ58/PLAW-117publ58.pdf.
[10] Inflation Reduction Act, Pub. L. 117-169, (August 16, 2022), https://www.congress.gov/117/plaws/publ169/PLAW-117publ169.pdf.

climate pledges do not explicitly model the actual policy instruments and mechanisms that countries might adopt to meet their pledges – due to lack of sufficient literature on policies and regulations over the longer time horizon of focus in this study. Instead, these scenarios assume that countries achieve their pledges within their geographic boundaries through a combination of cost-effective strategies. The results from these scenarios could be different depending on the actual policies and mechanisms that countries use to meet their pledges in reality.

C. Organization of the Report

Following the Background and Introduction sections of the Report, Section IV of the report presents a more detailed review of the study methodology, scenario design, and key assumptions. This section introduces the scenarios, the versions of GCAM and NEMS models used for the Global and Domestic Analyses, respectively, and the Life Cycle Analysis methodology. Section V includes key results by scenario:

- Levels of U.S. LNG exports by scenario
- Global natural gas and primary energy metrics including including natural gas production consumption and trade, and primary global energy consumption and GHG emissions
- Implications for U.S. energy systems
- Life cycle analysis

Section VI summarizes the conclusions drawn from the report.

IV. SCENARIOS, METHODOLOGY, AND KEY ASSUMPTIONS

Three primary analytical frameworks were used for this analysis: i) the Global Change Analysis Model (GCAM) developed and maintained at the Pacific Northwest National Laboratory's (PNNL's) Joint Global Change Research Institute, ii) the National Energy Modeling System (NEMS) developed by EIA and modified for this study by OnLocation, and iii) the natural gas system life cycle analysis (LCA) model developed and maintained by NETL. These frameworks and key assumptions are described below.

A. GCAM Model and Global Scenarios Design

GCAM is a model of global energy, economy, agriculture, land use, water, and climate systems.[11] These systems are represented in 32 geopolitical regions, 384 land subregions, and 235 water basins across the globe. GCAM operates in five-year time-steps from 2015 (calibration year) to 2100 by solving for equilibrium prices and quantities of various energy, agricultural, water, land use, and greenhouse gas (GHG) markets in each time period and in each region. Outcomes of GCAM are driven by exogenous assumptions about population growth, labor participation rates and labor productivity in the 32 geo-political regions, along with representations of resources, technologies, and policy.

Commented [WS41]: When was this model created?

Commented [IGC42R41]: The model was first built in the 80's.

GCAM tracks emissions of twenty-four gases, including GHGs, short-lived species, and ozone precursors, endogenously based on the resulting energy, agriculture, and land use systems. GCAM's energy system contains representations of fossil resources (coal, oil, and gas), uranium, and renewable sources (wind, solar, geothermal, hydro, biomass, and traditional biomass) along with processes that transform these resources to final energy carriers (electricity generation, refining, hydrogen production, natural gas processing (NGP), and district heat), which are ultimately used to deliver goods and services demanded by end use sectors (residential buildings, commercial buildings, transportation, and industry). Natural gas competes for share with other fuels in the electricity generation sector, and with other fuels and electricity in the buildings, industrial, and transportation sectors. Each of the sectors in GCAM includes technological detail. In every sector within GCAM, individual technologies compete for market share based on the levelized cost of a technology (see appendix for more details). The version of GCAM used in this study also includes a representation of three carbon dioxide (CO_2) removal strategies that were deployed in scenarios with emissions policies, namely, direct air capture (DAC), bioenergy in combination with carbon capture, utilization, and storage (BECCS), and afforestation.

Commented [AA43]: Consider defining or briefly explaining the difference between these two.

Commented [IGC44R43]: That could be a distraction for this study, since biomass is not a focus of this study. More details are available in the GCAM documentation page:

http://jgcri.github.io/gcam-doc/supply_energy.html which is referenced in the first sentence of the report.

The version of GCAM used in this study includes a representation of natural gas trade that creates price-based competition between domestic and imported natural gas. This representation introduces realistic inertia in the evolution of trade from current patterns. Natural gas can be imported as liquefied natural gas (LNG) or through pipelines. Traded LNG is represented as a single global market. All producers of natural gas can export to a global LNG pool from which importers can import. While the price of domestic gas is based on extraction costs that are derived from long-term regional resource supply curves, the price of imported LNG includes costs for shipping, liquefaction, and regasification in addition to extraction costs. Traded pipeline gas is represented in six regional markets (North America, Latin America, Europe, Russia+, Africa and Middle East, and Asia-Pacific). Exporters of pipeline gas export to

[11] The full documentation of the model is available at the GCAM documentation page (http://jgcri.github.io/gcam-doc/), and the description here and in the appendix is a summary of the online documentation.

one of the six regional pipeline blocs from which importers can import. Inter-pipeline bloc trade can also occur. For example, GCAM's China region exports only to the "Asia-Pacific" pipeline bloc but can import from the "Russia+" pipeline bloc and the "Asia-Pacific" pipeline bloc. These pipeline trade relationships are based on existing relationships. The price of imported pipeline gas includes the costs of building and operating pipeline infrastructure in addition to resource extraction costs. Gross exports and imports of LNG and pipeline gas are calibrated to historical data in GCAM's historical calibration year (2015). In a future model period, trade volumes evolve from historical patterns depending on future demands and prices. For the purposes of this project, historical natural gas producer prices in the U.S. are calibrated to the Henry Hub prices from the EIA[12] and in Canada, they are calibrated to Alberta marker prices from the BP Statistical Review.[13] For the rest of the world, natural gas producer prices in each GCAM region are based on the cost, insurance, and freight (CIF) prices from S&P (see Table A-1 in the appendix).[14] In a future model period, as demand changes, the change in regional producer prices from the historical calibrated values are calculated endogenously using regional supply curves that represent increasing cost of extraction as cumulative extraction increases. GCAM also tracks turnover of trade infrastructure (e.g., liquefaction and regasification units, and pipelines). Trade infrastructure can either retire naturally or in response to economic changes (e.g., those driven by an emissions policy).

Using GCAM, we explored seven scenarios spanning a range of plausible U.S. LNG export outcomes by 2050 (Table 2). All of our scenarios include the 2022 Inflation Reduction Act in the U.S. and current emission policies in the rest of the world. The scenarios also include a constraint on Russian exports such that Russian pipeline exports to European Union (EU) declined to a level below current levels by 2035 and then remain flat, LNG exports from Russia remain flat beyond 2025, and Russian pipeline exports to the east (e.g., to China) continue to increase. Our scenarios include planned and existing LNG capacity additions in major economies including the U.S., Middle East, Australia, Canada, Southeast Asia, and Africa. Socioeconomic (population and economic growth) assumptions for the U.S. were harmonized to the AEO2023 Reference scenario.

Commented [AA45]: Or "case". The paper uses both terms.

Commented [IGC46R45]: Note to tech editor to ensure consistency across the report while referring to AEO Reference Case/ AEO Reference Scenario.

The seven scenarios include:

> ***S1: Reference Exports.*** This scenario assumes that the U.S. LNG exports follow the trajectory from the Reference case of EIA's AEO2023 to grow to 27.34 Bcf/day in 2050. The AEO2023 Reference case incorporated U.S. LNG export projects that were either operating or under construction as of August 2022 and then added capacity based on the cost-competitiveness of exporting U.S. LNG to the international market including an annual capacity build-constraint. More specifically, in AEO2023, LNG export facilities had a combined operating capacity of 10.3 Bcf/d with an additional 4.5 Bcf/d of operating capacity under construction. AEO2023 projected an additional 12.6 Bcf/d of operating capacity that was assumed to be constructed in response to international demand for U.S. LNG.

[12] U.S. EIA (2023). Henry Hub Natural Gas Spot Price. Available at: https://www.eia.gov/dnav/ng/hist/rngwhhda.htm
[13] BP (2022). bp Statistical Review of World Energy. 71st edition. Available at: https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2022-full-report.pdf
[14] S&P Global (2023). S&P Global Commodity Insights. Historical and forecasted LNG prices data sheet.

S2: Market Response. This scenario has assumptions consistent with S1 and assumes economically-driven, market-based outcomes for U.S. LNG exports.

S3: High Global Demand. This scenario includes the same assumptions as in *S2*, but assumes a higher population growth in regions outside of the U.S. consistent with the Shared Socioeconomic Pathways – 3.[15] This results in approximately one billion more people globally in *S3* by 2050 compared to *S1 and S2* and explores the effects of higher U.S. LNG exports driven by higher demand for all energy sources (including natural gas) compared to *S2*.

S4. Regional Import Limits. This scenario includes the same assumptions as in *S2*, but with constraints on natural gas imports globally to maximize the use of domestically produced natural gas across the world. This scenario explores the effects of lower U.S. and global LNG exports driven by global energy security concerns and trade limitations.

S5: Low-cost Renewables. *S5* includes the same assumptions as in *S2* but assumes lower capital costs for renewable energy technologies such as onshore and offshore wind, solar photovoltaic, concentrated solar power, and geothermal. This scenario explores the effects of faster technological improvements in competing technologies. While technology cost assumptions in other scenarios are consistent with NREL's Annual Technology Baseline (ATB) "Medium" assumptions, capital cost assumptions for onshore and offshore wind, solar photovoltaic, concentrated solar power, and geothermal technologies under *S5* are based on the "Low" assumptions.

S6: Energy Transition (Ref Cap) **and** ***S7: Energy Transition***. Both scenarios assume an emission pathway that is consistent with a global temperature change of 1.5°C by 2100 derived from published peer-reviewed literature.[16,17,18] Both of these scenarios assume that countries achieve their emission pledges as made during the 26th Conference of Parties of the United Nations Framework on Climate Change held in Glasgow, Scotland, United Kingdom. The pledges include nationally-determined contributions that outline emission reduction plans through 2030, long-term strategies, and net-zero pledges through mid-century. The U.S. is assumed to reduce economy-wide greenhouse gas emissions by 51% in 2030 and 100% by 2050. Countries without pledges are assumed to follow an emissions pathway defined by a minimum decarbonization rate of 8% that is indicative of strong mitigation policies and significant departure from historically observed decarbonization rates. The scenarios assume that countries achieve their pledges within their geographic boundaries without trading emissions. Scenario *S6* differs from *S7* in that it also retains U.S. LNG exports to the values from the AEO2023 Reference case. A key distinction between scenarios *S1* and *S6* is that while the former assumes the U.S. LNG exports to follow the AEO2023 Reference case exactly, the latter assumes the values from the AEO2023

---

[15] Samir, K. C., & Lutz, W. (2017). The human core of the shared socioeconomic pathways: Population scenarios by age, sex and level of education for all countries to 2100. Global Environmental Change, 42, 181-192.
[16] Fawcett, A. A., et al. (2015). Can Paris pledges avert severe climate change? Science, 350(6265), 1168-1169.
[17] Ou, Y., Iyer, G., et al. (2021). Can updated climate pledges limit warming well below 2°C? Science, 374(6568), 693-695.
[18] Iyer, G., Ou, Y., et al. (2022). Ratcheting of climate pledges needed to limit peak global warming. Nature Climate Change, 12(12), 1129-1135.

Reference case to be an upper bound. Nevertheless, scenario *S6* enables comparisons with *S1*, and scenario *S7* enables comparisons with *S2*.

Table 2. Scenario Descriptions

Scenario	Description	U.S. LNG Export Volumes (Bcf/d)
***S1*: Reference Exports**	Reference scenario in which U.S. LNG exports follow EIA's 2023 Annual Energy Outlook (AEO). Incorporates U.S. policy assumptions (including the 2022 Inflation Reduction Act). Assumes existing policies and measures, globally.	Grow to 27.3 Bcf/d by 2050
***S2*: Market Response**	Assumes policies consistent with *S1*, but U.S. LNG exports are determined by global market equilibrium.	GCAM Market Response
***S3*: High Global Demand**	Same assumptions as *S2*, U.S. LNG exports determined by global market equilibrium, but assumes higher population growth outside of the U.S.	
***S4*: Regional Import Limits**	Same assumptions as *S2*, U.S. LNG exports determined by global market equilibrium, but includes constraints on importing and exporting natural gas with a global focus to maximize use of domestic gas.	
***S5*: Low-cost Renewables**	Same assumptions as *S2*, U.S. LNG exports determined by global market equilibrium, but assumes lower capital costs for renewable energy technologies.	
***S6*: Energy Transition (Ref Exp)**	Assumes an emissions pathway consistent with a global temperature change of 1.5°C by end of century. Countries' emissions are constrained to announced GHG pledges, including the U.S. following a path to net-zero GHG emissions by 2050. NEMS follows CO_2 emissions constraint from GCAM. U.S. LNG exports are limited to the values from the AEO 2023 Reference scenario.	Grow to 27.3 Bcf/d by 2050
***S7*: Energy Transition**	Same emissions pathway assumptions as *S6*, but U.S. LNG exports are determined by global market equilibrium.	GCAM Market Response

Commented [UP47]: Here the Table although the same as in Executive Summary has different coloring. Personally I think looks better blue/white versus two shades of blue throughout.

Commented [UP48]: Same comment on the 2-digits Bcf/d as I had in Executive Summary section. 1-digit would be better to show in a report.

B. NEMS Models and Analysis Methodology

NEMS is a national energy-economic model of the U.S. It projects supply, demand, imports, and exports of major energy commodities, and drivers such as macroeconomic conditions, world energy markets, technology choices and costs, resource availability, and demographics. The NEMS model includes both cost minimization representative of competitive markets and behavioral representations of the energy market.

Commented [AA49]: Consider: "It projects supply, demand conversion, imports, exports of major energy commodities, **and** drivers such as macroeconomic conditions..."

Commented [DH50R49]: Agreed, added "and" to improve readability

The NEMS model includes four supply modules covering oil, natural gas, coal, and renewables. There are two conversion modules converting primary fuels into electricity and petroleum and other liquids into liquid fuel products, respectively. There are four demand modules covering the residential, commercial, industrial, and transportation sectors. Other modules include the macroeconomic module, emissions policy modules, and an integrating module that synthesizes the output across all other modules. NEMS solves iteratively to reach a general market equilibrium across the energy economy. The EIA provides an archive of the NEMS model with source code and input sufficient to reproduce the reference and side cases comprising the Annual Energy Outlook.

1. AEO2023-NEMS

AEO2023-NEMS is OnLocation's version of the NEMS model, modified to allow exogenous input of U.S. LNG exports. The AEO2023 reference scenario has a macroeconomic growth assumption of 1.9% average growth per year. The model has the EIA's interpretation of the Inflation Reduction Act (IRA) which includes most major provisions of the law. The model does not include carbon capture at industrial sites (ethanol, hydrogen, NGP, and cement) or direct air capture (DAC). Therefore, the IRA 45Q credit for DAC is not included. Similarly, IRA 45V hydrogen credits are also not represented in the AEO2023 version of NEMS as it does not have the hydrogen module.

2. FECM-NEMS

FECM-NEMS is a version of NEMS that is based on OnLocation's version of the Annual Energy Outlook 2022 (AEO2022) NEMS model and includes updates that allow for the modeling of deep decarbonization technologies and strategies. FECM-NEMS models the IRA based on FECM's interpretation of the policy. It includes major IRA energy-related provisions including but not limited to the extension of 45Q CO_2 sequestration credits, clean vehicle tax credits, energy efficient home tax credits and rebate programs, clean energy Production Tax Credit (PTC) and Investment Tax Credit (ITC), zero emission nuclear credits, and hydrogen tax credits. Additional modeling updates include provisions from the Bipartisan Infrastructure Law (BIL) such as funding for carbon capture demos, CO_2 transportation and storage infrastructure, and updated EPA/NHTSA Corporate Average Fuel Economy standards. For consistency with updated economic assumptions, FECM-NEMS uses the low economic growth assumption from AEO2022, assuming a real GDP average growth of 1.8% per year to 2050.

FECM-NEMS represents several CO_2 mitigation technologies including carbon capture and sequestration (CCS), DAC, BECCS, and hydrogen (H_2) processes included in the Hydrogen Market Module (HMM). These technologies allow the economy modeled by FECM-NEMS to fully decarbonize and enable the modeling of scenarios with net-zero carbon emissions. Industrial carbon capture is found in the liquid fuels module which allows for the construction of new hydrogen and ethanol facilities with CCS. It also allows for existing hydrogen, ethanol, and natural gas processing plants to retrofit CCS capability. The

Commented [AA51]: This is a little duplicative of paragraph one and two of this section. Consider revising this section to eliminate repetitiveness.

Commented [DH52R51]: We reorganized this section to remove some of the redundant information cement industry has also been enhanced to include CCS opportunities. Industries have the option to send captured CO_2 to an enhanced oil recovery market or store it in saline aquifers.

The HMM is integrated into NEMS to produce hydrogen via conventional and low carbon processes. The hydrogen production technologies available in the HMM include steam methane reformation (SMR), SMR with CCS, biomass gasification with CCS, and electrolysis.

The NEMS macroeconomic module uses a commercial econometric model designed to provide economic feedback from the broader economy with input perturbations from the energy baseline provided by NEMS. The *S6* and *S7* scenarios represent such profound changes that the EIA's baseline is no longer useful. As a result, FECM-NEMS does not utilize the macroeconomic module when modeling net-zero scenarios.

3. Harmonizing GCAM and NEMS

While GCAM and NEMS are distinct models, coordination between them is necessary to maintain consistency and tie the NEMS results back to the global LNG market forecast. Harmonization efforts ensured that LNG exports (for all scenarios) and CO_2 emissions (in the net-zero scenarios) were consistent between the two models.

The EIA's AEO2023 reference case was selected to define *S1*. In AEO2023-NEMS, the AEO2023 reference case solution file was adopted for all variables. LNG exports from the AEO2023 reference case were then used as exogenous inputs into the GCAM model in place of endogenous estimates. For *S2* through *S7*, the process was reversed: the scenarios were first run in the GCAM model, from which endogenously-calculated LNG export curves were taken and input exogenously into AEO2023-NEMS. The endogenous algorithm used by NEMS to calculate LNG exports was turned off for these scenarios. Since a key driver of LNG exports is the differential between domestic and world natural gas prices, domestic natural gas prices from NEMS were then compared with North American prices in GCAM. In all scenarios except *S5*, technology and resource were aligned between GCAM and the AEO2023 reference scenario. In *S5*, both models adjusted power generation technology assumptions consistent with the AEO2023 Low Renewable Cost scenario from the AEO.

For *S6* and *S7*, the net-zero scenarios were first run in the GCAM model, which uses global interactions and feedback to model U.S. LNG under a criteria of net-zero GHG by 2050. As part of the modeling process, GCAM generates a set of emissions curves that list quantities of CO_2, methane (CH_4), nitrous oxide (N_2O), and fluorinated gases emitted in various economic sectors, including emissions and removals from land use, land-use change, and forestry (LULUCF). These curves were outputs of the model, although the sum of individual emissions was defined in the model inputs such that they reached or exceeded a net-zero target in 2050. The output emissions curves from GCAM were used to specify how the net-zero scenario was implemented in FECM-NEMS.

Commented [AA53]: Spell out if this is the first time mentioning these gases.

Commented [DH54R53]: Spelled out CH4 and N2O, and removed F, which is not used later in the report. Also reorganized the section slightly to improve readability

The values of CO_2 emissions from the energy sector were taken from the GCAM output and used explicitly as the carbon cap in FECM-NEMS to model the net-zero scenarios. The carbon cap curve (used to define both *S6* and *S7*) is plotted in Figure 1.

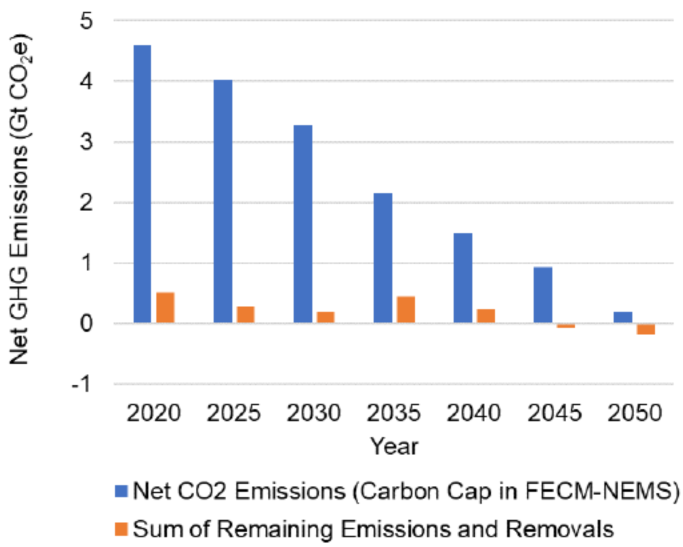


Figure 1. U.S. GHG emissions and removals in the net-zero scenarios

Referring to this carbon cap each model year, FECM-NEMS calculates emissions and removals throughout the model and adjusts a carbon price to equalize them with the carbon cap. With this method, FECM-NEMS ensures that the CO_2 emissions from the energy sector match the corresponding emissions from GCAM. Although FECM-NEMS calculates CH_4 emissions from natural gas systems, they were excluded from the carbon cap in favor of adopting the values calculated by GCAM.

The carbon cap used in FECM-NEMS for both net-zero scenarios ended with 0.19 Gt CO_2 in 2050. Although this value does not equal zero, it was balanced by the sum of non-energy CO_2, non-CO_2 GHGs, and LULUCF-sector emissions and removals calculated by the GCAM model which added together total -0.19 Gt CO_2 equivalent (the total was negative because of large quantities of LULUCF-sector removals). The remaining emissions and removals (non-energy CO_2, non-CO_2 GHGs, and LULUCF) were treated as exogenous to FECM-NEMS and could be added with the endogenous CO_2 emissions to calculate net total GHG emissions (which would equal near-zero in 2050). The sum of non-energy CO_2, non-CO_2 GHGs, and LULUCF-sector emissions and removals is also plotted in Figure 1.

C. NETL Life Cycle Analysis Model Methodology

Commented [TC55]: I believe Tim has had discussions with the modeling team since adding comments to this draft, the comments here may have already been shared with the team.

Past life cycle studies conducted by NETL on natural gas and LNG have been attributional studies that estimate the emissions and other impacts associated with current units of natural gas/LNG delivered. These LCA studies have not, to date, considered the *consequences* of delivering LNG, such as how domestic or foreign energy markets may be affected by increasing the supply of natural gas (e.g., whether different sources of natural gas compete in the market, or whether, given additional supply, natural gas-fired power plants in Europe might take market share from other types of electric plants).

Such market-based effects could lead to consequential increases or decreases in GHG emissions. As part of this study, these consequential effects were estimated by tracking differences in global GHG emissions and quantities of LNG exported from the GCAM model results.

This section details the various existing representations of the natural gas supply chain within the context of the NETL natural gas model and the GCAM model. The purpose of documenting these representations is to subsequently apply the insights from the GCAM model to the NETL LCA framework.

1. Past NETL Natural Gas Life Cycle Reports

As shown in the top half of Table 3, the NETL Natural Gas model[19] is separated into five stages that generally align with categories used in other federal efforts such as the US EPA's Greenhouse Gas Reporting Program (GHGRP)[20] and Greenhouse Gas Inventory (GHGI)[21]. Results of this model are provided for two scopes: Production through Transmission (e.g., for large scale industrial users, like power plants and LNG facilities that are directly connected to a pipeline), and Production through Distribution (e.g., for residential or smaller industrial users where the natural gas is delivered through smaller distribution pipelines). Results are provided for various techno-basins of production, regions, and U.S. average production, using a variety of Intergovernmental Panel on Climate Change (IPCC) Assessment Report Global Warming Potential (GWP) values on 100-year or 20-year basis.

In addition, past work by NETL has modeled the additional processing stages to produce and deliver LNG, adding another four stages in the bottom half of Table 3.

Table 3. Natural Gas and Liquefied Natural Gas Life Cycle Stages (as in NETL Natural Gas Model)

Stage Name	Description
Natural Gas Production Only Stages	
Production	Drilling and construction of conventional and unconventional wells (e.g., from hydraulic fracturing), and extraction of gas, including liquids unloading operations.
Gathering and Boosting	Movement of natural gas from wells via gathering pipelines and delivered to treatment and/or processing plants. Boosting systems may include compressors, dehydration, and pneumatic devices and pumps.
Treatment and Processing	Removal of impurities and compression of input gas to meet transmission pipeline standards. May include acid gas removal (AGR), dehydration), natural gas liquids recovery, etc.

[19] Khutal, H., et al. Life Cycle Analysis of Natural Gas Extraction and Power Generation: U.S. 2020 Emissions Profile. National Energy Technology Laboratory, Pittsburgh, July 7, 2023
[20] US EPA Greenhouse Gas Reporting Program, https://www.epa.gov/ghgreporting, last accessed Sept 1, 2023.
[21] US EPA , Inventory of U.S. Greenhouse Gas Emissions and Sinks, https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks, last accessed Sept 1, 2023.

Commented [AA56]: Consider adding as parenthetical to the title of Table 3 - (NETL Natural Gas Model).

Commented [SM57R56]: Done

Commented [ST58]: The 2020 report and model are not public. The reference will need updated upon release of the 2020 report.

I checked the ISSST Presentation and it is marked "do not cite" and does not contain the production thru transmission result of 7.4 g. Not a good reference.

Evaluating U.S. Natural Gas Environmental Performance, ISSST 2023 Conference, June 14, 2023, Fort Collins, CO.

Commented [SM59R58]: We believe that the 2020 report will be released imminently, and thus available when this LNG study is released.

Commented [AA60]: Spell out because this is the first time mentioning the IPCC.

Transmission and Storage	Construction of pipelines, and movement of bulk quantities of natural gas in large pipelines to large users or city gates for subsequent distribution. Typically includes compressor stations along pipelines. Storage includes insertion of gas into units such as underground storage facilities as well as additional gas processing and compression after removal from storage before injection into the transmission pipeline network.
Distribution*	Movement of gas from transmission or storage facilities to city gates for subsequent delivery to smaller consumers via small diameter pipelines. (*may or may not be included depending on scope)
Additional Stages to Produce and Deliver LNG	
Liquefaction	Pre-treatment of gas, liquefaction to low temperatures and storage.
Loading/Unloading	Process to load (and unload) LNG to and from tankers to facilities.
Ocean Transport	Shipment of LNG on ocean-going vessels of varying technology types to distant ports for subsequent regasification. Depending on technology, may use LNG as fuel.
Regasification	Regasification of LNG and injection into transmission pipelines.
Destination Transmission / Distribution	Similar processes as described above, and not functionally different than as described for the natural gas only part.

Quantitatively, the NETL natural gas model has estimated ranges of GHG emissions by species and by stage for the domestic natural gas supply chain as shown in Figure 2. Given the scope of domestic natural gas production through the transmission stage, the mean U.S. average total CO_2-equivalent emissions are about 7.44 g CO_2e/Megajoule (MJ) (IPCC AR6, 100-year basis), with a confidence interval of the mean of 4.6-11.1 g CO_2e/MJ. The GCAM model results generated in this report estimated GWP intensity of natural gas extraction in different geographic regions of the US, which have higher or lower intensity, as compared to the U.S. average. However, these results are in terms of Higher Heating Value (HHV) of natural gas, while the GCAM model uses Lower Heating Value (LHV), so it needed to be subsequently adjusted, resulting in a value of 8.18 g CO_2e/MJ (IPCC AR6, 100-year, LHV basis). Further discussion of these adjustments are discussed below.

Commented [ST61]: Report the LHV result here that aligns to GCAM.

Need to provide/cite the HHV to LHV values for the adjustment factor.

Commented [SM62R61]: Done. These are in appendix also.

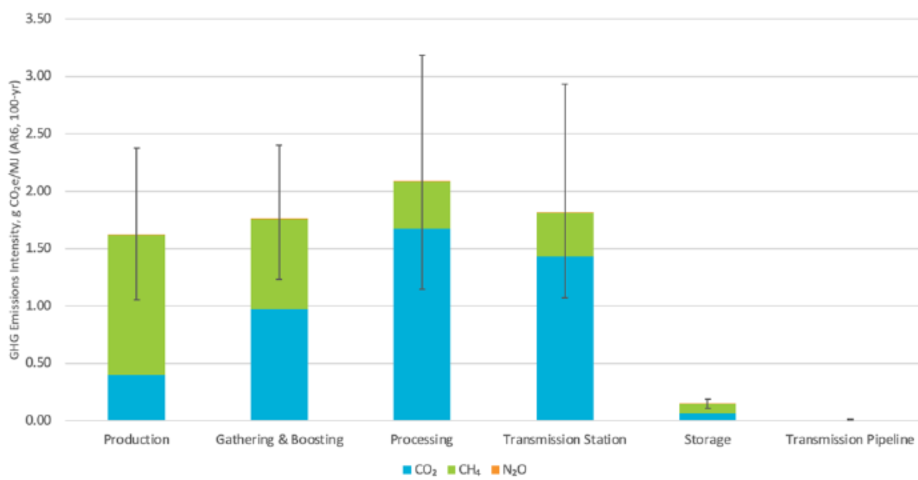


Figure 2. Life cycle GHG emissions from the 2020 U.S. average Natural Gas supply chain, HHV basis (Source: NETL 2023)

Commented [ST63]: Y-axis: units should read g CO2e/MJ before AR6, 100-year.

CO2e: removed hyphen between the "2" and "e".

Legend: need to subscript "2" and "4".

Past work by NETL also estimated the greenhouse gas emissions implications of the additional stages to produce and deliver U.S. average LNG around the world. While these values are estimated on a per-MJ delivered basis, their presentation is complicated by the variability associated with the distance shipped, which can be large in many cases (LNG shipped relatively short distances has a significantly smaller GWP footprint than that shipped long distances). Using data from the 2019 NETL LNG report[22]. and adjusting to the 2020 NETL NG report and GHGRP basis used here, LNG delivered from New Orleans to Rotterdam (8,990 km) would be expected to result in 20 g CO_2e/MJ delivered to regasification facility (IPCC AR6, 100-year basis, LHV) or 18.1 g CO_2e/MJ (HHV). In short, the additional processes and natural gas needed to liquefy and shipnatural gas to Rotterdam adds about 9.9 g CO_2e/MJ delivered (IPCC AR6, 100-year basis, LHV). The GHG emissions intensity result on a per MJ NG delivered to liquefaction plant basis is 8.2 g CO2e/MJ (AR6, 100-yr, LHV) but accounting for NG losses that occur in the downstream stages results in a higher volume of NG needed upstream, leading to a contribution of 10.2 g CO_2e/MJ NG delivered to the regasification facility (AR6, 100-yr, LHV) by the upstream NG supply chain stages (production through transmission network)[23]. Given the many possible delivery routes and distances for such LNG, these specific results are intended only to provide contextual perspective of the GWP intensity of the added LNG stages.

Commented [ST64]: Please confirm that the US upstream was also adjusted to use the 2020 NG profile, as well as the GWP reference.

This change should also be noted in footnote 20.

[22] Roman-White, S., Rai, S., Littlefield, J., Cooney, G., & Skone, T. J. (2019). Life cycle greenhouse gas perspective on exporting liquefied natural gas from the Unites States: 2019 update. National Energy Technology Laboratory (NETL), Pittsburgh, September 12, 2019.

[23] Results from Roman-White 2019, Exhibit A-2, adjusted from g CO_2e/MWh to g CO_2e/MJ using heat rate of 145 kg natural gas/MWh, and higher heating value of 54.3 MJ/kg.

The previous NETL work on natural gas cited above are attributional analyses of the domestic natural gas system. The results sought to identify and attribute the emissions associated with the various unit processes that created them. These methods differ in scope than consequential analysis, which more broadly considers the global changes in GHG emissions when additional volumes of U.S. natural gas are produced and delivered across the world, or, in other words, the market-based effects of producing domestic natural gas and exporting it. Further discussion on how the LCA section of this project can support consequential analysis is discussed in Section V.G.

Commented [AA65]: A word appears to be missing here.

Commented [SM66R65]: Reworded paragraph to hopefully make this more clear.

2. Market Adjustment Factors

In order to quantify the global market effects associated with increasing exports of U.S. LNG, the GCAM results were used to estimate the change in global GHG emissions per unit of LNG exported between various scenarios. This market adjustment factor (MAF) is defined as:

Commented [LBD67]: Unclear what these two dimensions/adjectives are; could this just be "global market effects"?

Commented [ST68]: Page 51: MAF is defined as "market effect adjustment factor". Recommend removing effect for consistency with in the report.

Commented [ST69]: The equation below's font size is too large to match the document style.

$$MAF_{scenario\ n} = \frac{Global\ Emissions_{scenario\ n} - Global\ Emissions_{scenario\ 1}}{US\ LNG\ Exports_{scenario\ n} - US\ LNG\ Exports_{scenario\ 1}}$$

and represents a ratio of the change in GHG emissions for a given scenario compared to a base scenario, versus the change in U.S. LNG exports between the same two scenarios. For example, a comparison of Scenario *S2* vs. Scenario *S1* would compare the differences in GCAM values for these two scenarios. The MAF can be calculated for every model year (2015-2050) and can also use linearly interpolated values of emissions and US LNG exports for the non-modeled years.

V. RESULTS

The following sections describe the results of the global analysis using GCAM, the U.S. analysis using NEMS, and the life-cycle analysis in that order. We begin our discussion with a description of U.S. LNG export outcomes across scenarios (section VA). Subsequently, we highlight the implications of the availability of additional U.S. LNG in the global market, by comparing *S1* and *S2* (section VB). We then discuss *S6* and *S7* to illustrate the implications of additional U.S. LNG in the global market under a global transition toward 1.5°C (sections VC and VD). Subsequently, we discuss results from the remaining scenarios (*S3*-*S5*) (section VE).

A. U.S. LNG exports

Across all scenarios, the U.S. is a net exporter of natural gas. As shown in Figure 3, U.S. LNG exports increase beyond existing and planned capacity in all scenarios by 2050, except *S1* in which U.S. LNG export volumes follow AEO2023 and *S6* in which export volumes were limited to AEO2023 by design. Across all the scenarios, LNG exports range from 23-49 Bcf/day. This range is consistent with the U.S. EIA's analysis (15-48 Bcf/day).[24]

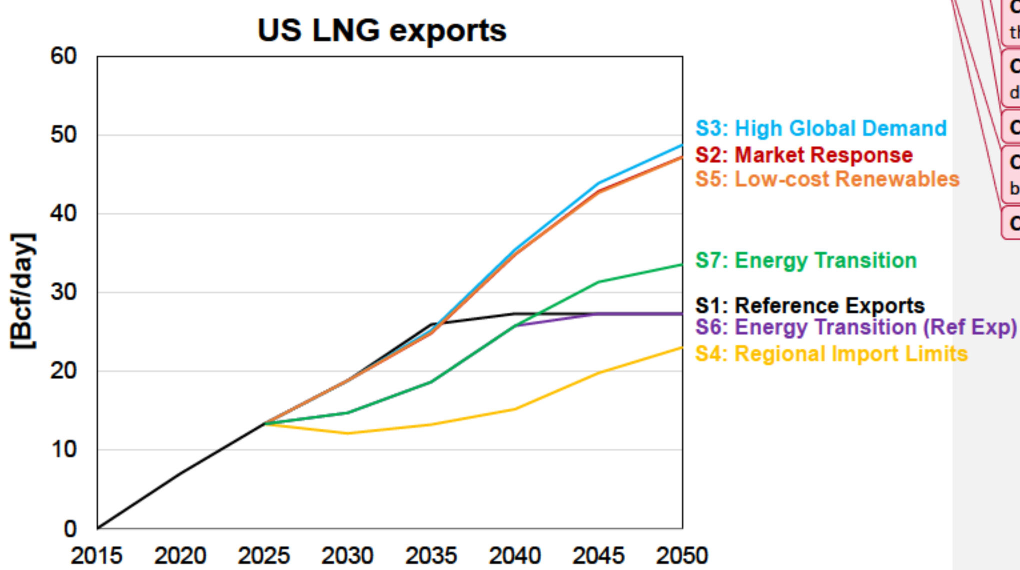


Figure 3. U.S. LNG exports across the scenarios. Note that the U.S. LNG export outcomes for S2 and S5 are very close to each other.

[24] U.S. EIA. (2023). Issues in Focus: Effects of Liquefied Natural Gas Exports on the U.S. Natural Gas. Available at: Markethttps://www.eia.gov/outlooks/aeo/IIF_LNG/

Commented [LBD70]: This stated order doesn't seem to start until after Section A?

Maybe it could be better explained here -- this seems to apply to Section B (S1 & S2) and C/D (S6 & S7), and then all scenarios together in other sections.

Section A treats the 7 scenarios in numerical order for export volumes, setting the stage for following sections.

Commented [IGC71R70]: Thanks. We've clarified this.

Commented [LBD72]: S3? S2 would have been discussed along with S1.

Commented [IGC73R72]: Agreed. Thanks.

Commented [UP74]: Shouldn't this be 49 Bcf/d based on S3 scenario (see page 21)?

Commented [IGC75R74]: Yes. Thanks.

Under *S2,* in which all outcomes – including U.S. LNG exports – are economically-driven and market-based, U.S. LNG exports increase to approximately 47 Bcf/day in 2050.

U.S. LNG exports under *S3*, the scenario with increased global population, increase to 49 Bcf/day in 2050, emerging as the upper bound. With higher population assumptions in *S3*, total energy demand – and consequently natural gas demand – outside the U.S. increase compared to *S2*, resulting in an increase in U.S. LNG exports to satisfy the increased international demand. However, the increase is not proportional to the increase in population because part of the higher demand in *S3* is supplied by an increase in international production.

U.S. LNG exports under *S4* increase only to approximately 23 Bcf/day in 2050, emerging as the lower bound. The lower increase in U.S. LNG exports in *S4* compared to other scenarios is driven by international limits on natural gas imports to maximize the use of locally produced natural gas.

U.S. LNG exports under *S5* increase to approximately the same level as *S2* in 2050. This is because, cheaper solar and wind technologies in this scenario mostly displace fuels other than natural gas (e.g., biomass). Hence, the demand for natural gas and consequently, U.S. LNG exports, remain materially unaffected compared to *S2*. Under *S7,* which assumes a global transition toward 1.5°C, U.S. LNG exports continue to increase, albeit at a lower level than *S2,* to approximately 34 Bcf/day in 2050. As discussed below, the lower increase in U.S. LNG exports in this scenario compared to *S2* is driven by the economy-wide transition to low-carbon fuels to meet emission reduction commitments and pledges.

Commented [UP76]: Is this an assumption where all importing countries have readily available locally-produced natural gas they can use instead? Should we say regionally vs locally?

Commented [IGC77R76]: The detailed assumptions for this scenario are in Table A-1. I am OK with "locally" but open to other thoughts.

Commented [AA78]: Recommend spelling out instead of using symbol.

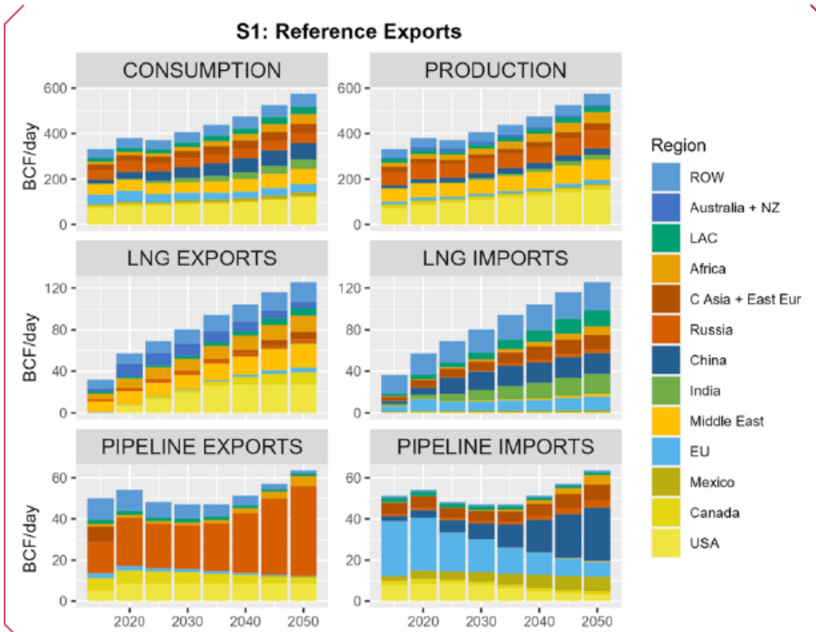
B. Global Natural Gas Consumption, Production, and Trade Under Scenarios *S1* And *S2*

As shown in Figure 4, under *S1*, production, consumption, and trade of natural gas increases in all regions, globally driven by growing demands in the electricity generation, industrial, and buildings sectors (see Figure A-1 in Appendix A). Under *S1*, U.S. LNG exports follows the AEO2023 Reference case to grow to 27.3 BCF/day by 2050 (by design).

Commented [IGC79]: Note to tech editor: Please make sure we're consistent throughout about AEO2023 Reference case vs. AEO2023 Reference scenario.

Commented [WS80]: Global comment: this report consistently uses bar charts rather than actual figures. Can we include all these figures in appendices?

Commented [IGC81R80]: Yes.



Commented [WS82]: S1 shows global gas consumption increasing to 2050 (and maybe beyond?). Even S6 and S7 seem to show global gas consumption plateauing in 2045 (but not decreasing event then). Meanwhile, we understand that this month the IEA will release a global outlook document that will project gas consumption peaking this decade. This seems like a vast discrepancy and perhaps one that should be addressed. Is it feasible to run another scenario? If not, how would we defend the validity of our assumptions as compared to those of others?

Commented [IGC83R82]: Please see our response in the consolidated response document.

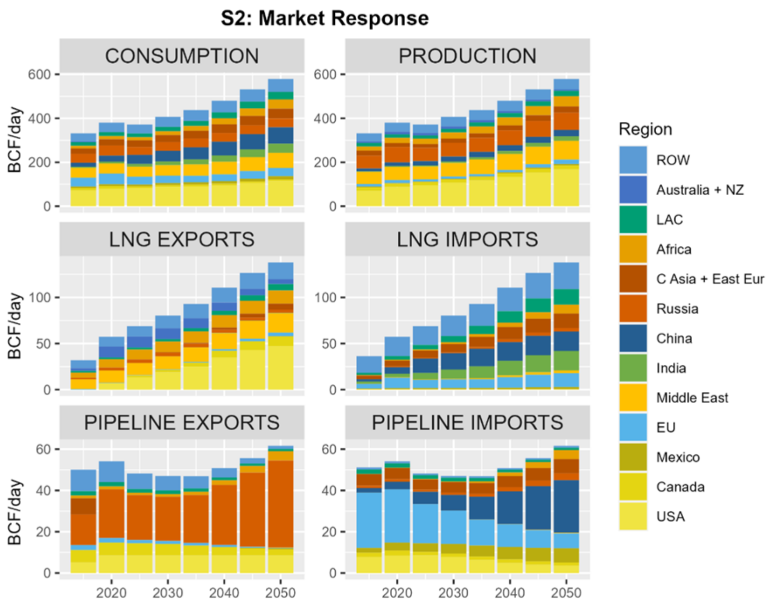


Figure 4 Natural gas consumption, production, and trade by region under S1 (upper) and S2 (lower) To convert from BCF/day to TCF/ yr and vice versa, the conversion factors are as follows: 1 TCF/yr = 2.74 Bcf/day and 1 BCF/day = 0.36 TCF/yr.

Under *S2*, in which U.S. LNG exports are determined by market equilibrium, U.S. natural gas production and LNG exports increase compared to *S1* to satisfy the growing demands of natural gas globally. Under *S2*, U.S. LNG exports grow to approximately 47 Bcf/day by 2050. Figure 5 shows the changes in natural gas consumption, production, and trade by region in *S2* versus *S1*. The additional U.S. LNG exports in *S2* compared to *S1* is 20 Bcf/day in 2050. The availability of additional U.S. natural gas in the global natural gas market at competitive prices results under *S2* in a reduction in production and LNG exports from other parts of the world compared to *S1*. The increased availability of U.S. LNG under *S2* also results in higher LNG imports and reduced pipeline trade outside of the U.S. In addition, natural gas consumption outside of the U.S. increases by 7 Bcf/day compared to *S1*. However, U.S. natural gas consumption under *S2* decreases (by 3 Bcf/day in 2050) driven by domestic price increases in response to increased domestic production. Thus, the net increase in global natural gas consumption in *S2* compared to *S1* is 4 Bcf/day. Compared to the total natural gas consumption globally in 2050 in *S1* (574 Bcf/day), this change is <1%. Consequently, global primary energy consumption and GHG emissions under *S2* do not change much compared to *S1*, as shown in Figure 6.

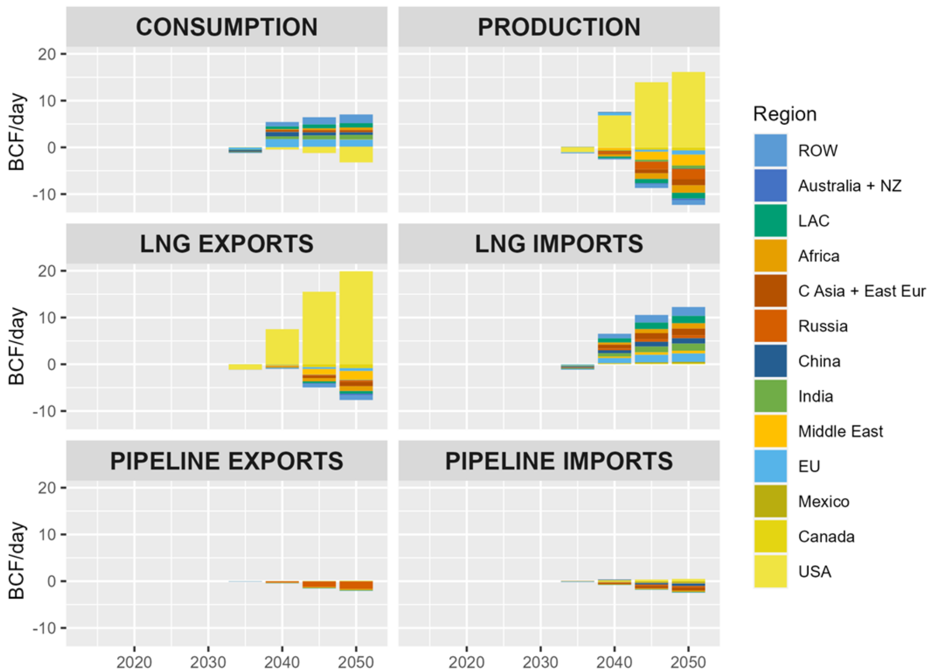


Figure 5. Changes in natural gas consumption, production, and trade by region in S2 vs. S1 To convert from BCF/day to TCF/ yr and vice versa, the conversion factors are as follows: 1 TCF/yr = 2.74 Bcf/day and 1 BCF/day = 0.36 TCF/yr.

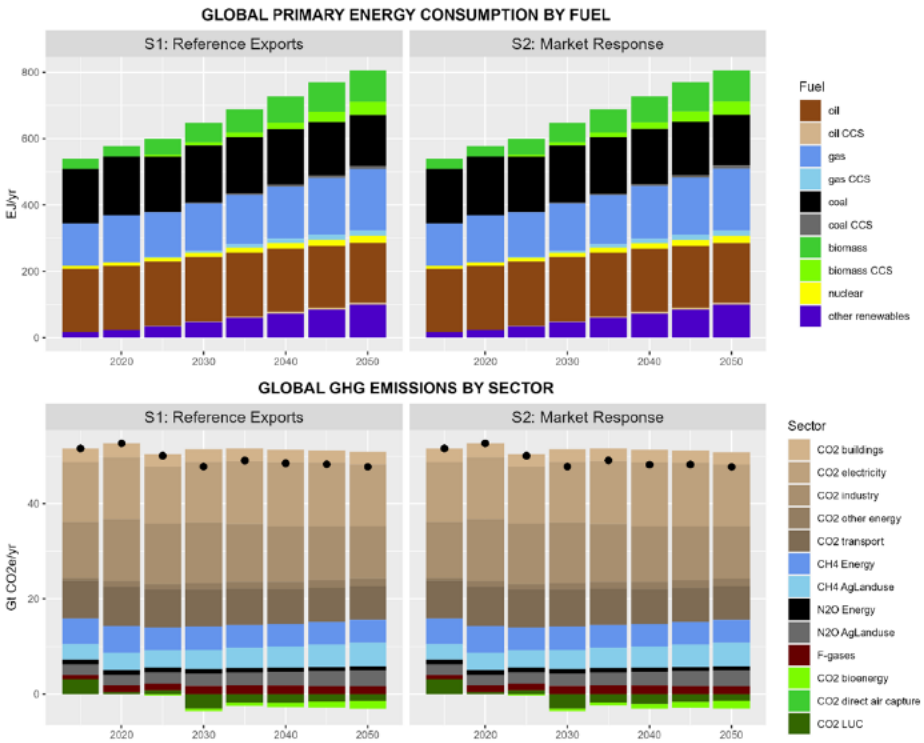


Figure 6. Global primary energy consumption by fuel and GHG emissions by sector under S2 and S1. Changes in S2 relative to S1 are <1% and are presented in the data tables in Appendix A. Net GHG emissions are shown as a dot in each bar.

C. Global Primary Energy Consumption by Fuel and GHG Emissions by Sector Under *S6* And *S7*

Under *S6* and *S7*, global GHG emissions from all sectors of the economy are reduce significantly compared to *S1* and *S2,* as shown in Figure 6 and Figure 7. Figure 7This is by design as these scenarios are assumed to include emissions pledges and constraints on emissions consistent with limiting global temperature change this century to 1.5°C. Under these scenarios, although global GHG emissions are net-positive (approximately 17 $GtCO_2e$), global CO_2 emissions are approximately 0 in 2050. These global emissions outcomes are broadly consistent with 1.5°C scenarios in the literature.[25]

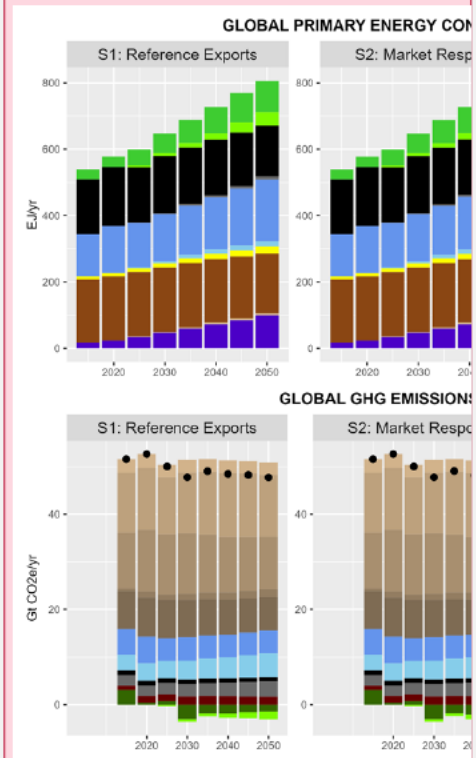
These scenarios are characterized by a combination of the following decarbonization strategies: i) a reduction in fossil fuel consumption without carbon capture utilization and storage (CCUS), ii) increased deployment of CCUS with fossil fuels, iii) increased deployment of renewables, iv) a net reduction in

[25] Riahi et al. 2022, Chapter 3 in the Sixth Assessment Report of the IPCC

Commented [ST84]: Need S2 minus S1 delta figures.

Commented [IGC85R84]: We prefer not to show the delta figures here since the changes very small (<1%) and within solution tolerance. We instead point to the data tables in the appendix. In addition, the revised text now includes a description of the small changes.

Below is a version with deltas. As you can see, the deltas are really small and can be distracting.



Commented [WS86]: Figure 6 is almost impossible to read. It seems like there are differences between S1 and S2 but the reader can't judge the magnitude just by looking at the bar charts.

Commented [IGC87R86]: We have included data tables for this all other figures in the Appendix. We have also included additional panels in Figure 6 showing the changes in S2 relative to S1.

energy consumption, and v) increased deployment of carbon dioxide removal (CDR) applications such as bioenergy in combination with CCUS (BECCS), afforestation, and direct air capture (DAC), compared with *S1* and *S2*. Notably, the scale and distribution of CDR deployment varies by type and region. By 2050, about 6.8, 4, and 0.4 $GtCO_2e$ respectively of BECCS, afforestation, and DAC are deployed globally in *S6* and *S7*, as shown in Figure 9Figure 9. While BECCS and afforestation are distributed more evenly across regions, most of the DAC is deployed in the U.S. primarily due to the availability of carbon storage.

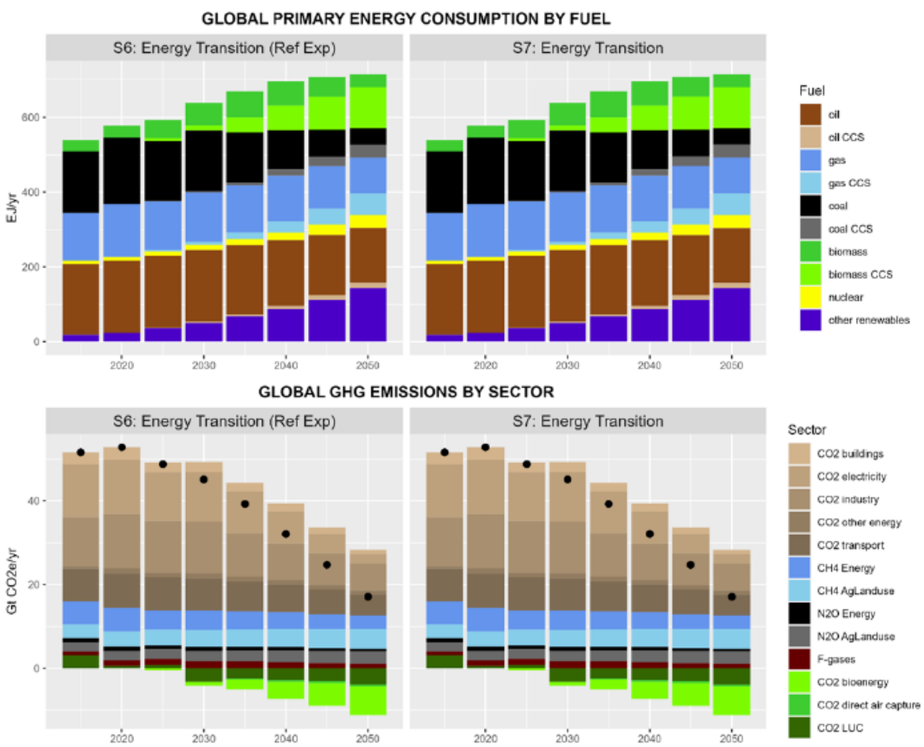


Figure 7. Global primary energy consumption by fuel and GHG emissions by sector under S6 and S7. Changes in S7 relative to S6 are presented in the data tables in Appendix A. Net GHG emissions are shown as a dot in each bar.

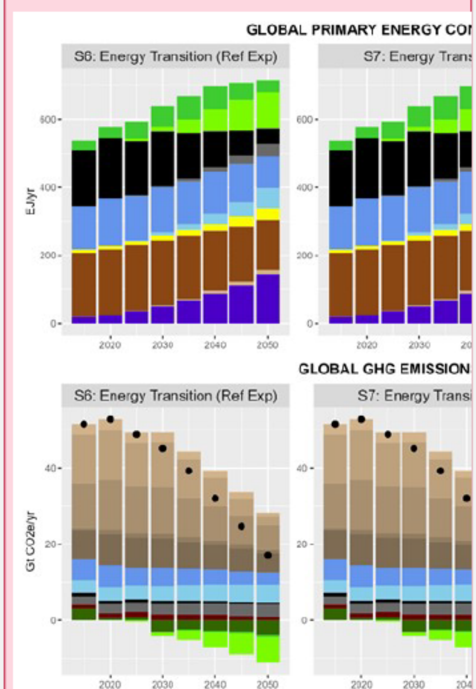
Commented [UP88]: Is this discussion related to Figure 8 or 9? Looks like one of these charts was dropped in and has no written content. All charts should be referenced with content. Prefer no drop and run charts.

Commented [IGC89R88]: This should point to Figure 9.

Commented [ST90]: Need S7 minus S6 delta figures.

Commented [IGC91R90]: We prefer not to show the delta figures here since the changes very small (<1%) and within solution tolerance. We instead point to the data tables in the appendix. In addition, the revised text now includes a description of the small changes.

Below is a version with deltas. As you can see, the deltas are really small and can be distracting.



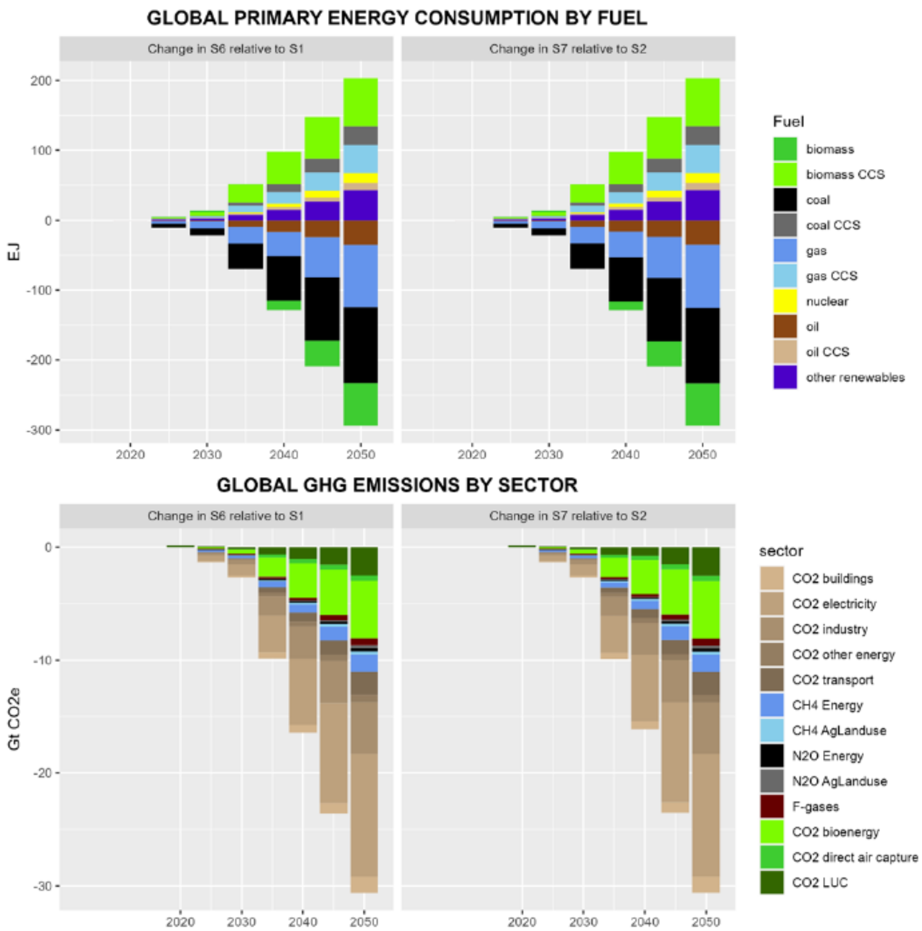


Figure 8. Changes in global primary energy consumption and GHG emissions under S6 and S7 relative to S1 and S2 respectively

Commented [ST92]: Recommend removing this figure. It is not related to LNG Exports. This result can easily be mis-interpreted given the focus of the project. This project is not about how effective climate policy is.

Commented [IGC93R92]: I think this figure is helpful in explaining that gas consumption in S6 and S7 are significantly lower than S1 and S2. Yet, demand for gas continues to grow because of deployment of gas-CCUS. That said, I do not have a strong opinion on this and happy to move this to the Appendix. If we decide to do that, we will need to work on figure numbering throughout the report.

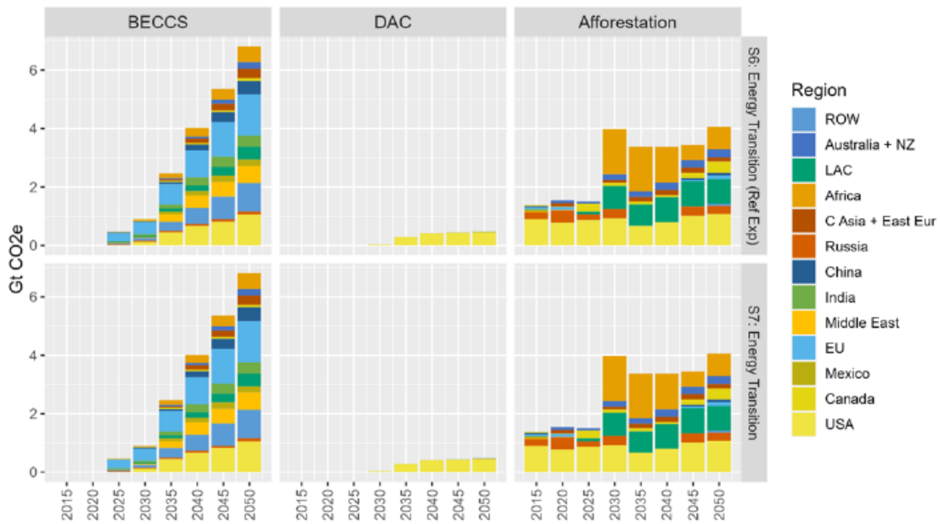


Figure 9. CDR deployment by type and region in S6 and S7

Interpretation of the energy transformation and emissions outcomes under *S6* and *S7* – particularly, those surrounding the regional and sectoral allocations – requires two careful considerations. First, these scenarios do not explicitly model the actual policy instruments and mechanisms that countries might adopt to meet their pledges – due to lack of sufficient literature on policies and regulations over the longer time horizon of focus in this study. Instead, these scenarios assume that countries achieve their pledges cost-effectively through a combination of decarbonization strategies discussed above. Second, *S6* and *S7* do not assume the availability of any emissions trading or offset mechanisms for countries to meet their pledges. Hence, countries with net-zero pledges – such as the U.S. – are assumed to meet those pledges in the stated target years through a combination of decarbonization strategies discussed above, including CDR deployment within their own geographic boundaries. The sectoral and geographic distributions of energy system transitions and emissions outcomes could be different depending on the actual policies and mechanisms that countries use to meet their pledges in reality.

Commented [ST94]: Need delta figures. The key message is "what changed" when we increase exports. I can not ascertain this result from the current results display.

The question of how/if renewables or other energy sources are displaced by natural gas is also not apparent in any of these results.

What countries changed their energy consumption profile because the US increased exports?

Did each countries response to change in energy consumption pattern increase or decrease their GHG emissions footprint?
...what sectors within each country?

Next - figures are nice, but would like to see full tabulated results in an Excel workbook be made available to provide transparency to the public on GCAM, NEMS, and LCA results.

Commented [IGC95R94]: Need delta figures. The key message is "what changed" when we increase exports. I can not ascertain this result from the current results display.

Response: As discussed in a previous response, we prefer not showing the delta figures here because the changes are really small (less than 1%) and within solution tolerance. Instead, we point to the data tables in the appendix which contain differences.

The question of how/if renewables or other energy sources are displaced by natural gas is also not apparent in any of these results.

Response: Again, these changes are really small and within solution tolerance. The data tables in the appendix contain these details.

What countries changed their energy consumption profile because the US increased exports? Did each countries response to change in energy consumption pattern increase or decrease their GHG emissions footprint?
...what sectors within each country?

Response: Note again that gas consumption changes, fuel substitution, and emissions changes in response to additional US LNG exports are all really small (<1%) and within solution tolerance. The description in this

D. Global Natural Gas Consumption, Production, and Trade Under Scenarios *S6* and *S7*

As shown in Figures 10 and 11, under *S6* and *S7*, natural gas consumption decreases compared to *S1* and *S2* in most regions largely driven by official net-zero pledges that require complete decarbonization of energy systems by 2050. However, in some regions with net-zero pledges that extend beyond 2050 (e.g., India), natural gas demand continues to grow through 2050 and consumption does not change much compared to *S1* and *S2*. Globally, although natural gas consumption in *S6* and *S7* is lower compared to *S1* and *S2*, it continues to grow due to the deployment of natural gas with CCUS in power and industrial sectors and direct air capture (DAC) applications (see Figure A-2 in appendix). The lower natural gas consumption in *S6* and *S7* compared to *S1* and *S2* results in lower global production, LNG exports, and LNG imports.

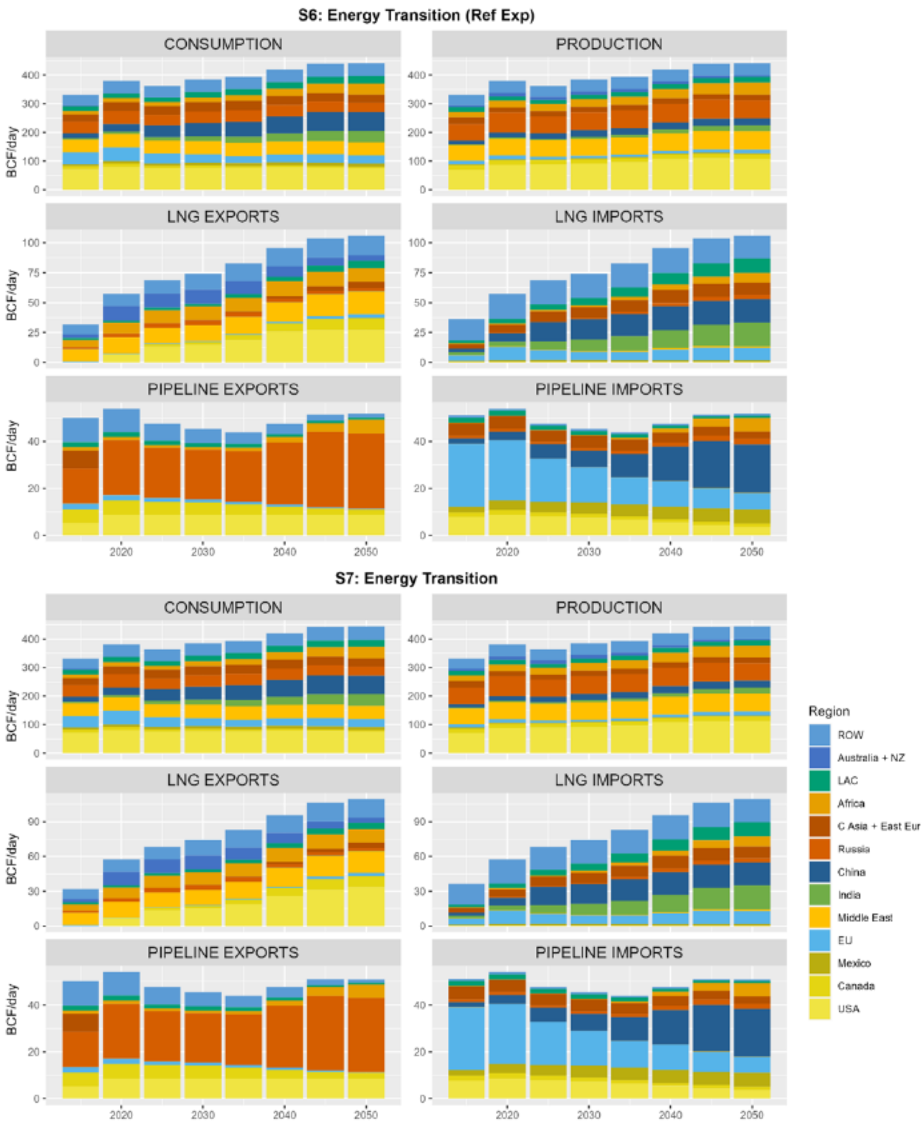


Figure 10. Natural gas consumption, production, consumption, and trade by region under S6 and S7 To convert from BCF/day to TCF/ yr and vice versa, the conversion factors are as follows: 1 TCF/yr = 2.74 Bcf/day and 1 BCF/day = 0.36 TCF/yr.

Commented [UP96]: Needs charts check. Looks like something going on with the Consumption and Production axis that are labeled as Bcf/d but with a max of 150 as the vertical axis (the way it was in prior draft in Tcf vs now Bcf/d). See also similar charts showing 600 Bcf/d on pages 22 and 23 for vertical axis which make more sense? Also the LNG exports between S6 and S7 hard to tell any difference with such small charts. They look identical with similar axis labels although difference may be small between 27.3 and 34 Bcf/d for the U.S.

Commented [IGC97R96]: Corrected.

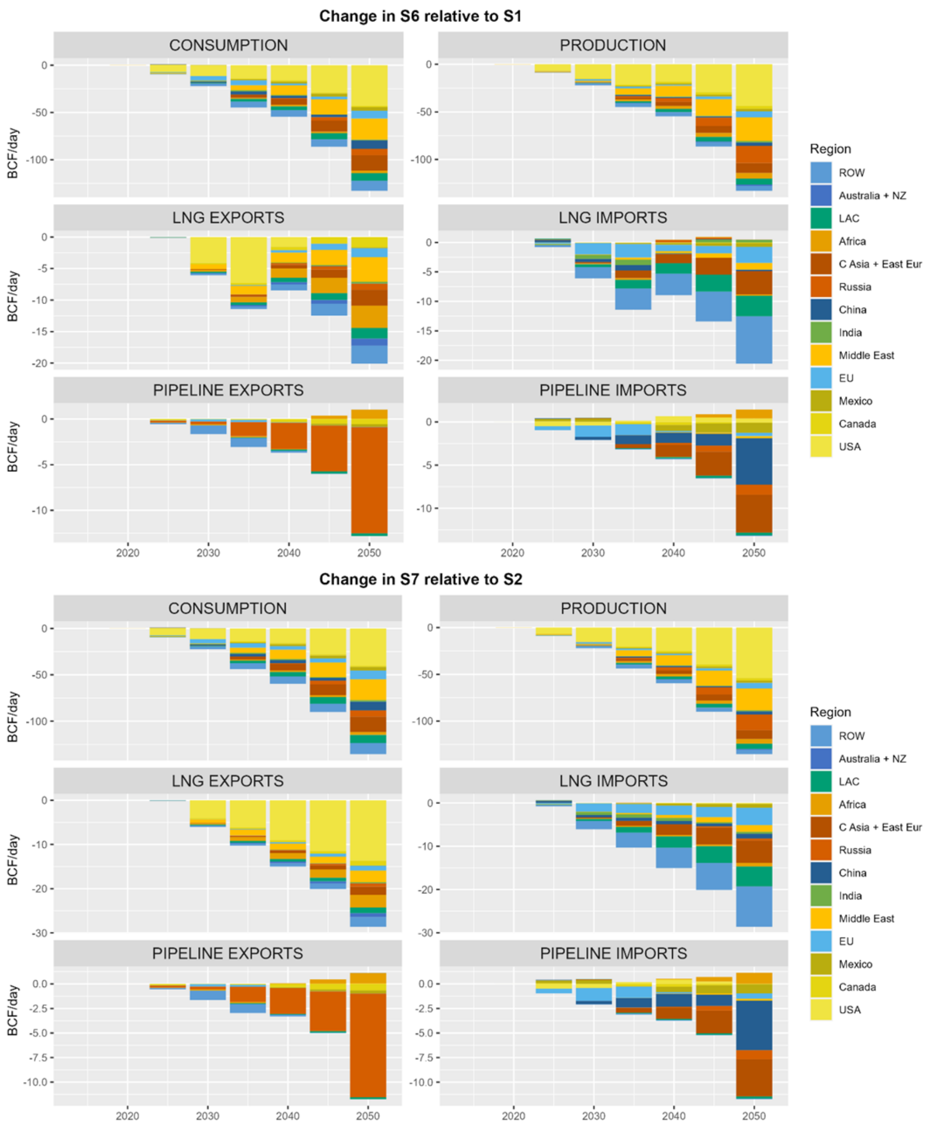


Figure 11. Changes in natural gas consumption, production, and trade by region: S6 vs S1 and S7 vs S2To convert from BCF/day to TCF/ yr and vice versa, the conversion factors are as follows: 1 TCF/yr = 2.74 Bcf/day and 1 BCF/day = 0.36 TCF/yr.

As shown in Figure 12Figure 12*, S6* and *S7* differ in the role of U.S. LNG exports in the global natural gas market. By 2050, U.S. LNG exports in *S6* are not different from *S1* because this scenario assumed the *S1* values (which are based on the AEO2023 Reference case) as an upper bound. Under *S7*, which assumes economically-driven outcomes, U.S. LNG exports increase by 6.3 Bcf/day to 34 Bcf/day in 2050. Similar to the comparison between *S1* and *S2*, the availability of additional U.S. LNG in *S7* results in a reduction in natural gas production, reduction in LNG exports, increase in LNG imports, and reduction in pipeline trade outside of the U.S. compared to *S6*. The availability of additional U.S. LNG in *S7* also results in a net increase in natural gas consumption of 1.6 Bcf/day outside of the U.S. In addition, U.S. natural gas consumption under *S7* decreases by 0.25 Bcf/day in 2050 compared to S6 (driven by domestic price increases in response to increased domestic production). Thus, the net increase in consumption globally in S7 compared with S6 is 1.37 Bcf/day. Compared to the total natural gas consumption globally in 2050 in S6 (442 Bcf/day), this change is a <1% increase. Consequently, global primary energy consumption under *S7* does not change much compared to *S6*, as shown in Figure 7. Note that there is no change in global emissions under *S7* relative to *S6* since both scenarios are constrained to the same values by design*.*

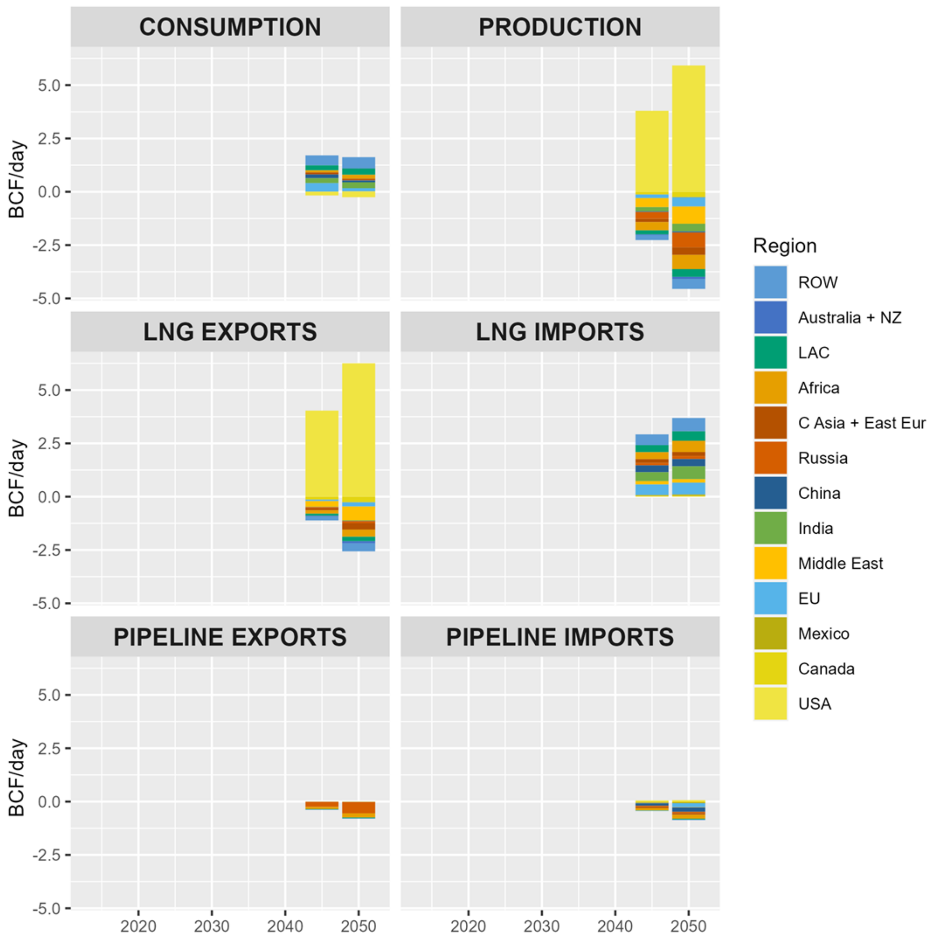


Figure 12. Changes in natural gas markets in S7 vs. S6To convert from BCF/day to TCF/ yr and vice versa, the conversion factors are as follows: 1 TCF/yr = 2.74 Bcf/day and 1 BCF/day = 0.36 TCF/yr.

E. Global Primary Energy Consumption and GHG Emissions Across All Scenarios

Overall, as shown in Figure 13, the seven scenarios explored in this study result in a range of outcomes for global primary energy consumption and emissions by 2050. Across *S1-S5*, global primary energy consumption in 2050 ranges from 802 to 833 EJ and global emissions range from 47.5 to 50.3 GtCO2e. In addition, the fuel composition of primary energy consumption and sectoral allocation of emissions are not very different across *S1-S5*. Total primary energy consumption and GHG emissions are highest under *S3* driven by higher population growth and associated increases in energy demand.

Notably, total emissions in 2050 under scenarios *S1* through *S5* are relatively similar to 2015 levels because these scenarios include current policies and measures to deploy lower emission technologies. However, total primary energy consumption in 2050 under these scenarios is significantly higher compared to 2015 primarily driven by population and economic growth.

By contrast, total energy and emissions are lowest under *S6* and *S7* due to assumptions about countries limiting emissions consistent with their pledges. Under these scenarios, global primary energy consumption in 2050 is 716 EJ and global GHG emission is 17 GtCO2e. As described earlier, these scenarios are also characterized by significant changes in the fuel composition of global energy consumption and the deployment of carbon dioxide removal technologies compared with *S1-S5*.

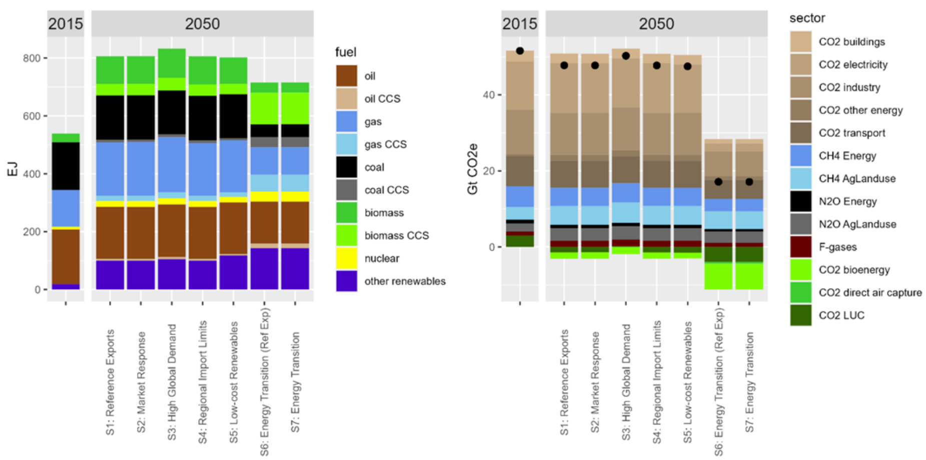


Figure 13. Primary energy consumption by fuel and GHG emissions by sector under all scenarios

F. NEMS Analysis: Implications for U.S. Energy Systems

1. Energy Impacts

AEO2023-NEMS and FECM-NEMS were used to model U.S.-specific results for *S1* through *S5,* and *S6* through *S7*, respectively. Similar to global energy consumption, primary energy consumption in the U.S. grew over time in each scenario.

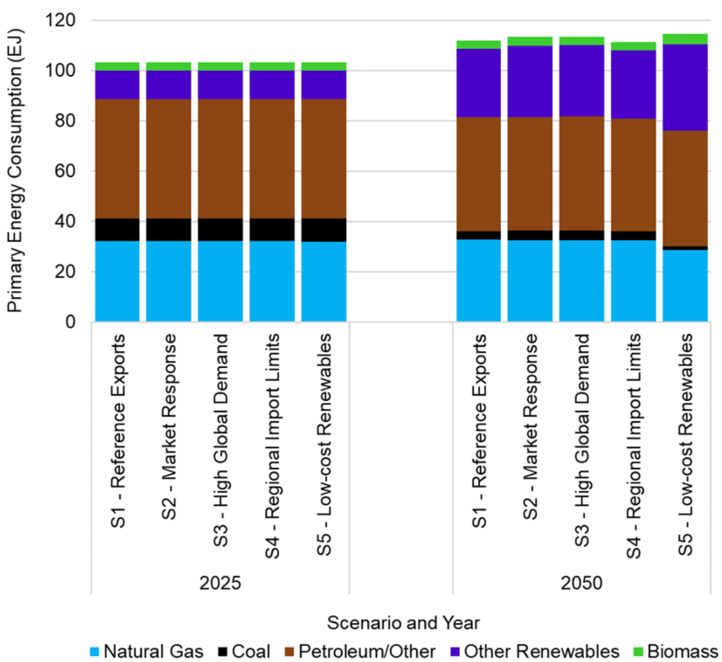


Figure 14. U.S. primary energy consumption, S1 through S5

In 2025, the primary energy consumption was at approximately 103 EJ in scenarios *S1* through *S5,* as shown in in Figure 14. By 2050, all scenarios saw an increase in total energy consumption, exceeding 110 EJ. The highest energy consumption was recorded in scenario *S5* at 115 EJ, and the lowest consumption was in scenario *S4* at 111 EJ.

The availability of low-cost renewables in scenario *S5* fosters the deployment of biomass and other renewable energy sources. A substantial decrease was noted in coal usage, with the most significant reduction occurring in scenario *S5*. Natural gas consumption remained steady across scenarios *S1* through *S4*, hovering around 32.1-32.7 EJ, but experienced a decline to 28.6 EJ in scenario *S5*.

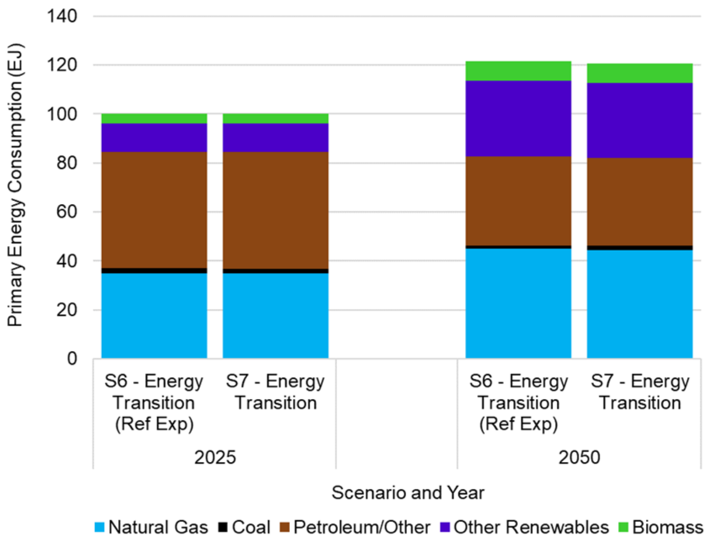


Figure 15. U.S. primary energy consumption S6 and S7

Figure 15 shows U.S. primary energy consumption across *S6* and *S7* in 2025 and 2050. In 2025, U.S. primary energy consumption was predominantly driven by fossil fuels, which accounted for 85% of the total energy use. By 2050, energy consumption rose across both scenarios relative to 2025, is distinguished by a notable increase in biomass and other renewables. Relative to *S6*, the increased LNG export trajectory in *S7* put pressure on the natural gas market, leading by 2050 to more expensive GHG mitigation strategies but ultimately a slight (.8%) decrease in U.S. natural gas consumption. Biomass and other renewable sources grew by 23.6 and 23.3 EJ from 2025 to 2050 in the *S6* and *S7* cases respectively, thereby contributing 32.1% of the total energy consumption in both cases. Natural gas consumption increased from 35.0 and 34.9 EJ in 2025 to 44.8 and 44.4 EJ in the energy transition scenarios *S6* and *S7* respectively. Remaining primary energy, primarily petroleum, decreased across both cases from 47.7 EJ in 2025 to 36.2 EJ in *S6* and 35.8 EJ in *S7* by 2050.

2. Natural Gas Production and Consumption Impacts

U.S. natural gas production increased across most cases to maintain projected export volumes. U.S. natural gas consumption, on the other hand, was relatively unchanged across the first four scenarios. Figure 16 plots total U.S. natural gas production, consumption, and export values over time. The LNG export values were identical to those plotted in Figure 3 and are included here as reference.

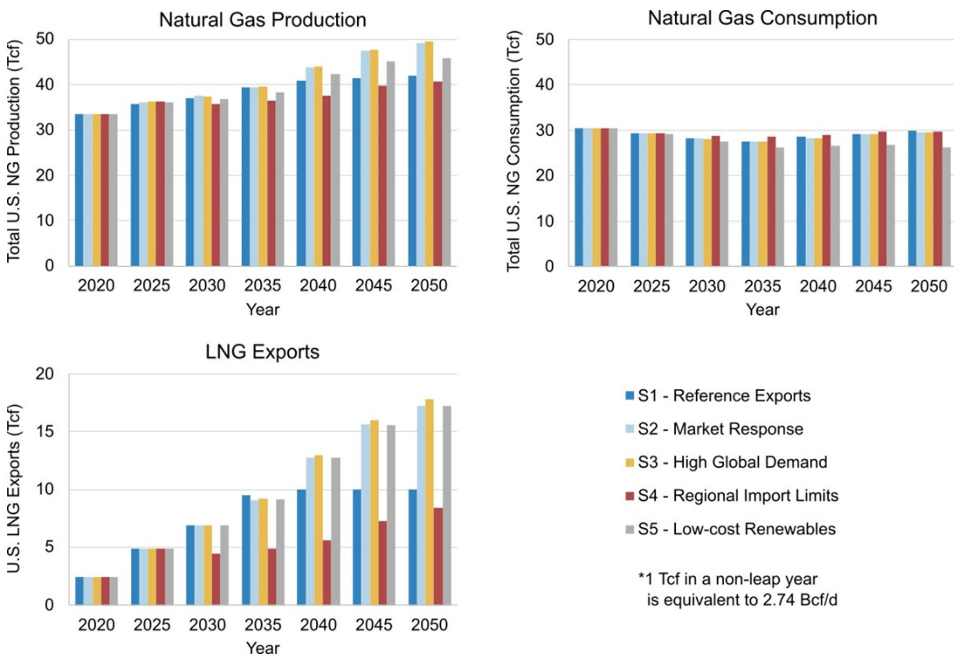


Figure 16. Total U.S. natural gas production, consumption, and export volumes over time, by scenario

From a starting point of 33.5 Tcf (91.5 Bcf/d) of natural gas production in 2020, production in each scenario increased, following a path that correlated with their LNG export curve. Natural gas production in *S1*, *S2*, and *S3* followed a similar trajectory by 2035, reaching 39.5, 39.4, and 39.5 Tcf respectively. *S1* production then slowed through 2040 and reached a peak of 42.0 Tcf by 2050. *S2* and *S3* production values accelerated through 2050, reaching 49.0 Tcf and 49.5 Tcf, respectively. Similar to the trends in LNG exports, *S4* production exhibited the lowest values, ending slightly below *S1* at 40.7 Tcf in 2050. *S5* production exhibited the same general path as *S2* and *S3*, but grew more slowly, reaching 38.2 Tcf and 45.7 Tcf in 2035 and 2050.

The natural gas consumption volumes from *S1*-*S3* followed similar paths, dipping from 30.5 Tcf in 2020 to 27.6, 27.5, and 27.4 Tcf in 2035 before ramping up to 29.8, 29.6 and 29.6 Tcf in 2050 in these scenarios. Although *S4* had exhibited lower LNG export and natural gas production quantities, the consumption volumes in *S4* remained slightly higher than the volumes in *S1*-*S3* through most model years, equalizing with *S1*-*S3* in the final timestep. *S4* reported 28.5 Tcf of natural gas consumption in 2035 and 29.8 Tcf in 2050. *S5* was the largest outlier with the lowest consumption of 26.2 Tcf in 2035 and almost no change in consumption values between 2035 and remaining flat at 26.2 Tcf in 2050.

The lower natural gas production and consumption volumes in *S5* (when compared to *S2* and *S3*) are explained by the effect of low renewables costs on the energy system. *S5* adopted many of the same inputs as EIA's AEO2023-NEMS low zero-carbon technology cost case. These inputs drove down the cost of renewables and caused *S5* to switch from natural gas to cheaper renewable energy sources, affecting both production and consumption. The remaining scenarios showed similar levels of natural gas consumption, but different levels of natural gas production, suggesting that most increases in natural gas production were passing directly to LNG exports.

Figure 17 plots the natural gas production, consumption, and exports for the two net-zero scenarios. Natural gas production in Scenarios *S6* and *S7* is 37.6 Tcf and 37.1 Tcf in 2035, respectively, but quickly rise to 54.7 Tcf and 56.5 Tcf by 2050. *S6* and *S7* exhibited a flatter trend in total consumption through 2040, but reached 41.9 Tcf and 41.5 Tcf, respectively, by 2050. The differences between the two net-zero scenarios were similar to differences observed between *S1* through *S5*: changes in production were correlated with changes in LNG exports, but differences in consumption between scenarios were minimal.

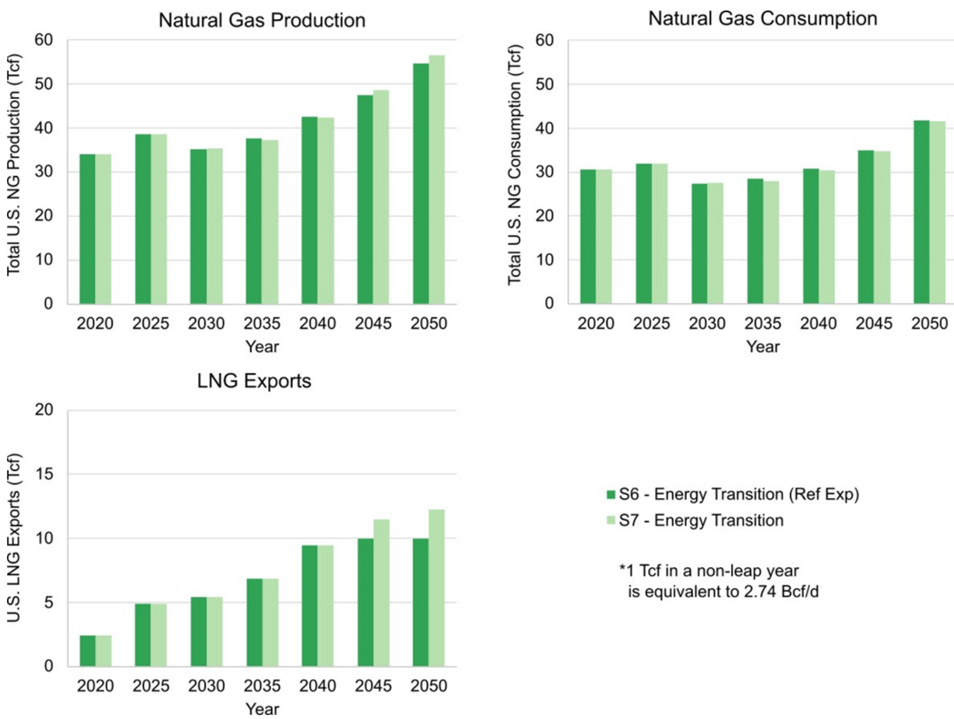


Figure 17. Total U.S. natural gas production, consumption, and export volumes, net-zero scenarios

The rapid increase in natural gas production and consumption for the net-zero scenarios after 2040 came from a substantial increase in natural gas to power direct air capture (DAC) facilities, plotted in Figure B-5 of the appendices. Natural gas consumption accounted for 16.8 Tcf and 16.2 Tcf in 2050 for *S6* and *S7*, respectively. More detail on CO_2 emissions and removals is provided in the Section "U.S. Greenhouse Gas Results".

3. Natural Gas Henry Hub Prices Impacts

Although total U.S. natural gas consumption volumes were similar across the first five scenarios, higher LNG exports increased natural gas prices by up to 33% in 2050. The natural gas price of the net-zero scenarios rose above the prices from *S1* through *S5*, driven mostly by demand for natural gas to power DAC facilities. Figure 18 plots the natural gas price at the Henry Hub in $2022/Mcf over time for all scenarios.

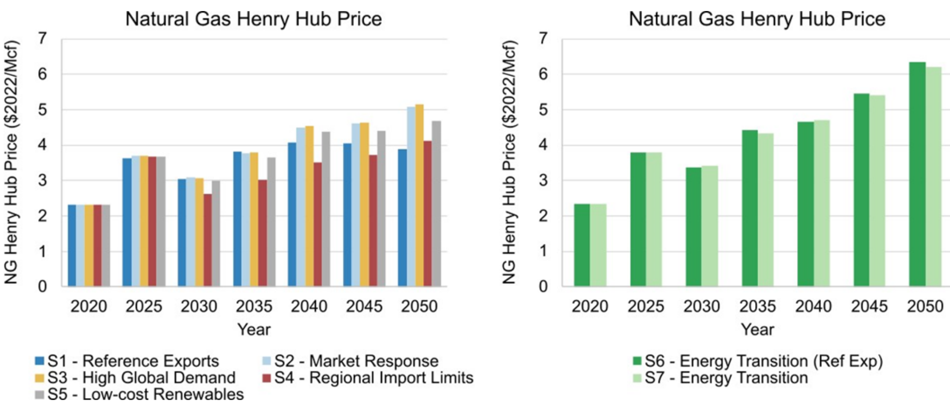


Figure 18. Total U.S. natural gas Henry Hub price by scenario ($2022)

The natural gas price in *S1* increased to a maximum of $4.08/Mcf in 2040 before moderating to $3.88/Mcf in 2050. The natural gas prices in *S2*, *S3*, and *S5* were mostly consistent with the reference case through 2035 but ultimately rose to levels of $5.09/Mcf, $5.15/Mcf, and $4.67/Mcf, respectively, by 2050. The difference in prices correlated with the differences in LNG export curves, while LNG exports in *S1* plateaued after 2035 and saw a drop in natural gas prices. Scenarios *S2*, *S3*, and *S5* all exhibited both increasing exports and prices. *S4* had lower natural gas prices over most of the modeling period, but ultimately exceeded *S1* in 2050 with a price of $4.12/Mcf; the persistent increase in *S4* prices after 2030 was consistent with increases in LNG exports throughout the same time period.

The influence of LNG exports on natural gas prices shown in Figure 18 was similar to the effect reported by EIA in their May 2023 "Issues in Focus" report on LNG.[26] The EIA's "Fast Builds Plus High LNG Price" case, which modeled the effect on U.S. energy markets of accelerated construction of LNG infrastructure in an environment with elevated international demand for LNG, reported a 2050 natural gas price of $4.81/MMBtu (equal to $4.98/Mcf) at 48.2 Bcf/d of exports. These values are close to the results from *S2* of $5.09/Mcf at 47.2 Bcf/d of exports and demonstrate good agreement between the two studies on the relationship between LNG exports and natural gas prices.

Overall U.S. natural gas consumption did not change appreciably in response to higher prices, but there were some shifts in consumption behavior on a sector-by-sector basis. These sector-specific differences are presented in greater detail in the Appendix in Figure B-3.

[26] U.S. EIA (2023). AEO2023 Issues in Focus: Effects of Liquefied Natural Gas Exports on the U.S. Natural Gas Market. Available at: https://www.eia.gov/outlooks/aeo/IIF_LNG/pdf/LNG_Issue_in_Focus.pdf.

The natural gas price of the net-zero scenarios rose above the prices from *S1* through *S5*, driven mostly by demand for natural gas to power DAC facilities. Natural gas prices for S6 and S7 were similar to prices in *S1* through 2030, but afterwards rapidly increased on a trajectory consistent with the growth of DAC. *S6* and *S7* reached prices of $6.34/Mcf and $6.20/Mcf, respectively, by 2050. The difference in price between *S6* and *S7* was within the tolerance of the model.

4. U.S. Macroeconomic Outcomes

While NEMS has rich detail about the energy system, a separate macroeconomic activity module (MAM) provides projections of economic drivers underpinning NEMS' energy supply, demand, and conversion modules. The MAM incorporates IHS Markit's (now S&P Global's) model of the U.S. economy, along with EIA's extensions of industrial output, employment, and models of regional economies. The S&P Global module is modified to include EIA's key assumptions, such as world oil price, yielding a baseline trajectory of the economy. The baseline cannot appropriately respond to the wider economic changes in the net-zero scenarios, so such analysis is not included here. Within a NEMS scenario, feedback from the other NEMS modules includes:

- Production of energy, including coal, natural gas, petroleum, biomass, and other fuels;
- Trade in energy, including net exports coal, petroleum, natural gas, and biofuels;
- Total and end-use demand for energy, including sales of electricity;
- Consumer spending on energy, disaggregated to fuel oil motor fuels, electricity, natural gas, and highway consumption of gasoline;
- Energy prices, including a price index for consumer prices and wholesale prices; and
- Industrial production indices for oil and gas extraction and coal mining.

Since the MAM does not track individual projects, GDP estimates do not include economic activity associated with specific export facilities and thus the impacts are approximate.

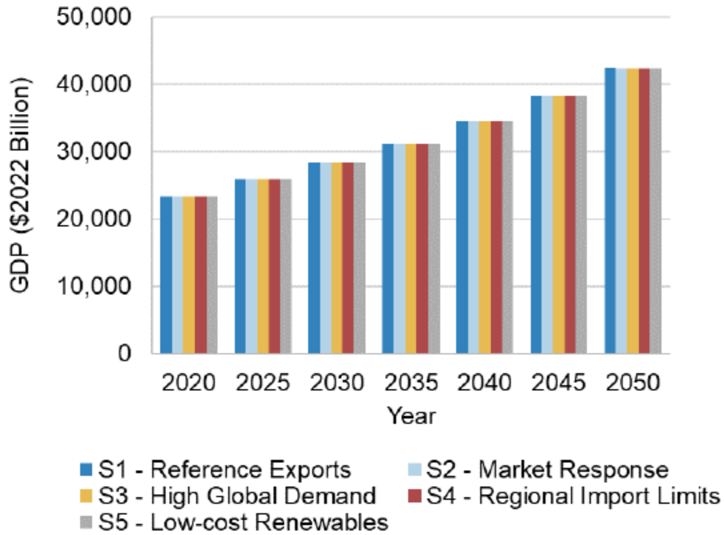


Figure 19. U.S. real GDP changes

GDP estimates in NEMS are only loosely coupled with the energy market representation and therefore there is a some uncertainty in the GDP metric. In addition, because NEMS is a domestic model, trade effects are not represented in as granular a level as domestic energy markets. One result is that in general modeled GDP growth is in general inversely proportional to the growth in natural gas prices, uncertainty increases as the forecast horizon increases. With those caveats, Figure 19, shows U.S. GDP growth across scenarios. The growth rate through 2045 remained essentially constant across all five scenarios, increasing at 1.9% annually. Higher natural gas exports caused natural gas prices to rise by up to 33% in 2050, reducing economic activity in some sectors but increasing in others. The impact of increased LNG exports was positive on GDP by less than 0.1% across scenarios the through 2045. Accelerating natural gas prices in the last five years of the projection period in S2 reduced consumption of other products and tended to slightly reduce the overall rate of economic growth relative to *S1*. Overall, GDP changes in 2050 relative to 2020 were within 0.3%, $42.4 in S1 vs $42.3 S2 – S5.

Commented [WS98]: A few points:
1. This data should be presented in numbers as well as visually.
2. We state that higher exports is positive on GDP until 2050, but S1 seems greater than S2 throughout the entire time series.
3. Does the last sentence mean we think that 0.3% of GDP is a small amount that doesn't warrant further discussion? 0.3% of 42 trillion is over 100 billion. Are we saying that incremental exports of 20 Bcf/d would reduce the size of the US economy by that amount? Over $5b per Bcf/d? If so that seems like a very consequential finding and one that should be explored in greater depth.

A few points:
1. This data should be presented in numbers as well as visually.
2. We state that higher exports is positive on GDP until 2050, but S1 seems greater than S2 throughout the entire time series.
3. Does the last sentence mean we think that 0.3% of GDP is a small amount that doesn't warrant further discussion? 0.3% of 42 trillion is over 100 billion. Are we saying that incremental exports of 20 Bcf/d would reduce the size of the US economy by that amount? Over $5b per Bcf/d? If so that seems like a very consequential finding and one that should be explored in greater depth.

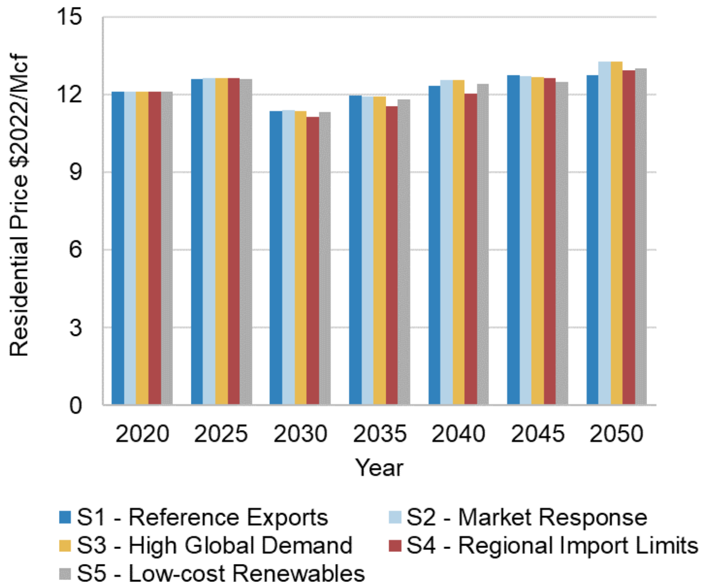


Figure 20. U.S. residential natural gas prices

Figure 20 shows the residential natural gas price in each of the five key scenarios. In 2050, natural gas prices in *S3* (when exports are the highest) were 4% higher than S1, when exports were the lowest. Overall, natural gas price differences between the scenarios were generally close to 1-2% across the scenarios.

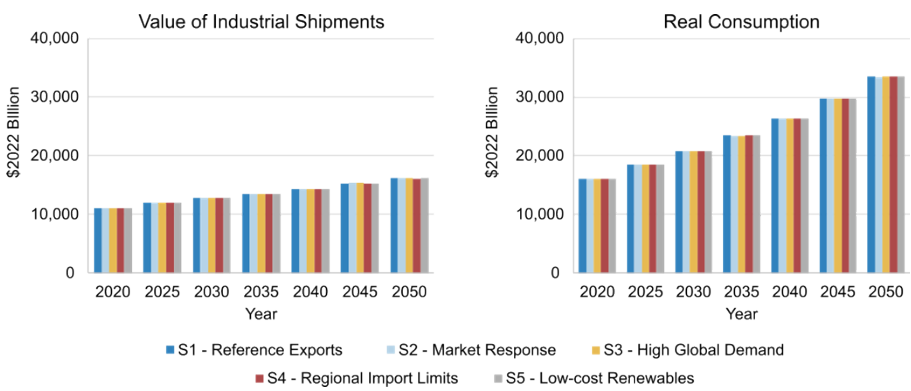


Figure 21. U.S. value of industrial shipments and real consumption

One component of GDP tracked by NEMS is the value of industrial shipments, shown in Figure 21. Industrial processes are sensitive to natural gas prices, which were generally higher than *S1*. However, increased production, processing, and transportation of natural gas requires additional equipment which tends to increase industrial shipments. Overall, NEMS showed a very slight increase in the value of industrial shipments in *S2* relative to *S1* of 0.2% in 2050. The value declined in S4 vs S1, reflecting lower natural gas production and exports.

The NEMS analysis shows LNG exports could benefit consumers through increased labor income and the return on capital expended on facilities to produce and export the commodity. Exports increased the value of the dollar, decreasing the cost of some imports. However, increased demand for natural gas, including exports, raised the price of natural gas and the costs of products that require natural gas as an input. This can be observed in the change in aggregate consumption which is another component of GDP. When energy prices rise, consumers must pay more for natural gas, but purchases of other goods decrease. Across all the scenarios, the effect on natural gas prices was small, and, while wealth transfers may occur between consumers as some groups benefit more than others through increased production, this was not reflected in the aggregate output of the model. Changes across all the scenarios were essentially flat. Overall, by 2050 consumption changes were less than 0.2%.

Commented [UP99]: Should this be LNG instead of NG? or does the NEMS analysis show benefits of all NG exports? We've been discussing LNG exports so far in the report so just checking?

Commented [DH100R99]: Yes apologies, this should be LNG. Edited.

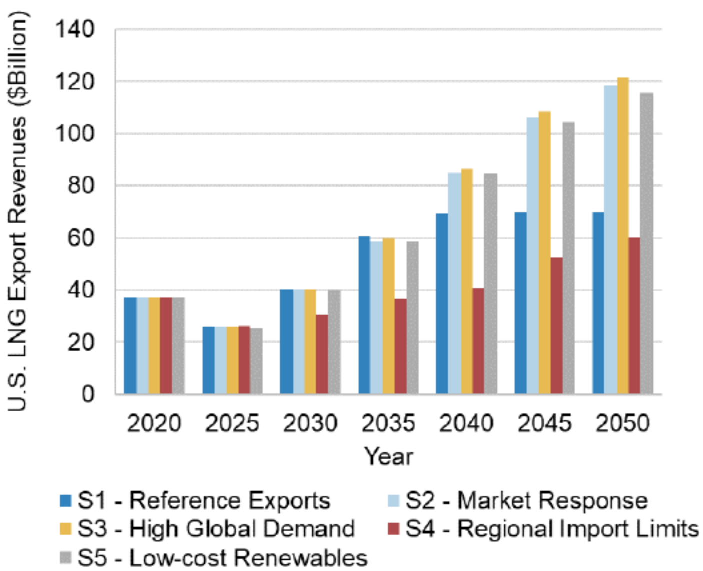


Figure 22. U.S. LNG export revenues

In a fully competitive market, the delivered price of LNG should be sufficient to fully accommodate the cost of production, liquefaction, and transportation of natural gas. Since much of this activity occurs domestically, it is a rough proxy for economic activity engendered by LNG exports. A representative price would be the price of imports to the EU. Figure 22 shows estimates of export revenues as the product of the LNG export volumes and the EU LNG price.

5. U.S. GHG Results

AEO2023-NEMS tracks CO_2 emissions from the combustion and use of fossil fuels. These CO_2 emissions did not change significantly among scenarios in response to varying LNG export levels. Figure 23 plots CO_2 emissions from fossil fuels for *S1* through *S5*.

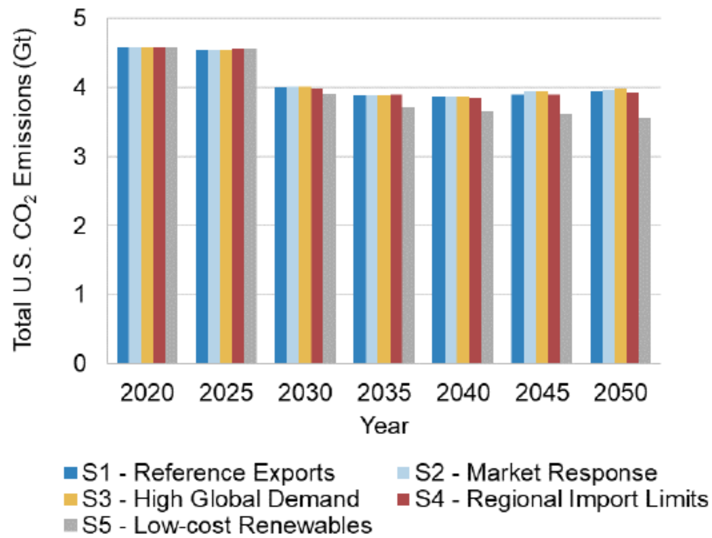


Figure 23. Total U.S. CO_2 emissions from fossil fuel combustion

From a starting point of 4.58 Gt CO_2 emissions in the U.S. in 2020, the first four scenarios declined to between 3.99 and 4.02 Gt CO_2 in 2030 and followed a flatter trajectory to 3.93-3.98 Gt CO_2 in 2050. There was a weak connection between LNG exports and CO_2 emissions: cases with the highest exports (*S2* and *S3*) had slightly higher CO_2 emissions levels in 2050 of 3.97 and 3.98 Gt, respectively, whereas cases with lower exports (*S1* and *S4*) reported respective CO_2 emissions of 3.94 and 3.93 Gt. The relationship was small, however, and accounted for only a 1% difference in emissions. The small differences between the first four scenarios were consistent with the relatively unchanged natural gas consumption volumes observed in Figure 16. *S5* was an outlier, continuing to decrease through 2030 (3.91 Gt CO_2) and reaching 3.57 Gt CO_2 emissions by 2050. The lower emissions from *S5* were explained by the assumptions used for low renewable costs rather than by changes in LNG exports.

Commented [WS101]: Should these be 3940 and 3930?

Commented [DH102R101]: Yes, thanks for catching that - updated to be 3.94 and 3.93 Gt CO2

S6 and *S7* were modeled in FECM-NEMS, which endogenously calculated some additional emissions that AEO2023-NEMS is missing (most relevant being CH_4 leakage from natural gas production and processing infrastructure). To retain consistency between the two models, only the CO_2 emissions reported by FECM-NEMS were included in the analysis and used to define the net-zero GHG scenarios. The remaining non-CO_2 emissions (which still contributed to the overall net-zero GHG cap) were calculated endogenously within GCAM and used in FECM-NEMS as an exogenous input.

Figure 24 plots the CO_2 emissions and removals for *S6* and *S7*. Both scenarios had both lower emissions than *S1* and significant amounts of CO_2 removals, reaching net-zero by 2050.

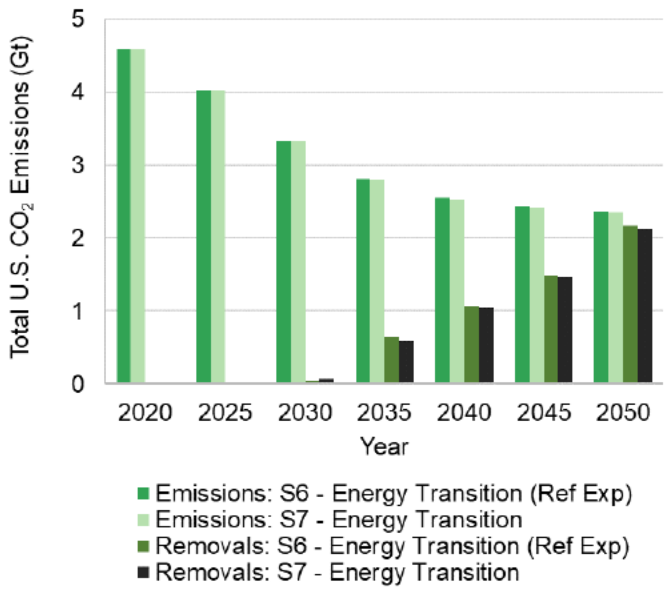


Figure 24. Total U.S. CO_2 emissions from fossil fuel combustion and removals, S6 and S7

CO_2 emissions from *S6* and *S7* began at 4.58 Gt and declined continuously through 2050, ending at 2.37 and 2.35 Gt CO_2, respectively. These declines were primarily driven by electrification of broad sections of the economy with a combination of renewables and CCS. The decline in emissions was accompanied by an increase in removals, which started growing rapidly in 2030 and eventually reached 2.16 Gt CO_2 for *S6* and 2.13 Gt CO_2 for *S7* in 2050. The majority of removals (87-89% by 2050) came from DAC, with the remainder coming from H_2 production with biomass and BECCS. The specific breakdown of removal technologies is explored in Section D of Appendix B. While the removals did not completely counterbalance the 2.35-2.37 Gt of CO_2 emissions, the difference is offset by the sum of the changes in land-use and non-CO_2 emissions calculated within GCAM and used as exogenous inputs, which were net negative.

Commented [PW103]: Added land-use

G. NETL Life Cycle Analysis

The goals of the LCA component of this project were twofold: first, to help contextualize how the other results of this study (i.e., NEMS and GCAM models) connect to past studies of U.S. natural gas and LNG operations and, second, to leverage the results of the other models to quantitatively represent the international global warming potential (GWP) consequences from changes in quantities of U.S. exported LNG.

In support of the first goal, the following work was completed:

- Assessed whether NEMS results suggested significant changes in domestic supply (and thus, resulting in potential future upstream GWP intensity or emissions changes).
- Compared and aligned GCAM and NETL results to create a representation of the global natural gas supply chain that is consistent with existing NETL natural gas LCA studies.

In support of the second goal, the following work was completed:

- Developed a quantitative "market adjustment factor" that represents the consequences of additional export volumes of U.S. LNG, such as how additional available quantities of natural gas led to changes in the energy sectors of countries that purchase the LNG. These consequential effects were estimated by tracking differences in global GHG emissions and quantities of U.S. LNG exported from the GCAM model scenarios and assessed in comparison to existing NETL quantitative estimates of the upstream natural gas production.

In this project, the NEMS and GCAM models sought to represent economic and environmental changes associated with the defined changes in U.S. LNG exports. The GCAM model estimated global GHG emissions effects, including emissions associated with upstream natural gas. To compare the GCAM results with the NETL life cycle analysis work used by DOE in support of natural gas and LNG export decisions, NETL assessed and aligned the emissions estimates per unit of gas produced and delivered to large end users (e.g., LNG export facilities) in the US of the GCAM and NEMS models to the NETL life cycle GHG intensity for U.S. average natural gas production and delivery to large end users using the ratio of the NETL and GCAM results. Non-U.S region natural gas production and delivery GHG emissions intensity values were also adjusted to align with NETL life cycle GHG intensity values based on the same ratio of US values. This process was conducted for all years and regions reported by GCAM.

1. Assessment of NEMS Domestic Natural Gas Production by Region

The NEMS modeling focused on domestic changes that would be expected to occur in the seven scenarios modeled. NETL evaluated the regional sources of natural gas using outputs from NEMS to compare them to the mix of regions NETL uses in existing assessments of upstream natural gas emissions.

As shown in Appendix C, the NEMS results suggested only modest changes in the production mix by region and thus would not be expected to substantially change the domestic average GHG intensity per MJ of natural gas produced compared to previous analyses. As such, no regional adjustments were made to the U.S. results.

2. Comparison of GCAM and NETL Estimates of GHG Emissions of the Natural Gas Sector

As discussed above, the GCAM model represents economic activity (and associated GHG emissions) by sectors and technologies, and their respective inputs and outputs, for regions, years, and scenarios. However, only a subset of these was relevant to the scope of the natural gas LCA-focused effort.

Only three sectors in the GCAM model include greenhouse gas emissions of the natural gas sector: *natural gas*, *gas pipeline*, and *other industrial energy use* (see Appendix C for more detail). Using the basis of process stages as represented in the NETL Natural Gas model, Figure 25 shows the relevant GCAM sectors that have associated CO_2 and non-CO_2 emissions. While the overall GCAM model has 16

Commented [AA104]: Delete or "that is"

Commented [ST105]: Results were not aligned to the past NETL work on LNG exports. Work was aligned to the current NETL 2020 natutal gas upstream thru transmission to a large end user U.S. average GHG emissions per unit of natual gas delivered.

Commented [SM106R105]: Agreed, edited (slightly modified the suggested revision).

Commented [AA107]: Spell out if first time using this unit alone.

Commented [SM108R107]: Defined earlier, and added to glossary, thanks!

species of GHG emissions, for the three sectors above relevant to the upstream natural gas sector, only emissions of CO_2, CH_4, and N_2O were represented.

As summarized in Figure 25, all stages of the NETL LCA are explicitly represented in GCAM except for Ocean Transport, which was included as part of other industrial energy use but could not be separated out for this analysis. As a result, the comparison in this report was focused on a comparison of emissions from production of natural gas in the U.S. through delivery to a large end user rather than LNG delivered around the world.

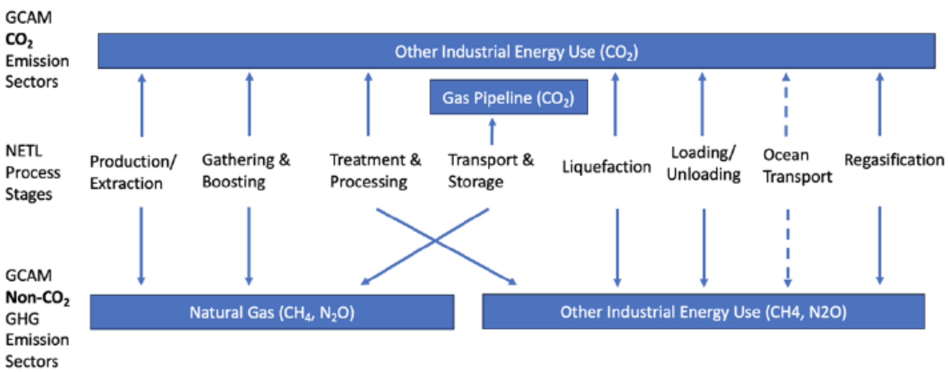


Figure 25. Mapping of NETL natural gas stages to GCAM sectors

Quantitative values of emissions intensities in the year 2020 of the various GCAM sectors for the "USA" region for the three natural gas-relevant sectors are listed and compared to NETL natural gas model results in Appendix C. Note, in order to compare NETL and GCAM results, NETL model results were regenerated using LHV basis as shown below and differ from those published (as HHV by default) in the report.

Overall, the estimated upstream emissions for the USA in the GCAM model in the year 2020 for Scenario 1 were about 8.52 g CO_2e/MJ (on an IPCC AR6 100-year, LHV basis), which is slightly higher than those of the NETL model for the boundary of production through transmission to large end user (8.18 g CO_2e/MJ, LHV basis). Using the relationship between those estimates, emissions results in the three GCAM natural gas sectors were adjusted by a factor of 8.18/8.52, or 0.96 (a 4% reduction) to maintain consistency with past NETL studies of the natural gas sector. This adjustment factor was used for all regions and for all years in the model. Similar adjustment factors were found for IPCC AR6 20-year and IPCC AR5 100-year and 20-year bases (see Appendix C for further details). The results are similar whether using the adjusted or unadjusted values.

For context, in the GCAM results for *S1* in Year 2020, total global GHG emissions are approximately 53,000 Tg. The NETL adjustment post-processing of the GCAM model results on the IPCC AR6 100-year basis of the GCAM *gas pipeline* and *natural gas* sectors reduces emissions by about -7 and -35 Tg CO_2e, respectively, when considering those of S1 in the Year 2020. Post-processing adjustments of the GCAM model results of the *other industrial energy use* sector reduce emissions by about -10 Tg CO_2e when

Commented [ST109]: Labels in "blue" boxes need capitalized.

Subscript the 2 and 4 in CO2, CH4, and N2O.

NETL Process Stage labels should be centered with the arrows.

Commented [SM110R109]: Fixed.

Commented [ST111]: The rest of the report uses "U.S." instead of "USA".

Commented [SM112R111]: Just referring to the actual GCAM model region name here

Commented [ST113]: See previous comment, this numeric values used need to be stated.

Commented [SM114R113]: Added

Commented [ST115]: Is the GCAM value consistent over the 35 year time horizon?

Is this the levelized average over 35 years that includes performance improvements within GCAM? Or is it the year 2020 value?

Are the values different for S7/S6 when climate pledges and net zero are considered? How did this effect the MAF calculation when considering temporal and economic variability?

Commented [ST116R115]: Need to state that the 8.52 is **the year 2020 GHG emissions intensity.**

Added to text - please confirm edit.

After reading the report, I don't think the value is levelized over 35 years. Unclear how GCAM GHG intensity per unit of LNG changes over time within the GCAM model (or NEMS).

Commented [SM117R115]: We apply the same adjustment factor through all the years, for all regions. This maintains the built-in methane

Commented [WS118]: If we used the GCAM estimate, how would that affect our GHG projections? Some will argue that we cherry picked a more

Commented [SM119R118]: We show results using the raw and adjusted values in the report.

Commented [ST120]: Why the italicized label? Not italicized in other parts of the report?

Commented [SM121R120]: Rest of report does have italicized Scenario references.

considering those of *S1* in the Year 2020. The adjustments for these three sectors needed to align with past NETL studies and have the cumulative effect of reducing estimated emissions from the GCAM model by about 0.2% (in *S1* in the Year 2020).

This same process was undertaken for different IPCC GWP values, and the resulting alignment tables and adjustment factors are provided in Appendix C.

3. Market Adjustment Factor Results

Market adjustment factors (MAF) quantitatively estimate the consequential effect on global emissions as a function of U.S. LNG exported based on the GCAM model results of this study. MAFs for *S2* were estimated versus a baseline of *S1*, while the MAF for *S7* was estimated versus a baseline of *S6* given the significantly different global economy modeled in these scenarios.

MAFs were calculated using the post-processed LHV NETL-adjusted GCAM results described previously as well as the unadjusted GCAM results (HHV results are shown in the Appendix). The MAF was calculated for each scenario by aggregating annual MAF values over the time horizon of the model (i.e., the MAF for *S2* versus *S1* was defined as the cumulative difference in annually estimated global emissions over the 35-year period divided by the cumulative difference in annually estimated exported LNG over the 35-year period).

All MAFs were found using a variety of IPCC Assessment Report GWP values over 20- and 100-year time horizons, and with the raw and post-processed NETL adjusted GCAM results. MAF results from the IPCC Sixth Assessment Report on a 100-year time horizon are presented here, while results for other IPCC Assessment Reports and time horizons (and unadjusted GCAM results) are shown in Appendix C.

Table 4 shows the MAFs for *S2* (vs. *S1*), which varied from -5.34 to -5.35 g CO_2e/MJ on a 100-year time horizon (LHV basis). Also included is a summary reminder of the differences in the modeled scenarios (e.g., where *S1* is the baseline and *S2* added an economic solution for LNG exports, making a direct comparison of the two appropriate).

Table 4. Market Adjustment Factors for S2 vs. S1 (IPCC AR6, 100 year)

Results (g CO_2e/ MJ, LHV)			
MAF Case	GCAM	GCAM with LHV NETL adjustment	Scenario Difference
S2* vs. *S1	-5.34	-5.35	Adds economic solution for LNG exports.

Table 5 shows market adjustment factors for *S7* vs. *S6*, both of which represented significantly different energy and economic investments in support of a low-carbon economy through climate policies. The *S7* MAFs vary from -2.95 to -3.01 on a 100-year time horizon (LHV).

Table 5. Market Adjustment Factors for S7 vs. S6 (IPCC AR6, 100 year)

Results (g CO_2e/ MJ, LHV)			
MAF Case	GCAM	GCAM with LHV NETL adjustment	Scenario Difference

Commented [ST122]: All results need to be on a HHV basis to document what will actually be used by NETL when added to the attributional results.

I am okay with report comparing to GCAM in LHV, however, that is not the result that needs documented for use in future export analyses that include consequential market effects. This report needs to document the values that will be used in future work.

Commented [SM123R122]: Will add HHV values to Appendix.

Commented [ST124]: Add HHV results.

Commented [ST125]: Add HHV results.

S7* vs. *S6	-3.01	-2.95	S6 1.5°C pathway, economic solution for LNG exports

4. Interpretation of Global Market Adjustment Factor Results

On an IPCC AR6 100-year basis, for *S2-S1*, the MAF result was approximately -5.4 g CO_2e/MJ (LHV). For purposes of comparison, NETL estimated natural gas upstream emissions prior to delivery to a large domestic industrial end user (like an LNG terminal) are 8.18 g CO_2e/MJ (LHV), equivalent to 7.44 g CO_2e/MJ (HHV). The MAF indicates that as U.S. LNG exports increased, the induced global market effects would result in an overall reduction in GHG emissions that is about 65% of the estimated upstream emissions associated with production through delivery of the natural gas to a large industrial end user in the U.S. Similarly, the MAF result for *S7-S6* was about -3 g CO_2e/MJ (LHV). In a decarbonizing world, the overall reduction in emissions was 36% of the estimated upstream emissions associated with production through delivery of the natural gas to a large industrial end user in the U.S.

As noted in Section C.1, NETL Natural Gas reports estimated life cycle GHG emissions associated with delivery of US LNG to a regasification facility in Europe to be 20 g CO_2e/MJ (IPCC AR6, 100 year, LHV basis) and 18.1 g CO_2e/MJ (HHV basis). Thus on a life cycle basis and considering cumulatively through 2050, the induced global market effects per unit of increased LNG exports are equivalent to an overall reduction in GHG emissions that is about: 27% of the estimated emissions associated with US LNG delivered to Europe under reference climate policy assumptions (LHV basis, 30% on HHV basis) and 15% of the estimated emissions associated with US LNG delivered to Europe under global decarbonization policy assumptions (LHV basis, 16% on HHV basis).

These results are consistent with the idea that as the broader findings of this study that the global economy decarbonizes, the induced global decarbonization benefit of increased U.S. LNG will be less. Overall, both of these results were consistent with the overall GCAM results that increased U.S. exports did not lead to increased global GHG emissions. Global changes in GHG emissions were constant to slightly negative as U.S. natural gas exports increased and global energy demand increased. The GHG reductions represented by the negative MAF were not so large that U.S. LNG should be regarded as a global climate reduction strategy but, at the same time, a negative MAF suggested that increased U.S. LNG exports could be compatible with global decarbonization efforts. A positive MAF would suggest U.S. LNG was leading to overall increased global emissions. The results were aggregated in relation to estimated future volumes of exported LNG from the U.S. in the context of a global model. They represent overall expected effects and not those of individual shipments or authorizations of LNG. It is not possible to conclude that every MJ of exported LNG from domestic natural gas sources would directly lead to lower GHG emissions results when supplied around the world.

VI. Conclusions

The purpose of this study was to examine the potential global and U.S. energy system and greenhouse gas (GHG) emissions implications of a wide range of economic levels of U.S. LNG exports. The study comprised three coordinated analyses: 1) **a Global Analysis** to explore a wide range of scenarios of U.S. LNG exports under alternative assumptions about future population and economic growth, regional preferences for domestically produced natural gas, pace of technological change in competing technologies (e.g., renewables), and countries' announced GHG emissions pledges and policies; 2) **a U.S. Domestic Analysis** of the implications of the various U.S. LNG export levels derived from the Global

Commented [TC126]: For the leadership briefing, Tim recalculated this interpretation as follows. Can you confirm these calculations and change the section to reflect this interpretation? (Tim also has the calculations in a comment below).

On a life cycle basis through 2050, the induced global market effects per unit of increased LNG exports are equivalent to an **overall reduction in GHG emissions** that is about:
27% of the estimated emissions associated with U.S. LNG delivered to Europe **under reference climate policy assumptions** (LHV basis, 24% on HHV basis)
15% of the estimated emissions associated with U.S. LNG delivered to Europe **under global decarbonization policy assumptions** (LHV basis, 15% on HHV basis)

Commented [ST127]: Reported as 7.44 previously in the report.

Commented [ST128]: I calculate a 66% reduction. 70% is generous rounding.

Commented [WS129]: (b)(5)

(b)(5)

Commented [ST130]: Results need to be also reported in context of delivered LNG to provide a more complete perspective on the actual magnitude of percent change in delivered LNG cargo.

Commented [ST131]: Add: result through delivered LNG.

E.g.

Commented [LBD132]: It's not completely clear to me why this comparison is made - it seems like there is a projected reduction in GHG emissions from S1 to S2, but it's small? A global reduction equal to 70% of the LC emissions of one large industrial user? If that's

Commented [SM133R132]: We added the scope of delivered LNG to Europe, and reworded here - hopefully this is less confusing now.

Commented [ST134]: This paragraph needs to explain how -3 translates to a 56% reduction upstream NG emission profile to support the key insights.

Analysis for the supply and demand of natural gas within the U.S. and the U.S. economy; and 3) **a Life Cycle Analysis** to examine the life cycle emissions implications of the various levels of U.S. LNG exports derived from the Domestic and Global analyses. A number of key insights from this study are summarized below. Table 6 provides a data summary of the results across scenarios.

1. Across all modeled scenarios, U.S. LNG exports continue to grow beyond current operational export capacity (14.3 Bcf/day) through 2050. In addition, U.S. natural gas production grows beyond current levels through 2050. Across all the scenarios, LNG exports range from 23-49 Bcf/day. The range of U.S. LNG exports from this study is consistent with the U.S. EIA's analysis (15-48 Bcf/day).[27] Compared to a scenario in which U.S. LNG exports follow the Reference Case from the AEO2023 (*S1*, growing to 27.3 Bcf/day by 2050), a scenario that assumes economically-driven LNG export levels (*S2*) results in significant growth in U.S. LNG exports to 47 Bcf/day by 2050. The availability of additional U.S. natural gas at competitive prices in the global natural gas market in the latter scenario (*S2*) results in a reduction in production, reduction in LNG exports, increase in LNG imports, and reduction in pipeline trade outside of the U.S.
2. Global natural gas consumption increases by <1 percent under a scenario with increased availability of U.S. natural gas in the global market that reflects economically-driven LNG export levels (*S2*) compared to the reference scenario (*S1*). Instead, it results in a shift in the regional composition of natural gas production and trade. The majority of U.S. natural gas substitutes for other global sources of natural gas.
3. U.S. natural gas prices as measured at the Henry Hub increases modestly when comparing a scenario that reflects global market demand for exports (*S2*) to the reference scenario (*S1*). Across those scenarios, 2050 Henry Hub prices are projected to increase from $3.88/Mcf to $5.09/Mcf, both of which are less than the reference 2050 price expected in the most recent study DOE[6] commissioned on the economic impacts from U.S. LNG exports in 2018.
4. U.S. residential prices are projected to be 4% higher in 2050 when comparing a scenario that reflects global market demand for exports (*S2*) to the reference scenario (*S1*). In none of the scenarios did the change in residential prices exceed 4% and the percentage difference was generally substantially less.
5. The value of industrial shipments remains essentially unchanged (increasing less than 0.1% by 2050) when comparing a scenario that reflects global market demand for exports *(S2)* to the reference scenario *(S1)*. The impact of increased LNG exports on GDP is essentially flat, positive by less than 0.1% across scenarios through 2045 while all changes are within 0.3% in 2050.
6. Even though U.S. LNG exports continue to grow beyond existing and planned nameplate capacity across scenarios *S1* through *S5* to 23-49 Bcf/day by 2050, global and U.S. GHG emissions do not change appreciably. Global emissions in these scenarios range from 47.5-50.3 $GtCO_2e$ and U.S. emissions range from 4.3-4.6 $GtCO_2e$ across these scenarios.
7. The induced global market effects of a case that reflects reference climate policies are equivalent to an overall reduction in GHG emissions of about 30% of the estimated upstream emissions associated with production through delivery of the natural gas to an LNG regasification facility in Europe. Such induced market effects in a case representing future global decarbonization policies are equivalent to a overall reduction of 16%.

[27] U.S. EIA. (2023). Issues in Focus: Effects of Liquefied Natural Gas Exports on the U.S. Natural Gas. Available at: Markethttps://www.eia.gov/outlooks/aeo/IIF_LNG/

Commented [UP135]: Shouldn't this be 49 Bcf/d based on S3 scenario (see page 21)?

Commented [IGC136R135]: Yes. Thanks.

Commented [UP137]: Here we're using 1-digit 27.3 Bcf/d versus 27.34 Bcf/d in earlier tables. I prefer 1-digit but we should be consistent with the decimal for the AEO 2023 forecast of LNG exports.

Commented [AA138]: Recommend adding clarifying language. Note description used early makes it clear that the reduction in production/export was from "other parts of the world." See:

Under *S2*, U.S. LNG exports grew to ~47 Bcf/day by 2050. In this scenario, the availability of additional U.S. natural gas in the global natural gas market at competitive prices resulted in a reduction in production and LNG exports from other parts of the world. The increased availability of U.S. LNG in the global market also resulted in higher LNG imports and reduced pipeline trade outside of the U.S.

Commented [IGC139R138]: The sentence includes "outside of the U.S." at the end.

Commented [LBD140]: Hard to describe as a "modest" increase, if in constant dollars. The increase is almost 1/3.

Commented [LBD141]: This point was not included in the summary of findings in the Ex Sum.

Commented [WS142]: As noted above, this statement needs further explanation.

Commented [UP143]: Number check? 49?

Commented [LBD144]: It's not completely clear to me why this comparison is made - it seems like there is a projected reduction in GHG emissions from S1 to S2, but it's small? A global reduction equal to 70% of the LC emissions of one large industrial user? If that's correct, it might be clearer to just present the percentage reduction, or say that it was essentially the same level of emissions.

Commented [SM145R144]: We moved to using the "delivered LNG basis" that was added above.

8. When compared to the other scenarios, *S6* and *S7* – in which countries are assumed to achieve their GHG emissions pledges and pursue ambitious GHG mitigation policies consistent with limiting global warming to 1.5°C – are characterized by a global transition resulting in lower in natural gas, coal, and oil consumption without CCUS; higher deployment of gas, coal and biomass with CCUS, and renewables; higher deployment of carbon dioxide removal strategies; and lower overall energy consumption. While in scenario *S6*, in which U.S. LNG exports are limited to the values from the AEO2023 Reference case (by design) and grow to 27.3 Bcf/day by 2050, *S7* assume economically driven outcomes resulting in U.S. LNG exports growing to 34 Bcf/day by 2050. The higher growth in U.S. LNG exports in *S7* compared to *S6* is driven by increased global demand for natural gas with CCUS in the power and industrial sectors. Similar to the comparison between *S1* and *S2*, the availability of additional U.S. LNG in *S7* in the global natural gas market results in a reduction in production, reduction in LNG exports, increase in LNG imports, and reduction in pipeline trade in the rest of the world compared to *S6*. In addition, global natural gas consumption increases by <1% under *S7* compared to *S6*. Furthermore, with the higher U.S. LNG exports in *S7* compared to *S6*, U.S. natural gas prices are essentially unchanged within modeling tolerance, reaching $6.34/Mcf in *S6* and $6.20/Mcf in *S7* by 2050.

Table 6. Key Results for U.S. and globe in 2050 across scenarios

Scenarios	U.S. LNG Exports (Bcf/d)	U.S. NG Henry Hub Price ($2022/Mcf)	US Net GHG Emissions ($GtCO_2e$)	Global Net GHG Emissions ($GtCO_2e$)
S1	27.3	$3.88	4.5	47.7
S2-S5	23.1 – 48.7	$4.12-$5.15	4.3-4.6	47.5-50.3
S6-S7	27.3 – 33.6	$6.20-$6.34	0	17.1

Commented [ST146]: Consider splitting the conclusions into two parts: S1/S2 and S6/S7 to improve clarity.

Commented [IGC147R146]: This bullet focuses on S6-S7 only.

Commented [ST148]: Did we run another set of S6 and S7 results with and without CCUS? Where do these findings come from without CCUS?

Commented [IGC149R148]: As noted previously, all of our scenarios include both fossil fuel technologies w/ and w/o CCUS. The point of this statement is to compare S6 and S7 that have climate policy with other scenarios S1-S5 without climate policy. Compared to the scenarios *without* climate policy (S1-S5), the scenarios *with* climate policy (S6-S7) have lower fossil w/o CCUS.

Commented [UP150]: 2-digit here?

Commented [ST151]: Equivalent level of results are missing for S6/S7 as reported in Items #1 thru #7. MAF for S6/S7 is not discussed in the conclusion section, for example.

Appendix A: Global Analysis and Description of GCAM

A. Additional detail about GCAM's energy system

The Global Change Analysis Model's (GCAM's) energy system contains representations of fossil resources (coal, oil, gas), uranium, and renewable sources (wind, solar, geothermal, hydro, biomass, and traditional biomass) along with processes that transform these resources to final energy carriers (electricity generation, refining, hydrogen production, natural gas processing, and district heat) which are ultimately used to deliver goods and services demanded by end use sectors (residential buildings, commercial buildings, transportation, and industry). Each of the sectors in GCAM includes technological detail. For example, the electricity generation sector includes several different technology options to convert coal to electricity such as pulverized coal with and without carbon capture, utilization, and storage (CCUS), and coal integrated gasification combined cycle (IGCC) with and without CCUS. The full list of technologies in various sectors in GCAM is documented in the GCAM documentation page (http://jgcri.github.io/gcam-doc/).

In every sector within GCAM, individual technologies compete for market share based on the levelized cost of a technology. The cost of a technology in any period depends on (1) its exogenously specified non-energy cost, (2) its endogenously calculated fuel cost, and (3) any cost of emissions as determined by the climate policy. The first term, non-energy cost, represents capital, fixed and variable operating and maintenance (O&M) costs incurred over the lifetime of the equipment (except for fuel or electricity costs), expressed per unit of output. For example, the non-energy cost of coal-fired power plant is calculated as the sum of overnight capital cost (amortized using a capital recovery factor and converted to dollars per unit of energy output by applying a capacity factor), fixed and variable operations and maintenance costs. The second term, fuel or electricity cost, depends on the specified efficiency of the technology, which determines the amount of fuel or electricity required to produce each unit of output, as well as the cost of the fuel or electricity. The various data sources and assumptions are documented in the GCAM documentation page (http://jgcri.github.io/gcam-doc/). The prices of fossil fuels and uranium are calculated endogenously. Fossil fuel resource supply in GCAM is modeled using graded resource supply curves that represent increasing cost of extraction as cumulative extraction increases. Wind and rooftop PV technologies include resource costs that are also calculated from exogenous supply curves that represent marginal costs that increase with deployment, such as long-distance transmission line costs that would be required to produce power from remote wind resources. Utility-scale solar photovoltaic and concentrated solar power technologies are assumed to have constant marginal resource costs regardless of deployment levels.

In GCAM, technology choice is determined by market competition. The market share captured by a technology increases as its costs decline, but GCAM uses a logit model of market competition. This approach is designed to represent decision making among competing options when only some characteristics of the options can be observed and avoids a "winner take all" response.

For the purposes of this project, historical natural gas producer prices in the U.S. are calibrated to the Henry Hub prices from the EIA[28] and in Canada, they are calibrated to Alberta marker prices from the BP

[28] U.S. EIA (2023). Henry Hub Natural Gas Spot Price. Available at: https://www.eia.gov/dnav/ng/hist/rngwhhda.htm

Statistical Review.[29] For the rest of the world, natural gas producer prices in each GCAM region are based on the cost, insurance, and freight (CIF) prices from S&P (see Table A-1).[30] In a future model period, as demand changes, the change in regional producer prices from the historical calibrated values are calculated endogenously using regional supply curves that represent increasing cost of extraction as cumulative extraction increases.

Table A-1. Historical natural gas producer prices used for calibration in GCAM.

GCAM region	Natural gas producer prices (2022 $/MMBtu)
European Free Trade Association	1.61
Australia_NZ	1.89
Canada	2.45
Middle East	2.66
Africa_Northern	3.13
USA	3.17
Indonesia	3.61
South Asia	4.48
Southeast Asia	4.48
Central America and Caribbean	4.56
South America_Southern	4.56
Russia	5.76
Africa_Western	6.11
EU-12	8.61
EU-15	8.61
Europe_Non_EU	8.61
Africa_Eastern	9.48
Africa_Southern	9.48
China	11.08
India	11.08
Pakistan	11.08
Taiwan	11.97
Argentina	13.19
Brazil	13.19
Colombia	13.19
South America_Northern	13.19
Mexico	13.19
South Korea	13.37
Japan	13.43

[29] BP (2022). bp Statistical Review of World Energy. 71st edition. Available at: https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2022-full-report.pdf

[30] S&P Global (2023). S&P Global Commodity Insights. Historical and forecasted LNG prices data sheet.

B. Additional detail about scenario design

Table A-1. Detailed assumptions in the S4: Regional Import Limits scenario

Commented [IGC152]: Note to tech editor: Change numbering

Region Type	GCAM Regions	High-level target / sanction
Developed countries, natural gas importers with sufficient domestic resources	EU-12, EU-15, Europe_Eastern, Europe_Non_EU	Reduce gross imports to 90% by 2035 and zero by 2040
Developed countries, natural gas importers with low domestic natural gas resources	Japan, South Korea, Taiwan	Maintain current import dependence through 2050
Developing countries, natural gas importers	Brazil, China, India, Pakistan, Southeast Asia, Mexico, South Africa	Maintain current import dependence through 2050
Natural gas exporters	USA, Africa_Eastern, Africa_Northern, Africa_Southern, Africa_Western, Australia_NZ, Canada, Central America and Caribbean, Central Asia, European Free Trade Association, Indonesia, Middle East, South America_Southern, South America_Northern, South Asia, Colombia, Argentina	Reduce gross imports to 90% by 2035 and zero by 2040
Russia	Russia	Same as *S2*

C. Additional GCAM results

Commented [UP153]: In the body of the report, we showed results in Bcf/d but in Appendix reverted back to Tcf making the comparisons of consumption and production not matching to the body of the report. LNG exports here are still shown as Bcf/d though so not consistent.

Commented [IGC154R153]: For the figures in main report, we need to stick with the same units for all panels so enhance readability. However, figures in the appendix follow more conventional untis (Tcf/yr for consumption and production; and Bcf/day for imports and exports). We have included data corresponding to all figures in the main section of the report in the corresponding units in Appendix D. To facilitate comparison between figures in the main report and this appendix, we have included conversion factors in the legends.

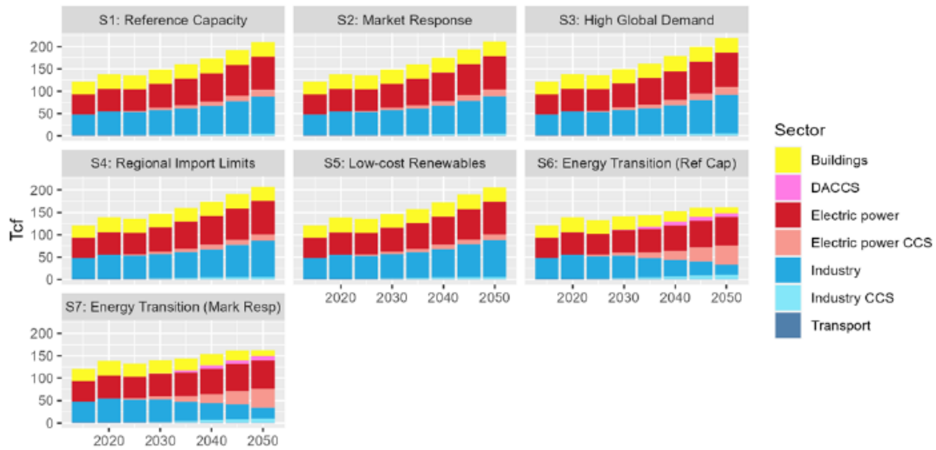


Figure A-1. Global natural gas consumption by sector across all scenarios. To convert from BCF/day to TCF/ yr and vice versa, the conversion factors are as follows: 1 TCF/yr = 2.74 Bcf/day and 1 BCF/day = 0.36 TCF/yr.

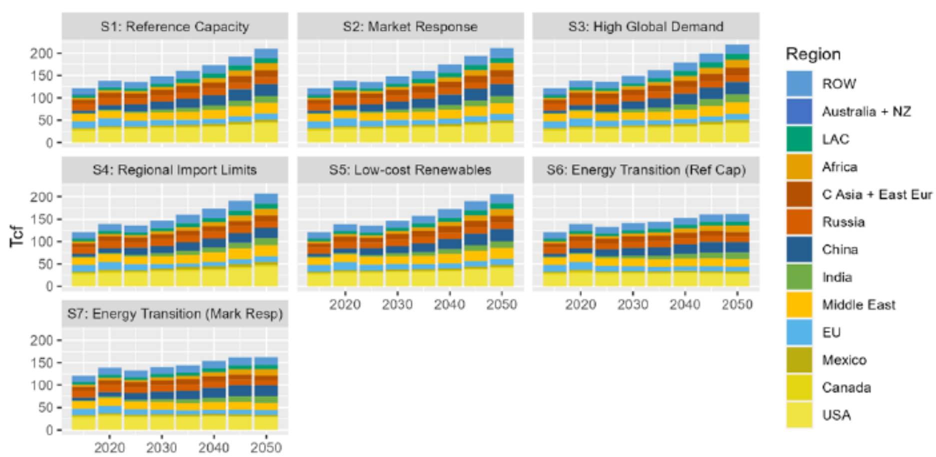


Figure A-2. Global natural gas consumption by region across all scenarios. To convert from BCF/day to TCF/ yr and vice versa, the conversion factors are as follows: 1 TCF/yr = 2.74 Bcf/day and 1 BCF/day = 0.36 TCF/yr.

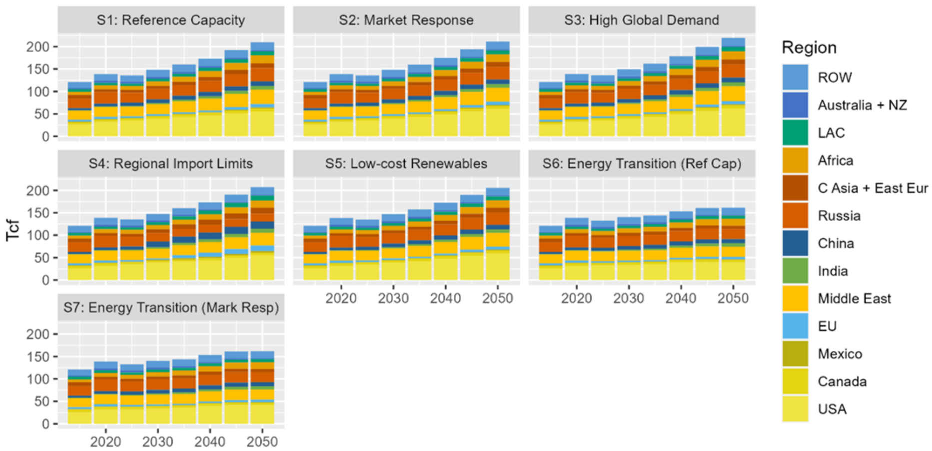


Figure A-3. Global natural gas production by region across all scenarios. To convert from BCF/day to TCF/ yr and vice versa, the conversion factors are as follows: 1 TCF/yr = 2.74 Bcf/day and 1 BCF/day = 0.36 TCF/yr.

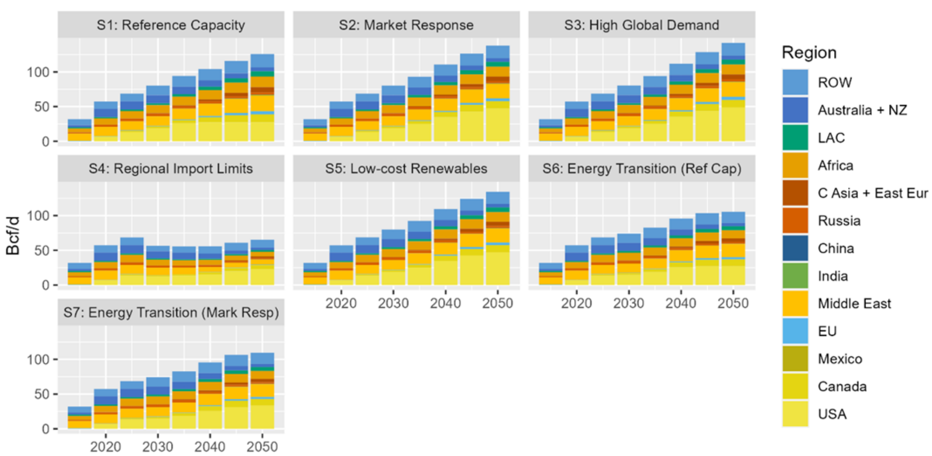


Figure A-4. Global LNG exports by region across all scenarios. To convert from BCF/day to TCF/ yr and vice versa, the conversion factors are as follows: 1 TCF/yr = 2.74 Bcf/day and 1 BCF/day = 0.36 TCF/yr.

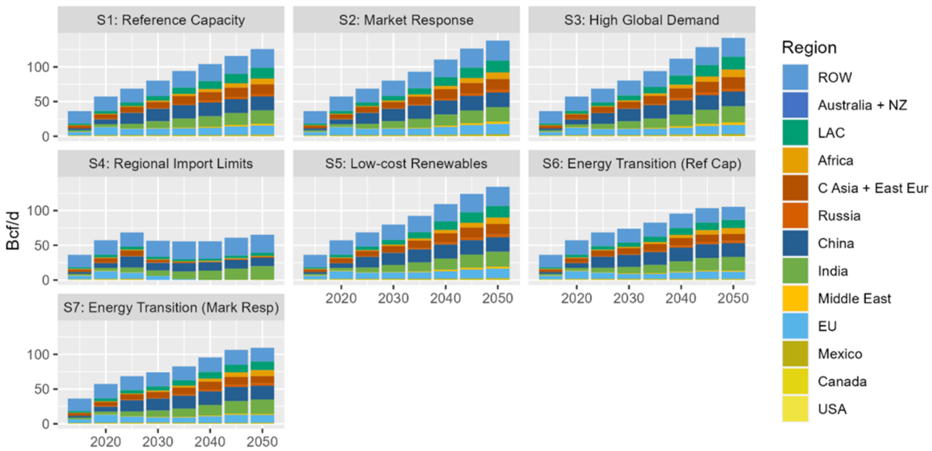


Figure A-5. Global LNG imports by region across all scenarios. To convert from BCF/day to TCF/ yr and vice versa, the conversion factors are as follows: 1 TCF/yr = 2.74 Bcf/day and 1 BCF/day = 0.36 TCF/yr.

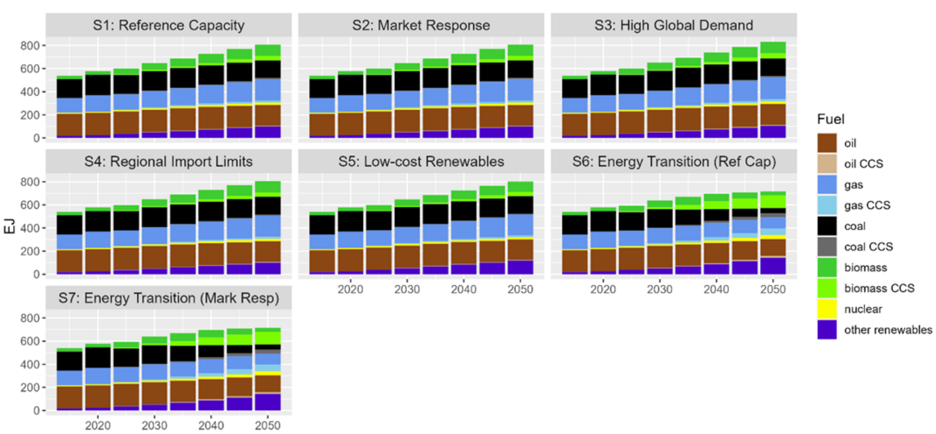


Figure A-6. Global primary energy consumption by fuel across all scenarios.

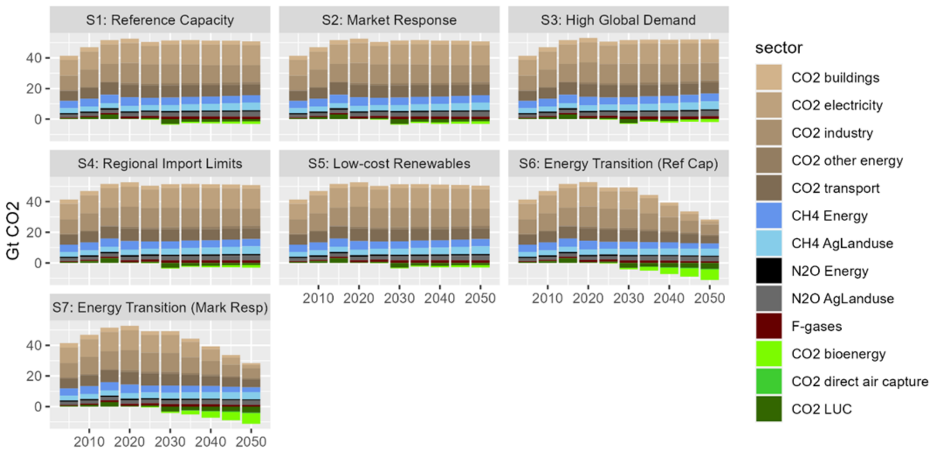


Figure A-7. Global GHG emissions by sector across all scenarios

Appendix B: U.S. Analysis and Description of AEO2023-NEMS and FECM-NEMS

A. Modeling U.S. LNG exports

AEO2023-NEMS and FECM-NEMS have two methods available to calculate LNG export capacity: endogenous and exogenous. There is a switch in the input files that can be toggled between the two methods before executing a run. *S1* is the EIA AEO2023 reference case, which calculates LNG export capacity endogenously; *S2* through *S7* are initialized with exogenous LNG export capacity, which use LNG export values from the GCAM model for each scenario. The LNG export capacity in *S6* is exogenously set to equal the capacity in *S1* and the EIA AEO2023 reference case. Both AEO2023-NEMS and FECM-NEMS follow a similar process with only minor differences in a small number of input values. In most cases (including all cases discussed in this report) LNG exports will equal LNG export capacity because the cost to construct capacity is so high that capacity will rarely be left unused once built. Therefore, the following description can be treated as an explanation for how AEO2023-NEMS and FECM-NEMS calculate LNG Export volumes.

Commented [UP155]: Is this sentence correct? Maybe was written pre-S7? I edited it but needs a check.

Commented [DH156R155]: The sentence was inaccurate - we've reworded it to clarify that S1 is endogenous and S2 through S7 are exogenous, even though the values from S6 equal S1.

The algorithm for calculating LNG export capacity endogenously has two steps. In the first step, AEO2023-NEMS considers LNG exports from existing or planned LNG export facilities. Beginning with Cheniere's Sabine Pass facility, which started exporting LNG in 2016, AEO2023-NEMS runs through a list of export facilities specified in an input file. This list is updated with each version of the AEO; AEO2023-NEMS includes existing and planned facilities expected to start or expand production by the end of 2025. For each facility, AEO2023-NEMS slowly increases production over the first few months to represent an export facility ramping up to full capacity.

The second step in the endogenous algorithm involves a prediction of future LNG exports. AEO2023-NEMS uses a set of exogenous values in an input file to specify how much demand Europe and Asia will have for LNG imports, as well as how much supply of non-U.S. LNG will exist on the market. Then, considering the volume of U.S. LNG exports at a given model year, AEO2023-NEMS calculates how the ratio of supply and demand changes over time. This ratio, together with the world oil price, is used to calculate the price at which international customers will purchase U.S. LNG. The purchase price algorithm is constructed in such a way that rises in the oil price, decreases or slowdowns in future LNG supply, or increases in future LNG demand will all increase the purchase price of LNG, and vice-versa. The influence that each factor has on LNG purchase price is controlled by several input parameters.

In addition to a purchase price, AEO2023-NEMS calculates the price at which U.S. LNG could be sold for. This "sale price" combines the natural gas Henry Hub price with various costs that represent the stages of preparing pipeline gas for LNG transport (including liquefaction, fuel consumption, shipping, and regasification). AEO2023-NEMS then compares the sale price to purchase prices at different destinations and determines a discounted net present value (NPV) of new LNG construction over the subsequent 20 years. Depending on the NPV, AEO2023-NEMS will decide to increase LNG export capacity by 0 to 600 Bcf/d. The increase in capacity takes effect after a four year "construction" period and brief "phase-in" period.

An input file is read by AEO2023-NEMS to define LNG export capacity exogenously. A table in an input file lists LNG export capacity by year; these values are used by AEO2023-NEMS to set LNG exports for that year. In *S2* through *S7*, various parameters, including LNG export volumes, are calculated by the

Commented [UP157]: S7?

Commented [DH158R157]: Apologies, S7 is correct

GCAM model. The LNG export volumes are converted to the correct input format and adopted by AEO2023-NEMS as the exogenous LNG export capacity.

B. Additional detail on U.S. natural gas markets

1. Regional natural gas production

Figure B-1 and Figure B-2 plot onshore natural gas production by region for the first five scenarios and the net-zero scenarios, respectively, in 2025 and 2050. Offshore natural gas production comprises a small portion of the total (<4 % in all scenarios and years) and is omitted from these figures.

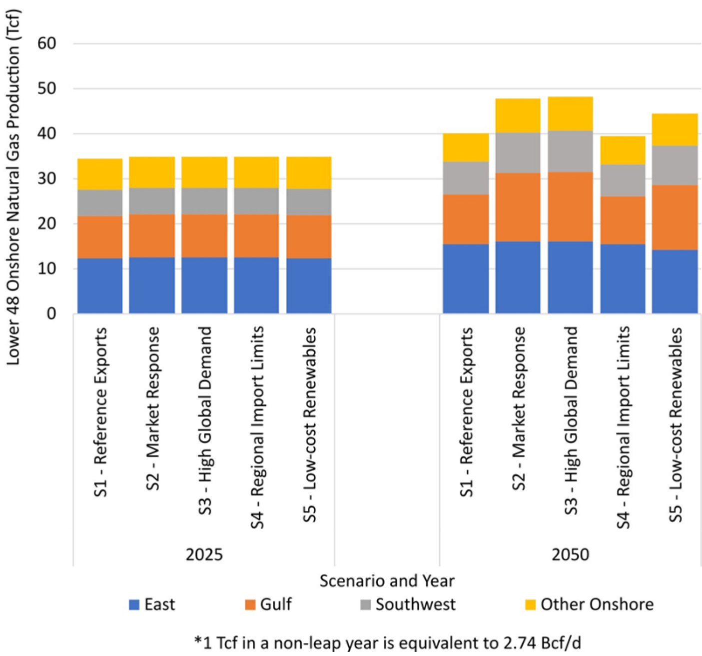


Figure B-1. U.S. Regional Natural gas production, S1 through S5

Onshore natural gas production experienced an upward trend across all scenarios by 2050, equaling or exceeding 39 Tcf. *S3* exhibited the highest production level at 48.3 Tcf, influenced by the global demand for natural gas. Expansion is primarily characterized by a significant increase in production in the Gulf region, subsequently followed by the Southwest and the East. Conversely, scenario *S4* sees the lowest natural gas production with least production growth in the Gulf region (1.4 Tcf from 2025 to 2050).

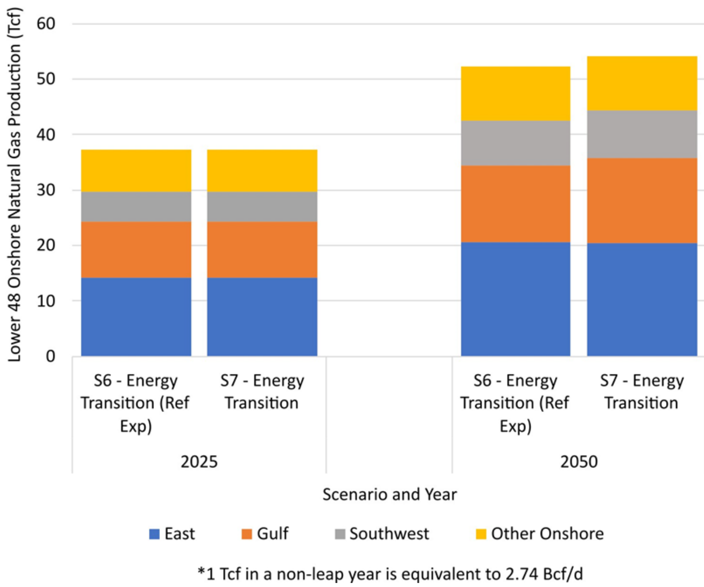


Figure B-2. U.S. regional natural gas production in S6 and S7

Similarly, onshore natural gas production grows significantly from 2025 to 2050 for both net-zero scenarios, rising from 37.3 Tcf in 2025 to 52.3 Tcf in *S6* and 54.1 Tcf in *S7*, respectively, by 2050. The large growth in natural gas production is primarily due to demand from DAC facilities, with only a small increase associated with elevated LNG exports in the *S7* scenario. Natural gas production rises in all regions, with the largest absolute increases coming from the East (6.4 Tcf in *S6* and 6.2 Tcf in *S7*) and Gulf (3.8 Tcf in *S6* and 5.2 Tcf in *S7*) regions and the largest increase by percentage coming from the Southwest (47% in *S6* and 58% in *S7*).

2. Natural gas consumption by economic sector

Figure B-3 plots natural gas consumption for electric power, industry, residential use, commercial use, and transportation over time for *S1* through *S5*. These sector-by-sector plots sum to equal the "Natural Gas Consumption" subplot displayed in Figure 16.

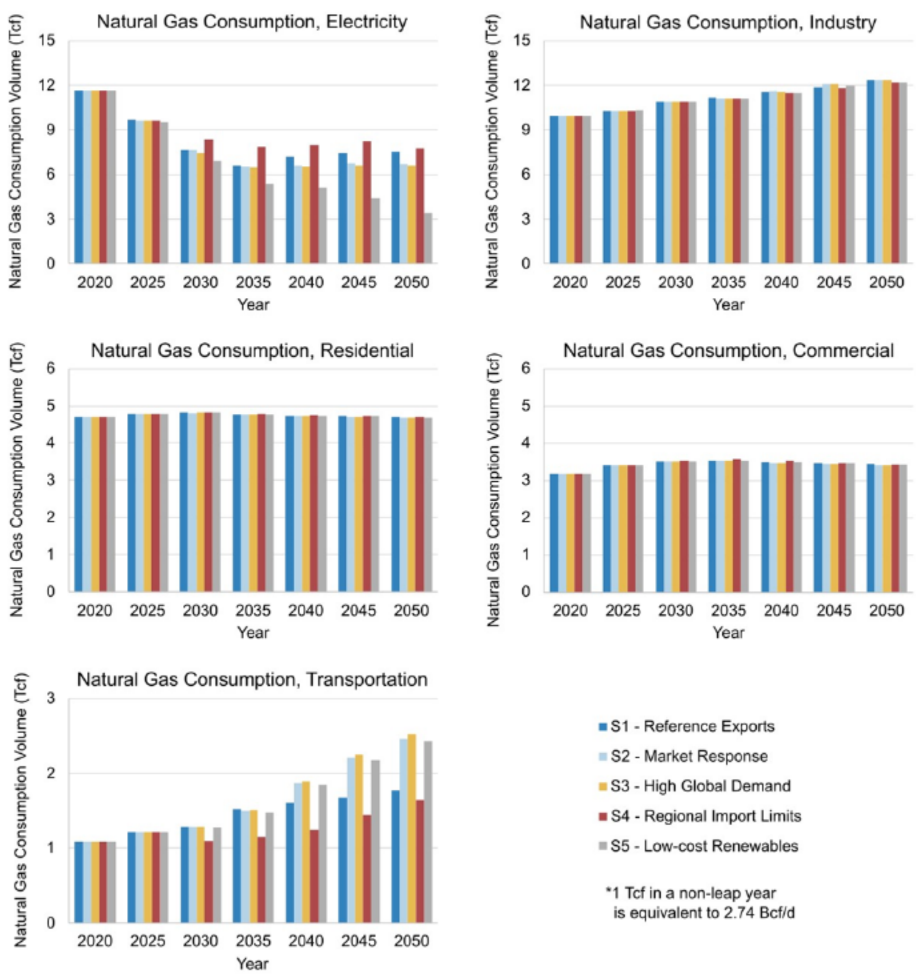


Figure B-3. U.S. natural gas consumption by sector, S1 through S5

Commented [UP159]: Hard to compare by sector data to the totals in the report as the report had the data in Bcf/d and in the Appendix we are now showing results in Tcf.

Commented [DH160R159]: Added a sentence to emphasize that this figure should be compared against Figure 16, and included a note about conversions from Tcf to Bcf/d. We will go through the report to improve unit consistency.

Natural gas consumed for electricity was inversely correlated with LNG exports and natural gas prices for *S1-S4*. From a starting point of 11.6 Tcf in 2020, the first three scenarios drop to similar consumption volumes of 6.6,6.5, and 6.6 Tcf in 2035 before slightly increasing to 7.6 Tcf (*S1*) or plateauing at 6.7 and 6.6 Tcf (*S2* and *S3*, respectively) in 2050. The increased consumption of natural gas for electricity in *S1* can be explained as a response to price reductions caused by plateauing LNG exports, whereas high prices and exports in *S2* and *S3* lead to a flat consumption trend. *S4* – the scenario with the fewest exports and lowest prices through the first half of the model – exhibited the highest consumption for electricity in 2035 of 7.9 Tcf, which rises and falls slightly to a similar level to *S1* in 2050 (7.8 Tcf). *S5* is again an outlier here, reporting consistently lower natural gas consumption that hit a minimum of 3.4 Tcf in 2050. This trend is a consequence of its low renewable costs reducing the demand for natural gas in the electric sector.

Unlike for electricity, there was no significant difference between scenarios in the rate of natural gas consumption in the industrial, residential, or commercial sectors. Industrial natural gas consumption rises from 9.9 Tcf in 2020 to 12.2-12.4 Tcf in 2050 across the five scenarios; residential consumption remains relatively unchanged at 4.7 Tcf from 2020 to 2050 with some small variations; and commercial consumption rises and falls slightly from 3.2 Tcf in 2020 to 3.4 Tcf in 2050.

Natural gas consumed for transportation has a different response to changes in LNG exports, compared with the other consumptions sectors. The transportation category is dominated by pipeline fuel: natural gas consumed to power infrastructure underlying the natural gas supply chain, which includes LNG exports. Increases in natural gas consumption for transportation therefore correlate strongly with the quantity of LNG exports; *S3* exhibits the highest consumption in the transportation sector by 2050 (2.5 Tcf), followed by *S2* and *S5* (2.5 and 2.4 Tcf), *S1*, and finally *S4* (1.6 Tcf).

The sector-by-sector changes across the five scenarios end up cancelling each other out for *S1-S4*, leading to nearly identical total natural gas consumption values, as seen in Figure 16 in the main text. Only *S5*, thanks to its low renewable costs, exhibits a lower overall U.S. natural gas consumption trend.

Significant changes to the energy economy (going from AEO2023-NEMS to FECM22-NEMS) that occur to satisfy the net-zero criteria make comparisons of *S1* through *S5* with *S6* and *S7* imprecise. Relative to *S1*, natural gas consumption values decline across most sectors in *S6* and *S7* but are substantially higher in the industry sector (where DAC consumption is categorized). Figure B-4 plots natural gas consumption for the net-zero cases on a sector-by-sector basis. The individual subplots are subsets of the "Natural Gas Consumption" subplot displayed in Figure 17.

Commented [UP161]: Do we want to say this like this-that it's complicated to go from AEO2023-NEMS to FECM22-NEMS? Again sounds too informal for a description of a model. All forecasting is complicated😉

Commented [DH162R161]: Reworded to make the statement more formal

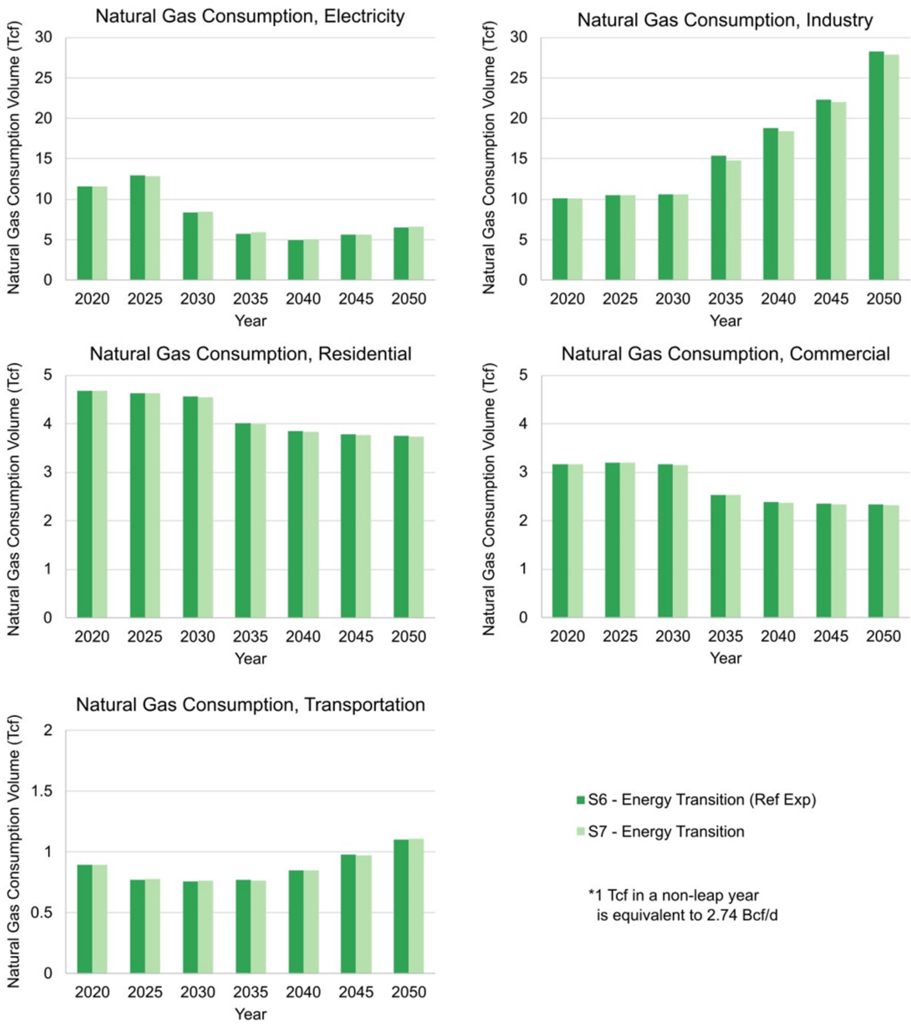


Figure B-4. U.S. natural gas consumption by sector, net-zero scenarios

Differences in historical natural gas consumption and subsequent short-term effects cause a difference in natural gas consumption for electricity in 2020 and 2025 between *S6* and *S7* (from the FECM-NEMS model) and *S1* through *S5* (from the AEO2023-NEMS model). Similar differences in the historical data exist for all sector-specific consumption values. Volumes of natural gas consumed for electricity track closely between the two net-zero cases across most of the modeling years, ranging from 5.7 to 5.9 Tcf in 2035 for *S6* and *S7*, respectively, and rising in later years to 6.5 Tcf and 6.6 Tcf. *S6* reports a lower

natural gas consumption value in 2050 than *S1* (7.6 Tcf), but the corresponding result for *S7* is fairly close to *S2* (6.7 Tcf).

Industry-sector natural gas consumption exhibits the largest change between S6 and S7 relative to *S1* through *S5*, thanks to the strong influence of DAC. Whereas industry consumption of natural gas in *S1* and *S2* both increase from 9.9 Tcf to 12.3 Tcf from 2020-2050, the net-zero scenarios diverge after 2030 and grow rapidly to 28.2 and 27.8 Tcf for *S6* and *S7*, respectively, by 2050. The difference in consumption values is consistent with the natural gas consumption for DAC, which is plotted below in Figure B-5.

Residential- and commercial-sector natural gas consumption follow similar behavior. These values decrease in both net-zero scenarios across the model years 2020-2030 from 4.7 to 3.7 Tcf (residential) and from 3.2 to 2.3 Tcf (commercial). By comparison, both *S1* and *S2* have static or slightly increasing trends, with both reporting 4.7 Tcf in 2020 and 2050 for residential consumption and 3.2 to 3.4 Tcf from 2020 to 2050 for commercial consumption.

Transportation is the smallest of the five sectors in terms of natural gas consumption volumes, and calculation differences between AEO2023-NEMS and FECM-NEMS lead to large impacts on the consumption values. As a result, these values are not directly comparable between the three scenarios. *S6* and *S7* have nearly identical volumes of natural gas consumed for the transportation sector, varying from 0.9 Tcf in 2020 to 0.8 Tcf in 2035 and 1.1 Tcf in 2050. By comparison, *S1* and *S2* report consistently higher natural gas consumption for transportation across the model years, ranging from 1.1 Tcf in 2020 to 1.8 and 2.3 Tcf, respectively, in 2050.

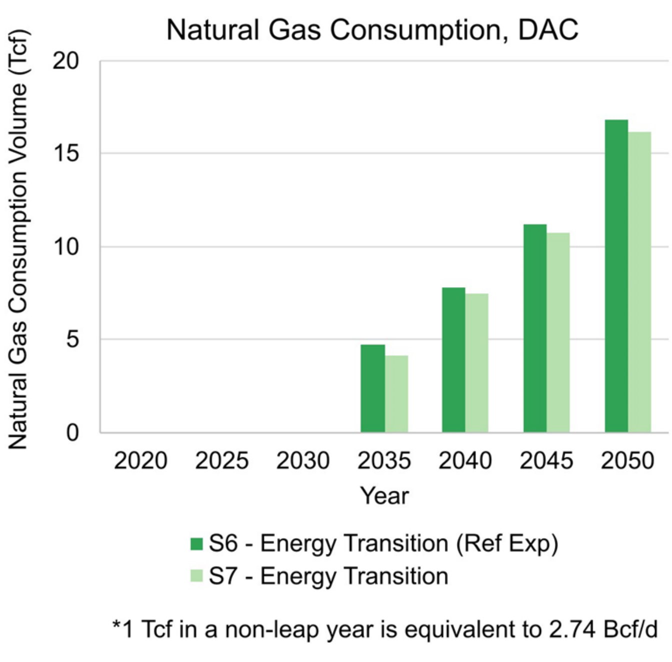


Figure B-5. Natural gas consumed for DAC, net-zero scenarios

DAC is the main technology used by FECM-NEMS to meet the CO_2 cap and by 2050 is responsible for removing 1.93 Gt CO_2 per year in *S6* and 1.85 Gt CO_2 per year in *S7*. A considerable amount of natural gas is consumed to support these levels of DAC: 16.8 Tcf and 16.2 Tcf in 2050 for *S6* and *S7*, respectively. More detail on cost assumptions for DAC in FECM-NEMS is given in the section below.

Commented [WS163]: Would be very helpful to state our assumptions regarding the cost of DAC over the 2035 to 2050 period.

In conclusion, even though four out of the five sectors exhibit decreases when comparing natural gas consumption in the net-zero scenarios to *S1* and *S2*, the strong increases in the industrial sector (mainly from increases in DAC) cause overall U.S. natural gas consumption to be significantly higher by 2050 in *S6* and *S7*. There is minimal difference between the *S6* and *S7* results, suggesting that the differences in LNG exports between the net-zero scenarios play a limited role in altering natural gas consumptions trends.

C. CO_2 removal technologies and carbon prices in FECM-NEMS

CO_2 removals in FECM-NEMS are driven by three technologies: production of hydrogen with sequestered biomass, BECCS, and DAC. Figure B-6 plots CO_2 removals for each technology and scenario by year.

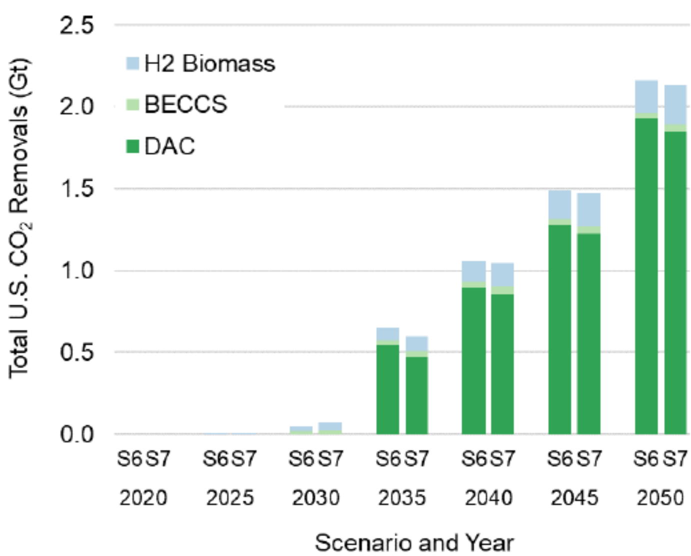


Figure B-6. U.S. CO_2 emissions and removals, net-zero scenarios

DAC is most widely used in both net-zero scenarios and scales up rapidly after 2030 to account for 1.93 Gt CO_2 removed in *S6* and 1.85 Gt CO_2 removed in *S7* (89% and 87% of total removals, respectively) by 2050. H_2 production with biomass and BECCS see significantly less adoption by 2050 in both scenarios;

the former reaches 0.20 (9% of total) and 0.24 (11% of total) Gt CO_2 removed in *S6* and *S7*, respectively, whereas the later reaches approximately 0.04 Gt CO_2 removed in both scenarios (2% of total removals).

Table B-1 lists specific cost and technical assumptions underlying DAC in FECM-NEMS:

Table B-1. DAC technology assumptions in FECM-NEMS

	Capex, $2022/ton	CRF	Capex, $2022/ton-year	Opex, $2022/ton-year	Electricity demand, kwhr/ton	Natural gas demand, MMBtu/ton
Grid	$1,451	7.1%	$125	$79.2	450	8.75
NG Only	$1,674	7.1%	$144	$93.3	0	9.27

Commented [DH164]: @Peter Whitman Hi Pete, I updated the $ year for the prices here and reworded some things. Is there anything else we can add to the description here?

FECM-NEMS relies on two sets of DAC technology assumptions: "grid", and "NG only," derived from the literature using updated cost and performance data from FECM.[31] Both use natural gas to power the capture process; DAC-grid offsets some of the natural gas demand by using electricity. Both technologies follow a learning curve that reduces the capital cost of deployment over time, and both use a capital recovery factor of 7.1%.

The effect of DAC on natural gas markets in *S6* and *S7* can be seen in the rapid growth of total natural gas consumption and subsequent rise in natural gas prices (Figure 18) in the main text. By 2050, natural gas consumption equals 16.8 Tcf and 16.2 Tcf for *S6*, and *S7*, respectively, reaching natural gas prices of $6.34/Mcf and $6.20/Mcf ($2022).

FECM-NEMS models the deployment of carbon removal technologies by determining a CO_2 price that represents the market equilibrium cost to capture and abate CO_2 emissions. FECM-NEMS adjusts the CO_2 price in accordance with the imposed carbon cap to ensure that the correct number of CO_2 emissions are abated each year. End-use prices are then adjusted by the product of the unsequestered carbon content of the fuel and the implied carbon price to reflect the carbon penalty of combustion. Residential natural gas prices, reflecting the implied carbon penalty, are $34.97/Mcf and $35.24/Mcf in *S6* and *S7*, respectively, by 2050.

[31] National Academies of Sciences, Engineering, and Medicine. (2019). Negative Emissions Technologies and Reliable Sequestration: A Research Agenda. Washington, DC: The National Academies Press. https://doi.org/10.17226/25259.

APPENDIX C: SUPPORTING LCA ANALYSIS

A. NEMS and NETL LCA model comparison

The NEMS modeling done in this project focused on domestic changes that would be expected to occur in the seven scenarios modeled. NETL reviewed the NEMS data to evaluate if the regional production mix of natural gas would be expected to change over time. If the NEMS results suggested that production would be expected to shift significantly from the current mix of regions, and especially if to distinctly higher or lower intensity regions, then adjustments would be recommended to the assumed GHG intensity for U.S. natural gas in the results.

For *S1 - S7*, NEMS modeled data of dry natural gas production of "Production by OGSM District" was mapped to a state and then to an NETL natural gas model region as shown in Table C-1. Note that several "states" are offshore regions. OGSM is the Oil and Gas Supply Module in NEMS.

Commented [UP165]: What's OGSM? Needs to also be included under Acronyms/Abbreviations Table.

Commented [PW166R165]: Added to table

Table C-1. Matching NEMS (OGMP States) to NETL states and subsequently regions

Production by OGSM District	State	Region
Alabama, North	Alabama	Southeast
Alabama, South	Alabama	Southeast
Arizona	Arizona	Southwest
Arkansas	Arkansas	Southeast
California	California	Pacific
Colorado	Colorado	Rocky Mountain
Connecticut	Connecticut	Northeast
Delaware	Delaware	Northeast
Florida	Florida	Southeast
Georgia	Georgia	Southeast
Idaho	Idaho	Rocky Mountain
Illinois	Illinois	Midwest
Indiana	Indiana	Midwest
Iowa	Iowa	Midwest
Kansas	Kansas	Midwest
Kentucky	Kentucky	Southeast
Louisiana, North	Louisiana	Southeast
Louisiana, South	Louisiana	Southeast
Maryland	Maryland	Northeast
Massachusetts	Massachusetts	Northeast
Michigan	Michigan	Midwest
Minnesota	Minnesota	Midwest
Mississippi, North	Mississippi	Southeast
Mississippi, South	Mississippi	Southeast
Missouri	Missouri	Midwest
Montana	Montana	Rocky Mountain

Production by OGSM District	State	Region
Nebraska	Nebraska	Midwest
Nevada	Nevada	Rocky Mountain
New Hampshire	New Hampshire	Northeast
New Jersey	New Jersey	Northeast
New Mexico, East	New Mexico	Southwest
New Mexico, West	New Mexico	Southwest
New York	New York	Northeast
North Carolina	North Carolina	Southeast
North Dakota	North Dakota	Midwest
Ohio	Ohio	Midwest
Oklahoma	Oklahoma	Southwest
Oregon	Oregon	Pacific
Pennsylvania	Pennsylvania	Northeast
Rhode Island	Rhode Island	Northeast
South Carolina	South Carolina	Southeast
South Dakota	South Dakota	Midwest
Tennessee	Tennessee	Southeast
Texas RRC 1	Texas	Southwest
Texas RRC 2	Texas	Southwest
Texas RRC 3	Texas	Southwest
Texas RRC 4	Texas	Southwest
Texas RRC 5	Texas	Southwest
Texas RRC 6	Texas	Southwest
Texas RRC 7B	Texas	Southwest
Texas RRC 7C	Texas	Southwest
Texas RRC 8	Texas	Southwest
Texas RRC 8A	Texas	Southwest
Texas RRC 9	Texas	Southwest
Texas RRC 10	Texas	Southwest
Utah	Utah	Rocky Mountain
Virginia	Virginia	Northeast
Washington	Washington	Pacific
West Virginia	West Virginia	Northeast
Wisconsin	Wisconsin	Midwest
Wyoming	Wyoming	Rocky Mountain
Alabama State Offshore	Alabama	Southeast
Louisiana State Offshore	Louisiana	Southeast
Texas State Offshore	Texas	Southwest
California State Offshore	California	Pacific
North Atlantic Federal Offshore	North Carolina	Southeast

Production by OGSM District	State	Region
Mid Atlantic Federal Offshore	Federal Offshore - GoM	Southeast
South Atlantic Federal Offshore	South Carolina	Southeast
Eastern GOM Federal Offshore	Federal Offshore - GoM	Southeast
Central GOM Federal Offshore	Federal Offshore - GoM	Southeast
Western GOM Federal Offshore	Federal Offshore - GoM	Southeast
California Federal Offshore	California	Pacific
Northern Pacific Federal Offshore	Federal Offshore - GoM	Southeast
Alaska Federal Offshore	Federal Offshore - GoM	Southeast

This classification enables the aggregation of dry production data (excluding extraction losses) by region for each respective year, as summarized with every 10 years of data in Table C-2.

Table C-2 Regional dry production (trillion cubic feet) between 2020 and 2050, S1

Region	2020	2030	2040	2050
Midwest	3.27	2.82	2.41	2.09
Northeast	9.54	11.14	13.03	14.08
Pacific	0.16	0.29	0.30	0.28
Rocky Mountain	3.33	2.90	2.80	2.69
Southeast	4.59	6.08	6.65	5.72
Southwest	12.28	13.37	15.28	16.65

From this aggregated data, the production share is calculated by dividing the region-specific production by the total U.S. production for each year and is summarized in Table C-3.

Table C-3 Regional NG dry production shares, S1

Region	2020	2030	2040	2050
Midwest	0.099	0.077	0.060	0.050
Northeast	0.288	0.304	0.322	0.339
Pacific	0.005	0.008	0.007	0.007
Rocky Mountain	0.100	0.079	0.069	0.065
Southeast	0.138	0.166	0.164	0.138
Southwest	0.370	0.365	0.378	0.401

Figure C-1 shows the percent of natural gas dry production for each region of *S1* as compared to total production in each year between 2020 and 2050. The same process was done for the other scenarios.

Commented [ST167]: Why every 10 years of data when the raw data is provided on an annual basis from NEMS?

Commented [SM168R167]: The model uses annual data this is just to avoid cluttering the document, is why as an example every 10 years of data is included.

Commented [ST169]: How much variability in dry production volume is considered significant? Northeast is a 55% increase.
60% decrease in Midwest.

Commented [ST170]: No discussion of Table C-3.

Ratio compared to what?

I think these are annual percentages. Column sums to 100%.

Caption needs better clarity.

Commented [SM171R170]: As a proportion of total US production. Additional text provided above Table C-3 for clarity.

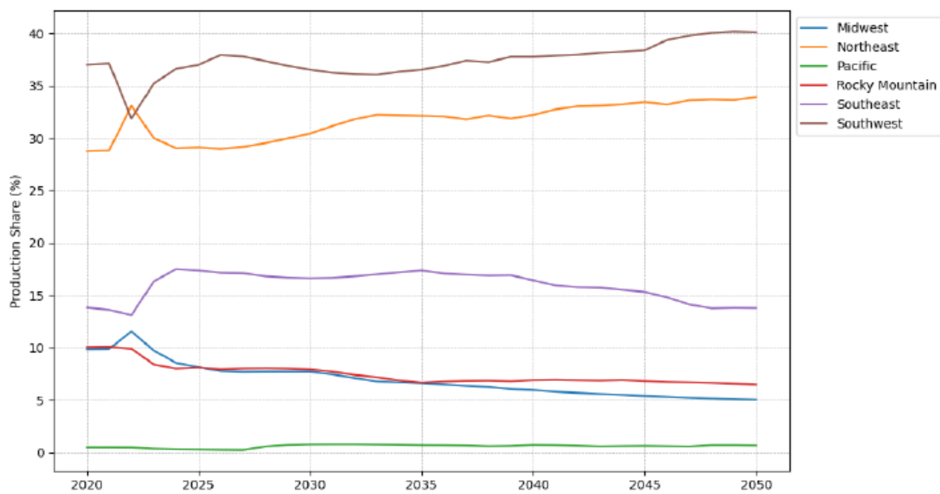


Figure C-1. Dry NG production percentage time-series for each region

The regional production shares estimated based on NEMS data are disaggregated to a techno-basin level based on the proportion of regional NG production shares in the 2020 NETL NG report [cite]. Based on the 2020 NETL NG report, Table C-4 provides the techno-basin to region mapping details and Table C-5 reports the GHG emissions intensity results for NG production from all techno-basins, for the production through transmission network life cycle boundary, using US average transmission network data. Table C-4. Techno-basin to Region Mapping

Techno-basin	Region
Alaska Offshore	Pacific
Anadarko Conventional	Southwest
Anadarko Shale	Southwest
Anadarko Tight	Southwest
Appalachian Shale	Northeast
Arkla Conventional	Southeast
Arkla Shale	Southeast
Arkla Tight	Southeast
Arkoma Conventional	Southwest
Arkoma Shale	Southwest
East Texas Conventional	Southwest
East Texas Shale	Southwest
East Texas Tight	Southwest
Fort Worth Shale	Southwest
GoM Offshore	Southeast
Green River Conventional	Rocky Mountain

Commented [ST172]: GHG Emissions Intensity

Commented [ST173]: There should be a space between the measurement unit and the descriptor of what was measured/reported.

E.g., g CO2e (with the 2 subscripted)

Commented [ST174]: How were the regional profiles converted to a single Weighted Average GHG Emissions Intensity value?

Techno-basin	Region
Green River Tight	Rocky Mountain
Gulf Conventional	Southwest
Gulf Shale	Southwest
Gulf Tight	Southwest
Permian Conventional	Southwest
Permian Shale	Southwest
Piceance Tight	Rocky Mountain
San Juan CBM	Southwest
San Juan Shale	Southwest
South Oklahoma Shale	Southwest
Strawn Shale	Southwest
Uinta Conventional	Rocky Mountain
Uinta Tight	Rocky Mountain

Table C-5. GHG Emissions Intensity by Techno-basin, Production through Transmission network boundary using U.S. average transmission data (g CO_2e/MJ, IPCC AR6 100-yr GWP)

Techno-basin	GHG Emissions Intensity (g CO_2e/MJ)
Alaska Offshore	6.99E+00
Anadarko Conv	1.62E+01
Anadarko Shale	9.68E+00
Anadarko Tight	1.17E+01
Appalachian Shale	6.41E+00
Arkla Conv	6.40E+00
Arkla Shale	6.39E+00
Arkla Tight	1.16E+01
Arkoma Conv	1.54E+01
Arkoma Shale	1.22E+01
East Texas Conv	7.70E+00
East Texas Shale	8.01E+00
East Texas Tight	7.74E+00
Fort Worth Shale	1.32E+01
GoM Offshore	6.20E+00
Green River Conv	1.28E+01
Green River Tight	1.32E+01
Gulf Conv	8.51E+00
Gulf Shale	7.44E+00
Gulf Tight	9.38E+00
Permian Conv	9.61E+00
Permian Shale	1.03E+01

Techno-basin	GHG Emissions Intensity (g CO_2e/MJ)
Piceance Tight	8.55E+00
San Juan CBM	1.77E+01
San Juan Shale	2.72E+01
South Oklahoma Shale	8.64E+00
Strawn Shale	1.34E+01
Uinta Conv	3.44E+01
Uinta Tight	1.84E+01

Note: The GHG emissions intensity results are provided on a per MJ NG delivered, LHV basis. Results from the 2020 NETL NG report were converted from HHV to LHV basis for this work.

Overall, Figure C-2 suggests that the NEMS-modeled changes in domestic NG production by region across the scenarios are not expected to significantly affect the projected domestic GHG emissions intensities of natural gas production.

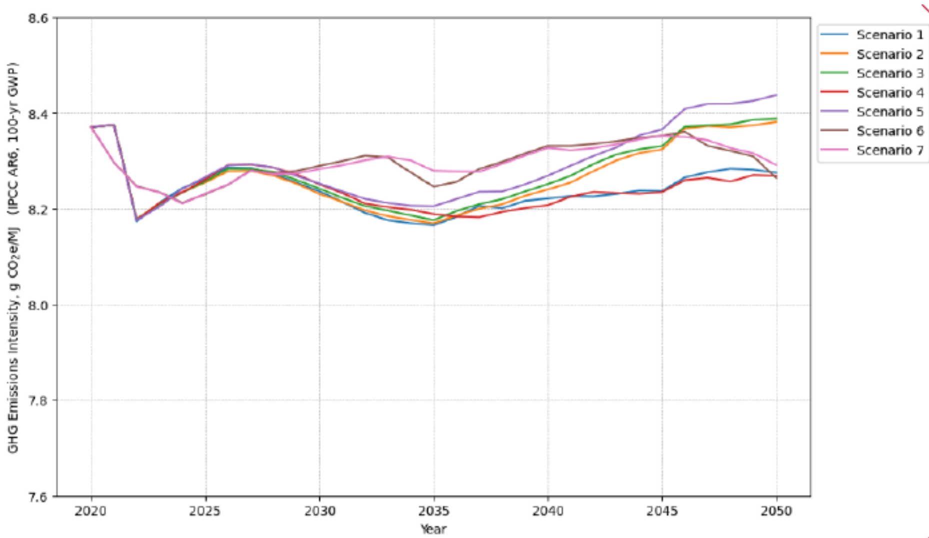


Figure C-2. Estimated U.S. Average GHG Intensity (g CO_2e/MJ) (S1 through S7), Production through Transmission (2020 - 2050)

B. Global Change Assessment Model – data inputs to LCA

Across all years and scenarios, GCAM has 105 discrete sectors, 377 discrete technologies, and many sector-technology pairs that can vary depending on the model configuration. However, only a subset of these factors is relevant to this analysis (i.e., with a focus on the natural gas sector).

Commented [ST175]: NEMS includes endogenous learning. How much did the GHG emissions intensity of natural gas by region change in the model?

Should be different for S1 set versus S6/S7 set of model runs.

Commented [HK176]: Figure C-2 provides the variation in GHG emissions intensity as a function of changing regional NG production shares. It uses a constant set of techno-basin emission factors from the 2020 NG report (provided in Table C-5) and applies it across a range of production mixes over 30 years.

Commented [ST177]: Y axis, add "Emissions" and units and GWP version to label; U.S. Weighted Average GHG Emissions Intensity, g CO2e/MJ (IPCC AR6 100-yr GWP)

Commented [ST178]: Why does S4 have a steeper and lower GHG emissions intensity per unit of gas produced in 2050 than S6 or S7?

Commented [ST179]: Quantitative data discussion is needed to justify why the change is "not significant" and that domestic market effects can be ignored.

The data and conclusion show that a change occurs. Southwest (permian) gas increase. Permian is high GHG intense gas. Why is this not a market effect that needs to be considered?

GCAM shows a reduction in GHGs from exports.

NEMS shows an increase in GHGs from exports.

The scale/magnitude of the GCAM results are -5 and -3 g CO2e/MJ.

What is the equivalent sum over 35 years for the change between S2 and S1, and S7 and S6? The 2050 value change appears very small.

I think the conclusion that domestic changes are less significant compared to non-US global changes is valid.

However, I am concerned about saying there is "no" domestic market effect which is the outcome when we choose to not include domestic market effects in

Commented [SM180R179]: From previous discussions, agreed that the graph shows negligible effects given the compressed y-axis.

Results provided by PNNL for the various Scenarios (1-7) and years modeled were provided as described in Table C-5, and were processed accordingly.

Table C-5. Provided set of GCAM Data Documentation

File	Data Represented
co2_em_tech_2023.06.22	Provides data showing CO_2 emissions in megatons per year (Mt CO_2/yr) for various sectors, energy sources or "technology" for 6 different scenarios across each of 37 regions.
non_co2_em_tech_2023.06.22	Provides data showing non-CO_2 emissions in Gigagrams (Gg) equivalent to metric kilotons or 1,000 metric tons, for various sectors, energy sources or "technology" and 6 different scenarios across each of 37 regions.
inputs.by.tech_2023.06.22	Provides detailed information about energy consumption and capacity in different regions and sectors along with specific technologies and years.
outputs.by.tech_2023.06.22	Reports the energy production within the various regions, by sectors, (sub-sector is not applicable in this dataset) along with specific technologies and years.
Columns	**Description**
scenario	Scenario or context for which the data is provided such as "S1: Reference Exports" which suggests that the data corresponds to the existing capacity or infrastructure in the region.
Region	This column specifies the geo-political region under consideration.
Sector	This column categorizes the different sectors or areas of activity for which carbon dioxide emissions are being measured, e.g., "agricultural energy use", "cement", "air_CO_2", etc.
sub-sector	Within each sector, there may be further divisions or subcategories to specify the specific aspect of the sector being measured, e.g., "mobile", "stationary," etc., indicating different types of energy use within a single sector.
technology	This column identifies the specific technology or energy source being utilized within the subsector. For example, "refined liquids" and "biomass".
year	The specific year or time period for which the CO_2 emissions values are provided, this ranges from 2015 to 2050.
value	Corresponding carbon dioxide emissions values for the given combination of scenario, region, sector, subsector, technology, and year. The values represent the estimated or projected amount of CO_2 emissions in megatons per year in this specific file as depicted in the "Units" column (not mentioned separately in this table).
ghg	Refers to the greenhouse gas that is being emitted. It identifies the specific type of gas responsible for the emissions, e.g., CH_4, N_2O, HFC125, C_2F_6, etc.
input, output	Additional details or characteristics about the technology or process.
output	Additional details or characteristics about the technology or process.

Commented [ST181]: Capitalization of column heading names seems to vary in this table. Intentional?

Commented [ST182]: Subscript

Commented [ST183]: Is this the column heading or column response?

C. GCAM and NETL emissions intensity comparison

As noted in the main report, only three sectors of the GCAM model have information relevant to the upstream natural gas supply chain. The GCAM *gas pipeline* and *natural gas* sectors are assumed to wholly incorporate natural gas-relevant emissions, and so total emissions are extracted from GCAM model output result files.

However, the *other industrial energy use* sector contains a diverse set of activities without explicitly representing emissions related to natural gas. GCAM incorporates a variety of data sources to represent activity in this sector. Relevant to natural gas activities for this sector, 2015 IEA data on energy use by oil and gas production activities used by the GCAM modeling team were provided and utilized to apportion GHG emissions associated with natural gas activity, as in Table C-6. The provided data (not shown) details what percent of energy use in the sector was from the IEA energy flows (e.g., 25% of total sectoral energy use in a region from Extraction and Gathering and Boosting). As 99.5% of GHG emissions in the *other industrial energy use* sector are CO_2, only the IEA data source was used and only CO_2 data for that sector was adjusted.

Table C-6. LCA Stage Cross-Mapping

NETL LCA stage	IEA energy flow	GCAM sector – energy & CO_2
Extraction	Oil and Gas Extract	Other Industrial Energy Use

	ion	
Gathering and Boosting	Oil and Gas Extraction	Other Industrial Energy Use
Processing	Gasworks	Other Industrial Energy Use
Domestic Pipelin	Pipeline Transpo	Gas Pipeline

eTransport[1]	rt	
Liquefaction	Liquefaction (LNG)/Regasification Plan	Other Industrial Energy Use

	ts	
Ocean Transport	International Marine Bunkers	Trn_shipping_intl
Regasification	Liquefaction (LNG)/Re	Other Industrial Energy Use

	gasificationPlants	
PipelineTransport(at destinatio	PipelineTransport	Gas Pipeline

n)		

The IEA data is aggregated into oil and gas activities such as "Extraction, Gathering and Boosting", "Processing", and "Liquefaction and Regasification". However, a challenge is that the IEA data represent aggregated activities of extraction of both oil and gas resources. Given the lack of data on liquefaction and regasification in the 2015 IEA data (including for the U.S.), emissions from those activities are excluded from the analysis, consistent with the focus on upstream natural gas effects.

Commented [ST184]: What does this mean? Unclear.

The emissions intensity cells in Table C-7 show the underlying equation used to generate values on an AR6-100 basis, where the numerator is the total emissions from the GCAM model for the USA region for Scenario *S1* for the year 2020 for each of the three greenhouse gases (if available), normalized by the total production of U.S. natural gas and oil from the GCAM model in 2020 (32.46 EJ and 22.46 EJ, respectively). Units of emissions intensity follow those internal to the GCAM model, which are Tg CO_2 equivalent per Exajoule, which conveniently are equal to g CO_2e/MJ, the same units as used in the NETL model. Thus, the bottom rows in Table C-7show comparisons to those of the NETL model.

As implemented, this adjustment factor of 0.96 is directly applied to GHG emissions in all regions of the model for the *natural gas* and *gas pipeline* sectors as they wholly related to natural gas activities. By linearly scaling all regional values in this way, the existing and diverse methane mitigation trends for each region in the underlying GCAM emissions factors for the *natural gas* sector were preserved by using this adjustment method.

Commented [ST185]: How was it preserved?

Does the MAF change every year (model time step) due to endogenous learning in the model?

For the *other industrial energy use* sector, the adjustment is complicated by the fact that the sector includes many activities beyond natural gas. If the adjustment factor were wholly applied to the GHG emissions of the sector, then the total emissions in GCAM would be reduced for both natural gas and non-natural gas activities. A compromise was made to estimate the total needed reductions in emissions associated with only natural gas activity for each region, and to reduce the emissions of the other industrial energy use sector by that amount. While this does not achieve a full alignment of these associated emissions (i.e., it does not lead to a 4% reduction in emissions intensity for the other industrial energy use sector), it avoids the outcome where that sector's emissions are reduced for all of the other activities.

These adjustments to emissions from all regions, all scenarios, and all years were applied to existing GCAM model results (i.e., the GCAM model was not re-run or scenarios optimized based on these adjustments).

Table C-7. GCAM Emissions Intensities for Sectors (S1, 2020, USA region, AR6-100 basis)

			Estimated GCAM Emissions Intensity (LHV) (Tg CO_2e / EJ, g CO_2e / MJ) [IPCC AR6 100 yr]		
GCAM Sector	NETL LCA Stage	Comments/Potential mapping inaccuracy	CO_2	CH_4	N_2O
gas pipeline	Transmission and Storage	Have assumed this fully represents the Transmission sector	38.0/32.5 = 1.17	-	-

		equivalent to the NETL NG model.			
natural gas	Production + Gathering & Boosting + Processing	From discussions with GCAM team, this sector represents all other natural gas related activities, thus the mapping to all other NETL stages other than transmission.	-	139.0/32.5 = 4.28	.015/32.5 = 4.5 E-4
other industrial energy use (technology = gas or gas cogen)[a]	**For 2015**, Extraction, Gathering & Boosting	Estimates from IEA energy shares. For technology = gas or gas cogen, all GHG emissions allocated to the natural gas product. For technology = refined liquids or refined liquids cogen, GHG emissions are allocated to the natural gas and crude oil products on an energy (EJ) produced basis from GCAM output data.	92.9/32.5 = 2.86	-	-
other industrial energy use (technology = refined liquids and refined liquids cogen)[a]			11/(32.5+22.5) = 0.2	-	-
other industrial energy use (electricity)[a]			-	-	-
Total GCAM by gas (LHV)			= 1.17 + 2.86 + .2 = 4.23	4.28	4.5 E-4
Total GCAM (LHV)			8.52		
Subtotal from NETL Model, Processing through Transmission boundary – LHV basis			8.18		
Adjustment factor (LHV)			8.18/8.52 = 0.96		

Using the same detailed approach, Tables C-8 through C-10 more succinctly summarize the provided GCAM values and adjustments identified for the IPCC AR values.

Table C-8. GCAM Emissions Intensities for Sectors (S1, 2020, USA region, AR6-20 basis)

	Estimated GCAM Emissions Intensity (Tg CO_2e / EJ, g CO_2e / MJ) [IPCC AR6 20 yr]		
GCAM Sector	**CO_2**	**CH_4**	**N_2O**
gas pipeline	1.17	-	-
natural gas	-	11.86	4.5 E-4

other industrial energy use (technology = gas or gas cogen)	2.86	-	-
other industrial energy use (technology = refined liquids and refined liquids cogen)	0.2	-	-
Total GCAM by gas (LHV)	= 1.17 + 2.86 + .2 = 4.23	11.86	4.5 E-4
Total GCAM (LHV)	16.1		
NETL (LHV basis)	13.8		
Adjustment Factor (LHV)	0.86		

Table C-9. GCAM Emissions Intensities for Sectors (S1, 2020, USA region, AR5-100 basis)

	Estimated GCAM Emissions Intensity (Tg CO_2e / EJ, g CO_2e / MJ) [IPCC AR5 100 yr]		
GCAM Sector	**CO_2**	**CH_4**	**N_2O**
gas pipeline	1.17	-	-
natural gas	-	5.18	4.9 E-4
other industrial energy use (technology = gas or gas cogen)	2.86	-	-
other industrial energy use (technology = refined liquids and refined liquids cogen)	0.2	-	-
Total GCAM by gas (LHV)	= 1.17 + 2.86 + .2 = 4.23	5.18	4.9 E-4
Total GCAM (LHV)	9.41		
NETL (LHV basis)	8.84		
Adjustment Factor (LHV)	0.94		

Table C-10. GCAM Emissions Intensities for Sectors (S1, 2020, USA region, AR5-20 basis)

	Estimated GCAM Emissions Intensity (Tg CO_2e / EJ, g CO_2e / MJ) [IPCC AR5 20 yr]

GCAM Sector	CO_2	CH_4	N_2O
gas pipeline	1.17	-	-
natural gas	-	12.36	4.4 E-4
other industrial energy use (technology = gas or gas cogen)	2.86	-	-
other industrial energy use (technology = refined liquids and refined liquids cogen)	0.2	-	-
Total GCAM by gas (LHV)	= 1.17 + 2.86 + .2 = 4.23	12.36	4.4 E-4
Total GCAM (LHV)	16.6		
NETL (LHV basis)	14.2		
Adjustment Factor (LHV)	0.86		

Table C-11 shows the GWP of key greenhouse gases which were used in conjunction with the emissions factors to derive the overall lifecycle greenhouse gas intensity.

Table C-11. GWP Values Used in this Analysis (Source: IPCC)

Greenhouse Gas	AR5-100 (with ccf)	AR5-20 (with ccf)	AR6-100	AR6-20
CH_4 (fossil)	36	86	29.8	82.5
CH_4 (non-fossil)	34	84	27.2	80.8
N_2O (fossil)	298	268	273	273
N_2O (non-fossil)	298	268	273	273
HFC125	3691	6207	3740	6740
HFC134a	1549	3789	1530	4140
HFC143a	5508	7064	5810	7840
HFC23	13856	11005	14600	12400
HFC32	817	2502	771	2690
SF_6	26087	17783	24300	18200
HFC245fa	1032	2992	962	3170
HFC365mfc	966	2724	914	2920
C_2F_6	12340	8344	12400	8940
CF_4	7349	4954	7380	5300
HFC43	1952	4403	1600	3960
HFC152a	167	524	164	591
HFC227ea	3860	3860	3600	5850
HFC236fa	8998	9810	8690	7450

Note that unlike the natural gas system-specific emission comparisons and adjustments discussed above which focus on CO_2, CH_4, and N_2O, GCAM estimates emissions of sixteen GHGs and all are included in this study.

1. Market Adjustment Factors for other IPCC GWP Values

Table C-12 shows all MAF results for Scenario 2.

Table C-12. NETL-adjusted MAF results for S2

Results (g CO_2e/ MJ, LHV basis)					
MAF Case	AR5, 100 with ccf	AR5, 20 with ccf	AR6-100	AR6-20	Scenario Difference
***S2* vs. *S1* - unadjusted**	-5.85	-9.17	-5.34	-8.86	Adds economic solution for LNG exports.
***S2* vs. *S1* - adjusted**	-5.86	-9.12	-5.35	-8.74	

Table C-13 shows all MAF results for *Scenario 7*.

Table C-13 NETL-adjusted MAF results for S7

Results (g CO_2e/ MJ, LHV basis)					
MAF Case	**AR5, 100 with ccf**	**AR5, 20**	**AR6-100**	**AR6-20**	**Scenario Difference**
***S7* vs. *S6* - unadjusted**	-3.54	-7.54	-3.01	-7.25	S6 1.5°C pathway, economic solution for LNG exports
***S7* vs. *S6* - adjusted**	-3.44	-7.26	-2.95	-6.61	

Table C-14 shows the underlying annual CO_2e emissions and US LNG export volumes used in the MAF calculations above for the AR6-100 case (LHV, with NETL adjustments). Cumulative MAF values are calculated by finding the cumulative sum of delta values from 2015 to the current year for both LNG export volumes and global GHG emissions, and the cumulative values for 2050 match those shown above in the report.

Commented [ST186]: What does "with adjustments mean?

Table C-14. Annual US Export Volumes of LNG , NETL-Adjusted Global CO_2 Emissions (IPCC AR6, 100-yr GWP)and Annual Market Adjustment Factors

Scenario	Year	US LNG S1 (EJ)	Global CO_2e S1 (Tg)	US LNG S2 (EJ)	Global CO2e S2 (Tg)	Delta CO2e (Tg)	Delta US LNG (EJ)	Annual MAF	Cumulative MAF
S2	2015	0.02	49,656.39	0.02	49,656.39	0.00	0.00	NA	NA
S2	2016	0.54	50,410.51	0.54	50,410.51	0.00	0.00	NA	NA
S2	2017	1.06	51,164.63	1.06	51,164.63	0.00	0.00	NA	NA
S2	2018	1.58	51,918.75	1.58	51,918.75	0.00	0.00	NA	NA
S2	2019	2.10	52,672.87	2.10	52,672.87	0.00	0.00	NA	NA
S2	2020	2.62	53,426.99	2.62	53,426.99	0.00	0.00	NA	NA
S2	2021	3.09	52,816.08	3.09	52,816.08	0.00	0.00	NA	NA
S2	2022	3.55	52,205.17	3.55	52,205.17	0.00	0.00	NA	NA
S2	2023	4.02	51,594.26	4.02	51,594.26	0.00	0.00	NA	NA
S2	2024	4.49	50,983.35	4.49	50,983.35	0.00	0.00	NA	NA
S2	2025	4.96	50,372.43	4.96	50,372.43	0.00	0.00	NA	NA
S2	2026	5.37	50,692.94	5.37	50,692.94	0.00	0.00	NA	NA
S2	2027	5.78	51,013.45	5.78	51,013.45	0.00	0.00	NA	NA

Commented [ST187]: Break this table by Scenario.

Add to S2, S3, S4, and S5 a column showing the change in GHG Emissions by year compared to the S1 (the reference scenario).

Same comment for S7 with S6 comparison by year.

S2	2028	6.19	51,333.96	6.19	51,333.96	0.00	0.00	NA	NA
S2	2029	6.60	51,654.47	6.60	51,654.47	0.00	0.00	NA	NA
S2	2030	7.01	51,974.98	7.01	51,974.98	0.00	0.00	NA	NA
S2	2031	7.54	51,974.45	7.46	51,975.00	0.54	-0.08	-6.63	-6.63
S2	2032	8.07	51,973.92	7.91	51,975.01	1.09	-0.16	-6.63	-6.63
S2	2033	8.60	51,973.39	8.36	51,975.02	1.63	-0.25	-6.63	-6.63
S2	2034	9.13	51,972.85	8.81	51,975.03	2.18	-0.33	-6.63	-6.63
S2	2035	9.66	51,972.32	9.25	51,975.04	2.72	-0.41	-6.63	-6.63
S2	2036	9.77	51,862.93	10.00	51,862.21	-0.73	0.23	-3.15	-7.43
S2	2037	9.87	51,753.55	10.74	51,749.37	-4.18	0.87	-4.79	-25.14
S2	2038	9.97	51,644.16	11.48	51,636.53	-7.63	1.51	-5.04	-3.15
S2	2039	10.07	51,534.78	12.22	51,523.70	-11.08	2.15	-5.14	-4.37
S2	2040	10.17	51,425.39	12.96	51,410.86	-14.53	2.79	-5.20	-4.73
S2	2041	10.17	51,339.60	13.56	51,323.22	-16.38	3.39	-4.83	-4.77
S2	2042	10.17	51,253.81	14.16	51,235.58	-18.23	3.99	-4.57	-4.71
S2	2043	10.17	51,168.03	14.75	51,147.94	-20.09	4.58	-4.38	-4.63
S2	2044	10.17	51,082.24	15.35	51,060.30	-21.94	5.18	-4.24	-4.54

S2	2045	10.17	50,996.45	15.95	50,972.66	-23.79	5.78	-4.12	-4.46
S2	2046	10.17	50,853.84	16.27	50,824.21	-29.63	6.10	-4.86	-4.53
S2	2047	10.17	50,711.23	16.60	50,675.76	-35.47	6.43	-5.52	-4.68
S2	2048	10.17	50,568.62	16.92	50,527.31	-41.31	6.75	-6.12	-4.88
S2	2049	10.17	50,426.01	17.25	50,378.85	-47.16	7.08	-6.66	-5.11
S2	2050	10.17	50,283.40	17.57	50,230.40	-53.00	7.40	-7.16	-5.35
Scenario	**Year**	**US LNG - S6 (EJ)**	**Global CO2e - S6 (Tg)**	**US LNG - S7 (EJ)**	**Global CO2e - S7 (Tg)**	**Delta CO2e (Tg)**	**Delta US LNG (EJ)**	**Annual MAF**	**Cumulative MAF**
S7	2015	0.02	49656.39	0.02	49656.39	0.00	0.00	NA	NA
S7	2016	0.54	50410.92	0.54	50410.92	0.00	0.00	NA	NA
S7	2017	1.06	51165.45	1.06	51165.45	0.00	0.00	NA	NA
S7	2018	1.58	51919.97	1.58	51919.97	0.00	0.00	NA	NA
S7	2019	2.10	52674.50	2.10	52674.50	0.00	0.00	NA	NA
S7	2020	2.62	53429.03	2.62	53429.03	0.00	0.00	NA	NA
S7	2021	3.09	52542.09	3.09	52542.09	0.00	0.00	NA	NA
S7	2022	3.55	51655.16	3.55	51655.16	0.00	0.00	NA	NA
S7	2023	4.02	50768.22	4.02	50768.22	0.00	0.00	NA	NA
S7	2024	4.49	49881.28	4.49	49881.28	0.00	0.00	NA	NA

S7	2025	4.96	48994.35	4.96	48994.35	0.00	0.00	NA	NA		
S7	2026	5.07	49084.34	5.07	49084.34	0.00	0.00	NA	NA		
S7	2027	5.17	49174.33	5.17	49174.33	0.00	0.00	NA	NA		
S7	2028	5.28	49264.33	5.28	49264.33	0.00	0.00	NA	NA		
S7	2029	5.38	49354.32	5.38	49354.32	0.00	0.00	NA	NA		
S7	2030	5.49	49444.31	5.49	49444.31	0.00	0.00	NA	NA		
S7	2031	5.78	48082.73	5.78	48082.74	0.00	0.00	404.93	423.34		
S7	2032	6.07	46721.16	6.07	46721.16	0.00	0.00	401.86	409.02		
S7	2033	6.37	45359.58	6.37	45359.58	0.00	0.00	400.84	404.93		
S7	2034	6.66	43998.00	6.66	43998.00	0.00	0.00	400.33	403.09		
S7	2035	6.95	42636.42	6.95	42636.42	0.00	0.00	400.02	402.06		
S7	2036	7.48	41287.64	7.48	41287.64	0.00	0.00	282.77	371.75		
S7	2037	8.01	39938.86	8.01	39938.86	0.00	0.00	170.52	330.27		
S7	2038	8.54	38590.08	8.54	38590.08	0.00	0.00	62.94	283.77		
S7	2039	9.07	37241.30	9.07	37241.30	0.00	0.00	-40.25	234.92		
S7	2040	9.60	35892.52	9.60	35892.52	0.00	0.00	-139.31	185.02		
S7	2041	9.71	34455.49	10.01	34454.66	-0.83	0.30	-2.76	-2.72		

S7	204 2	9.83	33018.45	10.43	33016.79	-1.66	0.60	-2.76	-2.75		
S7	204 3	9.94	31581.41	10.84	31578.93	-2.49	0.90	-2.76	-2.75		
S7	204 4	10.06	30144.38	11.26	30141.06	-3.32	1.20	-2.76	-2.76		
S7	204 5	10.17	28707.34	11.67	28703.20	-4.14	1.50	-2.76	-2.76		
S7	204 6	10.17	27334.61	11.84	27329.82	-4.79	1.67	-2.87	-2.79		
S7	204 7	10.17	25961.87	12.00	25956.45	-5.43	1.83	-2.96	-2.83		
S7	204 8	10.17	24589.14	12.17	24583.07	-6.07	2.00	-3.04	-2.87		
S7	204 9	10.17	23216.41	12.33	23209.69	-6.71	2.16	-3.11	-2.91		
S7	205 0	10.17	21843.67	12.50	21836.32	-7.35	2.33	-3.16	-2.95		

Commented [ST188]: I expected to find the index of country GHG emissions intensity to show the relative differences before and after adjustment.

I also expected to see more detail on "what" changed within each countries energy portfolio as a result of increased US LNG exports.

There is a larger "report" decision that will need to be made regarding additional transparency needed to support the conclusions.

This would be more in-line with the expectations described in the August 17, 2023 email to Scott/Matt from Tim.

NO ACTION REQUIRED AT THIS TIME UNTIL FURTHE REPORT WIDE GUIDANCE ON TRANSPARNCY/LEVEL OF DETAIL PROVIDED

APPENDIX D: TABULATED VALUES FROM FIGURES

Table D-1. U.S. LNG exports across the scenarios, tabulated by year (Figure 3)

Scenario	Unit	2015	2020	2025	2030	2035	2040	2045	2050
S1: Reference Exports	Bcf/d	0.05	7.03	13.33	18.85	25.98	27.33	27.33	27.33
S2: Market Response	Bcf/d	0.05	7.03	13.33	18.85	24.87	34.84	42.86	47.23
S3: High Global Demand	Bcf/d	0.05	7.03	13.33	18.84	25.22	35.47	43.91	48.74
S4: Regional Import Limits	Bcf/d	0.05	7.03	13.33	12.15	13.26	15.22	19.81	23.06
S5: Low-cost Renewables	Bcf/d	0.05	7.03	13.33	18.85	24.94	34.89	42.69	47.18
S6: Energy Transition (Ref Exp)	Bcf/d	0.05	7.03	13.33	14.75	18.68	25.79	27.33	27.33
S7: Energy Transition	Bcf/d	0.05	7.03	13.33	14.75	18.68	25.79	31.37	33.59
S1 - S1	Bcf/d	0	0	0	0	0	0	0	0
S2 - S1	Bcf/d	0	0	0	0	-1.1	7.51	15.52	19.9
S3 - S1	Bcf/d	0	0	0	-0.01	-0.75	8.14	16.58	21.41
S4 - S1	Bcf/d	0	0	0	-6.71	-12.71	-12.11	-7.53	-4.27
S5 - S1	Bcf/d	0	0	0	0	-1.04	7.56	15.35	19.84
S6 - S1	Bcf/d	0	0	0	-4.1	-7.29	-1.54	0	0
S7 - S1	Bcf/d	0	0	0	-4.1	-7.29	-1.54	4.03	6.25
S1 - S1	%	0	0	0	0	0	0	0	0
S2 - S1	%	0	0	0	0	-4.2	27.5	56.8	72.8
S3 - S1	%	0	0	0	0	-2.9	29.8	60.6	78.3
S4 - S1	%	0	0	0	-35.6	-48.9	-44.3	-27.5	-15.6
S5 - S1	%	0	0	0	0	-4	27.6	56.2	72.6
S6 - S1	%	0	0	0	-21.7	-28.1	-5.6	0	0
S7 - S1	%	0	0	0	-21.7	-28.1	-5.6	14.8	22.9

Table D-2. Natural gas consumption, production, and trade by region under S1 and S2 (Figure 4) and changes in natural gas consumption, production, and trade by region in S2 vs. S1 (Figure 5)

Scenario	Region	Unit	NG Volumes	2015	2020	2025	2030	2035	2040	2045	2050
S1: Reference exports	ROW	Bcf/d	Consumption	36.63	42.29	40.4	45.44	48.91	50.95	53.93	55.91
S1: Reference exports	Australia + NZ	Bcf/d	Consumption	3.85	0.79	0.31	0.43	0.38	0.51	0.76	1.11
S1: Reference exports	LAC	Bcf/d	Consumption	16.2	17.55	16.48	19.77	23.42	26.72	30.13	33.06
S1: Reference exports	Africa	Bcf/d	Consumption	12.32	14.45	14.21	17.09	21.45	26.78	33.49	41.44
S1: Reference exports	C Asia + East Eur	Bcf/d	Consumption	23.97	28.95	30.4	32.56	35.76	39.02	42.05	44.38

S1: Reference exports	Russia	Bcf/d	Consumption	41.18	45.82	35.98	39.62	39.94	39.92	39.91	39.81
S1: Reference exports	China	Bcf/d	Consumption	17.41	27.43	41.41	47.78	55.34	61.76	68.74	73.96
S1: Reference exports	India	Bcf/d	Consumption	5.07	7.96	11.89	17.19	22.88	28.35	34.63	41.12
S1: Reference exports	Middle East	Bcf/d	Consumption	44.96	46.53	46.04	47.58	51.74	56.93	63.16	67.9
S1: Reference exports	EU	Bcf/d	Consumption	40.32	48.18	35.83	33.46	29.99	28.83	32.7	36.46
S1: Reference exports	Mexico	Bcf/d	Consumption	6.91	8.28	8.06	9.36	10.7	12.08	13.4	14.74
S1: Reference exports	Canada	Bcf/d	Consumption	10.91	11.44	7.98	8.3	7.89	7.46	6.82	5.98
S1: Reference exports	USA	Bcf/d	Consumption	71.81	80.43	82.48	87.93	90.3	95.39	106.72	119
S1: Reference exports		**Bcf/d**	**Total**	**331.53**	**380.11**	**371.45**	**406.51**	**438.72**	**474.7**	**526.45**	**574.88**
S1: Reference exports	ROW	Bcf/d	Production	36.73	41.02	37.93	43.12	45.75	46.59	47.87	48.66
S1: Reference exports	Australia + NZ	Bcf/d	Production	6.84	12.71	12.21	12.11	11.09	9.61	7.82	6.59
S1: Reference exports	LAC	Bcf/d	Production	16.56	15.44	13.76	15.88	17.84	19.94	22.71	25.42
S1: Reference exports	Africa	Bcf/d	Production	18.43	23.83	24.67	27.6	31.5	36.6	42.46	48.39
S1: Reference exports	C Asia + East Eur	Bcf/d	Production	23.23	17.31	17.56	18.75	20.56	23.38	26.73	30.13
S1: Reference exports	Russia	Bcf/d	Production	58.04	70.26	59.82	63.01	63.57	67.82	74.16	80.12
S1: Reference exports	China	Bcf/d	Production	12.49	16.74	19.82	22.5	24.88	26.36	27.6	28.26
S1: Reference exports	India	Bcf/d	Production	2.89	4.02	4.91	7.13	9.9	13.37	17.64	22.27
S1: Reference exports	Middle East	Bcf/d	Production	55	59.51	58.6	60.95	66.4	73	81.24	87.94
S1: Reference exports	EU	Bcf/d	Production	11.72	13.69	10.05	10.19	9.82	10.22	15.81	20.86
S1: Reference exports	Mexico	Bcf/d	Production	3.8	3.21	2.55	3.35	3.91	4.48	5.36	6.46
S1: Reference exports	Canada	Bcf/d	Production	15.4	15.11	14.05	14.59	15.24	16.86	18.23	18.12
S1: Reference exports	USA	Bcf/d	Production	70.47	87.25	95.51	107.34	118.25	126.46	138.82	151.65

S1: Reference exports		**Bcf/d**	**Total**	**331.61**	**380.11**	**371.45**	**406.51**	**438.72**	**474.69**	**526.45**	**574.88**
S1: Reference exports	ROW	Bcf/d	LNG exports	8.59	10.56	11.11	13.82	15.57	16.43	18.02	19.15
S1: Reference exports	Australia + NZ	Bcf/d	LNG exports	3.02	11.93	11.9	11.69	10.72	9.11	7.07	5.66
S1: Reference exports	LAC	Bcf/d	LNG exports	1.82	1.83	2.2	2.67	3.51	4.71	6.27	7.61
S1: Reference exports	Africa	Bcf/d	LNG exports	5.56	9.09	10.65	11.58	12.46	13.6	14.77	15.28
S1: Reference exports	C Asia + East Eur	Bcf/d	LNG exports	0.02	0.06	0.17	0.42	1.07	2.52	4.88	7.51
S1: Reference exports	Russia	Bcf/d	LNG exports	1.64	3.05	3.82	3.9	3.67	3.34	3.25	3.47
S1: Reference exports	China	Bcf/d	LNG exports	0	0	0	0.01	0.02	0.06	0.11	0.15
S1: Reference exports	India	Bcf/d	LNG exports	0.05	0.01	0.01	0.04	0.09	0.2	0.41	0.64
S1: Reference exports	Middle East	Bcf/d	LNG exports	10.41	13.4	13.05	14	15.75	17.71	20.44	22.91
S1: Reference exports	EU	Bcf/d	LNG exports	0.71	0.37	0.46	0.63	0.87	1.68	3.17	4.5
S1: Reference exports	Mexico	Bcf/d	LNG exports	0	0	0	0.01	0.03	0.09	0.2	0.34
S1: Reference exports	Canada	Bcf/d	LNG exports	0	0.01	2.01	2.65	4.39	7.38	10.05	11.15
S1: Reference exports	USA	Bcf/d	LNG exports	0.05	7.03	13.33	18.85	25.98	27.33	27.33	27.33
S1: Reference exports		**Bcf/d**	**Total**	**0**	**57.34**	**68.72**	**80.27**	**94.13**	**104.15**	**115.98**	**125.71**
S1: Reference exports	ROW	Bcf/d	LNG imports	18.06	20.88	20.26	22.28	23.89	24.6	25.95	26.95
S1: Reference exports	Australia + NZ	Bcf/d	LNG imports	0.03	0.01	0	0	0	0	0.01	0.18
S1: Reference exports	LAC	Bcf/d	LNG imports	2.26	3.94	4.92	6.56	9.09	11.49	13.69	15.24
S1: Reference exports	Africa	Bcf/d	LNG imports	0.67	0.97	1.16	1.95	3.14	4.32	6.08	8.44
S1: Reference exports	C Asia + East Eur	Bcf/d	LNG imports	3.91	6.4	7.97	9.15	11.15	12.55	13.61	14.19
S1: Reference exports	Russia	Bcf/d	LNG imports	0	0.82	0.68	0.81	1.82	2.62	3.13	3.33
S1: Reference exports	China	Bcf/d	LNG imports	2.62	6.98	15.66	17.75	19.34	19.68	19.85	19.88

S1: Reference exports	India	Bcf/d	LNG imports	2.24	3.95	7	10.1	13.08	15.18	17.39	19.5
S1: Reference exports	Middle East	Bcf/d	LNG imports	0.37	0.43	0.48	0.63	1.07	1.54	2.13	2.52
S1: Reference exports	EU	Bcf/d	LNG imports	4.98	11.32	8.86	9.21	9.65	10.24	12.01	13.18
S1: Reference exports	Mexico	Bcf/d	LNG imports	0.73	1.15	1.34	1.44	1.57	1.64	1.77	1.95
S1: Reference exports	Canada	Bcf/d	LNG imports	0.18	0.21	0.15	0.15	0.14	0.19	0.25	0.26
S1: Reference exports	USA	Bcf/d	LNG imports	0.27	0.26	0.26	0.23	0.18	0.1	0.1	0.1
S1: Reference exports		**Bcf/d**	**Total**	**36.32**	**57.34**	**68.72**	**80.27**	**94.13**	**104.15**	**115.98**	**125.71**
S1: Reference exports	ROW	Bcf/d	Pipeline exports	10.37	10.05	7.51	7.05	6.05	4.62	2.67	1.52
S1: Reference exports	Australia + NZ	Bcf/d	Pipeline exports	0	0	0	0	0	0	0	0
S1: Reference exports	LAC	Bcf/d	Pipeline exports	2.15	2.11	1.82	1.79	1.6	1.36	1.22	1.23
S1: Reference exports	Africa	Bcf/d	Pipeline exports	1.36	1.42	1.13	1.23	1.58	2.35	3.38	4.8
S1: Reference exports	C Asia + East Eur	Bcf/d	Pipeline exports	7.81	0.07	0.05	0.05	0.04	0.03	0.01	0.01
S1: Reference exports	Russia	Bcf/d	Pipeline exports	14.83	23.46	21.67	21.37	23.15	29.3	37.12	43.78
S1: Reference exports	China	Bcf/d	Pipeline exports	0	0	0	0	0	0	0	0
S1: Reference exports	India	Bcf/d	Pipeline exports	0	0	0	0	0	0	0	0
S1: Reference exports	Middle East	Bcf/d	Pipeline exports	0.03	0.03	0.02	0.03	0.03	0.04	0.06	0.09
S1: Reference exports	EU	Bcf/d	Pipeline exports	2.36	2.21	1.61	1.49	1.25	0.92	0.49	0.27
S1: Reference exports	Mexico	Bcf/d	Pipeline exports	0.01	0.01	0	0.01	0.05	0.15	0.35	0.56
S1: Reference exports	Canada	Bcf/d	Pipeline exports	5.97	6.23	5.87	5.51	4.76	3.97	3.3	2.81
S1: Reference exports	USA	Bcf/d	Pipeline exports	5.17	8.53	8.53	8.53	8.53	8.52	8.53	8.53
S1: Reference exports		**Bcf/d**	**Total**	**50.07**	**54.11**	**48.21**	**47.06**	**47.04**	**51.26**	**57.14**	**63.59**
S1: Reference exports	ROW	Bcf/d	Pipeline imports	1.01	1	0.83	0.91	0.88	0.8	0.8	0.98

S1: Reference exports	Australia + NZ	Bcf/d	Pipeline imports	0	0	0	0	0	0	0	0
S1: Reference exports	LAC	Bcf/d	Pipeline imports	2.15	2.11	1.82	1.79	1.6	1.36	1.22	1.23
S1: Reference exports	Africa	Bcf/d	Pipeline imports	0.14	0.15	0.16	0.35	0.84	1.81	3.11	4.68
S1: Reference exports	C Asia + East Eur	Bcf/d	Pipeline imports	5.58	5.37	5.09	5.13	5.17	5.64	6.61	7.59
S1: Reference exports	Russia	Bcf/d	Pipeline imports	1.11	1.25	0.97	1.08	1.37	2.12	3	3.62
S1: Reference exports	China	Bcf/d	Pipeline imports	2.29	3.7	5.93	7.54	11.14	15.78	21.4	25.97
S1: Reference exports	India	Bcf/d	Pipeline imports	0	0	0	0	0	0	0	0
S1: Reference exports	Middle East	Bcf/d	Pipeline imports	0.05	0.02	0.03	0.03	0.06	0.14	0.29	0.45
S1: Reference exports	EU	Bcf/d	Pipeline imports	26.7	25.74	18.99	16.18	12.65	10.96	8.54	7.18
S1: Reference exports	Mexico	Bcf/d	Pipeline imports	2.39	3.93	4.18	4.6	5.29	6.2	6.81	7.23
S1: Reference exports	Canada	Bcf/d	Pipeline imports	2.06	2.35	1.66	1.72	1.66	1.75	1.7	1.56
S1: Reference exports	USA	Bcf/d	Pipeline imports	7.74	8.48	8.56	7.73	6.38	4.7	3.67	3.11
S1: Reference exports		**Bcf/d**	**Total**	**51.21**	**54.11**	**48.21**	**47.06**	**47.04**	**51.27**	**57.14**	**63.59**
S2: Market Response	ROW	Bcf/d	Consumption	36.63	42.29	40.4	45.44	48.76	51.9	55.46	57.76
S2: Market Response	Australia + NZ	Bcf/d	Consumption	3.85	0.79	0.31	0.43	0.37	0.52	0.78	1.13
S2: Market Response	LAC	Bcf/d	Consumption	16.2	17.55	16.48	19.77	23.34	27.29	30.97	33.98
S2: Market Response	Africa	Bcf/d	Consumption	12.32	14.45	14.21	17.09	21.44	26.94	33.87	42
S2: Market Response	C Asia + East Eur	Bcf/d	Consumption	23.97	28.95	30.4	32.56	35.69	39.41	42.46	44.78
S2: Market Response	Russia	Bcf/d	Consumption	41.18	45.82	35.98	39.62	39.93	39.98	39.98	39.88
S2: Market Response	China	Bcf/d	Consumption	17.41	27.43	41.41	47.78	55.04	62.68	69.41	74.51
S2: Market Response	India	Bcf/d	Consumption	5.07	7.96	11.89	17.19	22.78	28.94	35.5	42.11
S2: Market Response	Middle East	Bcf/d	Consumption	44.96	46.53	46.04	47.58	51.75	56.89	63.14	67.95

S2: Market Response	EU	Bcf/d	Consumption	40.32	48.18	35.83	33.46	29.54	30.59	34.25	37.95
S2: Market Response	Mexico	Bcf/d	Consumption	6.91	8.28	8.06	9.36	10.7	12.08	13.42	14.76
S2: Market Response	Canada	Bcf/d	Consumption	10.91	11.44	7.98	8.3	7.9	7.47	6.92	6.11
S2: Market Response	USA	Bcf/d	Consumption	71.81	80.43	82.48	87.93	90.36	94.97	105.54	115.78
S2: Market Response		**Bcf/d**	**Total**	**331.53**	**380.11**	**371.45**	**406.51**	**437.59**	**479.66**	**531.68**	**578.69**
S2: Market Response	ROW	Bcf/d	Production	36.73	41.02	37.93	43.12	45.71	46.36	47.03	47.63
S2: Market Response	Australia + NZ	Bcf/d	Production	6.84	12.71	12.21	12.11	11.09	9.58	7.65	6.24
S2: Market Response	LAC	Bcf/d	Production	16.56	15.44	13.76	15.88	17.88	19.55	21.78	24.2
S2: Market Response	Africa	Bcf/d	Production	18.43	23.83	24.67	27.6	31.53	36.13	41.24	46.78
S2: Market Response	C Asia + East Eur	Bcf/d	Production	23.23	17.31	17.56	18.75	20.59	23.12	25.9	28.85
S2: Market Response	Russia	Bcf/d	Production	58.04	70.26	59.82	63.01	63.59	67.37	72.53	77.91
S2: Market Response	China	Bcf/d	Production	12.49	16.74	19.82	22.5	24.83	26.5	27.57	28.17
S2: Market Response	India	Bcf/d	Production	2.89	4.02	4.91	7.13	9.92	13.25	17.23	21.64
S2: Market Response	Middle East	Bcf/d	Production	55	59.51	58.6	60.95	66.41	72.45	79.54	85.59
S2: Market Response	EU	Bcf/d	Production	11.72	13.69	10.05	10.19	9.67	10.83	15.39	19.98
S2: Market Response	Mexico	Bcf/d	Production	3.8	3.21	2.55	3.35	3.91	4.48	5.31	6.4
S2: Market Response	Canada	Bcf/d	Production	15.4	15.11	14.05	14.59	15.23	16.78	17.78	17.52
S2: Market Response	USA	Bcf/d	Production	70.47	87.25	95.51	107.34	117.24	133.28	152.75	167.78
S2: Market Response		**Bcf/d**	**Total**	**331.61**	**380.11**	**371.45**	**406.51**	**437.59**	**479.66**	**531.68**	**578.69**
S2: Market Response	ROW	Bcf/d	LNG exports	8.59	10.56	11.11	13.82	15.59	16.26	17.28	18.13
S2: Market Response	Australia + NZ	Bcf/d	LNG exports	3.02	11.93	11.9	11.69	10.72	9.06	6.88	5.32
S2: Market Response	LAC	Bcf/d	LNG exports	1.82	1.83	2.2	2.67	3.5	4.63	5.9	7.03

S2: Market Response	Africa	Bcf/d	LNG exports	5.56	9.09	10.65	11.58	12.46	13.43	14.04	14.24
S2: Market Response	C Asia + East Eur	Bcf/d	LNG exports	0.02	0.06	0.17	0.42	1.07	2.45	4.37	6.58
S2: Market Response	Russia	Bcf/d	LNG exports	1.64	3.05	3.82	3.9	3.67	3.3	3.07	3.14
S2: Market Response	China	Bcf/d	LNG exports	0	0	0	0.01	0.02	0.05	0.09	0.13
S2: Market Response	India	Bcf/d	LNG exports	0.05	0.01	0.01	0.04	0.09	0.19	0.36	0.55
S2: Market Response	Middle East	Bcf/d	LNG exports	10.41	13.4	13.05	14	15.71	17.51	19.25	21.03
S2: Market Response	EU	Bcf/d	LNG exports	0.71	0.37	0.46	0.63	0.87	1.6	2.79	3.93
S2: Market Response	Mexico	Bcf/d	LNG exports	0	0	0	0.01	0.03	0.08	0.17	0.29
S2: Market Response	Canada	Bcf/d	LNG exports	0	0.01	2.01	2.65	4.38	7.26	9.47	10.36
S2: Market Response	USA	Bcf/d	LNG exports	0.05	7.03	13.33	18.85	24.87	34.84	42.86	47.23
S2: Market Response		**Bcf/d**	**Total**	**0**	**57.34**	**68.72**	**80.27**	**92.98**	**110.68**	**126.53**	**137.96**
S2: Market Response	ROW	Bcf/d	LNG imports	18.06	20.88	20.26	22.28	23.73	25.6	27.58	28.82
S2: Market Response	Australia + NZ	Bcf/d	LNG imports	0.03	0.01	0	0	0	0	0.01	0.21
S2: Market Response	LAC	Bcf/d	LNG imports	2.26	3.94	4.92	6.56	8.96	12.38	15.09	16.82
S2: Market Response	Africa	Bcf/d	LNG imports	0.67	0.97	1.16	1.95	3.09	4.78	6.95	9.58
S2: Market Response	C Asia + East Eur	Bcf/d	LNG imports	3.91	6.4	7.97	9.15	11.01	13.37	14.88	15.6
S2: Market Response	Russia	Bcf/d	LNG imports	0	0.82	0.68	0.81	1.76	2.97	3.72	3.98
S2: Market Response	China	Bcf/d	LNG imports	2.62	6.98	15.66	17.75	19.14	20.33	20.86	21.03
S2: Market Response	India	Bcf/d	LNG imports	2.24	3.95	7	10.1	12.94	15.88	18.63	21.02
S2: Market Response	Middle East	Bcf/d	LNG imports	0.37	0.43	0.48	0.63	1.03	1.87	2.67	3.1
S2: Market Response	EU	Bcf/d	LNG imports	4.98	11.32	8.86	9.21	9.44	11.34	13.61	14.99
S2: Market Response	Mexico	Bcf/d	LNG imports	0.73	1.15	1.34	1.44	1.56	1.77	2.02	2.27

S2: Market Response	Canada	Bcf/d	LNG imports	0.18	0.21	0.15	0.15	0.14	0.25	0.35	0.37
S2: Market Response	USA	Bcf/d	LNG imports	0.27	0.26	0.26	0.23	0.17	0.15	0.16	0.17
S2: Market Response		**Bcf/d**	**Total**	**36.32**	**57.34**	**68.72**	**80.27**	**92.98**	**110.68**	**126.53**	**137.96**
S2: Market Response	ROW	Bcf/d	Pipeline exports	10.37	10.05	7.51	7.05	5.97	4.59	2.65	1.5
S2: Market Response	Australia + NZ	Bcf/d	Pipeline exports	0	0	0	0	0	0	0	0
S2: Market Response	LAC	Bcf/d	Pipeline exports	2.15	2.11	1.82	1.79	1.61	1.3	1.12	1.1
S2: Market Response	Africa	Bcf/d	Pipeline exports	1.36	1.42	1.13	1.23	1.58	2.25	3.18	4.52
S2: Market Response	C Asia + East Eur	Bcf/d	Pipeline exports	7.81	0.07	0.05	0.05	0.04	0.03	0.01	0.01
S2: Market Response	Russia	Bcf/d	Pipeline exports	14.83	23.46	21.67	21.37	23.14	29.04	35.93	42.16
S2: Market Response	China	Bcf/d	Pipeline exports	0	0	0	0	0	0	0	0
S2: Market Response	India	Bcf/d	Pipeline exports	0	0	0	0	0	0	0	0
S2: Market Response	Middle East	Bcf/d	Pipeline exports	0.03	0.03	0.02	0.03	0.03	0.04	0.06	0.08
S2: Market Response	EU	Bcf/d	Pipeline exports	2.36	2.21	1.61	1.49	1.23	0.92	0.48	0.25
S2: Market Response	Mexico	Bcf/d	Pipeline exports	0.01	0.01	0	0.01	0.05	0.15	0.35	0.58
S2: Market Response	Canada	Bcf/d	Pipeline exports	5.97	6.23	5.87	5.51	4.76	3.99	3.36	2.9
S2: Market Response	USA	Bcf/d	Pipeline exports	5.17	8.53	8.53	8.53	8.53	8.53	8.53	8.53
S2: Market Response		**Bcf/d**	**Total**	**50.07**	**54.11**	**48.21**	**47.06**	**46.94**	**50.82**	**55.66**	**61.63**
S2: Market Response	ROW	Bcf/d	Pipeline imports	1.01	1	0.83	0.91	0.88	0.8	0.78	0.93
S2: Market Response	Australia + NZ	Bcf/d	Pipeline imports	0	0	0	0	0	0	0	0
S2: Market Response	LAC	Bcf/d	Pipeline imports	2.15	2.11	1.82	1.79	1.61	1.3	1.12	1.1
S2: Market Response	Africa	Bcf/d	Pipeline imports	0.14	0.15	0.16	0.35	0.86	1.71	2.9	4.41
S2: Market Response	C Asia + East Eur	Bcf/d	Pipeline imports	5.58	5.37	5.09	5.13	5.2	5.4	6.06	6.92

S2: Market Response	Russia	Bcf/d	Pipeline imports	1.11	1.25	0.97	1.08	1.38	1.98	2.73	3.29
S2: Market Response	China	Bcf/d	Pipeline imports	2.29	3.7	5.93	7.54	11.09	15.91	21.06	25.44
S2: Market Response	India	Bcf/d	Pipeline imports	0	0	0	0	0	0	0	0
S2: Market Response	Middle East	Bcf/d	Pipeline imports	0.05	0.02	0.03	0.03	0.06	0.12	0.24	0.37
S2: Market Response	EU	Bcf/d	Pipeline imports	26.7	25.74	18.99	16.18	12.53	10.94	8.53	7.16
S2: Market Response	Mexico	Bcf/d	Pipeline imports	2.39	3.93	4.18	4.6	5.32	6.07	6.6	6.94
S2: Market Response	Canada	Bcf/d	Pipeline imports	2.06	2.35	1.66	1.72	1.67	1.69	1.62	1.47
S2: Market Response	USA	Bcf/d	Pipeline imports	7.74	8.48	8.56	7.73	6.35	4.91	4.02	3.59
S2: Market Response		**Bcf/d**	**Total**	**51.21**	**54.11**	**48.21**	**47.06**	**46.94**	**50.82**	**55.66**	**61.63**
S2 - S1	ROW	Bcf/d	Consumption	0	0	0	0	-0.14	0.95	1.53	1.84
S2 - S1	Australia + NZ	Bcf/d	Consumption	0	0	0	0	0	0.01	0.02	0.02
S2 - S1	LAC	Bcf/d	Consumption	0	0	0	0	-0.08	0.57	0.84	0.93
S2 - S1	Africa	Bcf/d	Consumption	0	0	0	0	-0.02	0.16	0.37	0.56
S2 - S1	C Asia + East Eur	Bcf/d	Consumption	0	0	0	0	-0.08	0.4	0.41	0.4
S2 - S1	Russia	Bcf/d	Consumption	0	0	0	0	-0.02	0.07	0.07	0.07
S2 - S1	China	Bcf/d	Consumption	0	0	0	0	-0.3	0.92	0.67	0.55
S2 - S1	India	Bcf/d	Consumption	0	0	0	0	-0.11	0.59	0.87	0.98
S2 - S1	Middle East	Bcf/d	Consumption	0	0	0	0	0.01	-0.04	-0.02	0.04
S2 - S1	EU	Bcf/d	Consumption	0	0	0	0	-0.46	1.75	1.56	1.49
S2 - S1	Mexico	Bcf/d	Consumption	0	0	0	0	0	-0.01	0.02	0.02
S2 - S1	Canada	Bcf/d	Consumption	0	0	0	0	0	0.01	0.1	0.13
S2 - S1	USA	Bcf/d	Consumption	0	0	0	0	0.06	-0.43	-1.19	-3.22

S2 - S1		**Bcf/d**	**Total**	**0**	**0**	**0**	**0**	**-1.13**	**4.96**	**5.24**	**3.82**
S2 - S1	ROW	Bcf/d	Production	0	0	0	0	-0.05	-0.23	-0.85	-1.03
S2 - S1	Australia + NZ	Bcf/d	Production	0	0	0	0	0	-0.03	-0.17	-0.35
S2 - S1	LAC	Bcf/d	Production	0	0	0	0	0.05	-0.39	-0.93	-1.22
S2 - S1	Africa	Bcf/d	Production	0	0	0	0	0.02	-0.47	-1.22	-1.61
S2 - S1	C Asia + East Eur	Bcf/d	Production	0	0	0	0	0.03	-0.26	-0.83	-1.28
S2 - S1	Russia	Bcf/d	Production	0	0	0	0	0.02	-0.44	-1.63	-2.22
S2 - S1	China	Bcf/d	Production	0	0	0	0	-0.05	0.14	-0.03	-0.09
S2 - S1	India	Bcf/d	Production	0	0	0	0	0.03	-0.12	-0.41	-0.63
S2 - S1	Middle East	Bcf/d	Production	0	0	0	0	0.01	-0.55	-1.7	-2.35
S2 - S1	EU	Bcf/d	Production	0	0	0	0	-0.15	0.61	-0.42	-0.88
S2 - S1	Mexico	Bcf/d	Production	0	0	0	0	0	-0.01	-0.05	-0.05
S2 - S1	Canada	Bcf/d	Production	0	0	0	0	-0.01	-0.09	-0.45	-0.6
S2 - S1	USA	Bcf/d	Production	0	0	0	0	-1.01	6.82	13.93	16.13
S2 - S1		**Bcf/d**	**Total**	**0**	**0**	**0**	**0**	**-1.13**	**4.97**	**5.24**	**3.82**
S2 - S1	ROW	Bcf/d	LNG exports	0	0	0	0	0.02	-0.16	-0.75	-1.02
S2 - S1	Australia + NZ	Bcf/d	LNG exports	0	0	0	0	0	-0.04	-0.18	-0.34
S2 - S1	LAC	Bcf/d	LNG exports	0	0	0	0	-0.01	-0.08	-0.37	-0.57
S2 - S1	Africa	Bcf/d	LNG exports	0	0	0	0	-0.01	-0.17	-0.72	-1.03
S2 - S1	C Asia + East Eur	Bcf/d	LNG exports	0	0	0	0	0	-0.08	-0.51	-0.93
S2 - S1	Russia	Bcf/d	LNG exports	0	0	0	0	0	-0.03	-0.19	-0.34
S2 - S1	China	Bcf/d	LNG exports	0	0	0	0	0	0	-0.02	-0.03

S2 - S1	India	Bcf/d	LNG exports	0	0	0	0	0	-0.01	-0.05	-0.09
S2 - S1	Middle East	Bcf/d	LNG exports	0	0	0	0	-0.04	-0.2	-1.19	-1.88
S2 - S1	EU	Bcf/d	LNG exports	0	0	0	0	0	-0.07	-0.38	-0.56
S2 - S1	Mexico	Bcf/d	LNG exports	0	0	0	0	0	-0.01	-0.03	-0.05
S2 - S1	Canada	Bcf/d	LNG exports	0	0	0	0	-0.01	-0.12	-0.58	-0.79
S2 - S1	USA	Bcf/d	LNG exports	0	0	0	0	-1.1	7.51	15.52	19.9
S2 - S1		**Bcf/d**	**Total**	**0**	**0**	**0**	**0**	**-1.15**	**6.53**	**10.55**	**12.25**
S2 - S1	ROW	Bcf/d	LNG imports	0	0	0	0	-0.16	0.99	1.62	1.87
S2 - S1	Australia + NZ	Bcf/d	LNG imports	0	0	0	0	0	0	0.01	0.03
S2 - S1	LAC	Bcf/d	LNG imports	0	0	0	0	-0.13	0.89	1.39	1.57
S2 - S1	Africa	Bcf/d	LNG imports	0	0	0	0	-0.06	0.46	0.87	1.14
S2 - S1	C Asia + East Eur	Bcf/d	LNG imports	0	0	0	0	-0.14	0.83	1.27	1.42
S2 - S1	Russia	Bcf/d	LNG imports	0	0	0	0	-0.06	0.35	0.59	0.65
S2 - S1	China	Bcf/d	LNG imports	0	0	0	0	-0.2	0.65	1.02	1.15
S2 - S1	India	Bcf/d	LNG imports	0	0	0	0	-0.13	0.7	1.23	1.52
S2 - S1	Middle East	Bcf/d	LNG imports	0	0	0	0	-0.04	0.33	0.54	0.58
S2 - S1	EU	Bcf/d	LNG imports	0	0	0	0	-0.21	1.09	1.6	1.81
S2 - S1	Mexico	Bcf/d	LNG imports	0	0	0	0	-0.02	0.13	0.25	0.33
S2 - S1	Canada	Bcf/d	LNG imports	0	0	0	0	0	0.06	0.1	0.11
S2 - S1	USA	Bcf/d	LNG imports	0	0	0	0	-0.01	0.05	0.06	0.07
S2 - S1		**Bcf/d**	**Total**	**0**	**0**	**0**	**0**	**-1.15**	**6.53**	**10.55**	**12.25**
S2 - S1	ROW	Bcf/d	Pipeline exports	0	0	0	0	-0.08	-0.03	-0.02	-0.03

S2 - S1	Australia + NZ	Bcf/d	Pipeline exports	0	0	0	0	0	0	0	0
S2 - S1	LAC	Bcf/d	Pipeline exports	0	0	0	0	0.01	-0.06	-0.1	-0.12
S2 - S1	Africa	Bcf/d	Pipeline exports	0	0	0	0	0	-0.1	-0.2	-0.28
S2 - S1	C Asia + East Eur	Bcf/d	Pipeline exports	0	0	0	0	0	0	0	0
S2 - S1	Russia	Bcf/d	Pipeline exports	0	0	0	0	-0.01	-0.26	-1.2	-1.62
S2 - S1	China	Bcf/d	Pipeline exports	0	0	0	0	0	0	0	0
S2 - S1	India	Bcf/d	Pipeline exports	0	0	0	0	0	0	0	0
S2 - S1	Middle East	Bcf/d	Pipeline exports	0	0	0	0	0	0	0	-0.01
S2 - S1	EU	Bcf/d	Pipeline exports	0	0	0	0	-0.02	0	-0.01	-0.01
S2 - S1	Mexico	Bcf/d	Pipeline exports	0	0	0	0	0	0	0	0.02
S2 - S1	Canada	Bcf/d	Pipeline exports	0	0	0	0	0	0.02	0.06	0.09
S2 - S1	USA	Bcf/d	Pipeline exports	0	0	0	0	0	0	0	0
S2 - S1		**Bcf/d**	**Total**	**0**	**0**	**0**	**0**	**-0.1**	**-0.43**	**-1.49**	**-1.95**
S2 - S1	ROW	Bcf/d	Pipeline imports	0	0	0	0	0	-0.01	-0.02	-0.05
S2 - S1	Australia + NZ	Bcf/d	Pipeline imports	0	0	0	0	0	0	0	0
S2 - S1	LAC	Bcf/d	Pipeline imports	0	0	0	0	0.01	-0.06	-0.1	-0.12
S2 - S1	Africa	Bcf/d	Pipeline imports	0	0	0	0	0.01	-0.11	-0.2	-0.28
S2 - S1	C Asia + East Eur	Bcf/d	Pipeline imports	0	0	0	0	0.03	-0.24	-0.54	-0.67
S2 - S1	Russia	Bcf/d	Pipeline imports	0	0	0	0	0.01	-0.14	-0.27	-0.32
S2 - S1	China	Bcf/d	Pipeline imports	0	0	0	0	-0.06	0.13	-0.34	-0.53
S2 - S1	India	Bcf/d	Pipeline imports	0	0	0	0	0	0	0	0
S2 - S1	Middle East	Bcf/d	Pipeline imports	0	0	0	0	0	-0.02	-0.05	-0.08

S2 - S1	EU	Bcf/d	Pipeline imports	0	0	0	0	-0.12	-0.02	-0.01	-0.01
S2 - S1	Mexico	Bcf/d	Pipeline imports	0	0	0	0	0.02	-0.13	-0.21	-0.29
S2 - S1	Canada	Bcf/d	Pipeline imports	0	0	0	0	0	-0.06	-0.08	-0.09
S2 - S1	USA	Bcf/d	Pipeline imports	0	0	0	0	-0.03	0.21	0.35	0.48
S2 - S1		**Bcf/d**	**Total**	**0**	**0**	**0**	**0**	**-0.1**	**-0.44**	**-1.49**	**-1.95**
S2 - S1	ROW	%	Consumption	0	0	0	0	-0.29	1.87	2.83	3.3
S2 - S1	Australia + NZ	%	Consumption	0	0	0	0	-0.47	1.88	2.45	1.6
S2 - S1	LAC	%	Consumption	0	0	0	0	-0.34	2.13	2.77	2.8
S2 - S1	Africa	%	Consumption	0	0	0	0	-0.07	0.6	1.12	1.36
S2 - S1	C Asia + East Eur	%	Consumption	0	0	0	0	-0.21	1.02	0.98	0.9
S2 - S1	Russia	%	Consumption	0	0	0	0	-0.05	0.17	0.17	0.17
S2 - S1	China	%	Consumption	0	0	0	0	-0.54	1.5	0.97	0.75
S2 - S1	India	%	Consumption	0	0	0	0	-0.47	2.06	2.5	2.39
S2 - S1	Middle East	%	Consumption	0	0	0	0	0.02	-0.06	-0.03	0.06
S2 - S1	EU	%	Consumption	0	0	0	0	-1.52	6.08	4.77	4.1
S2 - S1	Mexico	%	Consumption	0	0	0	0	0.03	-0.05	0.17	0.12
S2 - S1	Canada	%	Consumption	0	0	0	0	0.05	0.11	1.42	2.19
S2 - S1	USA	%	Consumption	0	0	0	0	0.07	-0.45	-1.11	-2.71
S2 - S1		**%**	**Total**	**0**	**0**	**0**	**0**	**-3.82**	**16.87**	**19**	**17.03**
S2 - S1	ROW	%	Production	0	0	0	0	-0.1	-0.49	-1.77	-2.11
S2 - S1	Australia + NZ	%	Production	0	0	0	0	-0.04	-0.34	-2.2	-5.37
S2 - S1	LAC	%	Production	0	0	0	0	0.26	-1.96	-4.11	-4.79
S2 - S1	Africa	%	Production	0	0	0	0	0.08	-1.29	-2.87	-3.34
S2 - S1	C Asia + East Eur	%	Production	0	0	0	0	0.12	-1.12	-3.1	-4.26
S2 - S1	Russia	%	Production	0	0	0	0	0.02	-0.66	-2.2	-2.76
S2 - S1	China	%	Production	0	0	0	0	-0.18	0.54	-0.12	-0.31
S2 - S1	India	%	Production	0	0	0	0	0.26	-0.91	-2.35	-2.83
S2 - S1	Middle East	%	Production	0	0	0	0	0.01	-0.75	-2.09	-2.67

S2 - S1	EU	%	Production	0	0	0	0	-1.54	5.92	-2.64	-4.21
S2 - S1	Mexico	%	Production	0	0	0	0	-0.05	-0.18	-0.85	-0.85
S2 - S1	Canada	%	Production	0	0	0	0	-0.07	-0.51	-2.47	-3.3
S2 - S1	USA	%	Production	0	0	0	0	-0.85	5.39	10.03	10.63
S2 - S1		**%**	**Total**	**0**	**0**	**0**	**0**	**-2.09**	**3.64**	**-16.74**	**-26.16**
S2 - S1	ROW	%	LNG exports	0	0	0	0	0.14	-1	-4.15	-5.33
S2 - S1	Australi a + NZ	%	LNG exports	0	0	0	0	-0.02	-0.47	-2.61	-6.07
S2 - S1	LAC	%	LNG exports	0	0	0	0	-0.24	-1.61	-5.96	-7.51
S2 - S1	Africa	%	LNG exports	0	0	0	0	-0.05	-1.27	-4.9	-6.77
S2 - S1	C Asia + East Eur	%	LNG exports	0	0	0	0	-0.46	-3.04	-10.47	-12.43
S2 - S1	Russia	%	LNG exports	0	0	0	0	0.02	-0.95	-5.7	-9.74
S2 - S1	China	%	LNG exports	0	0	0	0	0.2	-8.45	-16.08	-16.59
S2 - S1	India	%	LNG exports	0	0	0	0	0.16	-4.38	-12.25	-14.07
S2 - S1	Middle East	%	LNG exports	0	0	0	0	-0.23	-1.14	-5.83	-8.21
S2 - S1	EU	%	LNG exports	0	0	0	0	0.09	-4.42	-11.87	-12.53
S2 - S1	Mexico	%	LNG exports	0	0	0	0	0.03	-6.1	-14.35	-15.78
S2 - S1	Canada	%	LNG exports	0	0	0	0	-0.3	-1.63	-5.77	-7.1
S2 - S1	USA	%	LNG exports	0	0	0	0	-4.25	27.48	56.79	72.79
S2 - S1		**%**	**Total**	**0**	**0**	**0**	**0**	**-4.92**	**-6.98**	**-43.14**	**-49.33**
S2 - S1	ROW	%	LNG imports	0	0	0	0	-0.65	4.04	6.26	6.95
S2 - S1	Australi a + NZ	%	LNG imports	0	0	0	0	-0.64	3.37	70.21	15.85
S2 - S1	LAC	%	LNG imports	0	0	0	0	-1.48	7.7	10.18	10.32
S2 - S1	Africa	%	LNG imports	0	0	0	0	-1.85	10.71	14.26	13.55
S2 - S1	C Asia + East Eur	%	LNG imports	0	0	0	0	-1.24	6.58	9.33	9.98
S2 - S1	Russia	%	LNG imports	0	0	0	0	-3.2	13.55	18.83	19.62
S2 - S1	China	%	LNG imports	0	0	0	0	-1.03	3.28	5.13	5.77
S2 - S1	India	%	LNG imports	0	0	0	0	-1.01	4.59	7.08	7.81
S2 - S1	Middle East	%	LNG imports	0	0	0	0	-3.4	21.78	25.32	22.96
S2 - S1	EU	%	LNG imports	0	0	0	0	-2.16	10.64	13.33	13.73
S2 - S1	Mexico	%	LNG imports	0	0	0	0	-1.21	7.78	14.18	16.8
S2 - S1	Canada	%	LNG imports	0	0	0	0	-0.55	31.63	41.39	42.83

S2 - S1	USA	%	LNG imports	0	0	0	0	-5.71	56.24	59.76	64.41
S2 - S1		**%**	**Total**	**0**	**0**	**0**	**0**	**-24.14**	**181.9**	**295.25**	**250.58**
S2 - S1	ROW	%	Pipeline exports	0	0	0	0	-1.28	-0.66	-0.93	-1.65
S2 - S1	Australia + NZ	%	Pipeline exports	0	0	0	0	0.05	-0.47	-1.41	-3.03
S2 - S1	LAC	%	Pipeline exports	0	0	0	0	0.61	-4.2	-8.18	-10.12
S2 - S1	Africa	%	Pipeline exports	0	0	0	0	0.07	-4.41	-6.05	-5.78
S2 - S1	C Asia + East Eur	%	Pipeline exports	0	0	0	0	-1.6	1.1	1.82	-0.02
S2 - S1	Russia	%	Pipeline exports	0	0	0	0	-0.05	-0.9	-3.23	-3.69
S2 - S1	China	%	Pipeline exports	0	0	0	0	2.5	-12.35	-15.31	-13.59
S2 - S1	India	%	Pipeline exports	0	0	0	0	2.25	-12.61	-15.36	-12.63
S2 - S1	Middle East	%	Pipeline exports	0	0	0	0	0.17	-4.45	-7.12	-8.16
S2 - S1	EU	%	Pipeline exports	0	0	0	0	-1.57	-0.46	-2.37	-3.96
S2 - S1	Mexico	%	Pipeline exports	0	0	0	0	-0.36	1.38	-0.44	3.13
S2 - S1	Canada	%	Pipeline exports	0	0	0	0	-0.02	0.56	1.67	3.14
S2 - S1	USA	%	Pipeline exports	0	0	0	0	0	0.05	0	0
S2 - S1		**%**	**Total**	**0**	**0**	**0**	**0**	**0.76**	**-37.41**	**-56.92**	**-56.36**
S2 - S1	ROW	%	Pipeline imports	0	0	0	0	0.34	-0.89	-2.63	-4.73
S2 - S1	Australia + NZ	%	Pipeline imports	0	0	0	0	-0.47	1.76	5.62	-8.96
S2 - S1	LAC	%	Pipeline imports	0	0	0	0	0.61	-4.2	-8.18	-10.12
S2 - S1	Africa	%	Pipeline imports	0	0	0	0	1.67	-5.81	-6.59	-5.94
S2 - S1	C Asia + East Eur	%	Pipeline imports	0	0	0	0	0.59	-4.29	-8.18	-8.81
S2 - S1	Russia	%	Pipeline imports	0	0	0	0	0.96	-6.5	-9.04	-8.93
S2 - S1	China	%	Pipeline imports	0	0	0	0	-0.5	0.84	-1.58	-2.05

S2 - S1	India	%	Pipeline imports	0	0	0	0	0.69	-1.85	-4.13	-5.15
S2 - S1	Middle East	%	Pipeline imports	0	0	0	0	2.49	-16.6	-18.59	-16.85
S2 - S1	EU	%	Pipeline imports	0	0	0	0	-0.92	-0.19	-0.14	-0.16
S2 - S1	Mexico	%	Pipeline imports	0	0	0	0	0.45	-2.11	-3.12	-4.02
S2 - S1	Canada	%	Pipeline imports	0	0	0	0	0.09	-3.43	-4.69	-5.58
S2 - S1	USA	%	Pipeline imports	0	0	0	0	-0.42	4.5	9.43	15.55
S2 - S1		**%**	**Total**	**0**	**0**	**0**	**0**	**5.6**	**-38.77**	**-51.84**	**-65.75**

Table D-3. Global primary energy consumption by fuel under S2 and S1 (Figure 6) and changes in S2 relative to S1

Scenario	**Fuel**	**Units**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
S1: Reference Exports	biomass	EJ	30.07	32.44	48.96	58.95	69.5	79.75	89.4	95.84
S1: Reference Exports	biomass CCS	EJ	0	0	5.66	9.4	13.7	20.24	29.79	39.58
S1: Reference Exports	coal	EJ	165.11	177.1	165.33	171.07	169.73	166.82	161.18	153.04
S1: Reference Exports	coal CCS	EJ	0	0	1.33	2.61	3.94	5.36	7.04	8.96
S1: Reference Exports	gas	EJ	126.84	141.53	133.91	142.14	148.85	157.25	171.51	184.76
S1: Reference Exports	gas CCS	EJ	0	0	3.39	6.49	9.74	12.7	15.18	17.7
S1: Reference Exports	nuclear	EJ	9.67	10.1	11.77	13.05	14.62	16.48	18.47	20.48
S1: Reference Exports	oil	EJ	189	192.82	192.8	193.97	193.85	191.61	185.81	179.87
S1: Reference Exports	oil CCS	EJ	0	0	1.13	2.41	3.86	4.9	5.4	5.97
S1: Reference Exports	other renewables	EJ	18.54	24.1	35.17	47.32	59.56	72.42	85.71	99.96
S1: Reference Exports	**Total**	**EJ**	**520.69**	**553.99**	**564.28**	**600.09**	**627.79**	**655.11**	**683.78**	**706.2**
S2: Market Response	biomass	EJ	30.07	32.44	48.96	58.95	69.66	79.06	88.77	95.48
S2: Market Response	biomass CCS	EJ	0	0	5.66	9.4	13.68	20.32	29.96	39.77
S2: Market Response	coal	EJ	165.11	177.1	165.33	171.07	169.88	166.22	160.57	152.42
S2: Market Response	coal CCS	EJ	0	0	1.33	2.61	3.93	5.37	7.04	8.95
S2: Market Response	gas	EJ	126.84	141.53	133.91	142.14	148.46	158.95	173.26	185.96
S2: Market Response	gas CCS	EJ	0	0	3.39	6.49	9.72	12.83	15.38	17.96
S2: Market Response	nuclear	EJ	9.67	10.1	11.77	13.05	14.62	16.47	18.45	20.45
S2: Market Response	oil	EJ	189	192.82	192.8	193.97	193.91	191.29	185.45	179.6

S2: Market Response	oil CCS	EJ	0	0	1.13	2.41	3.86	4.91	5.39	5.96
S2: Market Response	other renewables	EJ	18.54	24.1	35.17	47.32	59.57	72.34	85.59	99.86
S2: Market Response	**Total**	**EJ**	**509.16**	**545.65**	**550.49**	**588.46**	**617.63**	**648.7**	**681.09**	**710.93**
S2 - S1	biomass	EJ	0	0	0	0	0.16	-0.69	-0.63	-0.36
S2 - S1	biomass CCS	EJ	0	0	0	0	-0.02	0.08	0.17	0.19
S2 - S1	coal	EJ	0	0	0	0	0.15	-0.6	-0.61	-0.62
S2 - S1	coal CCS	EJ	0	0	0	0	-0.01	0.01	0	-0.01
S2 - S1	gas	EJ	0	0	0	0	-0.39	1.7	1.75	1.2
S2 - S1	gas CCS	EJ	0	0	0	0	-0.02	0.13	0.2	0.26
S2 - S1	nuclear	EJ	0	0	0	0	0	-0.01	-0.02	-0.03
S2 - S1	oil	EJ	0	0	0	0	0.06	-0.32	-0.36	-0.27
S2 - S1	oil CCS	EJ	0	0	0	0	0	0.01	-0.01	-0.01
S2 - S1	**Total**	**EJ**	**0**	**0**	**0**	**0**	**0.01**	**-0.08**	**-0.12**	**-0.1**
S2 - S1	biomass	%	0	0	0	0	0.00	-0.01	-0.01	0.00
S2 - S1	biomass CCS	%	0	0	0	0	0.00	0.00	0.01	0.00
S2 - S1	coal	%	0	0	0	0	0.00	0.00	0.00	0.00
S2 - S1	coal CCS	%	0	0	0	0	0.00	0.00	0.00	0.00
S2 - S1	gas	%	0	0	0	0	0.00	0.01	0.01	0.01
S2 - S1	gas CCS	%	0	0	0	0	0.00	0.01	0.01	0.01
S2 - S1	nuclear	%	0	0	0	0	0.00	0.00	0.00	0.00
S2 - S1	oil	%	0	0	0	0	0.00	0.00	0.00	0.00
S2 - S1	oil CCS	%	0	0	0	0	0.00	0.00	0.00	0.00
S2 - S1	**Total**	**%**	**0**	**0**	**0**	**0**	**0.00**	**0.00**	**0.00**	**0.00**

Table D-4. GHG emissions by sector under S2 and S1 (Figure 6) and changes in S2 relative to S1

Scenario	**Sector**	**Unit**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
S1: Reference Exports	CO2 buildings	Gt CO2e	2.84	2.92	2.56	2.63	2.63	2.61	2.59	2.54
S1: Reference Exports	CO2 electricity	Gt CO2e	12.64	13.02	12.06	12.81	13.26	13.46	13.39	13.04
S1: Reference Exports	CO2 industry	Gt CO2e	11.75	12.98	12.68	12.65	12.14	11.66	11.32	11.04
S1: Reference Exports	CO2 other energy	Gt CO2e	0.51	1.23	1.09	1.31	1.43	1.51	1.57	1.6
S1: Reference Exports	CO2 transport	Gt CO2e	7.89	8.24	8.06	7.87	7.58	7.31	7.16	7.04
S1: Reference Exports	CH4 Energy	Gt CO2e	5.43	5.6	4.71	4.85	4.84	4.73	4.78	4.8
S1: Reference Exports	CH4 AgLanduse	Gt CO2e	3.36	3.61	3.69	3.98	4.25	4.5	4.75	4.97

S1: Reference Exports	N2O Energy	Gt CO2e	0.96	0.97	0.93	0.96	0.92	0.86	0.87	0.88
S1: Reference Exports	N2O AgLanduse	Gt CO2e	2.17	2.32	2.48	2.65	2.79	2.93	3.1	3.28
S1: Reference Exports	F-gases	Gt CO2e	1.01	1.33	1.41	1.69	1.76	1.74	1.68	1.66
S1: Reference Exports	CO2 bioenergy	Gt CO2e	0	0	-0.34	-0.54	-0.74	-1	-1.33	-1.68
S1: Reference Exports	CO2 direct air capture	Gt CO2e	0	0	0	0	-0.01	-0.01	0	0
S1: Reference Exports	CO2 LUC	Gt CO2e	3.04	0.42	0.73	-3.08	-1.75	-1.79	-1.57	-1.42
S1: Reference Exports	**Total**	**Gt CO2e**	**51.6**	**52.64**	**50.06**	**47.78**	**49.1**	**48.51**	**48.31**	**47.75**
S2: Market Response	CO2 buildings	Gt CO2e	2.84	2.92	2.56	2.63	2.62	2.63	2.6	2.54
S2: Market Response	CO2 electricity	Gt CO2e	12.64	13.02	12.06	12.81	13.27	13.45	13.39	13.02
S2: Market Response	CO2 industry	Gt CO2e	11.75	12.98	12.68	12.65	12.14	11.66	11.32	11.04
S2: Market Response	CO2 other energy	Gt CO2e	0.51	1.23	1.09	1.31	1.43	1.51	1.57	1.6
S2: Market Response	CO2 transport	Gt CO2e	7.89	8.24	8.06	7.87	7.58	7.31	7.15	7.03
S2: Market Response	CH4 Energy	Gt CO2e	5.43	5.6	4.71	4.85	4.84	4.73	4.77	4.79
S2: Market Response	CH4 AgLanduse	Gt CO2e	3.36	3.61	3.69	3.98	4.25	4.49	4.74	4.97
S2: Market Response	N2O Energy	Gt CO2e	0.96	0.97	0.93	0.96	0.92	0.86	0.87	0.88
S2: Market Response	N2O AgLanduse	Gt CO2e	2.17	2.32	2.48	2.65	2.79	2.93	3.1	3.28
S2: Market Response	F-gases	Gt CO2e	1.01	1.33	1.41	1.69	1.76	1.74	1.68	1.67
S2: Market Response	CO2 bioenergy	Gt CO2e	0	0	-0.34	-0.54	-0.74	-1	-1.34	-1.69
S2: Market Response	CO2 direct air capture	Gt CO2e	0	0	0	0	-0.01	-0.01	0	0
S2: Market Response	CO2 LUC	Gt CO2e	3.04	0.42	0.73	-3.08	-1.72	-2.09	-1.61	-1.39
S2: Market Response	**Total**	**Gt CO2e**	**51.6**	**52.64**	**50.06**	**47.78**	**49.13**	**48.21**	**48.24**	**47.74**
S2 - S1	CO2 buildings	Gt CO2e	0	0	0	0	0	0.01	0.01	0.01
S2 - S1	CO2 electricity	Gt CO2e	0	0	0	0	0	-0.01	0	-0.02
S2 - S1	CO2 industry	Gt CO2e	0	0	0	0	0	0	0	-0.01
S2 - S1	CO2 other energy	Gt CO2e	0	0	0	0	0	0	0	0
S2 - S1	CO2 transport	Gt CO2e	0	0	0	0	0	0	-0.01	-0.01
S2 - S1	CH4 Energy	Gt CO2e	0	0	0	0	0	0	-0.01	-0.01
S2 - S1	CH4 AgLanduse	Gt CO2e	0	0	0	0	0	0	0	0
S2 - S1	N2O Energy	Gt CO2e	0	0	0	0	0	0	0	0
S2 - S1	N2O AgLanduse	Gt CO2e	0	0	0	0	0	0	0	0
S2 - S1	F-gases	Gt CO2e	0	0	0	0	0	0	0	0
S2 - S1	CO2 bioenergy	Gt CO2e	0	0	0	0	0	-0.01	-0.01	-0.01
S2 - S1	CO2 direct air capture	Gt CO2e	0	0	0	0	0	0	0	0

S2 - S1	CO2 LUC	Gt CO2e	0	0	0	0	0.03	-0.3	-0.04	0.03
S2 - S1	**Total**	**Gt CO2e**	**0**	**0**	**0**	**0**	**0.03**	**-0.31**	**-0.06**	**-0.02**
S2 - S1	CO2 buildings	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S2 - S1	CO2 electricity	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S2 - S1	CO2 industry	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S2 - S1	CO2 other energy	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S2 - S1	CO2 transport	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S2 - S1	CH4 Energy	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S2 - S1	CH4 AgLanduse	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S2 - S1	N2O Energy	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S2 - S1	N2O AgLanduse	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S2 - S1	F-gases	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S2 - S1	CO2 bioenergy	%	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01
S2 - S1	CO2 direct air capture	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S2 - S1	CO2 LUC	%	0.00	0.00	0.00	0.00	-0.02	0.17	0.03	-0.02
S2 - S1	**Total**	**%**	**0.00**	**0.00**	**0.00**	**0.00**	**-0.02**	**0.18**	**0.03**	**-0.02**

Table D-5. Global primary energy consumption by fuel under S6 and S7 (Figure 7) and changes in S7 relative to S6

Scenario	**Fuel**	**Units**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
S6: Energy Transition (Ref Exp)	biomass	EJ	30.06	32.44	49.56	60.69	69.95	65.82	52.85	35.59
S6: Energy Transition (Ref Exp)	biomass CCS	EJ	0	0	7.58	14.81	40.26	66.29	89.57	108.7
S6: Energy Transition (Ref Exp)	coal	EJ	165.11	177.09	159.14	161.43	133.25	103.67	70.56	44.43
S6: Energy Transition (Ref Exp)	coal CCS	EJ	0	0	1.7	3.45	8.16	16.42	26.45	35.07
S6: Energy Transition (Ref Exp)	gas	EJ	126.83	141.49	130.11	131.75	125.14	122.27	113.86	95.07
S6: Energy Transition (Ref Exp)	gas CCS	EJ	0	0	3.73	8.48	18.61	29.78	41.85	58.07
S6: Energy Transition (Ref Exp)	nuclear	EJ	9.67	10.1	11.98	13.55	16.43	21.14	27.44	34.96
S6: Energy Transition (Ref Exp)	oil	EJ	189	192.9	191.77	192.33	184.43	174.89	161.68	144.79

S6: Energy Transition (Ref Exp)	oil CCS	EJ	0	0	1.26	2.78	6.09	8.92	11.77	16.07
S6: Energy Transition (Ref Exp)	other renewables	EJ	18.54	24.1	36.56	49.97	67.18	87.31	112.36	142.92
S6: Energy Transition (Ref Exp)	**Total**	**EJ**	**539.21**	**578.12**	**593.39**	**639.24**	**669.5**	**696.51**	**708.39**	**715.67**
S7: Energy Transition	biomass	EJ	30.06	32.44	49.56	60.69	69.95	65.82	52.71	35.54
S7: Energy Transition	biomass CCS	EJ	0	0	7.58	14.81	40.26	66.29	89.62	108.7
S7: Energy Transition	coal	EJ	165.11	177.09	159.14	161.43	133.25	103.67	70.47	44.39
S7: Energy Transition	coal CCS	EJ	0	0	1.7	3.45	8.16	16.42	26.44	35.03
S7: Energy Transition	gas	EJ	126.83	141.49	130.11	131.76	125.14	122.27	114.19	95.24
S7: Energy Transition	gas CCS	EJ	0	0	3.73	8.48	18.61	29.78	42.08	58.41
S7: Energy Transition	nuclear	EJ	9.67	10.1	11.98	13.55	16.43	21.14	27.43	34.94
S7: Energy Transition	oil	EJ	189	192.9	191.77	192.33	184.43	174.89	161.59	144.71
S7: Energy Transition	oil CCS	EJ	0	0	1.26	2.78	6.09	8.92	11.75	16.04
S7: Energy Transition	other renewables	EJ	18.54	24.1	36.56	49.97	67.18	87.31	112.33	142.87
S7: Energy Transition	**Total**	**EJ**	**539.21**	**578.12**	**593.39**	**639.25**	**669.5**	**696.51**	**708.61**	**715.87**
S7 - S6	biomass	EJ	0	0	0	0	0	0	-0.13	-0.06
S7 - S6	biomass CCS	EJ	0	0	0	0	0	0	0.05	0
S7 - S6	coal	EJ	0	0	0	0	0	0	-0.09	-0.04
S7 - S6	coal CCS	EJ	0	0	0	0	0	0	-0.01	-0.05
S7 - S6	gas	EJ	0	0	0	0	0	0	0.34	0.17
S7 - S6	gas CCS	EJ	0	0	0	0	0	0	0.23	0.34
S7 - S6	nuclear	EJ	0	0	0	0	0	0	-0.01	-0.03
S7 - S6	oil	EJ	0	0	0	0	0	0	-0.1	-0.08
S7 - S6	oil CCS	EJ	0	0	0	0	0	0	-0.01	-0.03
S7 - S6	other renewables	EJ	0	0	0	0	0	0	-0.03	-0.05
S7 - S6	**Total**	**EJ**	**0**	**0**	**0**	**0**	**0**	**0**	**0.24**	**0.17**
S7 - S6	biomass	%	0	0	0	0	0	0	-0.002	-0.002
S7 - S6	biomass CCS	%	0	0	0	0	0	0	0.001	0.000
S7 - S6	coal	%	0	0	0	0	0	0	-0.001	-0.001
S7 - S6	coal CCS	%	0	0	0	0	0	0	0.000	-0.001

S7 - S6	gas	%	0	0	0	0	0	0	0.003	0.002
S7 - S6	gas CCS	%	0	0	0	0	0	0	0.005	0.006
S7 - S6	nuclear	%	0	0	0	0	0	0	0.000	-0.001
S7 - S6	oil	%	0	0	0	0	0	0	-0.001	-0.001
S7 - S6	oil CCS	%	0	0	0	0	0	0	-0.001	-0.002
S7 - S6	other renewables	%	0	0	0	0	0	0	0.000	0.000
S7 - S6	**Total**	**%**	**0**	**0**	**0**	**0**	**0**	**0**	**0.000**	**0.000**

Table D-6. GHG emissions by sector under S7 and S6 (Figure 7) and changes in S7 relative to S6

Scenario	**Sector**	**Unit**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
S6: Energy Transition (Ref Exp)	CO2 buildings	Gt CO2e	2.84	2.92	2.46	2.47	2.09	1.94	1.67	1.12
S6: Energy Transition (Ref Exp)	CO2 electricity	Gt CO2e	12.64	13.02	11.54	11.81	10.02	7.56	4.53	2.16
S6: Energy Transition (Ref Exp)	CO2 industry	Gt CO2e	11.75	12.98	12.46	12.27	10.42	8.83	7.58	6.47
S6: Energy Transition (Ref Exp)	CO2 other energy	Gt CO2e	0.51	1.23	1.06	1.27	1.11	1.08	1.04	0.95
S6: Energy Transition (Ref Exp)	CO2 transport	Gt CO2e	7.89	8.24	7.99	7.74	7.11	6.51	5.9	5
S6: Energy Transition (Ref Exp)	CH4 Energy	Gt CO2e	5.43	5.6	4.55	4.65	4.32	4	3.56	3.25
S6: Energy Transition (Ref Exp)	CH4 AgLanduse	Gt CO2e	3.36	3.61	3.68	3.95	4.14	4.33	4.51	4.69
S6: Energy Transition (Ref Exp)	N2O Energy	Gt CO2e	0.96	0.97	0.9	0.92	0.82	0.74	0.66	0.59
S6: Energy Transition (Ref Exp)	N2O AgLanduse	Gt CO2e	2.17	2.32	2.43	2.59	2.74	2.86	2.96	3.03
S6: Energy Transition (Ref Exp)	F-gases	Gt CO2e	1.01	1.33	1.37	1.62	1.58	1.5	1.23	1.07
S6: Energy Transition (Ref Exp)	CO2 bioenergy	Gt CO2e	0	0	-0.46	-0.9	-2.46	-4.02	-5.35	-6.81
S6: Energy Transition (Ref Exp)	CO2 direct air capture	Gt CO2e	0	0	0	-0.04	-0.28	-0.42	-0.44	-0.47
S6: Energy Transition (Ref Exp)	CO2 LUC	Gt CO2e	3.04	0.56	0.82	-3.26	-2.38	-2.84	-3.12	-3.92
S6: Energy Transition (Ref Exp)	**Total**	**Gt CO2e**	**51.6**	**52.78**	**48.8**	**45.09**	**39.23**	**32.07**	**24.73**	**17.13**
S7: Energy Transition	CO2 buildings	Gt CO2e	2.84	2.92	2.46	2.47	2.09	1.94	1.68	1.12

S7: Energy Transition	CO2 electricity	Gt CO2e	12.64	13.02	11.54	11.81	10.02	7.56	4.53	2.16
S7: Energy Transition	CO2 industry	Gt CO2e	11.75	12.98	12.46	12.27	10.42	8.83	7.58	6.47
S7: Energy Transition	CO2 other energy	Gt CO2e	0.51	1.23	1.06	1.27	1.11	1.08	1.04	0.95
S7: Energy Transition	CO2 transport	Gt CO2e	7.89	8.24	7.99	7.74	7.11	6.51	5.9	5
S7: Energy Transition	CH4 Energy	Gt CO2e	5.43	5.6	4.55	4.65	4.32	4	3.56	3.24
S7: Energy Transition	CH4 AgLanduse	Gt CO2e	3.36	3.61	3.68	3.95	4.14	4.33	4.51	4.69
S7: Energy Transition	N2O Energy	Gt CO2e	0.96	0.97	0.9	0.92	0.82	0.74	0.66	0.59
S7: Energy Transition	N2O AgLanduse	Gt CO2e	2.17	2.32	2.43	2.59	2.74	2.86	2.96	3.03
S7: Energy Transition	F-gases	Gt CO2e	1.01	1.33	1.37	1.62	1.58	1.5	1.23	1.07
S7: Energy Transition	CO2 bioenergy	Gt CO2e	0	0	-0.46	-0.9	-2.46	-4.02	-5.36	-6.81
S7: Energy Transition	CO2 direct air capture	Gt CO2e	0	0	0	-0.04	-0.28	-0.42	-0.44	-0.47
S7: Energy Transition	CO2 LUC	Gt CO2e	3.04	0.56	0.82	-3.26	-2.38	-2.84	-3.13	-3.92
S7: Energy Transition	**Total**	**Gt CO2e**	**51.6**	**52.78**	**48.8**	**45.09**	**39.23**	**32.07**	**24.72**	**17.12**
Delta S7 - S6	CO2 buildings	Gt CO2e	0	0	0	0	0	0	0	0
Delta S7 - S6	CO2 electricity	Gt CO2e	0	0	0	0	0	0	0	0
Delta S7 - S6	CO2 industry	Gt CO2e	0	0	0	0	0	0	0	0
Delta S7 - S6	CO2 other energy	Gt CO2e	0	0	0	0	0	0	0	0
Delta S7 - S6	CO2 transport	Gt CO2e	0	0	0	0	0	0	0	0
Delta S7 - S6	CH4 Energy	Gt CO2e	0	0	0	0	0	0	0	-0.01
Delta S7 - S6	CH4 AgLanduse	Gt CO2e	0	0	0	0	0	0	0	0
Delta S7 - S6	N2O Energy	Gt CO2e	0	0	0	0	0	0	0	0
Delta S7 - S6	N2O AgLanduse	Gt CO2e	0	0	0	0	0	0	0	0

Delta S7 - S6	F-gases	Gt CO2e	0	0	0	0	0	0	0	0
Delta S7 - S6	CO2 bioenergy	Gt CO2e	0	0	0	0	0	0	0	0
Delta S7 - S6	CO2 direct air capture	Gt CO2e	0	0	0	0	0	0	0	0
Delta S7 - S6	CO2 LUC	Gt CO2e	0	0	0	0	0	0	-0.01	0
Delta S7 - S6	**Total**	**Gt CO2e**	**0**	**0**	**0**	**0**	**0**	**0**	**-0.01**	**-0.01**
Delta S7 - S6	CO2 buildings	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Delta S7 - S6	CO2 electricity	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Delta S7 - S6	CO2 industry	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Delta S7 - S6	CO2 other energy	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Delta S7 - S6	CO2 transport	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Delta S7 - S6	CH4 Energy	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Delta S7 - S6	CH4 AgLanduse	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Delta S7 - S6	N2O Energy	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Delta S7 - S6	N2O AgLanduse	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Delta S7 - S6	F-gases	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Delta S7 - S6	CO2 bioenergy	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Delta S7 - S6	CO2 direct air capture	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Delta S7 - S6	CO2 LUC	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Delta S7 - S6	**Total**	**%**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Table D-7. Changes in global primary energy consumption under S6 and S7 relative to S1 and S2 respectively (Figure 8)

Scenario	Fuel	Units	2015	2020	2025	2030	2035	2040	2045	2050
S6 - S1	biomass	EJ	0	0	0.6	1.73	0.46	-13.94	-36.55	-60.25
S6 - S1	biomass CCS	EJ	0	0	1.92	5.41	26.55	46.05	59.78	69.12
S6 - S1	coal	EJ	0	-0.01	-6.19	-9.64	-36.48	-63.15	-90.63	-108.6
S6 - S1	coal CCS	EJ	0	0	0.38	0.84	4.22	11.06	19.41	26.11
S6 - S1	gas	EJ	0	-0.05	-3.8	-10.39	-23.71	-34.98	-57.65	-89.7
S6 - S1	gas CCS	EJ	0	0	0.34	1.99	8.87	17.07	26.67	40.37
S6 - S1	nuclear	EJ	0	0	0.21	0.49	1.81	4.66	8.97	14.48
S6 - S1	oil	EJ	0	0.07	-1.02	-1.63	-9.42	-16.72	-24.13	-35.08
S6 - S1	oil CCS	EJ	0	0	0.13	0.38	2.23	4.01	6.37	10.1
S6 - S1	other renewables	EJ	0	0	1.39	2.64	7.62	14.89	26.65	42.95
S6 - S1	**Total**	**EJ**	**0**	**0.01**	**-6.04**	**-8.18**	**-17.85**	**-31.05**	**-61.11**	**-90.51**

S7 - S2	biomass	EJ	0	0	0.6	1.73	0.3	-13.24	-36.06	-59.95
S7 - S2	biomass CCS	EJ	0	0	1.92	5.41	26.57	45.97	59.66	68.94
S7 - S2	coal	EJ	0	-0.01	-6.19	-9.64	-36.63	-62.55	-90.1	-108
S7 - S2	coal CCS	EJ	0	0	0.38	0.84	4.22	11.05	19.4	26.08
S7 - S2	gas	EJ	0	-0.05	-3.8	-10.39	-23.32	-36.68	-59.07	-90.72
S7 - S2	gas CCS	EJ	0	0	0.34	1.99	8.9	16.94	26.7	40.46
S7 - S2	nuclear	EJ	0	0	0.21	0.49	1.81	4.67	8.98	14.49
S7 - S2	oil	EJ	0	0.07	-1.02	-1.63	-9.48	-16.4	-23.86	-34.89
S7 - S2	oil CCS	EJ	0	0	0.13	0.38	2.23	4	6.36	10.09
S7 - S2	other renewables	EJ	0	0	1.39	2.64	7.61	14.97	26.74	43.01
S7 - S2	**Total**	**EJ**	**0**	**0.01**	**-6.04**	**-8.18**	**-17.79**	**-31.27**	**-61.25**	**-90.52**
S6 - S1	biomass	%	0.00	0.00	1.23	2.93	0.66	-17.48	-40.88	-62.87
S6 - S1	biomass CCS	%	0.00	0.00	33.92	57.55	193.80	227.52	200.67	174.63
S6 - S1	coal	%	0.00	-0.01	-3.74	-5.64	-21.49	-37.86	-56.23	-70.97
S6 - S1	coal CCS	%	0.00	0.00	28.57	32.18	107.11	206.34	275.71	291.41
S6 - S1	gas	%	0.00	-0.04	-2.84	-7.31	-15.93	-22.24	-33.61	-48.55
S6 - S1	gas CCS	%	0.00	0.00	10.03	30.66	91.07	134.41	175.69	228.08
S6 - S1	nuclear	%	0.00	0.00	1.78	3.75	12.38	28.28	48.57	70.70
S6 - S1	oil	%	0.00	0.04	-0.53	-0.84	-4.86	-8.73	-12.99	-19.50
S6 - S1	oil CCS	%	0.00	0.00	11.50	15.77	57.77	81.84	117.96	169.18
S6 - S1	other renewables	%	0.00	0.00	3.95	5.58	12.79	20.56	31.09	42.97
S6 - S1	**Total**	**%**	**0.00**	**0.00**	**-1.07**	**-1.36**	**-2.84**	**-4.74**	**-8.94**	**-12.82**
S7 - S2	biomass	%	0.00	0.00	1.23	2.93	0.43	-16.75	-40.62	-62.79
S7 - S2	biomass CCS	%	0.00	0.00	33.92	57.55	194.23	226.23	199.13	173.35
S7 - S2	coal	%	0.00	-0.01	-3.74	-5.64	-21.56	-37.63	-56.11	-70.88
S7 - S2	coal CCS	%	0.00	0.00	28.57	32.18	107.38	205.77	275.57	291.40
S7 - S2	gas	%	0.00	-0.04	-2.84	-7.31	-15.71	-23.08	-34.09	-48.78
S7 - S2	gas CCS	%	0.00	0.00	10.03	30.66	91.56	132.03	173.60	225.28
S7 - S2	nuclear	%	0.00	0.00	1.78	3.75	12.38	28.35	48.67	70.86
S7 - S2	oil	%	0.00	0.04	-0.53	-0.84	-4.89	-8.57	-12.87	-19.43
S7 - S2	oil CCS	%	0.00	0.00	11.50	15.77	57.77	81.47	118.00	169.30
S7 - S2	other renewables	%	0.00	0.00	3.95	5.58	12.77	20.69	31.24	43.07
S7 - S2	**Total**	**%**	**0.00**	**0.00**	**-1.10**	**-1.39**	**-2.88**	**-4.82**	**-8.99**	**-12.73**

Table D-8. Changes in global GHG emissions by sector under S6 and S7 relative to S1 and S2 respectively (Figure 8)

Scenario	Sector	Units	2015	2020	2025	2030	2035	2040	2045	2050
S6 - S1	CO2 buildings	Gt CO2e	0	0	-0.1	-0.16	-0.54	-0.67	-0.91	-1.42
S6 - S1	CO2 electricity	Gt CO2e	0	0	-0.52	-1	-3.25	-5.9	-8.86	-10.88

S6 - S1	CO2 industry	Gt CO2e	0	0	-0.22	-0.38	-1.71	-2.83	-3.75	-4.57
S6 - S1	CO2 other energy	Gt CO2e	0	0	-0.03	-0.05	-0.32	-0.43	-0.53	-0.65
S6 - S1	CO2 transport	Gt CO2e	0	0	-0.08	-0.13	-0.47	-0.8	-1.26	-2.03
S6 - S1	CH4 Energy	Gt CO2e	0	0	-0.16	-0.2	-0.52	-0.73	-1.21	-1.55
S6 - S1	CH4 AgLanduse	Gt CO2e	0	0	-0.01	-0.02	-0.11	-0.17	-0.24	-0.28
S6 - S1	N2O Energy	Gt CO2e	0	0	-0.03	-0.03	-0.1	-0.12	-0.21	-0.29
S6 - S1	N2O AgLanduse	Gt CO2e	0	0	-0.05	-0.06	-0.05	-0.06	-0.14	-0.25
S6 - S1	F-gases	Gt CO2e	0	0	-0.04	-0.07	-0.18	-0.23	-0.45	-0.59
S6 - S1	CO2 bioenergy	Gt CO2e	0	0	-0.12	-0.36	-1.71	-3.02	-4.02	-5.12
S6 - S1	CO2 direct air capture	Gt CO2e	0	0	0	-0.03	-0.27	-0.41	-0.44	-0.47
S6 - S1	CO2 LUC	Gt CO2e	0	0.14	0.09	-0.17	-0.62	-1.05	-1.55	-2.5
S6 - S1	**Total**	**Gt CO2e**	**0**	**0.14**	**-1.27**	**-2.66**	**-9.85**	**-16.4**	**-23.6**	**-30.6**
S7 - S2	CO2 buildings	Gt CO2e	0	0	-0.1	-0.16	-0.53	-0.68	-0.92	-1.43
S7 - S2	CO2 electricity	Gt CO2e	0	0	-0.52	-1	-3.25	-5.89	-8.85	-10.86
S7 - S2	CO2 industry	Gt CO2e	0	0	-0.22	-0.38	-1.71	-2.83	-3.74	-4.56
S7 - S2	CO2 other energy	Gt CO2e	0	0	-0.03	-0.05	-0.32	-0.43	-0.53	-0.65
S7 - S2	CO2 transport	Gt CO2e	0	0	-0.08	-0.13	-0.47	-0.8	-1.25	-2.03
S7 - S2	CH4 Energy	Gt CO2e	0	0	-0.16	-0.2	-0.52	-0.72	-1.21	-1.54
S7 - S2	CH4 AgLanduse	Gt CO2e	0	0	-0.01	-0.02	-0.11	-0.17	-0.24	-0.28
S7 - S2	N2O Energy	Gt CO2e	0	0	-0.03	-0.03	-0.1	-0.12	-0.21	-0.29
S7 - S2	N2O AgLanduse	Gt CO2e	0	0	-0.05	-0.06	-0.05	-0.06	-0.14	-0.25
S7 - S2	F-gases	Gt CO2e	0	0	-0.04	-0.07	-0.18	-0.24	-0.45	-0.6
S7 - S2	CO2 bioenergy	Gt CO2e	0	0	-0.12	-0.36	-1.72	-3.01	-4.01	-5.11
S7 - S2	CO2 direct air capture	Gt CO2e	0	0	0	-0.03	-0.27	-0.41	-0.44	-0.47
S7 - S2	CO2 LUC	Gt CO2e	0	0.14	0.09	-0.17	-0.66	-0.75	-1.52	-2.53
S7 - S2	**Total**	**Gt CO2e**	**0**	**0.14**	**-1.27**	**-2.66**	**-9.89**	**-16.1**	**-23.5**	**-30.6**
S6 - S1	CO2 buildings	%	0	0	-3.91	-6.08	-20.5	-25.7	-35.1	-55.91
S6 - S1	CO2 electricity	%	0	0	-4.31	-7.81	-24.5	-43.8	-66.2	-83.44
S6 - S1	CO2 industry	%	0	0	-1.74	-3	-14.1	-24.3	-33.1	-41.39
S6 - S1	CO2 other energy	%	0	0	-2.75	-3.82	-22.4	-28.5	-33.8	-40.63
S6 - S1	CO2 transport	%	0	0	-0.99	-1.65	-6.2	-10.9	-17.6	-28.84

S6 - S1	CH4 Energy	%	0	0	-3.4	-4.12	-10.7	-15.4	-25.3	-32.29
S6 - S1	CH4 AgLanduse	%	0	0	-0.27	-0.5	-2.59	-3.78	-5.05	-5.634
S6 - S1	N2O Energy	%	0	0	-3.23	-3.13	-10.9	-14	-24.1	-32.95
S6 - S1	N2O AgLanduse	%	0	0	-2.02	-2.26	-1.79	-2.05	-4.52	-7.622
S6 - S1	F-gases	%	0	0	-2.84	-4.14	-10.2	-13.2	-26.8	-35.54
S6 - S1	CO2 bioenergy	%	0	0	35.3	66.7	231	302	302	304.8
S6 - S1	CO2 direct air capture	%	0	0	0	0	2700	4100	0	0
S6 - S1	CO2 LUC	%	0	33.3	12.3	5.52	35.4	58.7	98.7	176.1
S6 - S1	**Total**	**%**	**0**	**0.27**	**-2.54**	**-5.57**	**-20.1**	**-33.8**	**-48.8**	**-64.08**
S7 - S2	CO2 buildings	%	0	0	-3.91	-6.08	-20.2	-25.9	-35.4	-56.3
S7 - S2	CO2 electricity	%	0	0	-4.31	-7.81	-24.5	-43.8	-66.1	-83.41
S7 - S2	CO2 industry	%	0	0	-1.74	-3	-14.1	-24.3	-33	-41.3
S7 - S2	CO2 other energy	%	0	0	-2.75	-3.82	-22.4	-28.5	-33.8	-40.63
S7 - S2	CO2 transport	%	0	0	-0.99	-1.65	-6.2	-10.9	-17.5	-28.88
S7 - S2	CH4 Energy	%	0	0	-3.4	-4.12	-10.7	-15.2	-25.4	-32.15
S7 - S2	CH4 AgLanduse	%	0	0	-0.27	-0.5	-2.59	-3.79	-5.06	-5.634
S7 - S2	N2O Energy	%	0	0	-3.23	-3.13	-10.9	-14	-24.1	-32.95
S7 - S2	N2O AgLanduse	%	0	0	-2.02	-2.26	-1.79	-2.05	-4.52	-7.622
S7 - S2	F-gases	%	0	0	-2.84	-4.14	-10.2	-13.8	-26.8	-35.93
S7 - S2	CO2 bioenergy	%	0	0	35.3	66.7	232	301	299	302.4
S7 - S2	CO2 direct air capture	%	0	0	0	0	2700	4100	0	0
S7 - S2	CO2 LUC	%	0	33.3	12.3	5.52	38.4	35.9	94.4	182
S7 - S2	**Total**	**%**	**0**	**0.27**	**-2.54**	**-5.57**	**-20.1**	**-33.4**	**-48.7**	**-64.1**

Table D-9. CDR deployment by type in S6 and S7 and changes in S7 relative to S6 (Figure 9)

Scenario	Sector	Units	2015	2020	2025	2030	2035	2040	2045	2050
S6: Energy Transition (Ref Exp)	BECCS	Gt CO2	0	0	0.46	0.9	2.46	4.02	5.35	6.81
S6: Energy Transition (Ref Exp)	DAC	Gt CO2	0	0	0	0.04	0.28	0.42	0.44	0.47
S6: Energy Transition (Ref Exp)	Afforestation	Gt CO2e	1.38	1.54	1.5	3.99	3.38	3.37	3.43	4.06
S6: Energy Transition (Ref Exp)	**Total**	**Gt CO2e**	**1.38**	**1.54**	**1.96**	**4.93**	**6.12**	**7.81**	**9.22**	**11.3**
S7: Energy Transition	BECCS	Gt CO2	0	0	0.46	0.9	2.46	4.02	5.36	6.81
S7: Energy Transition	DAC	Gt CO2	0	0	0	0.04	0.28	0.42	0.44	0.47
S7: Energy Transition	Afforestation	Gt CO2e	1.38	1.54	1.5	3.99	3.38	3.37	3.44	4.06
S7: Energy Transition	**Total**	**Gt CO2e**	**1.38**	**1.54**	**1.96**	**4.93**	**6.12**	**7.81**	**9.24**	**11.3**
S7 - S6	BECCS	Gt CO2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S7 - S6	DAC	Gt CO2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S7 - S6	Afforestation	Gt CO2e	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S7 - S6	**Total**	**Gt CO2e**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
S7 - S6	BECCS	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S7 - S6	DAC	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S7 - S6	Afforestation	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S7 - S6	**Total**	**%**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Table D-10. Natural gas consumption, production, consumption, and trade by region under S6 and S7 (Figure 10) and changes in S7 relative to S6 (Figure 12)

Scenario	Region	Unit	NG Volumes	2020	2025	2030	2035	2040	2045	2050
S6: Energy Transition (Ref Exp)	ROW	Bcf/d	Consumption	42.29	39.95	42.56	42.59	44	46.19	45.43
S6: Energy Transition (Ref Exp)	Australia + NZ	Bcf/d	Consumption	0.79	0.33	0.49	0.34	0.44	0.63	0.91
S6: Energy Transition (Ref Exp)	LAC	Bcf/d	Consumption	17.55	16.52	19.24	20.64	22.58	23.55	24.91
S6: Energy Transition (Ref Exp)	Africa	Bcf/d	Consumption	14.45	14.23	16.98	20.22	25.07	31.92	38.76
S6: Energy Transition (Ref Exp)	C Asia + East Eur	Bcf/d	Consumption	28.94	30.46	32.45	32.35	32.44	30.5	28.2
S6: Energy Transition (Ref Exp)	Russia	Bcf/d	Consumption	45.82	36.03	39.59	39.92	39.43	36.08	33.1
S6: Energy Transition (Ref Exp)	China	Bcf/d	Consumption	27.43	41.73	46.57	52.25	59.32	66.21	64.93
S6: Energy Transition (Ref Exp)	India	Bcf/d	Consumption	7.96	11.56	16.4	21.55	27.64	34.62	40.31

S6: Energy Transition (Ref Exp)	Middle East	Bcf/d	Consumption	46.41	45.15	47.15	46.26	46.8	47.07	45.5
S6: Energy Transition (Ref Exp)	EU	Bcf/d	Consumption	48.18	35	28.79	24.88	26.86	29.64	28.38
S6: Energy Transition (Ref Exp)	Mexico	Bcf/d	Consumption	8.28	8.19	9.5	9.81	9.99	10.28	10.83
S6: Energy Transition (Ref Exp)	Canada	Bcf/d	Consumption	11.44	8.25	8.26	6.72	5.99	5.53	4.98
S6: Energy Transition (Ref Exp)	USA	Bcf/d	Consumption	80.45	75.28	76.47	76.36	79.45	77.9	75.67
S6: Energy Transition (Ref Exp)		**Bcf/d**	**Total**	**380**	**362.69**	**384.44**	**393.88**	**420.01**	**440.11**	**441.92**
S7: Energy Transition	ROW	Bcf/d	Consumption	42.29	39.95	42.56	42.59	44	46.65	45.95
S7: Energy Transition	Australia + NZ	Bcf/d	Consumption	0.79	0.33	0.49	0.34	0.44	0.64	0.92
S7: Energy Transition	LAC	Bcf/d	Consumption	17.55	16.52	19.24	20.64	22.58	23.78	25.2
S7: Energy Transition	Africa	Bcf/d	Consumption	14.45	14.23	16.98	20.22	25.07	32.01	38.94
S7: Energy Transition	C Asia + East Eur	Bcf/d	Consumption	28.94	30.46	32.45	32.35	32.44	30.57	28.27
S7: Energy Transition	Russia	Bcf/d	Consumption	45.82	36.03	39.59	39.92	39.43	36.09	33.12
S7: Energy Transition	China	Bcf/d	Consumption	27.43	41.73	46.57	52.25	59.32	66.39	65.02
S7: Energy Transition	India	Bcf/d	Consumption	7.96	11.56	16.4	21.55	27.64	34.86	40.59
S7: Energy Transition	Middle East	Bcf/d	Consumption	46.41	45.15	47.15	46.26	46.8	47.06	45.5
S7: Energy Transition	EU	Bcf/d	Consumption	48.18	35	28.79	24.88	26.86	30.04	28.53
S7: Energy Transition	Mexico	Bcf/d	Consumption	8.28	8.19	9.5	9.81	9.99	10.28	10.84
S7: Energy Transition	Canada	Bcf/d	Consumption	11.44	8.25	8.26	6.72	5.99	5.54	5
S7: Energy Transition	USA	Bcf/d	Consumption	80.45	75.28	76.47	76.36	79.45	77.73	75.42
S7: Energy Transition		**Bcf/d**	**Total**	**380**	**362.69**	**384.44**	**393.88**	**420.01**	**441.64**	**443.29**
S6: Energy Transition (Ref Exp)	ROW	Bcf/d	Production	41.02	37.63	40.92	41.75	42.28	43.38	43.46
S6: Energy Transition (Ref Exp)	Australia + NZ	Bcf/d	Production	12.71	12.21	12.09	10.84	9.16	7.08	5.31

S6: Energy Transition (Ref Exp)	LAC	Bcf/d	Production	15.44	13.65	15.64	16.05	16.86	17.9	19.08
S6: Energy Transition (Ref Exp)	Africa	Bcf/d	Production	23.83	24.62	27.17	29.58	33.29	38.2	42.33
S6: Energy Transition (Ref Exp)	C Asia + East Eur	Bcf/d	Production	17.31	17.51	18.71	18.64	19.21	19.55	19.79
S6: Energy Transition (Ref Exp)	Russia	Bcf/d	Production	70.26	59.65	62.68	61.92	64.03	65.28	61.94
S6: Energy Transition (Ref Exp)	China	Bcf/d	Production	16.74	19.7	22.17	23.72	25.2	26.33	24.8
S6: Energy Transition (Ref Exp)	India	Bcf/d	Production	4.02	4.75	7.01	9.46	12.66	17	20.74
S6: Energy Transition (Ref Exp)	Middle East	Bcf/d	Production	59.39	57.77	59.86	59.95	61.7	63.69	63.1
S6: Energy Transition (Ref Exp)	EU	Bcf/d	Production	13.69	9.87	8.52	7.91	9.03	13.03	14.42
S6: Energy Transition (Ref Exp)	Mexico	Bcf/d	Production	3.21	2.39	3.14	3.2	3.3	3.52	3.96
S6: Energy Transition (Ref Exp)	Canada	Bcf/d	Production	15.11	14.11	14.29	13.94	14.97	15.66	15.04
S6: Energy Transition (Ref Exp)	USA	Bcf/d	Production	87.26	88.83	92.25	96.9	108.31	109.49	107.95
S6: Energy Transition (Ref Exp)		**Bcf/d**	**Total**	**379.99**	**362.69**	**384.45**	**393.86**	**420**	**440.11**	**441.92**
S7: Energy Transition	ROW	Bcf/d	Production	41.02	37.63	40.92	41.75	42.28	43.14	43
S7: Energy Transition	Australia + NZ	Bcf/d	Production	12.71	12.21	12.09	10.84	9.16	7.05	5.21
S7: Energy Transition	LAC	Bcf/d	Production	15.44	13.65	15.64	16.05	16.86	17.71	18.72
S7: Energy Transition	Africa	Bcf/d	Production	23.83	24.62	27.17	29.58	33.29	37.81	41.66
S7: Energy Transition	C Asia + East Eur	Bcf/d	Production	17.31	17.51	18.71	18.64	19.21	19.4	19.44
S7: Energy Transition	Russia	Bcf/d	Production	70.26	59.65	62.68	61.92	64.03	64.96	61.24
S7: Energy Transition	China	Bcf/d	Production	16.74	19.7	22.17	23.72	25.2	26.3	24.74
S7: Energy Transition	India	Bcf/d	Production	4.02	4.75	7.01	9.46	12.66	16.8	20.38
S7: Energy Transition	Middle East	Bcf/d	Production	59.39	57.77	59.86	59.95	61.7	63.27	62.29
S7: Energy Transition	EU	Bcf/d	Production	13.69	9.87	8.52	7.91	9.03	12.87	13.99

S7: Energy Transition	Mexico	Bcf/d	Production	3.21	2.39	3.14	3.2	3.3	3.5	3.93
S7: Energy Transition	Canada	Bcf/d	Production	15.11	14.11	14.29	13.94	14.97	15.55	14.81
S7: Energy Transition	USA	Bcf/d	Production	87.26	88.83	92.25	96.9	108.31	113.29	113.87
S7: Energy Transition		**Bcf/d**	**Total**	**379.99**	**362.69**	**384.45**	**393.86**	**420**	**441.65**	**443.28**
S6: Energy Transition (Ref Exp)	ROW	Bcf/d	LNG exports	10.56	11.06	13.52	15.16	15.5	16.15	16.3
S6: Energy Transition (Ref Exp)	Australia + NZ	Bcf/d	LNG exports	11.93	11.88	11.61	10.51	8.72	6.46	4.55
S6: Energy Transition (Ref Exp)	LAC	Bcf/d	LNG exports	1.83	2.17	2.46	3.06	4.03	5.2	5.93
S6: Energy Transition (Ref Exp)	Africa	Bcf/d	LNG exports	9.09	10.61	11.28	11.59	12.1	12.3	11.73
S6: Energy Transition (Ref Exp)	C Asia + East Eur	Bcf/d	LNG exports	0.06	0.16	0.33	0.81	1.94	3.6	5.03
S6: Energy Transition (Ref Exp)	Russia	Bcf/d	LNG exports	3.05	3.81	3.89	3.56	3.09	2.72	2.5
S6: Energy Transition (Ref Exp)	China	Bcf/d	LNG exports	0	0	0	0.02	0.04	0.07	0.09
S6: Energy Transition (Ref Exp)	India	Bcf/d	LNG exports	0.01	0.01	0.04	0.07	0.15	0.27	0.37
S6: Energy Transition (Ref Exp)	Middle East	Bcf/d	LNG exports	13.4	13.05	13.27	14.4	16.11	18.04	19.03
S6: Energy Transition (Ref Exp)	EU	Bcf/d	LNG exports	0.37	0.47	0.61	0.75	1.29	2.21	3.07
S6: Energy Transition (Ref Exp)	Mexico	Bcf/d	LNG exports	0	0	0.01	0.02	0.07	0.14	0.22
S6: Energy Transition (Ref Exp)	Canada	Bcf/d	LNG exports	0.01	2.01	2.42	4.08	6.85	9.01	9.49
S6: Energy Transition (Ref Exp)	USA	Bcf/d	LNG exports	7.03	13.33	14.75	18.68	25.79	27.33	27.33
S6: Energy Transition (Ref Exp)		**Bcf/d**	**Total**	**57.34**	**68.56**	**74.19**	**82.71**	**95.68**	**103.5**	**105.64**
S7: Energy Transition	ROW	Bcf/d	LNG exports	10.56	11.06	13.52	15.16	15.5	15.97	15.92
S7: Energy Transition	Australia + NZ	Bcf/d	LNG exports	11.93	11.88	11.61	10.51	8.72	6.42	4.46
S7: Energy Transition	LAC	Bcf/d	LNG exports	1.83	2.17	2.46	3.06	4.03	5.1	5.73
S7: Energy Transition	Africa	Bcf/d	LNG exports	9.09	10.61	11.28	11.59	12.1	12.14	11.4

S7: Energy Transition	C Asia + East Eur	Bcf/d	LNG exports	0.06	0.16	0.33	0.81	1.94	3.49	4.73
S7: Energy Transition	Russia	Bcf/d	LNG exports	3.05	3.81	3.89	3.56	3.09	2.68	2.4
S7: Energy Transition	China	Bcf/d	LNG exports	0	0	0	0.02	0.04	0.07	0.09
S7: Energy Transition	India	Bcf/d	LNG exports	0.01	0.01	0.04	0.07	0.15	0.26	0.34
S7: Energy Transition	Middle East	Bcf/d	LNG exports	13.4	13.05	13.27	14.4	16.11	17.77	18.37
S7: Energy Transition	EU	Bcf/d	LNG exports	0.37	0.47	0.61	0.75	1.29	2.14	2.87
S7: Energy Transition	Mexico	Bcf/d	LNG exports	0	0	0.01	0.02	0.07	0.14	0.2
S7: Energy Transition	Canada	Bcf/d	LNG exports	0.01	2.01	2.42	4.08	6.85	8.89	9.25
S7: Energy Transition	USA	Bcf/d	LNG exports	7.03	13.33	14.75	18.68	25.79	31.37	33.59
S7: Energy Transition		**Bcf/d**	**Total**	**57.34**	**68.56**	**74.19**	**82.71**	**95.68**	**106.44**	**109.35**
S6: Energy Transition (Ref Exp)	ROW	Bcf/d	LNG imports	20.88	19.92	20.38	20.28	20.94	20.86	18.94
S6: Energy Transition (Ref Exp)	Australia + NZ	Bcf/d	LNG imports	0.01	0	0	0	0	0.01	0.15
S6: Energy Transition (Ref Exp)	LAC	Bcf/d	LNG imports	3.94	5.05	6.06	7.64	9.75	10.85	11.76
S6: Energy Transition (Ref Exp)	Africa	Bcf/d	LNG imports	0.97	1.17	1.83	2.84	4.4	6.26	8.21
S6: Energy Transition (Ref Exp)	C Asia + East Eur	Bcf/d	LNG imports	6.4	8.07	8.92	9.85	10.96	10.75	10.25
S6: Energy Transition (Ref Exp)	Russia	Bcf/d	LNG imports	0.82	0.68	0.81	1.82	3	3.33	3.37
S6: Energy Transition (Ref Exp)	China	Bcf/d	LNG imports	6.98	16.04	17.19	18.43	19.58	19.91	19.61
S6: Energy Transition (Ref Exp)	India	Bcf/d	LNG imports	3.94	6.83	9.43	12.16	15.13	17.89	19.95
S6: Energy Transition (Ref Exp)	Middle East	Bcf/d	LNG imports	0.43	0.43	0.54	0.7	1.18	1.36	1.38
S6: Energy Transition (Ref Exp)	EU	Bcf/d	LNG imports	11.32	8.65	7.28	7.37	9.19	10.77	10.46
S6: Energy Transition (Ref Exp)	Mexico	Bcf/d	LNG imports	1.15	1.35	1.4	1.36	1.31	1.27	1.31
S6: Energy Transition (Ref Exp)	Canada	Bcf/d	LNG imports	0.21	0.15	0.15	0.12	0.13	0.17	0.19

S6: Energy Transition (Ref Exp)	USA	Bcf/d	LNG imports	0.26	0.24	0.18	0.14	0.12	0.08	0.08
S6: Energy Transition (Ref Exp)		**Bcf/d**	**Total**	**57.31**	**68.58**	**74.17**	**82.71**	**95.69**	**103.51**	**105.66**
S7: Energy Transition	ROW	Bcf/d	LNG imports	20.88	19.92	20.38	20.28	20.94	21.37	19.55
S7: Energy Transition	Australia + NZ	Bcf/d	LNG imports	0.01	0	0	0	0	0.01	0.17
S7: Energy Transition	LAC	Bcf/d	LNG imports	3.94	5.05	6.06	7.64	9.75	11.18	12.21
S7: Energy Transition	Africa	Bcf/d	LNG imports	0.97	1.17	1.83	2.84	4.4	6.59	8.74
S7: Energy Transition	C Asia + East Eur	Bcf/d	LNG imports	6.4	8.07	8.92	9.85	10.96	10.92	10.44
S7: Energy Transition	Russia	Bcf/d	LNG imports	0.82	0.68	0.81	1.82	3	3.45	3.51
S7: Energy Transition	China	Bcf/d	LNG imports	6.98	16.04	17.19	18.43	19.58	20.23	19.95
S7: Energy Transition	India	Bcf/d	LNG imports	3.94	6.83	9.43	12.16	15.13	18.31	20.55
S7: Energy Transition	Middle East	Bcf/d	LNG imports	0.43	0.43	0.54	0.7	1.18	1.52	1.54
S7: Energy Transition	EU	Bcf/d	LNG imports	11.32	8.65	7.28	7.37	9.19	11.26	11.01
S7: Energy Transition	Mexico	Bcf/d	LNG imports	1.15	1.35	1.4	1.36	1.31	1.31	1.36
S7: Energy Transition	Canada	Bcf/d	LNG imports	0.21	0.15	0.15	0.12	0.13	0.19	0.22
S7: Energy Transition	USA	Bcf/d	LNG imports	0.26	0.24	0.18	0.14	0.12	0.1	0.09
S7: Energy Transition		**Bcf/d**	**Total**	**57.31**	**68.58**	**74.17**	**82.71**	**95.69**	**106.44**	**109.34**
S6: Energy Transition (Ref Exp)	ROW	Bcf/d	Pipeline exports	10.05	7.37	6.09	5.05	4.42	2.64	1.55
S6: Energy Transition (Ref Exp)	Australia + NZ	Bcf/d	Pipeline exports	0	0	0	0	0	0	0
S6: Energy Transition (Ref Exp)	LAC	Bcf/d	Pipeline exports	2.11	1.81	1.81	1.53	1.2	0.97	0.92
S6: Energy Transition (Ref Exp)	Africa	Bcf/d	Pipeline exports	1.42	1.11	1.11	1.44	2.31	3.73	5.77
S6: Energy Transition (Ref Exp)	C Asia + East Eur	Bcf/d	Pipeline exports	0.07	0.05	0.04	0.03	0.03	0.01	0.01
S6: Energy Transition (Ref Exp)	Russia	Bcf/d	Pipeline exports	23.46	21.46	21.08	21.63	26.42	32.12	32.15

S6: Energy Transition (Ref Exp)	China	Bcf/d	Pipeline exports	0	0	0	0	0	0	0
S6: Energy Transition (Ref Exp)	India	Bcf/d	Pipeline exports	0	0	0	0	0	0	0
S6: Energy Transition (Ref Exp)	Middle East	Bcf/d	Pipeline exports	0.03	0.02	0.02	0.03	0.05	0.08	0.12
S6: Energy Transition (Ref Exp)	EU	Bcf/d	Pipeline exports	2.21	1.58	1.26	1.03	0.89	0.46	0.23
S6: Energy Transition (Ref Exp)	Mexico	Bcf/d	Pipeline exports	0.01	0	0.01	0.03	0.08	0.17	0.29
S6: Energy Transition (Ref Exp)	Canada	Bcf/d	Pipeline exports	6.23	5.73	5.48	4.68	3.66	2.79	2.23
S6: Energy Transition (Ref Exp)	USA	Bcf/d	Pipeline exports	8.53	8.53	8.53	8.53	8.53	8.53	8.53
S6: Energy Transition (Ref Exp)		**Bcf/d**	**Total**	**54.12**	**47.66**	**45.43**	**43.98**	**47.59**	**51.5**	**51.8**
S7: Energy Transition	ROW	Bcf/d	Pipeline exports	10.05	7.37	6.09	5.05	4.42	2.62	1.53
S7: Energy Transition	Australia + NZ	Bcf/d	Pipeline exports	0	0	0	0	0	0	0
S7: Energy Transition	LAC	Bcf/d	Pipeline exports	2.11	1.81	1.81	1.53	1.2	0.95	0.88
S7: Energy Transition	Africa	Bcf/d	Pipeline exports	1.42	1.11	1.11	1.44	2.31	3.62	5.58
S7: Energy Transition	C Asia + East Eur	Bcf/d	Pipeline exports	0.07	0.05	0.04	0.03	0.03	0.01	0.01
S7: Energy Transition	Russia	Bcf/d	Pipeline exports	23.46	21.46	21.08	21.63	26.42	31.88	31.62
S7: Energy Transition	China	Bcf/d	Pipeline exports	0	0	0	0	0	0	0
S7: Energy Transition	India	Bcf/d	Pipeline exports	0	0	0	0	0	0	0
S7: Energy Transition	Middle East	Bcf/d	Pipeline exports	0.03	0.02	0.02	0.03	0.05	0.07	0.12
S7: Energy Transition	EU	Bcf/d	Pipeline exports	2.21	1.58	1.26	1.03	0.89	0.46	0.23
S7: Energy Transition	Mexico	Bcf/d	Pipeline exports	0.01	0	0.01	0.03	0.08	0.17	0.28
S7: Energy Transition	Canada	Bcf/d	Pipeline exports	6.23	5.73	5.48	4.68	3.66	2.79	2.23
S7: Energy Transition	USA	Bcf/d	Pipeline exports	8.53	8.53	8.53	8.53	8.53	8.53	8.53
S7: Energy Transition		**Bcf/d**	**Total**	**54.12**	**47.66**	**45.43**	**43.98**	**47.59**	**51.1**	**51.01**

S6: Energy Transition (Ref Exp)	ROW	Bcf/d	Pipeline imports	1	0.82	0.86	0.77	0.7	0.74	0.88
S6: Energy Transition (Ref Exp)	Australia + NZ	Bcf/d	Pipeline imports	0	0	0	0	0	0	0
S6: Energy Transition (Ref Exp)	LAC	Bcf/d	Pipeline imports	2.11	1.81	1.81	1.53	1.2	0.97	0.92
S6: Energy Transition (Ref Exp)	Africa	Bcf/d	Pipeline imports	0.15	0.16	0.37	0.84	1.8	3.48	5.73
S6: Energy Transition (Ref Exp)	C Asia + East Eur	Bcf/d	Pipeline imports	5.37	5.09	5.19	4.7	4.24	3.82	3.2
S6: Energy Transition (Ref Exp)	Russia	Bcf/d	Pipeline imports	1.25	0.97	1.08	1.36	1.9	2.3	2.44
S6: Energy Transition (Ref Exp)	China	Bcf/d	Pipeline imports	3.7	5.99	7.21	10.12	14.58	20.04	20.62
S6: Energy Transition (Ref Exp)	India	Bcf/d	Pipeline imports	0	0	0	0	0	0	0
S6: Energy Transition (Ref Exp)	Middle East	Bcf/d	Pipeline imports	0.02	0.03	0.03	0.04	0.08	0.14	0.18
S6: Energy Transition (Ref Exp)	EU	Bcf/d	Pipeline imports	25.74	18.52	14.86	11.38	10.82	8.52	6.8
S6: Energy Transition (Ref Exp)	Mexico	Bcf/d	Pipeline imports	3.93	4.45	4.98	5.29	5.53	5.81	6.08
S6: Energy Transition (Ref Exp)	Canada	Bcf/d	Pipeline imports	2.35	1.73	1.72	1.42	1.4	1.5	1.47
S6: Energy Transition (Ref Exp)	USA	Bcf/d	Pipeline imports	8.48	8.07	7.32	6.52	5.34	4.19	3.51
S6: Energy Transition (Ref Exp)		**Bcf/d**	**Total**	**54.1**	**47.64**	**45.43**	**43.97**	**47.59**	**51.51**	**51.83**
S7: Energy Transition	ROW	Bcf/d	Pipeline imports	1	0.82	0.86	0.77	0.7	0.73	0.85
S7: Energy Transition	Australia + NZ	Bcf/d	Pipeline imports	0	0	0	0	0	0	0
S7: Energy Transition	LAC	Bcf/d	Pipeline imports	2.11	1.81	1.81	1.53	1.2	0.95	0.88
S7: Energy Transition	Africa	Bcf/d	Pipeline imports	0.15	0.16	0.37	0.84	1.8	3.38	5.53
S7: Energy Transition	C Asia + East Eur	Bcf/d	Pipeline imports	5.37	5.09	5.19	4.7	4.24	3.76	3.13
S7: Energy Transition	Russia	Bcf/d	Pipeline imports	1.25	0.97	1.08	1.36	1.9	2.25	2.38
S7: Energy Transition	China	Bcf/d	Pipeline imports	3.7	5.99	7.21	10.12	14.58	19.92	20.41
S7: Energy Transition	India	Bcf/d	Pipeline imports	0	0	0	0	0	0	0

S7: Energy Transition	Middle East	Bcf/d	Pipeline imports	0.02	0.03	0.03	0.04	0.08	0.13	0.16
S7: Energy Transition	EU	Bcf/d	Pipeline imports	25.74	18.52	14.86	11.38	10.82	8.51	6.62
S7: Energy Transition	Mexico	Bcf/d	Pipeline imports	3.93	4.45	4.98	5.29	5.53	5.77	6.03
S7: Energy Transition	Canada	Bcf/d	Pipeline imports	2.35	1.73	1.72	1.42	1.4	1.48	1.44
S7: Energy Transition	USA	Bcf/d	Pipeline imports	8.48	8.07	7.32	6.52	5.34	4.24	3.57
S7: Energy Transition		**Bcf/d**	**Total**	**54.1**	**47.64**	**45.43**	**43.97**	**47.59**	**51.12**	**51**
S7 - S6	ROW	Bcf/d	Consumption	0	0	0	0	0	0.45	0.52
S7 - S6	Australia + NZ	Bcf/d	Consumption	0	0	0	0	0	0.01	0.01
S7 - S6	LAC	Bcf/d	Consumption	0	0	0	0	0	0.23	0.29
S7 - S6	Africa	Bcf/d	Consumption	0	0	0	0	0	0.1	0.18
S7 - S6	C Asia + East Eur	Bcf/d	Consumption	0	0	0	0	0	0.07	0.07
S7 - S6	Russia	Bcf/d	Consumption	0	0	0	0	0	0.02	0.01
S7 - S6	China	Bcf/d	Consumption	0	0	0	0	0	0.18	0.09
S7 - S6	India	Bcf/d	Consumption	0	0	0	0	0	0.23	0.27
S7 - S6	Middle East	Bcf/d	Consumption	0	0	0	0	0	-0.01	-0.01
S7 - S6	EU	Bcf/d	Consumption	0	0	0	0	0	0.39	0.15
S7 - S6	Mexico	Bcf/d	Consumption	0	0	0	0	0	0	0.01
S7 - S6	Canada	Bcf/d	Consumption	0	0	0	0	0	0.01	0.01
S7 - S6	USA	Bcf/d	Consumption	0	0	0	0	0	-0.17	-0.25
S7 - S6		**Bcf/d**	**Total**	**0**	**0**	**0**	**0**	**0**	**1.53**	**1.37**
S7 - S6	ROW	Bcf/d	Production	0	0	0	0	0	-0.24	-0.47
S7 - S6	Australia + NZ	Bcf/d	Production	0	0	0	0	0	-0.03	-0.1

S7 - S6	LAC	Bcf/d	Production	0	0	0	0	0	-0.19	-0.36
S7 - S6	Africa	Bcf/d	Production	0	0	0	0	0	-0.39	-0.67
S7 - S6	C Asia + East Eur	Bcf/d	Production	0	0	0	0	0	-0.15	-0.35
S7 - S6	Russia	Bcf/d	Production	0	0	0	0	0	-0.32	-0.7
S7 - S6	China	Bcf/d	Production	0	0	0	0	0	-0.03	-0.05
S7 - S6	India	Bcf/d	Production	0	0	0	0	0	-0.2	-0.35
S7 - S6	Middle East	Bcf/d	Production	0	0	0	0	0	-0.42	-0.81
S7 - S6	EU	Bcf/d	Production	0	0	0	0	0	-0.16	-0.43
S7 - S6	Mexico	Bcf/d	Production	0	0	0	0	0	-0.01	-0.03
S7 - S6	Canada	Bcf/d	Production	0	0	0	0	0	-0.12	-0.23
S7 - S6	USA	Bcf/d	Production	0	0	0	0	0	3.79	5.92
S7 - S6		**Bcf/d**	**Total**	**0**	**0**	**0**	**0**	**0**	**1.53**	**1.37**
S7 - S6	ROW	Bcf/d	LNG exports	0	0	0	0	0	-0.18	-0.39
S7 - S6	Australia + NZ	Bcf/d	LNG exports	0	0	0	0	0	-0.04	-0.1
S7 - S6	LAC	Bcf/d	LNG exports	0	0	0	0	0	-0.09	-0.21
S7 - S6	Africa	Bcf/d	LNG exports	0	0	0	0	0	-0.16	-0.33
S7 - S6	C Asia + East Eur	Bcf/d	LNG exports	0	0	0	0	0	-0.11	-0.3
S7 - S6	Russia	Bcf/d	LNG exports	0	0	0	0	0	-0.04	-0.1
S7 - S6	China	Bcf/d	LNG exports	0	0	0	0	0	0	-0.01
S7 - S6	India	Bcf/d	LNG exports	0	0	0	0	0	-0.01	-0.02
S7 - S6	Middle East	Bcf/d	LNG exports	0	0	0	0	0	-0.27	-0.65
S7 - S6	EU	Bcf/d	LNG exports	0	0	0	0	0	-0.07	-0.19

S7 - S6	Mexico	Bcf/d	LNG exports	0	0	0	0	0	-0.01	-0.02
S7 - S6	Canada	Bcf/d	LNG exports	0	0	0	0	0	-0.13	-0.25
S7 - S6	USA	Bcf/d	LNG exports	0	0	0	0	0	4.03	6.25
S7 - S6		**Bcf/d**	**Total**	**0**	**0**	**0**	**0**	**0**	**2.92**	**3.69**
S7 - S6	ROW	Bcf/d	LNG imports	0	0	0	0	0	0.51	0.61
S7 - S6	Australia + NZ	Bcf/d	LNG imports	0	0	0	0	0	0	0.02
S7 - S6	LAC	Bcf/d	LNG imports	0	0	0	0	0	0.33	0.45
S7 - S6	Africa	Bcf/d	LNG imports	0	0	0	0	0	0.33	0.53
S7 - S6	C Asia + East Eur	Bcf/d	LNG imports	0	0	0	0	0	0.18	0.18
S7 - S6	Russia	Bcf/d	LNG imports	0	0	0	0	0	0.12	0.14
S7 - S6	China	Bcf/d	LNG imports	0	0	0	0	0	0.32	0.34
S7 - S6	India	Bcf/d	LNG imports	0	0	0	0	0	0.42	0.6
S7 - S6	Middle East	Bcf/d	LNG imports	0	0	0	0	0	0.16	0.16
S7 - S6	EU	Bcf/d	LNG imports	0	0	0	0	0	0.5	0.56
S7 - S6	Mexico	Bcf/d	LNG imports	0	0	0	0	0	0.04	0.06
S7 - S6	Canada	Bcf/d	LNG imports	0	0	0	0	0	0.02	0.03
S7 - S6	USA	Bcf/d	LNG imports	0	0	0	0	0	0.02	0.01
S7 - S6		**Bcf/d**	**Total**	**0**	**0**	**0**	**0**	**0**	**2.92**	**3.69**
S7 - S6	ROW	Bcf/d	Pipeline exports	0	0	0	0	0	-0.02	-0.02
S7 - S6	Australia + NZ	Bcf/d	Pipeline exports	0	0	0	0	0	0	0
S7 - S6	LAC	Bcf/d	Pipeline exports	0	0	0	0	0	-0.02	-0.04
S7 - S6	Africa	Bcf/d	Pipeline exports	0	0	0	0	0	-0.11	-0.19

S7 - S6	C Asia + East Eur	Bcf/d	Pipeline exports	0	0	0	0	0	0	0
S7 - S6	Russia	Bcf/d	Pipeline exports	0	0	0	0	0	-0.24	-0.53
S7 - S6	China	Bcf/d	Pipeline exports	0	0	0	0	0	0	0
S7 - S6	India	Bcf/d	Pipeline exports	0	0	0	0	0	0	0
S7 - S6	Middle East	Bcf/d	Pipeline exports	0	0	0	0	0	0	-0.01
S7 - S6	EU	Bcf/d	Pipeline exports	0	0	0	0	0	0	0
S7 - S6	Mexico	Bcf/d	Pipeline exports	0	0	0	0	0	0	-0.01
S7 - S6	Canada	Bcf/d	Pipeline exports	0	0	0	0	0	0	0
S7 - S6	USA	Bcf/d	Pipeline exports	0	0	0	0	0	0	0
S7 - S6		**Bcf/d**	**Total**	**0**	**0**	**0**	**0**	**0**	**-0.38**	**-0.8**
S7 - S6	ROW	Bcf/d	Pipeline imports	0	0	0	0	0	-0.01	-0.03
S7 - S6	Australia + NZ	Bcf/d	Pipeline imports	0	0	0	0	0	0	0
S7 - S6	LAC	Bcf/d	Pipeline imports	0	0	0	0	0	-0.02	-0.04
S7 - S6	Africa	Bcf/d	Pipeline imports	0	0	0	0	0	-0.11	-0.19
S7 - S6	C Asia + East Eur	Bcf/d	Pipeline imports	0	0	0	0	0	-0.06	-0.07
S7 - S6	Russia	Bcf/d	Pipeline imports	0	0	0	0	0	-0.05	-0.07
S7 - S6	China	Bcf/d	Pipeline imports	0	0	0	0	0	-0.12	-0.21
S7 - S6	India	Bcf/d	Pipeline imports	0	0	0	0	0	0	0
S7 - S6	Middle East	Bcf/d	Pipeline imports	0	0	0	0	0	-0.01	-0.01
S7 - S6	EU	Bcf/d	Pipeline imports	0	0	0	0	0	-0.01	-0.18
S7 - S6	Mexico	Bcf/d	Pipeline imports	0	0	0	0	0	-0.03	-0.04
S7 - S6	Canada	Bcf/d	Pipeline imports	0	0	0	0	0	-0.02	-0.03

S7 - S6	USA	Bcf/d	Pipeline imports	0	0	0	0	0	0.06	0.07
S7 - S6		**Bcf/d**	**Total**	**0**	**0**	**0**	**0**	**0**	**-0.38**	**-0.8**
S7 - S6	ROW	%	Consumption	0	0	0	0	0	0.98	1.14
S7 - S6	Australia + NZ	%	Consumption	0	0	0	0	0	1.77	1.61
S7 - S6	LAC	%	Consumption	0	0	0	0	0	0.99	1.18
S7 - S6	Africa	%	Consumption	0	0	0	0	0	0.31	0.47
S7 - S6	C Asia + East Eur	%	Consumption	0	0	0	0	0	0.24	0.24
S7 - S6	Russia	%	Consumption	0	0	0	0	0	0.05	0.05
S7 - S6	China	%	Consumption	0	0	0	0	0	0.27	0.14
S7 - S6	India	%	Consumption	0	0	0	0	0	0.67	0.68
S7 - S6	Middle East	%	Consumption	0	0	0	0	0	-0.01	-0.01
S7 - S6	EU	%	Consumption	0	0	0	0	0	1.33	0.52
S7 - S6	Mexico	%	Consumption	0	0	0	0	0	0	0.08
S7 - S6	Canada	%	Consumption	0	0	0	0	0	0.18	0.28
S7 - S6	USA	%	Consumption	0	0	0	0	0	-0.22	-0.33
S7 - S6		**%**	**Total**	**0**	**0**	**0**	**0**	**0**	**6.58**	**6.03**
S7 - S6	ROW	%	Production	0	0	0	0	0	-0.55	-1.08
S7 - S6	Australia + NZ	%	Production	0	0	0	0	0	-0.43	-1.88
S7 - S6	LAC	%	Production	0	0	0	0	0	-1.06	-1.89
S7 - S6	Africa	%	Production	0	0	0	0	0	-1.02	-1.58
S7 - S6	C Asia + East Eur	%	Production	0	0	0	0	0	-0.79	-1.79
S7 - S6	Russia	%	Production	0	0	0	0	0	-0.49	-1.13
S7 - S6	China	%	Production	0	0	0	0	0	-0.12	-0.21
S7 - S6	India	%	Production	0	0	0	0	0	-1.15	-1.7
S7 - S6	Middle East	%	Production	0	0	0	0	0	-0.66	-1.29
S7 - S6	EU	%	Production	0	0	0	0	0	-1.26	-2.96
S7 - S6	Mexico	%	Production	0	0	0	0	0	-0.32	-0.69
S7 - S6	Canada	%	Production	0	0	0	0	0	-0.75	-1.54
S7 - S6	USA	%	Production	0	0	0	0	0	3.47	5.48
S7 - S6		**%**	**Total**	**0**	**0**	**0**	**0**	**0**	**-5.14**	**-12.24**
S7 - S6	ROW	%	LNG exports	0	0	0	0	0	-1.14	-2.37

S7 - S6	Australia + NZ	%	LNG exports	0	0	0	0	0	-0.65	-2.12
S7 - S6	LAC	%	LNG exports	0	0	0	0	0	-1.81	-3.52
S7 - S6	Africa	%	LNG exports	0	0	0	0	0	-1.32	-2.8
S7 - S6	C Asia + East Eur	%	LNG exports	0	0	0	0	0	-3.04	-5.99
S7 - S6	Russia	%	LNG exports	0	0	0	0	0	-1.38	-4.11
S7 - S6	China	%	LNG exports	0	0	0	0	0	-6.48	-8.66
S7 - S6	India	%	LNG exports	0	0	0	0	0	-3.69	-6.53
S7 - S6	Middle East	%	LNG exports	0	0	0	0	0	-1.49	-3.43
S7 - S6	EU	%	LNG exports	0	0	0	0	0	-3.01	-6.22
S7 - S6	Mexico	%	LNG exports	0	0	0	0	0	-4.8	-7.91
S7 - S6	Canada	%	LNG exports	0	0	0	0	0	-1.41	-2.6
S7 - S6	USA	%	LNG exports	0	0	0	0	0	14.76	22.87
S7 - S6		**%**	**Total**	**0**	**0**	**0**	**0**	**0**	**-15.45**	**-33.37**
S7 - S6	ROW	%	LNG imports	0	0	0	0	0	2.42	3.2
S7 - S6	Australia + NZ	%	LNG imports	0	0	0	0	0	2.49	11.73
S7 - S6	LAC	%	LNG imports	0	0	0	0	0	3.04	3.79
S7 - S6	Africa	%	LNG imports	0	0	0	0	0	5.19	6.42
S7 - S6	C Asia + East Eur	%	LNG imports	0	0	0	0	0	1.65	1.8
S7 - S6	Russia	%	LNG imports	0	0	0	0	0	3.48	4.22
S7 - S6	China	%	LNG imports	0	0	0	0	0	1.61	1.74
S7 - S6	India	%	LNG imports	0	0	0	0	0	2.34	3.03
S7 - S6	Middle East	%	LNG imports	0	0	0	0	0	11.5	11.86
S7 - S6	EU	%	LNG imports	0	0	0	0	0	4.61	5.33
S7 - S6	Mexico	%	LNG imports	0	0	0	0	0	2.8	4.39
S7 - S6	Canada	%	LNG imports	0	0	0	0	0	14.16	15.65
S7 - S6	USA	%	LNG imports	0	0	0	0	0	20.21	17.02
S7 - S6		**%**	**Total**	**0**	**0**	**0**	**0**	**0**	**75.51**	**90.16**
S7 - S6	ROW	%	Pipeline exports	0	0	0	0	0	-0.65	-1.58
S7 - S6	Australia + NZ	%	Pipeline exports	0	0	0	0	0	-0.61	-2.03
S7 - S6	LAC	%	Pipeline exports	0	0	0	0	0	-2	-3.93

S7 - S6	Africa	%	Pipeline exports	0	0	0	0	0	-2.85	-3.32
S7 - S6	C Asia + East Eur	%	Pipeline exports	0	0	0	0	0	0.56	0.6
S7 - S6	Russia	%	Pipeline exports	0	0	0	0	0	-0.73	-1.66
S7 - S6	China	%	Pipeline exports	0	0	0	0	0	-7.94	-9.38
S7 - S6	India	%	Pipeline exports	0	0	0	0	0	-7.94	-9.28
S7 - S6	Middle East	%	Pipeline exports	0	0	0	0	0	-3.24	-4.39
S7 - S6	EU	%	Pipeline exports	0	0	0	0	0	-0.66	-1.62
S7 - S6	Mexico	%	Pipeline exports	0	0	0	0	0	-1.05	-1.83
S7 - S6	Canada	%	Pipeline exports	0	0	0	0	0	0.06	0.1
S7 - S6	USA	%	Pipeline exports	0	0	0	0	0	0	0
S7 - S6		**%**	**Total**	**0**	**0**	**0**	**0**	**0**	**-27.06**	**-38.34**
S7 - S6	ROW	%	Pipeline imports	0	0	0	0	0	-1.75	-3.55
S7 - S6	Australia + NZ	%	Pipeline imports	0	0	0	0	0	1.73	-7.8
S7 - S6	LAC	%	Pipeline imports	0	0	0	0	0	-2	-3.93
S7 - S6	Africa	%	Pipeline imports	0	0	0	0	0	-3.05	-3.4
S7 - S6	C Asia + East Eur	%	Pipeline imports	0	0	0	0	0	-1.52	-2.07
S7 - S6	Russia	%	Pipeline imports	0	0	0	0	0	-2.22	-2.76
S7 - S6	China	%	Pipeline imports	0	0	0	0	0	-0.58	-1.01
S7 - S6	India	%	Pipeline imports	0	0	0	0	0	-2.08	-3.14
S7 - S6	Middle East	%	Pipeline imports	0	0	0	0	0	-8.29	-8.39
S7 - S6	EU	%	Pipeline imports	0	0	0	0	0	-0.09	-2.62
S7 - S6	Mexico	%	Pipeline imports	0	0	0	0	0	-0.57	-0.73

S7 - S6	Canada	%	Pipeline imports	0	0	0	0	0	-1.48	-1.91
S7 - S6	USA	%	Pipeline imports	0	0	0	0	0	1.32	1.98
S7 - S6		%	**Total**	**0**	**0**	**0**	**0**	**0**	**-20.58**	**-39.33**

Table D-11. Changes in natural gas consumption, production, and trade by region: S6 vs S1 and S7 vs S2 (Figure 11)

Commented [IGC189]: Missing. Checking on it.

Scenario	Region	Unit	NG Volumes	2020	2025	2030	2035	2040	2045	2050
S6 - S1	ROW	Bcf/d	Consumption	0	-0.45	-2.88	-6.32	-6.95	-7.74	-10.48
S6 - S1	Australia + NZ	Bcf/d	Consumption	0	0.02	0.06	-0.04	-0.07	-0.13	-0.2
S6 - S1	LAC	Bcf/d	Consumption	0	0.04	-0.53	-2.78	-4.14	-6.58	-8.15
S6 - S1	Africa	Bcf/d	Consumption	0	0.02	-0.11	-1.23	-1.71	-1.57	-2.68
S6 - S1	C Asia + East Eur	Bcf/d	Consumption	-0.01	0.06	-0.11	-3.41	-6.58	-11.55	-16.18
S6 - S1	Russia	Bcf/d	Consumption	0	0.05	-0.03	-0.02	-0.49	-3.83	-6.71
S6 - S1	China	Bcf/d	Consumption	0	0.32	-1.21	-3.09	-2.44	-2.53	-9.03
S6 - S1	India	Bcf/d	Consumption	0	-0.33	-0.79	-1.33	-0.71	-0.01	-0.81
S6 - S1	Middle East	Bcf/d	Consumption	-0.12	-0.89	-0.43	-5.48	-10.13	-16.09	-22.4
S6 - S1	EU	Bcf/d	Consumption	0	-0.83	-4.67	-5.11	-1.97	-3.06	-8.08
S6 - S1	Mexico	Bcf/d	Consumption	0	0.13	0.14	-0.89	-2.09	-3.12	-3.91
S6 - S1	Canada	Bcf/d	Consumption	0	0.27	-0.04	-1.17	-1.47	-1.29	-1
S6 - S1	USA	Bcf/d	Consumption	0.02	-7.2	-11.46	-13.94	-15.94	-28.82	-43.33
S6 - S1		**Bcf/d**	**Total**	**-0.11**	**-8.76**	**-22.07**	**-44.84**	**-54.69**	**-86.34**	**-132.96**
S6 - S1	ROW	Bcf/d	Production	0	-0.3	-2.2	-4	-4.31	-4.49	-5.2
S6 - S1	Australia + NZ	Bcf/d	Production	0	0	-0.02	-0.25	-0.45	-0.74	-1.28
S6 - S1	LAC	Bcf/d	Production	0	-0.11	-0.24	-1.79	-3.08	-4.81	-6.34
S6 - S1	Africa	Bcf/d	Production	0	-0.05	-0.43	-1.92	-3.31	-4.26	-6.06
S6 - S1	C Asia + East Eur	Bcf/d	Production	0	-0.05	-0.04	-1.92	-4.17	-7.18	-10.34
S6 - S1	Russia	Bcf/d	Production	0	-0.17	-0.33	-1.65	-3.79	-8.88	-18.18
S6 - S1	China	Bcf/d	Production	0	-0.12	-0.33	-1.16	-1.16	-1.27	-3.46
S6 - S1	India	Bcf/d	Production	0	-0.16	-0.12	-0.44	-0.71	-0.64	-1.53
S6 - S1	Middle East	Bcf/d	Production	-0.12	-0.83	-1.09	-6.45	-11.3	-17.55	-24.84
S6 - S1	EU	Bcf/d	Production	0	-0.18	-1.67	-1.91	-1.19	-2.78	-6.44
S6 - S1	Mexico	Bcf/d	Production	0	-0.16	-0.21	-0.71	-1.18	-1.84	-2.5
S6 - S1	Canada	Bcf/d	Production	0	0.06	-0.3	-1.3	-1.89	-2.57	-3.08
S6 - S1	USA	Bcf/d	Production	0.01	-6.68	-15.09	-21.35	-18.15	-29.33	-43.7
S6 - S1		**Bcf/d**	**Total**	**-0.12**	**-8.76**	**-22.06**	**-44.86**	**-54.69**	**-86.34**	**-132.96**
S6 - S1	ROW	Bcf/d	LNG exports	0	-0.05	-0.3	-0.41	-0.93	-1.87	-2.85
S6 - S1	Australia + NZ	Bcf/d	LNG exports	0	-0.02	-0.08	-0.21	-0.39	-0.61	-1.11

S6 - S1	LAC	Bcf/d	LNG exports	0	-0.03	-0.21	-0.45	-0.68	-1.07	-1.68
S6 - S1	Africa	Bcf/d	LNG exports	0	-0.04	-0.3	-0.87	-1.5	-2.47	-3.55
S6 - S1	C Asia + East Eur	Bcf/d	LNG exports	0	-0.01	-0.09	-0.26	-0.58	-1.28	-2.48
S6 - S1	Russia	Bcf/d	LNG exports	0	-0.01	-0.01	-0.11	-0.25	-0.53	-0.97
S6 - S1	China	Bcf/d	LNG exports	0	0	-0.01	0	-0.02	-0.04	-0.06
S6 - S1	India	Bcf/d	LNG exports	0	0	0	-0.02	-0.05	-0.14	-0.27
S6 - S1	Middle East	Bcf/d	LNG exports	0	0	-0.73	-1.35	-1.6	-2.4	-3.88
S6 - S1	EU	Bcf/d	LNG exports	0	0.01	-0.02	-0.12	-0.39	-0.96	-1.43
S6 - S1	Mexico	Bcf/d	LNG exports	0	0	0	-0.01	-0.02	-0.06	-0.12
S6 - S1	Canada	Bcf/d	LNG exports	0	0	-0.23	-0.31	-0.53	-1.04	-1.66
S6 - S1	USA	Bcf/d	LNG exports	0	0	-4.1	-7.3	-1.54	0	0
S6 - S1		**Bcf/d**	**Total**	**0**	**-0.16**	**-6.08**	**-11.42**	**-8.47**	**-12.48**	**-20.07**
S6 - S1	ROW	Bcf/d	LNG imports	0	-0.34	-1.9	-3.61	-3.66	-5.09	-8.01
S6 - S1	Australia + NZ	Bcf/d	LNG imports	0	0	0	0	0	0	-0.03
S6 - S1	LAC	Bcf/d	LNG imports	0	0.13	-0.5	-1.45	-1.74	-2.84	-3.48
S6 - S1	Africa	Bcf/d	LNG imports	0	0.01	-0.12	-0.3	0.08	0.18	-0.23
S6 - S1	C Asia + East Eur	Bcf/d	LNG imports	0	0.1	-0.23	-1.3	-1.59	-2.86	-3.94
S6 - S1	Russia	Bcf/d	LNG imports	0	0	0	0	0.38	0.2	0.04
S6 - S1	China	Bcf/d	LNG imports	0	0.38	-0.56	-0.91	-0.1	0.06	-0.27
S6 - S1	India	Bcf/d	LNG imports	-0.01	-0.17	-0.67	-0.92	-0.05	0.5	0.45
S6 - S1	Middle East	Bcf/d	LNG imports	0	-0.05	-0.09	-0.37	-0.36	-0.77	-1.14
S6 - S1	EU	Bcf/d	LNG imports	0	-0.21	-1.93	-2.28	-1.05	-1.24	-2.72
S6 - S1	Mexico	Bcf/d	LNG imports	0	0.01	-0.04	-0.21	-0.33	-0.5	-0.64
S6 - S1	Canada	Bcf/d	LNG imports	0	0	0	-0.02	-0.06	-0.08	-0.07
S6 - S1	USA	Bcf/d	LNG imports	0	-0.02	-0.05	-0.04	0.02	-0.02	-0.02
S6 - S1		**Bcf/d**	**Total**	**-0.03**	**-0.14**	**-6.1**	**-11.42**	**-8.46**	**-12.47**	**-20.05**
S6 - S1	ROW	Bcf/d	Pipeline exports	0	-0.14	-0.96	-1	-0.2	-0.03	0.03
S6 - S1	Australia + NZ	Bcf/d	Pipeline exports	0	0	0	0	0	0	0
S6 - S1	LAC	Bcf/d	Pipeline exports	0	-0.01	0.02	-0.07	-0.16	-0.25	-0.31
S6 - S1	Africa	Bcf/d	Pipeline exports	0	-0.02	-0.12	-0.14	-0.04	0.35	0.97
S6 - S1	C Asia + East Eur	Bcf/d	Pipeline exports	0	0	-0.01	-0.01	0	0	0
S6 - S1	Russia	Bcf/d	Pipeline exports	0	-0.21	-0.29	-1.52	-2.88	-5	-11.63
S6 - S1	China	Bcf/d	Pipeline exports	0	0	0	0	0	0	0
S6 - S1	India	Bcf/d	Pipeline exports	0	0	0	0	0	0	0
S6 - S1	Middle East	Bcf/d	Pipeline exports	0	0	-0.01	0	0.01	0.02	0.03
S6 - S1	EU	Bcf/d	Pipeline exports	0	-0.03	-0.23	-0.22	-0.03	-0.03	-0.04
S6 - S1	Mexico	Bcf/d	Pipeline exports	0	0	0	-0.02	-0.07	-0.18	-0.27
S6 - S1	Canada	Bcf/d	Pipeline exports	0	-0.14	-0.03	-0.08	-0.31	-0.51	-0.58

S6 - S1	USA	Bcf/d	Pipeline exports	0	0	0	0	0.01	0	0
S6 - S1		**Bcf/d**	**Total**	**0.01**	**-0.55**	**-1.63**	**-3.06**	**-3.67**	**-5.64**	**-11.79**
S6 - S1	ROW	Bcf/d	Pipeline imports	0	-0.01	-0.05	-0.11	-0.1	-0.06	-0.1
S6 - S1	Australia + NZ	Bcf/d	Pipeline imports	0	0	0	0	0	0	0
S6 - S1	LAC	Bcf/d	Pipeline imports	0	-0.01	0.02	-0.07	-0.16	-0.25	-0.31
S6 - S1	Africa	Bcf/d	Pipeline imports	0	0	0.02	0	-0.01	0.37	1.05
S6 - S1	C Asia + East Eur	Bcf/d	Pipeline imports	0	0	0.06	-0.47	-1.4	-2.79	-4.39
S6 - S1	Russia	Bcf/d	Pipeline imports	0	0	0	-0.01	-0.22	-0.7	-1.18
S6 - S1	China	Bcf/d	Pipeline imports	0	0.06	-0.33	-1.02	-1.2	-1.36	-5.35
S6 - S1	India	Bcf/d	Pipeline imports	0	0	0	0	0	0	0
S6 - S1	Middle East	Bcf/d	Pipeline imports	0	0	0	-0.02	-0.06	-0.15	-0.27
S6 - S1	EU	Bcf/d	Pipeline imports	0	-0.47	-1.32	-1.27	-0.14	-0.02	-0.38
S6 - S1	Mexico	Bcf/d	Pipeline imports	0	0.27	0.38	0	-0.67	-1	-1.15
S6 - S1	Canada	Bcf/d	Pipeline imports	0	0.07	0	-0.24	-0.35	-0.2	-0.09
S6 - S1	USA	Bcf/d	Pipeline imports	0	-0.49	-0.41	0.14	0.64	0.52	0.4
S6 - S1		**Bcf/d**	**Total**	**-0.01**	**-0.57**	**-1.63**	**-3.07**	**-3.68**	**-5.63**	**-11.76**
S7 - S2	ROW	Bcf/d	Consumption	0	-0.45	-2.88	-6.17	-7.9	-8.81	-11.81
S7 - S2	Australia + NZ	Bcf/d	Consumption	0	0.02	0.06	-0.03	-0.08	-0.14	-0.21
S7 - S2	LAC	Bcf/d	Consumption	0	0.04	-0.53	-2.7	-4.71	-7.19	-8.78
S7 - S2	Africa	Bcf/d	Consumption	0	0.02	-0.11	-1.22	-1.87	-1.86	-3.06
S7 - S2	C Asia + East Eur	Bcf/d	Consumption	-0.01	0.06	-0.11	-3.34	-6.97	-11.89	-16.51
S7 - S2	Russia	Bcf/d	Consumption	0	0.05	-0.03	-0.01	-0.55	-3.89	-6.76
S7 - S2	China	Bcf/d	Consumption	0	0.32	-1.21	-2.79	-3.36	-3.02	-9.49
S7 - S2	India	Bcf/d	Consumption	0	-0.33	-0.79	-1.23	-1.3	-0.64	-1.52
S7 - S2	Middle East	Bcf/d	Consumption	-0.12	-0.89	-0.43	-5.49	-10.09	-16.08	-22.45
S7 - S2	EU	Bcf/d	Consumption	0	-0.83	-4.67	-4.66	-3.73	-4.21	-9.42
S7 - S2	Mexico	Bcf/d	Consumption	0	0.13	0.14	-0.89	-2.09	-3.14	-3.92
S7 - S2	Canada	Bcf/d	Consumption	0	0.27	-0.04	-1.18	-1.48	-1.38	-1.11
S7 - S2	USA	Bcf/d	Consumption	0.02	-7.2	-11.46	-14	-15.52	-27.81	-40.36
S7 - S2		**Bcf/d**	**Total**	**-0.11**	**-8.76**	**-22.07**	**-43.71**	**-59.65**	**-90.04**	**-135.4**
S7 - S2	ROW	Bcf/d	Production	0	-0.3	-2.2	-3.96	-4.08	-3.89	-4.63
S7 - S2	Australia + NZ	Bcf/d	Production	0	0	-0.02	-0.25	-0.42	-0.6	-1.03
S7 - S2	LAC	Bcf/d	Production	0	-0.11	-0.24	-1.83	-2.69	-4.07	-5.48
S7 - S2	Africa	Bcf/d	Production	0	-0.05	-0.43	-1.95	-2.84	-3.43	-5.12
S7 - S2	C Asia + East Eur	Bcf/d	Production	0	-0.05	-0.04	-1.95	-3.91	-6.5	-9.41
S7 - S2	Russia	Bcf/d	Production	0	-0.17	-0.33	-1.67	-3.34	-7.57	-16.67
S7 - S2	China	Bcf/d	Production	0	-0.12	-0.33	-1.11	-1.3	-1.27	-3.43
S7 - S2	India	Bcf/d	Production	0	-0.16	-0.12	-0.46	-0.59	-0.43	-1.26

S7 - S2	Middle East	Bcf/d	Production	-0.12	-0.83	-1.09	-6.46	-10.75	-16.27	-23.3
S7 - S2	EU	Bcf/d	Production	0	-0.18	-1.67	-1.76	-1.8	-2.52	-5.99
S7 - S2	Mexico	Bcf/d	Production	0	-0.16	-0.21	-0.71	-1.18	-1.81	-2.47
S7 - S2	Canada	Bcf/d	Production	0	0.06	-0.3	-1.29	-1.81	-2.23	-2.71
S7 - S2	USA	Bcf/d	Production	0.01	-6.68	-15.09	-20.34	-24.97	-39.46	-53.91
S7 - S2		**Bcf/d**	**Total**	**-0.12**	**-8.76**	**-22.06**	**-43.73**	**-59.66**	**-90.03**	**-135.41**
S7 - S2	ROW	Bcf/d	LNG exports	0	-0.05	-0.3	-0.43	-0.76	-1.31	-2.21
S7 - S2	Australia + NZ	Bcf/d	LNG exports	0	-0.02	-0.08	-0.21	-0.34	-0.46	-0.86
S7 - S2	LAC	Bcf/d	LNG exports	0	-0.03	-0.21	-0.44	-0.6	-0.8	-1.3
S7 - S2	Africa	Bcf/d	LNG exports	0	-0.04	-0.3	-0.87	-1.33	-1.9	-2.84
S7 - S2	C Asia + East Eur	Bcf/d	LNG exports	0	-0.01	-0.09	-0.26	-0.51	-0.88	-1.85
S7 - S2	Russia	Bcf/d	LNG exports	0	-0.01	-0.01	-0.11	-0.21	-0.39	-0.74
S7 - S2	China	Bcf/d	LNG exports	0	0	-0.01	0	-0.01	-0.02	-0.04
S7 - S2	India	Bcf/d	LNG exports	0	0	0	-0.02	-0.04	-0.1	-0.21
S7 - S2	Middle East	Bcf/d	LNG exports	0	0	-0.73	-1.31	-1.4	-1.48	-2.66
S7 - S2	EU	Bcf/d	LNG exports	0	0.01	-0.02	-0.12	-0.31	-0.65	-1.06
S7 - S2	Mexico	Bcf/d	LNG exports	0	0	0	-0.01	-0.01	-0.03	-0.09
S7 - S2	Canada	Bcf/d	LNG exports	0	0	-0.23	-0.3	-0.41	-0.58	-1.11
S7 - S2	USA	Bcf/d	LNG exports	0	0	-4.1	-6.19	-9.05	-11.49	-13.64
S7 - S2		**Bcf/d**	**Total**	**0**	**-0.16**	**-6.08**	**-10.27**	**-15**	**-20.09**	**-28.61**
S7 - S2	ROW	Bcf/d	LNG imports	0	-0.34	-1.9	-3.45	-4.66	-6.21	-9.27
S7 - S2	Australia + NZ	Bcf/d	LNG imports	0	0	0	0	0	0	-0.04
S7 - S2	LAC	Bcf/d	LNG imports	0	0.13	-0.5	-1.32	-2.63	-3.91	-4.61
S7 - S2	Africa	Bcf/d	LNG imports	0	0.01	-0.12	-0.25	-0.38	-0.36	-0.84
S7 - S2	C Asia + East Eur	Bcf/d	LNG imports	0	0.1	-0.23	-1.16	-2.41	-3.96	-5.16
S7 - S2	Russia	Bcf/d	LNG imports	0	0	0	0.06	0.03	-0.27	-0.47
S7 - S2	China	Bcf/d	LNG imports	0	0.38	-0.56	-0.71	-0.75	-0.63	-1.08
S7 - S2	India	Bcf/d	LNG imports	-0.01	-0.17	-0.67	-0.78	-0.75	-0.32	-0.47
S7 - S2	Middle East	Bcf/d	LNG imports	0	-0.05	-0.09	-0.33	-0.69	-1.15	-1.56
S7 - S2	EU	Bcf/d	LNG imports	0	-0.21	-1.93	-2.07	-2.15	-2.35	-3.98
S7 - S2	Mexico	Bcf/d	LNG imports	0	0.01	-0.04	-0.2	-0.46	-0.71	-0.91
S7 - S2	Canada	Bcf/d	LNG imports	0	0	0	-0.02	-0.12	-0.16	-0.15
S7 - S2	USA	Bcf/d	LNG imports	0	-0.02	-0.05	-0.03	-0.03	-0.06	-0.08
S7 - S2		**Bcf/d**	**Total**	**-0.03**	**-0.14**	**-6.1**	**-10.27**	**-14.99**	**-20.09**	**-28.62**
S7 - S2	ROW	Bcf/d	Pipeline exports	0	-0.14	-0.96	-0.92	-0.17	-0.03	0.03
S7 - S2	Australia + NZ	Bcf/d	Pipeline exports	0	0	0	0	0	0	0
S7 - S2	LAC	Bcf/d	Pipeline exports	0	-0.01	0.02	-0.08	-0.1	-0.17	-0.22
S7 - S2	Africa	Bcf/d	Pipeline exports	0	-0.02	-0.12	-0.14	0.06	0.44	1.06
S7 - S2	C Asia + East Eur	Bcf/d	Pipeline exports	0	0	-0.01	-0.01	0	0	0
S7 - S2	Russia	Bcf/d	Pipeline exports	0	-0.21	-0.29	-1.51	-2.62	-4.05	-10.54

S7 - S2	China	Bcf/d	Pipeline exports	0	0	0	0	0	0	0
S7 - S2	India	Bcf/d	Pipeline exports	0	0	0	0	0	0	0
S7 - S2	Middle East	Bcf/d	Pipeline exports	0	0	-0.01	0	0.01	0.01	0.04
S7 - S2	EU	Bcf/d	Pipeline exports	0	-0.03	-0.23	-0.2	-0.03	-0.02	-0.02
S7 - S2	Mexico	Bcf/d	Pipeline exports	0	0	0	-0.02	-0.07	-0.18	-0.3
S7 - S2	Canada	Bcf/d	Pipeline exports	0	-0.14	-0.03	-0.08	-0.33	-0.57	-0.67
S7 - S2	USA	Bcf/d	Pipeline exports	0	0	0	0	0	0	0
S7 - S2		**Bcf/d**	**Total**	**0.01**	**-0.55**	**-1.63**	**-2.96**	**-3.23**	**-4.56**	**-10.62**
S7 - S2	ROW	Bcf/d	Pipeline imports	0	-0.01	-0.05	-0.11	-0.1	-0.05	-0.08
S7 - S2	Australia + NZ	Bcf/d	Pipeline imports	0	0	0	0	0	0	0
S7 - S2	LAC	Bcf/d	Pipeline imports	0	-0.01	0.02	-0.08	-0.1	-0.17	-0.22
S7 - S2	Africa	Bcf/d	Pipeline imports	0	0	0.02	-0.02	0.09	0.48	1.12
S7 - S2	C Asia + East Eur	Bcf/d	Pipeline imports	0	0	0.06	-0.5	-1.16	-2.3	-3.79
S7 - S2	Russia	Bcf/d	Pipeline imports	0	0	0	-0.02	-0.08	-0.48	-0.91
S7 - S2	China	Bcf/d	Pipeline imports	0	0.06	-0.33	-0.97	-1.33	-1.14	-5.03
S7 - S2	India	Bcf/d	Pipeline imports	0	0	0	0	0	0	0
S7 - S2	Middle East	Bcf/d	Pipeline imports	0	0	0	-0.02	-0.04	-0.11	-0.21
S7 - S2	EU	Bcf/d	Pipeline imports	0	-0.47	-1.32	-1.15	-0.12	-0.02	-0.54
S7 - S2	Mexico	Bcf/d	Pipeline imports	0	0.27	0.38	-0.03	-0.54	-0.83	-0.91
S7 - S2	Canada	Bcf/d	Pipeline imports	0	0.07	0	-0.25	-0.29	-0.14	-0.03
S7 - S2	USA	Bcf/d	Pipeline imports	0	-0.49	-0.41	0.17	0.43	0.22	-0.02
S7 - S2		**Bcf/d**	**Total**	**-0.01**	**-0.57**	**-1.63**	**-2.97**	**-3.23**	**-4.54**	**-10.63**
S6 - S1	ROW	%	Consumption	0.00	-1.11	-6.34	-12.92	-13.64	-14.35	-18.74
S6 - S1	Australia + NZ	%	Consumption	0.00	6.45	13.95	-10.53	-13.73	-17.11	-18.02
S6 - S1	LAC	%	Consumption	0.00	0.24	-2.68	-11.87	-15.49	-21.84	-24.65
S6 - S1	Africa	%	Consumption	0.00	0.14	-0.64	-5.73	-6.39	-4.69	-6.47
S6 - S1	C Asia + East Eur	%	Consumption	-0.03	0.20	-0.34	-9.54	-16.86	-27.47	-36.46
S6 - S1	Russia	%	Consumption	0.00	0.14	-0.08	-0.05	-1.23	-9.60	-16.86
S6 - S1	China	%	Consumption	0.00	0.77	-2.53	-5.58	-3.95	-3.68	-12.21
S6 - S1	India	%	Consumption	0.00	-2.78	-4.60	-5.81	-2.50	-0.03	-1.97
S6 - S1	Middle East	%	Consumption	-0.26	-1.93	-0.90	-10.59	-17.79	-25.47	-32.99
S6 - S1	EU	%	Consumption	0.00	-2.32	-13.96	-17.04	-6.83	-9.36	-22.16
S6 - S1	Mexico	%	Consumption	0.00	1.61	1.50	-8.32	-17.30	-23.28	-26.53
S6 - S1	Canada	%	Consumption	0.00	3.38	-0.48	-14.83	-19.71	-18.91	-16.72
S6 - S1	USA	%	Consumption	0.02	-8.73	-13.03	-15.44	-16.71	-27.01	-36.41
S6 - S1		**%**	**Total**	**-0.03**	**-2.36**	**-5.43**	**-10.22**	**-11.52**	**-16.40**	**-23.13**

S6 - S1	ROW	%	Production	0.00	-0.79	-5.10	-8.74	-9.25	-9.38	-10.69
S6 - S1	Australia + NZ	%	Production	0.00	0.00	-0.17	-2.25	-4.68	-9.46	-19.42
S6 - S1	LAC	%	Production	0.00	-0.80	-1.51	-10.03	-15.45	-21.18	-24.94
S6 - S1	Africa	%	Production	0.00	-0.20	-1.56	-6.10	-9.04	-10.03	-12.52
S6 - S1	C Asia + East Eur	%	Production	0.00	-0.28	-0.21	-9.34	-17.84	-26.86	-34.32
S6 - S1	Russia	%	Production	0.00	-0.28	-0.52	-2.60	-5.59	-11.97	-22.69
S6 - S1	China	%	Production	0.00	-0.61	-1.47	-4.66	-4.40	-4.60	-12.24
S6 - S1	India	%	Production	0.00	-3.26	-1.68	-4.44	-5.31	-3.63	-6.87
S6 - S1	Middle East	%	Production	-0.20	-1.42	-1.79	-9.71	-15.48	-21.60	-28.25
S6 - S1	EU	%	Production	0.00	-1.79	-16.39	-19.45	-11.64	-17.58	-30.87
S6 - S1	Mexico	%	Production	0.00	-6.27	-6.27	-18.16	-26.34	-34.33	-38.70
S6 - S1	Canada	%	Production	0.00	0.43	-2.06	-8.53	-11.21	-14.10	-17.00
S6 - S1	USA	%	Production	0.01	-6.99	-14.06	-18.05	-14.35	-21.13	-28.82
S6 - S1		**%**	**Total**	**-0.03**	**-2.36**	**-5.43**	**-10.23**	**-11.52**	**-16.40**	**-23.13**
S6 - S1	ROW	%	LNG exports	0.00	-0.45	-2.17	-2.63	-5.66	-10.38	-14.88
S6 - S1	Australia + NZ	%	LNG exports	0.00	-0.17	-0.68	-1.96	-4.28	-8.63	-19.61
S6 - S1	LAC	%	LNG exports	0.00	-1.36	-7.87	-12.82	-14.44	-17.07	-22.08
S6 - S1	Africa	%	LNG exports	0.00	-0.38	-2.59	-6.98	-11.03	-16.72	-23.23
S6 - S1	C Asia + East Eur	%	LNG exports	0.00	-5.88	-21.43	-24.30	-23.02	-26.23	-33.02
S6 - S1	Russia	%	LNG exports	0.00	-0.26	-0.26	-3.00	-7.49	-16.31	-27.95
S6 - S1	China	%	LNG exports	0.00	0.00	-100.00	0.00	-33.33	-36.36	-40.00
S6 - S1	India	%	LNG exports	0.00	0.00	0.00	-22.22	-25.00	-34.15	-42.19
S6 - S1	Middle East	%	LNG exports	0.00	0.00	-5.21	-8.57	-9.03	-11.74	-16.94
S6 - S1	EU	%	LNG exports	0.00	2.17	-3.17	-13.79	-23.21	-30.28	-31.78
S6 - S1	Mexico	%	LNG exports	0.00	0.00	0.00	-33.33	-22.22	-30.00	-35.29
S6 - S1	Canada	%	LNG exports	0.00	0.00	-8.68	-7.06	-7.18	-10.35	-14.89
S6 - S1	USA	%	LNG exports	0.00	0.00	-21.75	-28.10	-5.63	0.00	0.00
S6 - S1		**%**	**Total**	**0.00**	**-0.23**	**-7.57**	**-12.13**	**-8.13**	**-10.76**	**-15.97**
S6 - S1	ROW	%	LNG imports	0.00	-1.68	-8.53	-15.11	-14.88	-19.61	-29.72
S6 - S1	Australia + NZ	%	LNG imports	0.00	0.00	0.00	0.00	0.00	0.00	-16.67
S6 - S1	LAC	%	LNG imports	0.00	2.64	-7.62	-15.95	-15.14	-20.75	-22.83
S6 - S1	Africa	%	LNG imports	0.00	0.86	-6.15	-9.55	1.85	2.96	-2.73
S6 - S1	C Asia + East Eur	%	LNG imports	0.00	1.25	-2.51	-11.66	-12.67	-21.01	-27.77
S6 - S1	Russia	%	LNG imports	0.00	0.00	0.00	0.00	14.50	6.39	1.20
S6 - S1	China	%	LNG imports	0.00	2.43	-3.15	-4.71	-0.51	0.30	-1.36
S6 - S1	India	%	LNG imports	-0.25	-2.43	-6.63	-7.03	-0.33	2.88	2.31
S6 - S1	Middle East	%	LNG imports	0.00	-10.42	-14.29	-34.58	-23.38	-36.15	-45.24
S6 - S1	EU	%	LNG imports	0.00	-2.37	-20.96	-23.63	-10.25	-10.32	-20.64
S6 - S1	Mexico	%	LNG imports	0.00	0.75	-2.78	-13.38	-20.12	-28.25	-32.82
S6 - S1	Canada	%	LNG imports	0.00	0.00	0.00	-14.29	-31.58	-32.00	-26.92
S6 - S1	USA	%	LNG imports	0.00	-7.69	-21.74	-22.22	20.00	-20.00	-20.00
S6 - S1		**%**	**Total**	**-0.05**	**-0.20**	**-7.60**	**-12.13**	**-8.12**	**-10.75**	**-15.95**

S6 - S1	ROW	%	Pipeline exports	0.00	-1.86	-13.62	-16.53	-4.33	-1.12	1.97
S6 - S1	Australia + NZ	%	Pipeline exports	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S6 - S1	LAC	%	Pipeline exports	0.00	-0.55	1.12	-4.38	-11.76	-20.49	-25.20
S6 - S1	Africa	%	Pipeline exports	0.00	-1.77	-9.76	-8.86	-1.70	10.36	20.21
S6 - S1	C Asia + East Eur	%	Pipeline exports	0.00	0.00	-20.00	-25.00	0.00	0.00	0.00
S6 - S1	Russia	%	Pipeline exports	0.00	-0.97	-1.36	-6.57	-9.83	-13.47	-26.56
S6 - S1	China	%	Pipeline exports	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S6 - S1	India	%	Pipeline exports	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S6 - S1	Middle East	%	Pipeline exports	0.00	0.00	-33.33	0.00	25.00	33.33	33.33
S6 - S1	EU	%	Pipeline exports	0.00	-1.86	-15.44	-17.60	-3.26	-6.12	-14.81
S6 - S1	Mexico	%	Pipeline exports	0.00	0.00	0.00	-40.00	-46.67	-51.43	-48.21
S6 - S1	Canada	%	Pipeline exports	0.00	-2.39	-0.54	-1.68	-7.81	-15.45	-20.64
S6 - S1	USA	%	Pipeline exports	0.00	0.00	0.00	0.00	0.12	0.00	0.00
S6 - S1		**%**	**Total**	**0.02**	**-1.14**	**-3.46**	**-6.51**	**-7.16**	**-9.87**	**-18.54**
S6 - S1	ROW	%	Pipeline imports	0.00	-1.20	-5.49	-12.50	-12.50	-7.50	-10.20
S6 - S1	Australia + NZ	%	Pipeline imports	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S6 - S1	LAC	%	Pipeline imports	0.00	-0.55	1.12	-4.38	-11.76	-20.49	-25.20
S6 - S1	Africa	%	Pipeline imports	0.00	0.00	5.71	0.00	-0.55	11.90	22.44
S6 - S1	C Asia + East Eur	%	Pipeline imports	0.00	0.00	1.17	-9.09	-24.82	-42.21	-57.84
S6 - S1	Russia	%	Pipeline imports	0.00	0.00	0.00	-0.73	-10.38	-23.33	-32.60
S6 - S1	China	%	Pipeline imports	0.00	1.01	-4.38	-9.16	-7.60	-6.36	-20.60
S6 - S1	India	%	Pipeline imports	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S6 - S1	Middle East	%	Pipeline imports	0.00	0.00	0.00	-33.33	-42.86	-51.72	-60.00
S6 - S1	EU	%	Pipeline imports	0.00	-2.47	-8.16	-10.04	-1.28	-0.23	-5.29
S6 - S1	Mexico	%	Pipeline imports	0.00	6.46	8.26	0.00	-10.81	-14.68	-15.91
S6 - S1	Canada	%	Pipeline imports	0.00	4.22	0.00	-14.46	-20.00	-11.76	-5.77
S6 - S1	USA	%	Pipeline imports	0.00	-5.72	-5.30	2.19	13.62	14.17	12.86
S6 - S1		**%**	**Total**	**-0.02**	**-1.18**	**-3.46**	**-6.53**	**-7.18**	**-9.85**	**-18.49**
S7 - S2	ROW	%	Consumption	0.00	-1.11	-6.34	-12.65	-15.22	-15.89	-20.45
S7 - S2	Australia + NZ	%	Consumption	0.00	6.45	13.95	-8.11	-15.38	-17.95	-18.58
S7 - S2	LAC	%	Consumption	0.00	0.24	-2.68	-11.57	-17.26	-23.22	-25.84
S7 - S2	Africa	%	Consumption	0.00	0.14	-0.64	-5.69	-6.94	-5.49	-7.29
S7 - S2	C Asia + East Eur	%	Consumption	-0.03	0.20	-0.34	-9.36	-17.69	-28.00	-36.87
S7 - S2	Russia	%	Consumption	0.00	0.14	-0.08	-0.03	-1.38	-9.73	-16.95

S7 - S2	China	%	Consumption	0.00	0.77	-2.53	-5.07	-5.36	-4.35	-12.74
S7 - S2	India	%	Consumption	0.00	-2.78	-4.60	-5.40	-4.49	-1.80	-3.61
S7 - S2	Middle East	%	Consumption	-0.26	-1.93	-0.90	-10.61	-17.74	-25.47	-33.04
S7 - S2	EU	%	Consumption	0.00	-2.32	-13.96	-15.78	-12.19	-12.29	-24.82
S7 - S2	Mexico	%	Consumption	0.00	1.61	1.50	-8.32	-17.30	-23.40	-26.56
S7 - S2	Canada	%	Consumption	0.00	3.38	-0.48	-14.94	-19.81	-19.94	-18.17
S7 - S2	USA	%	Consumption	0.02	-8.73	-13.03	-15.49	-16.34	-26.35	-34.86
S7 - S2		**%**	**Total**	**-0.03**	**-2.36**	**-5.43**	**-9.99**	**-12.44**	**-16.93**	**-23.40**
S7 - S2	ROW	%	Production	0.00	-0.79	-5.10	-8.66	-8.80	-8.27	-9.72
S7 - S2	Australia + NZ	%	Production	0.00	0.00	-0.17	-2.25	-4.38	-7.84	-16.51
S7 - S2	LAC	%	Production	0.00	-0.80	-1.51	-10.23	-13.76	-18.69	-22.64
S7 - S2	Africa	%	Production	0.00	-0.20	-1.56	-6.18	-7.86	-8.32	-10.94
S7 - S2	C Asia + East Eur	%	Production	0.00	-0.28	-0.21	-9.47	-16.91	-25.10	-32.62
S7 - S2	Russia	%	Production	0.00	-0.28	-0.52	-2.63	-4.96	-10.44	-21.40
S7 - S2	China	%	Production	0.00	-0.61	-1.47	-4.47	-4.91	-4.61	-12.18
S7 - S2	India	%	Production	0.00	-3.26	-1.68	-4.64	-4.45	-2.50	-5.82
S7 - S2	Middle East	%	Production	-0.20	-1.42	-1.79	-9.73	-14.84	-20.46	-27.22
S7 - S2	EU	%	Production	0.00	-1.79	-16.39	-18.20	-16.62	-16.37	-29.98
S7 - S2	Mexico	%	Production	0.00	-6.27	-6.27	-18.16	-26.34	-34.09	-38.59
S7 - S2	Canada	%	Production	0.00	0.43	-2.06	-8.47	-10.79	-12.54	-15.47
S7 - S2	USA	%	Production	0.01	-6.99	-14.06	-17.35	-18.73	-25.83	-32.13
S7 - S2		**%**	**Total**	**-0.03**	**-2.36**	**-5.43**	**-9.99**	**-12.44**	**-16.93**	**-23.40**
S7 - S2	ROW	%	LNG exports	0.00	-0.45	-2.17	-2.76	-4.67	-7.58	-12.19
S7 - S2	Australia + NZ	%	LNG exports	0.00	-0.17	-0.68	-1.96	-3.75	-6.69	-16.17
S7 - S2	LAC	%	LNG exports	0.00	-1.36	-7.87	-12.57	-12.96	-13.56	-18.49
S7 - S2	Africa	%	LNG exports	0.00	-0.38	-2.59	-6.98	-9.90	-13.53	-19.94
S7 - S2	C Asia + East Eur	%	LNG exports	0.00	-5.88	-21.43	-24.30	-20.82	-20.14	-28.12
S7 - S2	Russia	%	LNG exports	0.00	-0.26	-0.26	-3.00	-6.36	-12.70	-23.57
S7 - S2	China	%	LNG exports	0.00	0.00	-100.00	0.00	-20.00	-22.22	-30.77
S7 - S2	India	%	LNG exports	0.00	0.00	0.00	-22.22	-21.05	-27.78	-38.18
S7 - S2	Middle East	%	LNG exports	0.00	0.00	-5.21	-8.34	-8.00	-7.69	-12.65
S7 - S2	EU	%	LNG exports	0.00	2.17	-3.17	-13.79	-19.38	-23.30	-26.97
S7 - S2	Mexico	%	LNG exports	0.00	0.00	0.00	-33.33	-12.50	-17.65	-31.03
S7 - S2	Canada	%	LNG exports	0.00	0.00	-8.68	-6.85	-5.65	-6.12	-10.71
S7 - S2	USA	%	LNG exports	0.00	0.00	-21.75	-24.89	-25.98	-26.81	-28.88
S7 - S2		**%**	**Total**	**0.00**	**-0.23**	**-7.57**	**-11.05**	**-13.55**	**-15.88**	**-20.74**
S7 - S2	ROW	%	LNG imports	0.00	-1.68	-8.53	-14.54	-18.20	-22.52	-32.17
S7 - S2	Australia + NZ	%	LNG imports	0.00	0.00	0.00	0.00	0.00	0.00	-19.05
S7 - S2	LAC	%	LNG imports	0.00	2.64	-7.62	-14.73	-21.24	-25.91	-27.41
S7 - S2	Africa	%	LNG imports	0.00	0.86	-6.15	-8.09	-7.95	-5.18	-8.77
S7 - S2	C Asia + East Eur	%	LNG imports	0.00	1.25	-2.51	-10.54	-18.03	-26.61	-33.08
S7 - S2	Russia	%	LNG imports	0.00	0.00	0.00	3.41	1.01	-7.26	-11.81

S7 - S2	China	%	LNG imports	0.00	2.43	-3.15	-3.71	-3.69	-3.02	-5.14
S7 - S2	India	%	LNG imports	-0.25	-2.43	-6.63	-6.03	-4.72	-1.72	-2.24
S7 - S2	Middle East	%	LNG imports	0.00	-10.42	-14.29	-32.04	-36.90	-43.07	-50.32
S7 - S2	EU	%	LNG imports	0.00	-2.37	-20.96	-21.93	-18.96	-17.27	-26.55
S7 - S2	Mexico	%	LNG imports	0.00	0.75	-2.78	-12.82	-25.99	-35.15	-40.09
S7 - S2	Canada	%	LNG imports	0.00	0.00	0.00	-14.29	-48.00	-45.71	-40.54
S7 - S2	USA	%	LNG imports	0.00	-7.69	-21.74	-17.65	-20.00	-37.50	-47.06
S7 - S2		**%**	**Total**	**-0.05**	**-0.20**	**-7.60**	**-11.05**	**-13.54**	**-15.88**	**-20.75**
S7 - S2	ROW	%	Pipeline exports	0.00	-1.86	-13.62	-15.41	-3.70	-1.13	2.00
S7 - S2	Australia + NZ	%	Pipeline exports	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S7 - S2	LAC	%	Pipeline exports	0.00	-0.55	1.12	-4.97	-7.69	-15.18	-20.00
S7 - S2	Africa	%	Pipeline exports	0.00	-1.77	-9.76	-8.86	2.67	13.84	23.45
S7 - S2	C Asia + East Eur	%	Pipeline exports	0.00	0.00	-20.00	-25.00	0.00	0.00	0.00
S7 - S2	Russia	%	Pipeline exports	0.00	-0.97	-1.36	-6.53	-9.02	-11.27	-25.00
S7 - S2	China	%	Pipeline exports	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S7 - S2	India	%	Pipeline exports	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S7 - S2	Middle East	%	Pipeline exports	0.00	0.00	-33.33	0.00	25.00	16.67	50.00
S7 - S2	EU	%	Pipeline exports	0.00	-1.86	-15.44	-16.26	-3.26	-4.17	-8.00
S7 - S2	Mexico	%	Pipeline exports	0.00	0.00	0.00	-40.00	-46.67	-51.43	-51.72
S7 - S2	Canada	%	Pipeline exports	0.00	-2.39	-0.54	-1.68	-8.27	-16.96	-23.10
S7 - S2	USA	%	Pipeline exports	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S7 - S2		**%**	**Total**	**0.02**	**-1.14**	**-3.46**	**-6.31**	**-6.36**	**-8.19**	**-17.23**
S7 - S2	ROW	%	Pipeline imports	0.00	-1.20	-5.49	-12.50	-12.50	-6.41	-8.60
S7 - S2	Australia + NZ	%	Pipeline imports	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S7 - S2	LAC	%	Pipeline imports	0.00	-0.55	1.12	-4.97	-7.69	-15.18	-20.00
S7 - S2	Africa	%	Pipeline imports	0.00	0.00	5.71	-2.33	5.26	16.55	25.40
S7 - S2	C Asia + East Eur	%	Pipeline imports	0.00	0.00	1.17	-9.62	-21.48	-37.95	-54.77
S7 - S2	Russia	%	Pipeline imports	0.00	0.00	0.00	-1.45	-4.04	-17.58	-27.66
S7 - S2	China	%	Pipeline imports	0.00	1.01	-4.38	-8.75	-8.36	-5.41	-19.77
S7 - S2	India	%	Pipeline imports	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S7 - S2	Middle East	%	Pipeline imports	0.00	0.00	0.00	-33.33	-33.33	-45.83	-56.76
S7 - S2	EU	%	Pipeline imports	0.00	-2.47	-8.16	-9.18	-1.10	-0.23	-7.54
S7 - S2	Mexico	%	Pipeline imports	0.00	6.46	8.26	-0.56	-8.90	-12.58	-13.11
S7 - S2	Canada	%	Pipeline imports	0.00	4.22	0.00	-14.97	-17.16	-8.64	-2.04
S7 - S2	USA	%	Pipeline imports	0.00	-5.72	-5.30	2.68	8.76	5.47	-0.56

S7 - S2		**%**	**Total**	**-0.02**	**-1.18**	**-3.46**	**-6.33**	**-6.36**	**-8.16**	**-17.25**

Table D-12. Primary energy consumption by fuel in 2015 and under all scenarios in 2050 (Figure 13)

Scenario	Fuel	Units	2015	2050
S1: Reference Exports	biomass	EJ	30.07	95.84
S1: Reference Exports	biomass CCS	EJ	0	39.58
S1: Reference Exports	coal	EJ	165.11	153.04
S1: Reference Exports	coal CCS	EJ	0	8.96
S1: Reference Exports	gas	EJ	126.84	184.76
S1: Reference Exports	gas CCS	EJ	0	17.7
S1: Reference Exports	nuclear	EJ	9.67	20.48
S1: Reference Exports	oil	EJ	189	179.87
S1: Reference Exports	oil CCS	EJ	0	5.97
S1: Reference Exports	other renewables	EJ	18.54	99.96
S1: Reference Exports	**Total**	**EJ**	**539.23**	**806.16**
S2: Market Response	biomass	EJ	30.07	95.48
S2: Market Response	biomass CCS	EJ	0	39.77
S2: Market Response	coal	EJ	165.11	152.42
S2: Market Response	coal CCS	EJ	0	8.95
S2: Market Response	gas	EJ	126.84	185.96
S2: Market Response	gas CCS	EJ	0	17.96
S2: Market Response	nuclear	EJ	9.67	20.45
S2: Market Response	oil	EJ	189	179.6
S2: Market Response	oil CCS	EJ	0	5.96
S2: Market Response	other renewables	EJ	18.54	99.86
S2: Market Response	**Total**	**EJ**	**539.23**	**806.41**
S3: High Global Demand	biomass	EJ	30.07	100.36
S3: High Global Demand	biomass CCS	EJ	0	44.37
S3: High Global Demand	coal	EJ	165.11	151.31
S3: High Global Demand	coal CCS	EJ	0	10.39
S3: High Global Demand	gas	EJ	126.84	189.54
S3: High Global Demand	gas CCS	EJ	0	21.24
S3: High Global Demand	nuclear	EJ	9.67	21.48
S3: High Global Demand	oil	EJ	189	181.76
S3: High Global Demand	oil CCS	EJ	0	7.21
S3: High Global Demand	other renewables	EJ	18.54	104.99
S3: High Global Demand	**Total**	**EJ**	**539.23**	**832.65**
S4: Regional Import Limits	biomass	EJ	30.07	97.32
S4: Regional Import Limits	biomass CCS	EJ	0	39.07
S4: Regional Import Limits	coal	EJ	165.11	154.51
S4: Regional Import Limits	coal CCS	EJ	0	9.13

S4: Regional Import Limits	gas	EJ	126.83	182.31
S4: Regional Import Limits	gas CCS	EJ	0	17.73
S4: Regional Import Limits	nuclear	EJ	9.67	20.73
S4: Regional Import Limits	oil	EJ	189	179.54
S4: Regional Import Limits	oil CCS	EJ	0	5.93
S4: Regional Import Limits	other renewables	EJ	18.54	99.87
S4: Regional Import Limits	**Total**	**EJ**	**539.22**	**806.14**
S5: Low-cost Renewables	biomass	EJ	30.07	90.69
S5: Low-cost Renewables	biomass CCS	EJ	0	36.23
S5: Low-cost Renewables	coal	EJ	165.11	151.76
S5: Low-cost Renewables	coal CCS	EJ	0	7.88
S5: Low-cost Renewables	gas	EJ	126.84	179.4
S5: Low-cost Renewables	gas CCS	EJ	0	16.2
S5: Low-cost Renewables	nuclear	EJ	9.67	18.93
S5: Low-cost Renewables	oil	EJ	189	178.07
S5: Low-cost Renewables	oil CCS	EJ	0	4.89
S5: Low-cost Renewables	other renewables	EJ	18.54	117.95
S5: Low-cost Renewables	**Total**	**EJ**	**539.23**	**802**
S6: Energy Transition (Ref Exp)	biomass	EJ	30.06	35.59
S6: Energy Transition (Ref Exp)	biomass CCS	EJ	0	108.7
S6: Energy Transition (Ref Exp)	coal	EJ	165.11	44.43
S6: Energy Transition (Ref Exp)	coal CCS	EJ	0	35.07
S6: Energy Transition (Ref Exp)	gas	EJ	126.83	95.07
S6: Energy Transition (Ref Exp)	gas CCS	EJ	0	58.07
S6: Energy Transition (Ref Exp)	nuclear	EJ	9.67	34.96
S6: Energy Transition (Ref Exp)	oil	EJ	189	144.79
S6: Energy Transition (Ref Exp)	oil CCS	EJ	0	16.07
S6: Energy Transition (Ref Exp)	other renewables	EJ	18.54	142.92
S6: Energy Transition (Ref Exp)	**Total**	**EJ**	**539.21**	**715.67**
S7: Energy Transition	biomass	EJ	30.06	35.54
S7: Energy Transition	biomass CCS	EJ	0	108.7
S7: Energy Transition	coal	EJ	165.11	44.39
S7: Energy Transition	coal CCS	EJ	0	35.03
S7: Energy Transition	gas	EJ	126.83	95.24
S7: Energy Transition	gas CCS	EJ	0	58.41
S7: Energy Transition	nuclear	EJ	9.67	34.94
S7: Energy Transition	oil	EJ	189	144.71
S7: Energy Transition	oil CCS	EJ	0	16.04
S7: Energy Transition	other renewables	EJ	18.54	142.87
S7: Energy Transition	**Total**	**EJ**	**539.21**	**715.87**

Table D-13. GHG emissions by sector in 2015 and under all scenarios in 2050 (Figure 13)

Scenario	**Sector**	**2015**	**2050**
S1: Reference Exports	CO2 buildings	2.84	2.54
S1: Reference Exports	CO2 electricity	12.64	13.04
S1: Reference Exports	CO2 industry	11.75	11.04
S1: Reference Exports	CO2 other energy	0.51	1.60
S1: Reference Exports	CO2 transport	7.89	7.04
S1: Reference Exports	CH4 Energy	5.43	4.80
S1: Reference Exports	CH4 AgLanduse	3.36	4.97
S1: Reference Exports	N2O Energy	0.96	0.88
S1: Reference Exports	N2O AgLanduse	2.17	3.28
S1: Reference Exports	F-gases	1.01	1.66
S1: Reference Exports	CO2 bioenergy	0.00	-1.68
S1: Reference Exports	CO2 direct air capture	0.00	0.00
S1: Reference Exports	CO2 LUC	3.04	-1.42
S1: Reference Exports	**Total**	**51.58**	**47.74**
S2: Market Response	CO2 buildings	2.84	2.54
S2: Market Response	CO2 electricity	12.64	13.02
S2: Market Response	CO2 industry	11.75	11.04
S2: Market Response	CO2 other energy	0.51	1.60
S2: Market Response	CO2 transport	7.89	7.03
S2: Market Response	CH4 Energy	5.43	4.79
S2: Market Response	CH4 AgLanduse	3.36	4.97
S2: Market Response	N2O Energy	0.96	0.88
S2: Market Response	N2O AgLanduse	2.17	3.28
S2: Market Response	F-gases	1.01	1.67
S2: Market Response	CO2 bioenergy	0.00	-1.69
S2: Market Response	CO2 direct air capture	0.00	0.00
S2: Market Response	CO2 LUC	3.04	-1.39
S2: Market Response	**Total**	**51.58**	**47.72**
S3: High Global Demand	CO2 buildings	2.84	2.55
S3: High Global Demand	CO2 electricity	12.64	12.87
S3: High Global Demand	CO2 industry	11.75	11.27
S3: High Global Demand	CO2 other energy	0.51	1.63
S3: High Global Demand	CO2 transport	7.89	7.09
S3: High Global Demand	CH4 Energy	5.43	5.02
S3: High Global Demand	CH4 AgLanduse	3.36	5.34
S3: High Global Demand	N2O Energy	0.96	0.92
S3: High Global Demand	N2O AgLanduse	2.17	3.51
S3: High Global Demand	F-gases	1.01	1.76
S3: High Global Demand	CO2 bioenergy	0.00	-1.88
S3: High Global Demand	CO2 direct air capture	0.00	0.00

S3: High Global Demand	CO2 LUC	3.04	0.18
S3: High Global Demand	**Total**	**51.58**	**50.25**
S4: Regional Import Limits	CO2 buildings	2.84	2.44
S4: Regional Import Limits	CO2 electricity	12.64	13.13
S4: Regional Import Limits	CO2 industry	11.75	10.99
S4: Regional Import Limits	CO2 other energy	0.51	1.64
S4: Regional Import Limits	CO2 transport	7.89	7.05
S4: Regional Import Limits	CH4 Energy	5.43	4.75
S4: Regional Import Limits	CH4 AgLanduse	3.36	4.97
S4: Regional Import Limits	N2O Energy	0.96	0.88
S4: Regional Import Limits	N2O AgLanduse	2.17	3.28
S4: Regional Import Limits	F-gases	1.01	1.66
S4: Regional Import Limits	CO2 bioenergy	0.00	-1.65
S4: Regional Import Limits	CO2 direct air capture	0.00	0.00
S4: Regional Import Limits	CO2 LUC	3.04	-1.43
S4: Regional Import Limits	**Total**	**51.58**	**47.71**
S5: Low-cost Renewables	CO2 buildings	2.84	2.44
S5: Low-cost Renewables	CO2 electricity	12.64	12.78
S5: Low-cost Renewables	CO2 industry	11.75	11.08
S5: Low-cost Renewables	CO2 other energy	0.51	1.58
S5: Low-cost Renewables	CO2 transport	7.89	7.05
S5: Low-cost Renewables	CH4 Energy	5.43	4.74
S5: Low-cost Renewables	CH4 AgLanduse	3.36	4.99
S5: Low-cost Renewables	N2O Energy	0.96	0.87
S5: Low-cost Renewables	N2O AgLanduse	2.17	3.26
S5: Low-cost Renewables	F-gases	1.01	1.68
S5: Low-cost Renewables	CO2 bioenergy	0.00	-1.51
S5: Low-cost Renewables	CO2 direct air capture	0.00	0.00
S5: Low-cost Renewables	CO2 LUC	3.04	-1.50
S5: Low-cost Renewables	**Total**	**51.58**	**47.47**
S6: Energy Transition (Ref Exp)	CO2 buildings	2.84	1.12
S6: Energy Transition (Ref Exp)	CO2 electricity	12.64	2.16
S6: Energy Transition (Ref Exp)	CO2 industry	11.75	6.47
S6: Energy Transition (Ref Exp)	CO2 other energy	0.51	0.95
S6: Energy Transition (Ref Exp)	CO2 transport	7.89	5.00
S6: Energy Transition (Ref Exp)	CH4 Energy	5.43	3.25
S6: Energy Transition (Ref Exp)	CH4 AgLanduse	3.36	4.69
S6: Energy Transition (Ref Exp)	N2O Energy	0.96	0.59
S6: Energy Transition (Ref Exp)	N2O AgLanduse	2.17	3.03
S6: Energy Transition (Ref Exp)	F-gases	1.01	1.07
S6: Energy Transition (Ref Exp)	CO2 bioenergy	0.00	-6.81
S6: Energy Transition (Ref Exp)	CO2 direct air capture	0.00	-0.47
S6: Energy Transition (Ref Exp)	CO2 LUC	3.04	-3.92

S6: Energy Transition (Ref Exp)	**Total**	**51.58**	**17.13**
S7: Energy Transition	CO2 buildings	2.84	1.12
S7: Energy Transition	CO2 electricity	12.64	2.16
S7: Energy Transition	CO2 industry	11.75	6.47
S7: Energy Transition	CO2 other energy	0.51	0.95
S7: Energy Transition	CO2 transport	7.89	5.00
S7: Energy Transition	CH4 Energy	5.43	3.24
S7: Energy Transition	CH4 AgLanduse	3.36	4.69
S7: Energy Transition	N2O Energy	0.96	0.59
S7: Energy Transition	N2O AgLanduse	2.17	3.03
S7: Energy Transition	F-gases	1.01	1.07
S7: Energy Transition	CO2 bioenergy	0.00	-6.81
S7: Energy Transition	CO2 direct air capture	0.00	-0.47
S7: Energy Transition	CO2 LUC	3.04	-3.92
S7: Energy Transition	**Total**	**51.58**	**17.12**

Table D-1. U.S. GHG emissions and removals scenarios S6 and S7, by year (Figure 1)

Commented [IGC190]: NEMS tables start here and need to be renumbered.

CO_2 Emissions and Removals	Units	2020	2025	2030	2035	2040	2045	2050
Net CO_2 Emissions (Carbon Cap in FECM-NEMS)	Gt CO_2e	4.59	4.02	3.26	2.15	1.49	0.93	0.19
Sum of Remaining Emissions & Removals	Gt CO_2e	0.52	0.29	0.19	0.44	0.24	-0.07	-0.18

Table D-2. U.S. primary energy consumption, S1 through S5, tabulated by year (Figure 14)

Scenario	U.S. Primary Energy Consumption	Units	2020	2025	2030	2035	2040	2045	2050
S1: Reference Exports	Natural Gas	EJ	33.4	32.1	30.8	30.2	31.2	31.9	32.7
S1: Reference Exports	Coal	EJ	9.6	9.1	4.6	4.5	4.0	3.8	3.5
S1: Reference Exports	Petroleum / Other	EJ	44.4	47.3	46.1	44.8	43.8	44.3	45.2
S1: Reference Exports	Other Renewables	EJ	7.2	11.4	18.7	22.0	23.5	25.2	27.2
S1: Reference Exports	Biomass	EJ	3.1	3.2	3.2	3.2	3.2	3.3	3.4
S1: Reference Exports	**Total**	**EJ**	**97.7**	**103.1**	**103.4**	**104.7**	**105.8**	**108.4**	**111.9**
S2: Market Response	Natural Gas	EJ	33.4	32.1	30.8	30.1	30.9	32.0	32.4
S2: Market Response	Coal	EJ	9.6	9.2	4.7	4.6	4.2	4.1	3.9
S2: Market Response	Petroleum / Other	EJ	44.4	47.3	46.1	44.6	43.9	44.2	45.1
S2: Market Response	Other Renewables	EJ	7.2	11.4	18.7	22.1	24.4	26.2	28.6
S2: Market Response	Biomass	EJ	3.1	3.2	3.2	3.2	3.2	3.3	3.4

Scenario	U.S. Primary Energy Consumption	Units	2020	2025	2030	2035	2040	2045	2050
S2: Market Response	**Total**	**EJ**	**97.7**	**103.1**	**103.4**	**104.6**	**106.7**	**109.8**	**113.3**
S3: High Global Demand	Natural Gas	EJ	33.4	32.1	30.6	30.0	30.8	31.9	32.4
S3: High Global Demand	Coal	EJ	9.6	9.2	4.9	4.5	4.2	4.1	4.0
S3: High Global Demand	Petroleum / Other	EJ	44.4	47.3	46.1	44.6	44.0	44.5	45.3
S3: High Global Demand	Other Renewables	EJ	7.2	11.4	18.8	22.3	24.4	26.3	28.5
S3: High Global Demand	Biomass	EJ	3.1	3.2	3.2	3.2	3.2	3.3	3.4
S3: High Global Demand	**Total**	**EJ**	**97.7**	**103.1**	**103.5**	**104.8**	**106.8**	**110.0**	**113.5**
S4: Regional Import Limits	Natural Gas	EJ	33.4	32.1	31.4	31.2	31.7	32.5	32.6
S4: Regional Import Limits	Coal	EJ	9.6	9.2	4.2	4.2	3.7	3.6	3.4
S4: Regional Import Limits	Petroleum / Other	EJ	44.4	47.3	46.0	44.4	43.4	43.9	44.8
S4: Regional Import Limits	Other Renewables	EJ	7.2	11.4	18.2	20.6	22.7	24.3	27.2
S4: Regional Import Limits	Biomass	EJ	3.1	3.2	3.2	3.2	3.2	3.3	3.4
S4: Regional Import Limits	**Total**	**EJ**	**97.7**	**103.2**	**103.0**	**103.6**	**104.8**	**107.6**	**111.3**
S5: Low-cost Renewables	Natural Gas	EJ	33.4	32.0	30.0	28.7	29.2	29.3	28.6
S5: Low-cost Renewables	Coal	EJ	9.6	9.2	4.0	3.3	2.8	2.1	1.4
S5: Low-cost Renewables	Petroleum / Other	EJ	44.4	47.4	46.2	44.4	43.2	43.4	46.0
S5: Low-cost Renewables	Other Renewables	EJ	7.2	11.4	20.4	25.4	28.4	31.8	34.2
S5: Low-cost Renewables	Biomass	EJ	3.1	3.2	3.2	3.3	3.4	3.7	4.4
S5: Low-cost Renewables	**Total**	**EJ**	**97.7**	**103.2**	**103.8**	**105.2**	**107.0**	**110.2**	**114.6**
S2 – S1	Natural Gas	EJ	0.0	-0.1	0.0	-0.1	-0.3	0.1	-0.3
S2 – S1	Coal	EJ	0.0	0.1	0.1	0.1	0.2	0.3	0.4
S2 – S1	Petroleum / Other	EJ	0.0	0.0	0.0	-0.1	0.1	0.0	-0.1
S2 – S1	Other Renewables	EJ	0.0	0.0	0.0	0.1	0.9	1.0	1.4
S2 – S1	Biomass	EJ	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S2 – S1	**Total**	**EJ**	**0.0**	**0.0**	**0.0**	**-0.1**	**0.8**	**1.4**	**1.4**
S3 – S1	Natural Gas	EJ	0.0	0.0	-0.2	-0.2	-0.4	0.0	-0.3
S3 – S1	Coal	EJ	0.0	0.0	0.3	0.0	0.2	0.3	0.5
S3 – S1	Petroleum / Other	EJ	0.0	0.0	0.0	-0.1	0.2	0.2	0.1
S3 – S1	Other Renewables	EJ	0.0	0.0	0.0	0.3	0.9	1.1	1.3
S3 – S1	Biomass	EJ	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S3 – S1	**Total**	**EJ**	**0.0**	**0.0**	**0.1**	**0.1**	**0.9**	**1.6**	**1.6**
S4 – S1	Natural Gas	EJ	0.0	-0.1	0.6	1.0	0.5	0.6	-0.1
S4 – S1	Coal	EJ	0.0	0.1	-0.4	-0.3	-0.3	-0.2	-0.1

Scenario	U.S. Primary Energy Consumption	Units	2020	2025	2030	2035	2040	2045	2050
S4 – S1	Petroleum / Other	EJ	0.0	0.0	-0.1	-0.4	-0.4	-0.3	-0.4
S4 – S1	Other Renewables	EJ	0.0	0.0	-0.5	-1.4	-0.8	-0.8	0.0
S4 – S1	Biomass	EJ	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S4 – S1	**Total**	**EJ**	**0.0**	**0.0**	**-0.4**	**-1.1**	**-1.0**	**-0.8**	**-0.6**
S5 – S1	Natural Gas	EJ	0.0	-0.1	-0.8	-1.5	-2.1	-2.6	-4.0
S5 – S1	Coal	EJ	0.0	0.1	-0.6	-1.2	-1.2	-1.7	-2.1
S5 – S1	Petroleum / Other	EJ	0.0	0.1	0.2	-0.3	-0.6	-0.9	0.8
S5 – S1	Other Renewables	EJ	0.0	0.0	1.7	3.5	4.9	6.7	7.0
S5 – S1	Biomass	EJ	0.0	-0.1	0.0	0.1	0.1	0.4	1.0
S5 – S1	**Total**	**EJ**	**0.0**	**0.0**	**0.4**	**0.5**	**1.1**	**1.8**	**2.7**
S2 – S1	Natural Gas	% Difference	0.0	-0.2	0.0	-0.4	-1.1	0.3	-0.8
S2 – S1	Coal	% Difference	0.0	0.7	1.3	1.8	4.7	8.9	12.1
S2 – S1	Petroleum / Other	% Difference	0.0	0.0	0.0	-0.3	0.2	-0.1	-0.2
S2 – S1	Other Renewables	% Difference	0.0	0.0	-0.2	0.5	3.8	4.1	5.0
S2 – S1	Biomass	% Difference	0.0	0.0	0.0	0.0	-0.1	0.0	-0.1
S2 – S1	**Total**	**% Difference**	**0.0**	**0.0**	**0.0**	**-0.1**	**0.8**	**1.3**	**1.3**
S3 – S1	Natural Gas	% Difference	0.0	0.1	-0.6	-0.1	-0.1	-0.5	-0.1
S3 – S1	Coal	% Difference	0.0	-0.4	4.3	-1.1	0.2	0.3	2.3
S3 – S1	Petroleum / Other	% Difference	0.0	0.0	0.0	0.0	0.2	0.5	0.5
S3 – S1	Other Renewables	% Difference	0.0	0.0	0.4	1.1	0.1	0.3	-0.3
S3 – S1	Biomass	% Difference	0.0	0.0	0.2	0.1	0.1	0.1	0.0
S3 – S1	**Total**	**% Difference**	**0.0**	**0.0**	**0.1**	**0.1**	**0.1**	**0.2**	**0.2**
S4 – S1	Natural Gas	% Difference	0.0	-0.2	1.9	3.4	1.6	1.8	-0.3
S4 – S1	Coal	% Difference	0.0	0.9	-9.1	-7.5	-8.5	-4.8	-2.1
S4 – S1	Petroleum / Other	% Difference	0.0	0.0	-0.1	-0.8	-0.9	-0.8	-0.9
S4 – S1	Other Renewables	% Difference	0.0	0.0	-2.7	-6.2	-3.3	-3.3	-0.1
S4 – S1	Biomass	% Difference	0.0	0.0	0.1	0.2	-0.2	-0.2	-0.5
S4 – S1	**Total**	**% Difference**	**0.0**	**0.0**	**-0.4**	**-1.0**	**-1.0**	**-0.7**	**-0.5**
S5 – S1	Natural Gas	% Difference	0.0	-0.4	-2.7	-4.9	-6.6	-8.3	-12.3
S5 – S1	Coal	% Difference	0.0	0.7	-12.0	-25.9	-29.1	-44.9	-59.2
S5 – S1	Petroleum / Other	% Difference	0.0	0.3	0.4	-0.7	-1.4	-2.1	1.8
S5 – S1	Other Renewables	% Difference	0.0	0.4	8.8	15.7	20.8	26.5	25.7
S5 – S1	Biomass	% Difference	0.0	-2.5	0.1	1.6	3.5	12.8	28.9

Scenario	U.S. Primary Energy Consumption	Units	2020	2025	2030	2035	2040	2045	2050
S5 – S1	**Total**	**% Difference**	**0.0**	**0.0**	**0.4**	**0.5**	**1.1**	**1.7**	**2.4**

Table D-3. U.S. primary energy consumption, S6 and S7, by year (Figure 15)

Scenario	U.S. Primary Energy Consumption	Units	2020	2025	2030	2035	2040	2045	2050
S6: Energy Transition (Ref Exp)	Natural Gas	EJ	33.4	35.0	29.8	30.8	33.1	37.5	44.8
S6: Energy Transition (Ref Exp)	Coal	EJ	9.6	1.9	1.8	1.9	1.6	1.6	1.5
S6: Energy Transition (Ref Exp)	Petroleum / Other	EJ	44.5	47.7	44.5	40.1	37.6	36.6	36.2
S6: Energy Transition (Ref Exp)	Other Renewables	EJ	7.2	11.7	19.5	26.1	29.6	29.9	30.9
S6: Energy Transition (Ref Exp)	Biomass	EJ	3.2	3.7	4.6	5.9	6.7	7.5	8.1
S6: Energy Transition (Ref Exp)	**Total**	**EJ**	**97.8**	**99.9**	**100.3**	**104.8**	**108.7**	**113.0**	**121.5**
S7: Energy Transition	Natural Gas	EJ	33.4	34.9	30.0	30.3	32.8	37.1	44.4
S7: Energy Transition	Coal	EJ	9.6	1.9	2.1	1.9	1.9	1.9	1.6
S7: Energy Transition	Petroleum / Other	EJ	44.5	47.7	44.5	40.0	37.1	36.3	35.8
S7: Energy Transition	Other Renewables	EJ	7.2	11.7	19.0	25.9	29.4	29.5	30.5
S7: Energy Transition	Biomass	EJ	3.2	3.7	4.6	5.7	6.7	7.6	8.2
S7: Energy Transition	**Total**	**EJ**	**97.8**	**100.0**	**100.2**	**103.8**	**107.9**	**112.5**	**120.6**
S7 – S6	Natural Gas	EJ	0.0	0.0	0.1	-0.5	-0.4	-0.4	-0.4
S7 – S6	Coal	EJ	0.0	0.0	0.2	0.1	0.3	0.3	0.2
S7 – S6	Petroleum / Other	EJ	0.0	0.0	0.0	-0.2	-0.5	-0.2	-0.4
S7 – S6	Other Renewables	EJ	0.0	0.0	-0.6	-0.1	-0.2	-0.3	-0.4
S7 – S6	Biomass	EJ	0.0	0.0	0.1	-0.2	0.0	0.1	0.1
S7 – S6	**Total**	**EJ**	**0.0**	**0.0**	**-0.1**	**-1.0**	**-0.8**	**-0.5**	**-0.9**
S7 – S6	Natural Gas	% Difference	0.0	-0.1	0.5	-1.7	-1.1	-1.0	-0.9
S7 – S6	Coal	% Difference	0.0	1.9	11.9	3.5	16.3	21.0	10.7
S7 – S6	Petroleum / Other	% Difference	0.0	0.0	0.0	-0.5	-1.2	-0.7	-1.1
S7 – S6	Other Renewables	% Difference	0.0	0.0	-2.8	-0.6	-0.7	-1.1	-1.2
S7 – S6	Biomass	% Difference	0.0	0.8	1.3	-3.6	-0.6	1.5	1.5
S7 – S6	**Total**	**% Difference**	**0.0**	**0.0**	**-0.1**	**-1.0**	**-0.7**	**-0.4**	**-0.7**

Table D-4. Total U.S. natural gas production, consumption, and export volumes, S1 through S5, by year (Figure 16)

Scenario	Total U.S. Natural Gas Volumes	Units	2020	2025	2030	2035	2040	2045	2050
S1: Reference Exports	NG Production	Tcf	33.5	35.8	37.0	39.5	40.9	41.4	42.0
S2: Market Response	NG Production	Tcf	33.5	36.2	37.5	39.4	43.7	47.5	49.0
S3: High Global Demand	NG Production	Tcf	33.5	36.2	37.3	39.5	43.9	47.7	49.5
S4: Regional Import Limits	NG Production	Tcf	33.5	36.2	35.8	36.4	37.6	39.8	40.7
S5: Low-cost Renewables	NG Production	Tcf	33.5	36.1	36.8	38.2	42.3	45.0	45.7
S1: Reference Exports	NG Consumption	Tcf	30.5	29.4	28.2	27.6	28.5	29.2	29.8
S2: Market Response	NG Consumption	Tcf	30.5	29.3	28.2	27.5	28.2	29.2	29.6
S3: High Global Demand	NG Consumption	Tcf	30.5	29.3	28.0	27.4	28.2	29.1	29.6
S4: Regional Import Limits	NG Consumption	Tcf	30.5	29.3	28.7	28.5	29.0	29.7	29.8
S5: Low-cost Renewables	NG Consumption	Tcf	30.5	29.2	27.4	26.2	26.6	26.7	26.2
S1: Reference Exports	LNG Exports	Tcf	2.4	4.9	6.9	9.5	10.0	10.0	10.0
S2: Market Response	LNG Exports	Tcf	2.4	4.9	6.9	9.1	12.8	15.6	17.2
S3: High Global Demand	LNG Exports	Tcf	2.4	4.9	6.9	9.2	13.0	16.0	17.8
S4: Regional Import Limits	LNG Exports	Tcf	2.4	4.9	4.4	4.8	5.6	7.2	8.4
S5: Low-cost Renewables	LNG Exports	Tcf	2.4	4.9	6.9	9.1	12.8	15.6	17.2
S2 – S1	NG Production	Tcf	0.0	0.4	0.5	0.0	2.8	6.1	7.1
S3 – S1	NG Production	Tcf	0.0	0.4	0.3	0.1	3.1	6.3	7.6
S4 – S1	NG Production	Tcf	0.0	0.4	-1.3	-3.0	-3.3	-1.6	-1.3
S5 – S1	NG Production	Tcf	0.0	0.3	-0.2	-1.2	1.4	3.6	3.8
S2 – S1	NG Consumption	Tcf	0.0	-0.1	0.0	-0.1	-0.3	0.1	-0.2
S3 – S1	NG Consumption	Tcf	0.0	0.0	-0.2	-0.2	-0.4	0.0	-0.3
S4 – S1	NG Consumption	Tcf	0.0	-0.1	0.6	0.9	0.4	0.5	-0.1
S5 – S1	NG Consumption	Tcf	0.0	-0.1	-0.8	-1.3	-1.9	-2.4	-3.7
S2 – S1	LNG Exports	Tcf	0.0	0.0	0.0	-0.4	2.8	5.7	7.3
S3 – S1	LNG Exports	Tcf	0.0	0.0	0.0	-0.3	3.0	6.0	7.8
S4 – S1	LNG Exports	Tcf	0.0	0.0	-2.4	-4.6	-4.4	-2.8	-1.6
S5 – S1	LNG Exports	Tcf	0.0	0.0	0.0	-0.4	2.8	5.6	7.2
S2 – S1	NG Production	% Difference	0.0	1.1	1.3	-0.1	7.0	14.8	16.9
S3 – S1	NG Production	% Difference	0.0	1.1	0.9	0.1	7.5	15.3	18.1
S4 – S1	NG Production	% Difference	0.0	1.1	-3.4	-7.7	-8.0	-3.8	-3.1
S5 – S1	NG Production	% Difference	0.0	0.9	-0.6	-3.0	3.3	8.7	9.0

Scenario	Total U.S. Natural Gas Volumes	Units	2020	2025	2030	2035	2040	2045	2050
S2 – S1	NG Consumption	% Difference	0.0	-0.2	0.0	-0.4	-1.1	0.3	-0.8
S3 – S1	NG Consumption	% Difference	0.0	-0.1	-0.7	-0.6	-1.2	-0.2	-0.9
S4 – S1	NG Consumption	% Difference	0.0	-0.2	2.0	3.4	1.6	1.8	-0.3
S5 – S1	NG Consumption	% Difference	0.0	-0.4	-2.7	-4.9	-6.6	-8.3	-12.3
S2 – S1	LNG Exports	% Difference	0.0	0.0	0.0	-4.2	27.6	56.7	72.7
S3 – S1	LNG Exports	% Difference	0.0	0.0	0.0	-2.9	29.9	60.6	78.3
S4 – S1	LNG Exports	% Difference	0.0	0.0	-35.6	-48.9	-44.3	-27.6	-15.7
S5 – S1	LNG Exports	% Difference	0.0	0.0	0.0	-4.0	27.7	56.1	72.5

*1 Tcf in a non-leap year is equivalent to 2.74 Bcf/d

Table D-5. Total U.S. natural gas production, consumption, and export volumes, S6 and S7, by year (Figure 17)

Scenario	Total U.S. Natural Gas Volumes	Units	2020	2025	2030	2035	2040	2045	2050
S6: Energy Transition (Ref Exp)	NG Production	Tcf	34.1	38.5	35.1	37.6	42.6	47.4	54.7
S7: Energy Transition	NG Production	Tcf	34.1	38.5	35.3	37.1	42.3	48.6	56.5
S6: Energy Transition (Ref Exp)	NG Consumption	Tcf	30.5	32.0	27.4	28.4	30.8	35.0	41.9
S7: Energy Transition	NG Consumption	Tcf	30.5	31.9	27.5	27.9	30.5	34.7	41.5
S6: Energy Transition (Ref Exp)	LNG Exports	Tcf	2.4	4.9	5.4	6.8	9.4	10.0	10.0
S7: Energy Transition	LNG Exports	Tcf	2.4	4.9	5.4	6.8	9.4	11.4	12.3
S7 – S6	NG Production	Tcf	0.0	0.0	0.1	-0.4	-0.3	1.2	1.8
S7 – S6	NG Consumption	Tcf	0.0	0.0	0.1	-0.5	-0.3	-0.3	-0.3
S7 – S6	LNG Exports	Tcf	0.0	0.0	0.0	0.0	0.0	1.5	2.3
S7 – S6	NG Production	% Difference	0.0	-0.1	0.4	-1.1	-0.8	2.4	3.4
S7 – S6	NG Consumption	% Difference	0.0	-0.1	0.5	-1.7	-1.1	-0.9	-0.8
S7 – S6	LNG Exports	% Difference	0.0	0.0	0.0	0.0	0.0	14.8	22.9

*1 Tcf in a non-leap year is equivalent to 2.74 Bcf/d

Table D-6. U.S. natural gas Henry Hub price, S1 through S7, tabulated by year (Figure 18)

Scenario	Units	2020	2025	2030	2035	2040	2045	2050
S1: Reference Exports	$2022/Mcf	2.31	3.63	3.04	3.81	4.08	4.05	3.88
S2: Market Response	$2022/Mcf	2.31	3.70	3.09	3.77	4.50	4.61	5.09
S3: High Global Demand	$2022/Mcf	2.31	3.69	3.06	3.78	4.54	4.65	5.15
S4: Regional Import Limits	$2022/Mcf	2.31	3.68	2.63	3.03	3.52	3.73	4.12
S5: Low-cost Renewables	$2022/Mcf	2.31	3.68	3.00	3.65	4.38	4.41	4.67

Scenario	Units	2020	2025	2030	2035	2040	2045	2050
S2 – S1	$2022/Mcf	0.00	0.07	0.05	-0.04	0.42	0.56	1.22
S3 – S1	$2022/Mcf	0.00	0.07	0.02	-0.03	0.46	0.60	1.27
S4 – S1	$2022/Mcf	0.00	0.06	-0.41	-0.78	-0.56	-0.32	0.24
S5 – S1	$2022/Mcf	0.00	0.06	-0.04	-0.16	0.30	0.37	0.80
S2 – S1	% Difference	0.0	2.0	1.7	-1.1	10.4	13.9	31.4
S3 – S1	% Difference	0.0	1.9	0.5	-0.8	11.4	14.8	32.8
S4 – S1	% Difference	0.0	1.6	-13.5	-20.6	-13.6	-7.9	6.3
S5 – S1	% Difference	0.0	1.6	-1.2	-4.2	7.3	9.0	20.5
S6: Energy Transition (Ref Exp)	$2022/Mcf	2.35	3.80	3.36	4.42	4.67	5.46	6.34
S7: Energy Transition	$2022/Mcf	2.35	3.80	3.42	4.34	4.70	5.40	6.20
S7 – S6	$2022/Mcf	0.00	0.00	0.06	-0.08	0.03	-0.06	-0.14
S7 – S6	% Difference	0.0	0.0	1.8	-1.8	0.6	-1.1	-2.2

Table D-7. U.S. real GDP, S1 through S5, by year (Figure 19)

Scenario	Units	2020	2025	2030	2035	2040	2045	2050
S1: Reference Exports	$2022, Trillion	23.3	25.9	28.4	31.1	34.5	38.2	42.4
S2: Market Response	$2022, Trillion	23.3	25.9	28.4	31.1	34.5	38.3	42.3
S3: High Global Demand	$2022, Trillion	23.3	25.9	28.4	31.1	34.5	38.3	42.3
S4: Regional Import Limits	$2022, Trillion	23.3	25.9	28.4	31.1	34.4	38.2	42.3
S5: Low-cost Renewables	$2022, Trillion	23.3	25.9	28.4	31.1	34.4	38.3	42.3
S2 – S1	$2022, Trillion	0.0	0.0	0.0	0.0	0.0	0.0	-0.1
S3 – S1	$2022, Trillion	0.0	0.0	0.0	0.0	0.0	0.0	-0.1
S4 – S1	$2022, Trillion	0.0	0.0	0.0	0.0	0.0	0.0	-0.1
S5 – S1	$2022, Trillion	0.0	0.0	0.0	0.0	0.0	0.0	-0.1
S2 – S1	% Difference	0.0	0.0	0.0	0.0	0.0	0.1	-0.3
S3 – S1	% Difference	0.0	0.0	0.0	0.0	0.0	0.1	-0.2
S4 – S1	% Difference	0.0	0.0	0.0	0.0	-0.1	0.0	-0.2
S5 – S1	% Difference	0.0	-0.1	0.1	0.0	0.0	0.1	-0.2

Table D-8. U.S. residential natural gas prices, S1 through S5, by year (Figure 20)

Scenario	Units	2020	2025	2030	2035	2040	2045	2050
S1: Reference Exports	$2022/Mcf	12.09	12.58	11.37	11.96	12.33	12.75	12.74

Scenario	Units	2020	2025	2030	2035	2040	2045	2050
S2: Market Response	$2022/Mcf	12.09	12.65	11.41	11.93	12.56	12.69	13.28
S3: High Global Demand	$2022/Mcf	12.09	12.65	11.37	11.91	12.55	12.68	13.28
S4: Regional Import Limits	$2022/Mcf	12.09	12.65	11.12	11.53	12.04	12.64	12.92
S5: Low-cost Renewables	$2022/Mcf	12.09	12.58	11.33	11.83	12.41	12.48	13.00
S2 – S1	$2022/Mcf	0.00	0.06	0.04	-0.03	0.23	-0.06	0.54
S3 – S1	$2022/Mcf	0.00	0.06	-0.01	-0.05	0.23	-0.07	0.54
S4 – S1	$2022/Mcf	0.00	0.06	-0.25	-0.43	-0.29	-0.11	0.18
S5 – S1	$2022/Mcf	0.00	0.00	-0.05	-0.14	0.08	-0.28	0.26
S2 – S1	% Difference	0.0	0.5	0.3	-0.3	1.9	-0.5	4.2
S3 – S1	% Difference	0.0	0.5	-0.1	-0.4	1.8	-0.6	4.2
S4 – S1	% Difference	0.0	0.5	-2.2	-3.6	-2.3	-0.9	1.4
S5 – S1	% Difference	0.0	0.0	-0.4	-1.1	0.7	-2.2	2.0

Table D-9. U.S. value of industrial shipments and real consumption, S1 through S5, by year (Figure 21)

Scenario	Total U.S. Value	Units	2020	2025	2030	2035	2040	2045	2050
S1: Reference Exports	Industrial Shipments	$2022, Trillion	11.0	12.0	12.8	13.5	14.3	15.2	16.2
S2: Market Response	Industrial Shipments	$2022, Trillion	11.0	12.0	12.8	13.5	14.4	15.3	16.2
S3: High Global Demand	Industrial Shipments	$2022, Trillion	11.0	12.0	12.8	13.5	14.4	15.3	16.2
S4: Regional Import Limits	Industrial Shipments	$2022, Trillion	11.0	12.0	12.8	13.4	14.3	15.2	16.1
S5: Low-cost Renewables	Industrial Shipments	$2022, Trillion	11.0	12.0	12.8	13.5	14.3	15.3	16.2
S1: Reference Exports	Real Consumption	$2022, Trillion	16.0	18.5	20.8	23.4	26.4	29.8	33.5
S2: Market Response	Real Consumption	$2022, Trillion	16.0	18.4	20.8	23.4	26.4	29.8	33.5
S3: High Global Demand	Real Consumption	$2022, Trillion	16.0	18.4	20.8	23.4	26.4	29.8	33.5
S4: Regional Import Limits	Real Consumption	$2022, Trillion	16.0	18.5	20.8	23.5	26.4	29.8	33.5
S5: Low-cost Renewables	Real Consumption	$2022, Trillion	16.0	18.4	20.8	23.4	26.4	29.8	33.5
S2 – S1	Industrial Shipments	$2022, Trillion	0.0	0.0	0.0	0.0	0.0	0.1	0.0
S3 – S1	Industrial Shipments	$2022, Trillion	0.0	0.0	0.0	0.0	0.0	0.1	0.0
S4 – S1	Industrial Shipments	$2022, Trillion	0.0	0.0	0.0	0.0	-0.1	0.0	-0.1
S5 – S1	Industrial Shipments	$2022, Trillion	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S2 – S1	Real Consumption	$2022, Trillion	0.0	0.0	0.0	0.0	0.0	0.0	-0.1
S3 – S1	Real Consumption	$2022, Trillion	0.0	0.0	0.0	0.0	0.0	0.0	-0.1
S4 – S1	Real Consumption	$2022, Trillion	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S5 – S1	Real Consumption	$2022, Trillion	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Scenario	Total U.S. Value	Units	2020	2025	2030	2035	2040	2045	2050
S2 – S1	Industrial Shipments	% Difference	0.0	0.0	0.0	-0.1	0.3	0.7	0.1
S3 – S1	Industrial Shipments	% Difference	0.0	0.0	0.0	-0.1	0.3	0.7	0.2
S4 – S1	Industrial Shipments	% Difference	0.0	0.0	-0.1	-0.2	-0.4	-0.2	-0.4
S5 – S1	Industrial Shipments	% Difference	0.0	-0.1	0.1	-0.2	0.0	0.3	0.0
S2 – S1	Real Consumption	% Difference	0.0	0.0	0.0	0.0	0.0	0.1	-0.2
S3 – S1	Real Consumption	% Difference	0.0	0.0	0.0	0.0	0.0	0.1	-0.2
S4 – S1	Real Consumption	% Difference	0.0	0.0	0.0	0.1	-0.1	0.0	-0.1
S5 – S1	Real Consumption	% Difference	0.0	-0.1	0.1	0.0	0.0	0.1	-0.1

Table D-10. U.S. LNG export revenues, S1 through S5, by year (Figure 22)

Scenario	Units	2020	2025	2030	2035	2040	2045	2050
S1: Reference Exports	$2022, Billion	37.1	25.6	40.3	60.8	69.2	69.8	69.9
S2: Market Response	$2022, Billion	37.1	25.6	40.3	58.8	84.9	106.3	118.3
S3: High Global Demand	$2022, Billion	37.1	25.6	40.5	59.7	86.3	108.4	121.5
S4: Regional Import Limits	$2022, Billion	37.1	26.0	30.6	36.4	40.8	52.2	60.1
S5: Low-cost Renewables	$2022, Billion	37.0	25.5	40.2	58.7	84.5	104.5	115.7
S2 – S1	$2022, Billion	0.0	0.0	0.0	-2.0	15.7	36.6	48.4
S3 – S1	$2022, Billion	-0.1	0.0	0.2	-1.1	17.1	38.6	51.6
S4 – S1	$2022, Billion	0.0	0.4	-9.7	-24.3	-28.4	-17.5	-9.8
S5 – S1	$2022, Billion	-0.1	-0.1	-0.2	-2.1	15.3	34.7	45.8
S2 – S1	% Difference	0.0	0.0	0.0	-3.3	22.6	52.4	69.3
S3 – S1	% Difference	-0.2	0.0	0.5	-1.7	24.7	55.4	73.8
S4 – S1	% Difference	0.0	1.5	-24.0	-40.0	-41.1	-25.1	-14.0
S5 – S1	% Difference	-0.3	-0.4	-0.4	-3.4	22.0	49.8	65.5

Table D-11. Total U.S. CO_2 emissions from fossil fuel combustion, S1 through S5, by year (Figure 23)

Scenario	Units	2020	2025	2030	2035	2040	2045	2050
S1: Reference Exports	Gt CO_2	4.58	4.55	4.00	3.89	3.87	3.89	3.94
S2: Market Response	Gt CO_2	4.58	4.56	4.01	3.89	3.87	3.94	3.97
S3: High Global Demand	Gt CO_2	4.58	4.55	4.02	3.89	3.88	3.94	3.98
S4: Regional Import Limits	Gt CO_2	4.58	4.56	3.99	3.90	3.86	3.90	3.93
S5: Low-cost Renewables	Gt CO_2	4.58	4.56	3.91	3.71	3.67	3.62	3.57

Scenario	Units	2020	2025	2030	2035	2040	2045	2050
S2 – S1	Gt CO_2	0.00	0.00	0.00	0.00	0.00	0.04	0.03
S3 – S1	Gt CO_2	0.00	0.00	0.01	0.00	0.01	0.04	0.04
S4 – S1	Gt CO_2	0.00	0.00	-0.02	0.01	-0.01	0.01	-0.02
S5 – S1	Gt CO_2	0.00	0.01	-0.09	-0.18	-0.21	-0.28	-0.38
S2 – S1	% Difference	0.0	0.0	0.1	0.0	0.0	1.1	0.7
S3 – S1	% Difference	0.0	0.0	0.3	-0.1	0.1	1.1	0.9
S4 – S1	% Difference	0.0	0.1	-0.4	0.3	-0.3	0.3	-0.4
S5 – S1	% Difference	0.0	0.1	-2.3	-4.6	-5.3	-7.1	-9.6

Table D-12. U.S. CO_2 emissions, fossil fuel combustion and removals, S6 and S7, by year (Figure 24)

Scenario	CO_2 Emissions and Removals	Units	2020	2025	2030	2035	2040	2045	2050
S6: Energy Transition (Ref Exp)	Emissions	Gt CO_2	4.58	4.03	3.32	2.80	2.55	2.43	2.37
S7: Energy Transition	Emissions	Gt CO_2	4.58	4.02	3.33	2.80	2.53	2.41	2.35
S6: Energy Transition (Ref Exp)	Removals	Gt CO_2	0.00	0.00	0.05	0.65	1.06	1.49	2.16
S7: Energy Transition	Removals	Gt CO_2	0.00	0.00	0.07	0.60	1.04	1.48	2.13
S7 – S6	Emissions	Gt CO_2	0.00	-0.01	0.01	-0.01	-0.02	-0.02	-0.02
S7 – S6	Removals	Gt CO_2	0.00	0.00	0.02	-0.05	-0.01	-0.01	-0.03
S7 – S6	Emissions	% Difference	0.0	-0.1	0.2	-0.3	-0.8	-0.7	-1.0
S7 – S6	Removals	% Difference	0.0	-1.0	52.1	-8.3	-1.3	-0.7	-1.2

Table D-13. U.S. regional onshore natural gas production, S1 through S5, by year (Figure B-1)

Scenario	Natural Gas Volumes	Units	2020	2025	2030	2035	2040	2045	2050
S1: Reference Exports	East	Tcf	12.0	12.3	13.1	14.3	14.6	15.1	15.5
S1: Reference Exports	Gulf Coast	Tcf	7.0	9.5	9.2	10.5	11.2	11.0	11.0
S1: Reference Exports	Southwest	Tcf	5.1	5.8	6.0	6.4	6.8	7.1	7.4
S1: Reference Exports	Other Onshore	Tcf	8.2	6.9	6.9	6.5	6.6	6.4	6.3
S1: Reference Exports	**Total**	**Tcf**	**32.4**	**34.5**	**35.3**	**37.7**	**39.3**	**39.6**	**40.1**
S2: Market Response	East	Tcf	12.0	12.5	13.3	14.4	15.2	15.7	16.1
S2: Market Response	Gulf Coast	Tcf	7.0	9.6	9.4	10.3	12.6	14.3	15.1
S2: Market Response	Southwest	Tcf	5.1	5.8	6.1	6.4	7.3	8.3	9.1
S2: Market Response	Other Onshore	Tcf	8.2	7.0	7.0	6.6	7.0	7.4	7.5

Scenario	Natural Gas Volumes	Units	2020	2025	2030	2035	2040	2045	2050
S2: Market Response	**Total**	**Tcf**	**32.4**	**34.9**	**35.7**	**37.7**	**42.1**	**45.7**	**47.8**
S3: High Global Demand	East	Tcf	12.0	12.5	13.2	14.4	15.1	15.7	16.1
S3: High Global Demand	Gulf Coast	Tcf	7.0	9.6	9.4	10.4	12.8	14.5	15.4
S3: High Global Demand	Southwest	Tcf	5.1	5.8	6.1	6.4	7.3	8.3	9.2
S3: High Global Demand	Other Onshore	Tcf	8.2	7.0	7.0	6.6	7.1	7.4	7.6
S3: High Global Demand	**Total**	**Tcf**	**32.4**	**34.9**	**35.6**	**37.8**	**42.3**	**45.9**	**48.3**
S4: Regional Import Limits	East	Tcf	12.0	12.5	12.7	13.6	14.1	14.7	15.4
S4: Regional Import Limits	Gulf Coast	Tcf	7.0	9.7	8.8	8.9	9.5	10.3	10.6
S4: Regional Import Limits	Southwest	Tcf	5.1	5.8	5.8	5.9	6.1	6.8	7.2
S4: Regional Import Limits	Other Onshore	Tcf	8.2	7.0	6.8	6.3	6.3	6.3	6.1
S4: Regional Import Limits	**Total**	**Tcf**	**32.4**	**34.9**	**34.0**	**34.7**	**36.0**	**38.1**	**39.3**
S5: Low-cost Renewables	East	Tcf	12.0	12.4	12.8	13.6	14.3	14.4	14.2
S5: Low-cost Renewables	Gulf Coast	Tcf	7.0	9.6	9.3	10.1	12.3	13.6	14.4
S5: Low-cost Renewables	Southwest	Tcf	5.1	5.8	6.0	6.4	7.2	8.1	8.7
S5: Low-cost Renewables	Other Onshore	Tcf	8.2	7.0	6.9	6.5	6.9	7.1	7.2
S5: Low-cost Renewables	**Total**	**Tcf**	**32.4**	**34.8**	**35.1**	**36.5**	**40.7**	**43.2**	**44.4**
S2 – S1	East	Tcf	0.0	0.2	0.2	0.0	0.5	0.6	0.6
S2 – S1	Gulf Coast	Tcf	0.0	0.1	0.2	-0.2	1.3	3.3	4.2
S2 – S1	Southwest	Tcf	0.0	0.0	0.0	0.0	0.5	1.2	1.7
S2 – S1	Other Onshore	Tcf	0.0	0.1	0.1	0.1	0.4	1.0	1.2
S2 – S1	**Total**	**Tcf**	**0.0**	**0.4**	**0.5**	**-0.1**	**2.8**	**6.0**	**7.7**
S3 – S1	East	Tcf	0.0	0.2	0.1	0.0	0.5	0.5	0.7
S3 – S1	Gulf Coast	Tcf	0.0	0.1	0.2	-0.1	1.5	3.5	4.4
S3 – S1	Southwest	Tcf	0.0	0.0	0.0	0.0	0.6	1.2	1.7
S3 – S1	Other Onshore	Tcf	0.0	0.1	0.1	0.1	0.5	1.0	1.3
S3 – S1	**Total**	**Tcf**	**0.0**	**0.4**	**0.3**	**0.1**	**3.1**	**6.3**	**8.2**
S4 – S1	East	Tcf	0.0	0.2	-0.4	-0.7	-0.6	-0.4	0.0
S4 – S1	Gulf Coast	Tcf	0.0	0.2	-0.4	-1.5	-1.7	-0.6	-0.3
S4 – S1	Southwest	Tcf	0.0	0.0	-0.3	-0.6	-0.6	-0.3	-0.2
S4 – S1	Other Onshore	Tcf	0.0	0.0	-0.2	-0.2	-0.3	-0.2	-0.2
S4 – S1	**Total**	**Tcf**	**0.0**	**0.4**	**-1.3**	**-3.0**	**-3.2**	**-1.5**	**-0.7**
S5 – S1	East	Tcf	0.0	0.1	-0.3	-0.8	-0.4	-0.7	-1.3
S5 – S1	Gulf Coast	Tcf	0.0	0.1	0.1	-0.3	1.1	2.6	3.5

Scenario	Natural Gas Volumes	Units	2020	2025	2030	2035	2040	2045	2050
S5 – S1	Southwest	Tcf	0.0	0.0	0.0	-0.1	0.4	1.0	1.3
S5 – S1	Other Onshore	Tcf	0.0	0.1	0.0	0.0	0.3	0.7	0.9
S5 – S1	**Total**	**Tcf**	**0.0**	**0.3**	**-0.2**	**-1.2**	**1.4**	**3.6**	**4.4**
S2 – S1	East	% Difference	0.0	1.8	1.5	0.2	3.7	3.9	4.0
S2 – S1	Gulf Coast	% Difference	0.0	1.0	1.8	-1.6	11.8	30.1	38.1
S2 – S1	Southwest	% Difference	0.0	0.2	0.4	-0.1	7.9	16.6	22.3
S2 – S1	Other Onshore	% Difference	0.0	0.8	1.2	1.4	6.7	15.3	19.8
S2 – S1	**Total**	**% Difference**	**0.0**	**1.1**	**1.3**	**-0.1**	**7.2**	**15.2**	**19.2**
S3 – S1	East	% Difference	0.0	1.7	0.4	0.2	3.4	3.5	4.3
S3 – S1	Gulf Coast	% Difference	0.0	1.4	2.0	-0.7	13.3	32.0	40.5
S3 – S1	Southwest	% Difference	0.0	0.2	0.2	-0.2	8.3	17.1	23.6
S3 – S1	Other Onshore	% Difference	0.0	0.8	1.1	1.7	7.6	15.8	21.1
S3 – S1	**Total**	**% Difference**	**0.0**	**1.2**	**0.9**	**0.1**	**7.8**	**15.8**	**20.4**
S4 – S1	East	% Difference	0.0	1.4	-3.1	-5.1	-3.8	-2.8	-0.1
S4 – S1	Gulf Coast	% Difference	0.0	2.4	-4.6	-14.6	-15.5	-5.9	-3.0
S4 – S1	Southwest	% Difference	0.0	0.0	-4.3	-8.7	-9.3	-4.0	-3.0
S4 – S1	Other Onshore	% Difference	0.0	0.2	-2.3	-2.7	-4.7	-2.4	-2.7
S4 – S1	**Total**	**% Difference**	**0.0**	**1.2**	**-3.6**	**-8.0**	**-8.3**	**-3.8**	**-1.8**
S5 – S1	East	% Difference	0.0	0.7	-2.1	-5.5	-2.6	-4.8	-8.3
S5 – S1	Gulf Coast	% Difference	0.0	1.4	1.1	-3.3	9.5	23.9	31.5
S5 – S1	Southwest	% Difference	0.0	0.3	-0.2	-1.2	6.1	14.2	16.9
S5 – S1	Other Onshore	% Difference	0.0	1.1	0.0	0.3	4.5	10.6	14.9
S5 – S1	**Total**	**% Difference**	**0.0**	**0.9**	**-0.5**	**-3.2**	**3.5**	**9.0**	**10.9**

*1 Tcf in a non-leap year is equivalent to 2.74 Bcf/d

Table D-14. U.S. regional onshore natural gas production, S6 and S7, by year (Figure B-2)

Scenario	Natural Gas Volumes	Units	2020	2025	2030	2035	2040	2045	2050
S6: Energy Transition (Ref Exp)	East	Tcf	12.5	14.2	12.7	13.7	15.0	17.4	20.6
S6: Energy Transition (Ref Exp)	Gulf Coast	Tcf	6.8	10.1	8.5	9.2	11.6	12.2	13.9
S6: Energy Transition (Ref Exp)	Southwest	Tcf	5.5	5.4	5.4	5.7	6.3	7.1	8.0
S6: Energy Transition (Ref Exp)	Other Onshore	Tcf	8.1	7.5	6.9	6.9	7.5	8.6	9.8
S6: Energy Transition (Ref Exp)	**Total**	**Tcf**	**33.0**	**37.3**	**33.5**	**35.5**	**40.3**	**45.2**	**52.3**
S7: Energy Transition	East	Tcf	12.5	14.2	12.7	13.6	15.0	17.3	20.4

Scenario	Natural Gas Volumes	Units	2020	2025	2030	2035	2040	2045	2050
S7: Energy Transition	Gulf Coast	Tcf	6.8	10.2	8.6	9.0	11.3	13.1	15.4
S7: Energy Transition	Southwest	Tcf	5.5	5.4	5.4	5.6	6.3	7.2	8.6
S7: Energy Transition	Other Onshore	Tcf	8.1	7.5	6.9	6.9	7.5	8.7	9.7
S7: Energy Transition	**Total**	**Tcf**	**33.0**	**37.3**	**33.6**	**35.1**	**40.0**	**46.3**	**54.1**
S7 – S6	East	Tcf	0.0	0.0	0.0	-0.1	0.1	-0.1	-0.2
S7 – S6	Gulf Coast	Tcf	0.0	0.0	0.1	-0.2	-0.3	1.0	1.5
S7 – S6	Southwest	Tcf	0.0	0.0	0.0	0.0	0.0	0.2	0.6
S7 – S6	Other Onshore	Tcf	0.0	0.0	0.0	-0.1	0.0	0.1	-0.1
S7 – S6	**Total**	**Tcf**	**0.0**	**0.0**	**0.1**	**-0.4**	**-0.3**	**1.1**	**1.8**
S7 – S6	East	% Difference	0.0	-0.3	0.3	-0.8	0.4	-0.4	-0.9
S7 – S6	Gulf Coast	% Difference	0.0	0.1	1.0	-2.0	-2.7	8.0	10.8
S7 – S6	Southwest	% Difference	0.0	0.0	0.1	-0.5	-0.2	2.2	7.6
S7 – S6	Other Onshore	% Difference	0.0	0.0	-0.1	-1.1	-0.7	0.8	-1.2
S7 – S6	**Total**	**% Difference**	**0.0**	**-0.1**	**0.4**	**-1.1**	**-0.7**	**2.5**	**3.4**

*1 Tcf in a non-leap year is equivalent to 2.74 Bcf/d

Table D-15. U.S. natural gas consumption by sector, S1 through S5, by year (Figure B-3)

Scenario	Natural Gas Volumes	Units	2020	2025	2030	2035	2040	2045	2050
S1: Reference Exports	Electricity	Tcf	11.6	9.7	7.7	6.6	7.2	7.5	7.6
S2: Market Response	Electricity	Tcf	11.6	9.6	7.7	6.6	6.6	6.8	6.7
S3: High Global Demand	Electricity	Tcf	11.6	9.6	7.5	6.5	6.5	6.6	6.6
S4: Regional Import Limits	Electricity	Tcf	11.6	9.6	8.3	7.9	8.0	8.2	7.8
S5: Low-cost Renewables	Electricity	Tcf	11.6	9.5	6.9	5.4	5.1	4.4	3.4
S1: Reference Exports	Industry	Tcf	9.9	10.3	10.9	11.1	11.5	11.8	12.3
S2: Market Response	Industry	Tcf	9.9	10.3	10.9	11.1	11.6	12.1	12.3
S3: High Global Demand	Industry	Tcf	9.9	10.3	10.9	11.1	11.6	12.1	12.4
S4: Regional Import Limits	Industry	Tcf	9.9	10.3	10.9	11.1	11.5	11.8	12.2
S5: Low-cost Renewables	Industry	Tcf	9.9	10.3	10.9	11.1	11.5	12.0	12.2
S1: Reference Exports	Residential	Tcf	4.7	4.8	4.8	4.8	4.7	4.7	4.7
S2: Market Response	Residential	Tcf	4.7	4.8	4.8	4.8	4.7	4.7	4.7
S3: High Global Demand	Residential	Tcf	4.7	4.8	4.8	4.8	4.7	4.7	4.7
S4: Regional Import Limits	Residential	Tcf	4.7	4.8	4.8	4.8	4.7	4.7	4.7
S5: Low-cost Renewables	Residential	Tcf	4.7	4.8	4.8	4.8	4.7	4.7	4.7

Scenario	Natural Gas Volumes	Units	2020	2025	2030	2035	2040	2045	2050
S1: Reference Exports	Commercial	Tcf	3.2	3.4	3.5	3.5	3.5	3.5	3.4
S2: Market Response	Commercial	Tcf	3.2	3.4	3.5	3.5	3.5	3.5	3.4
S3: High Global Demand	Commercial	Tcf	3.2	3.4	3.5	3.5	3.5	3.5	3.4
S4: Regional Import Limits	Commercial	Tcf	3.2	3.4	3.5	3.6	3.5	3.5	3.4
S5: Low-cost Renewables	Commercial	Tcf	3.2	3.4	3.5	3.5	3.5	3.5	3.4
S1: Reference Exports	Transportation	Tcf	1.1	1.2	1.3	1.5	1.6	1.7	1.8
S2: Market Response	Transportation	Tcf	1.1	1.2	1.3	1.5	1.9	2.2	2.5
S3: High Global Demand	Transportation	Tcf	1.1	1.2	1.3	1.5	1.9	2.2	2.5
S4: Regional Import Limits	Transportation	Tcf	1.1	1.2	1.1	1.1	1.2	1.4	1.6
S5: Low-cost Renewables	Transportation	Tcf	1.1	1.2	1.3	1.5	1.8	2.2	2.4
S1: Reference Exports	**Total**	**Tcf**	**30.5**	**29.4**	**28.2**	**27.6**	**28.5**	**29.2**	**29.8**
S2: Market Response	**Total**	**Tcf**	**30.5**	**29.3**	**28.2**	**27.5**	**28.2**	**29.2**	**29.6**
S3: High Global Demand	**Total**	**Tcf**	**30.5**	**29.3**	**28.0**	**27.4**	**28.2**	**29.1**	**29.6**
S4: Regional Import Limits	**Total**	**Tcf**	**30.5**	**29.3**	**28.7**	**28.5**	**29.0**	**29.7**	**29.8**
S5: Low-cost Renewables	**Total**	**Tcf**	**30.5**	**29.2**	**27.4**	**26.2**	**26.6**	**26.7**	**26.2**
S2 – S1	Electricity	Tcf	0.0	-0.1	0.0	-0.1	-0.6	-0.7	-0.9
S3 – S1	Electricity	Tcf	0.0	0.0	-0.2	-0.1	-0.6	-0.9	-1.0
S4 – S1	Electricity	Tcf	0.0	-0.1	0.7	1.2	0.8	0.8	0.2
S5 – S1	Electricity	Tcf	0.0	-0.2	-0.8	-1.3	-2.1	-3.0	-4.2
S2 – S1	Industry	Tcf	0.0	0.0	0.0	0.0	0.0	0.3	0.0
S3 – S1	Industry	Tcf	0.0	0.0	0.0	0.0	0.0	0.3	0.0
S4 – S1	Industry	Tcf	0.0	0.0	0.0	0.0	-0.1	0.0	-0.1
S5 – S1	Industry	Tcf	0.0	0.1	0.0	0.0	0.0	0.1	-0.1
S2 – S1	Residential	Tcf	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S3 – S1	Residential	Tcf	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S4 – S1	Residential	Tcf	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S5 – S1	Residential	Tcf	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S2 – S1	Commercial	Tcf	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S3 – S1	Commercial	Tcf	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S4 – S1	Commercial	Tcf	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S5 – S1	Commercial	Tcf	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S2 – S1	Transportation	Tcf	0.0	0.0	0.0	0.0	0.3	0.5	0.7
S3 – S1	Transportation	Tcf	0.0	0.0	0.0	0.0	0.3	0.6	0.7

Scenario	Natural Gas Volumes	Units	2020	2025	2030	2035	2040	2045	2050
S4 – S1	Transportation	Tcf	0.0	0.0	-0.2	-0.4	-0.4	-0.2	-0.1
S5 – S1	Transportation	Tcf	0.0	0.0	0.0	0.0	0.2	0.5	0.7
S2 – S1	**Total**	**Tcf**	**0.0**	**-0.1**	**0.0**	**-0.1**	**-0.3**	**0.1**	**-0.2**
S3 – S1	**Total**	**Tcf**	**0.0**	**0.0**	**-0.2**	**-0.2**	**-0.4**	**0.0**	**-0.3**
S4 – S1	**Total**	**Tcf**	**0.0**	**-0.1**	**0.6**	**0.9**	**0.4**	**0.5**	**-0.1**
S5 – S1	**Total**	**Tcf**	**0.0**	**-0.1**	**-0.8**	**-1.3**	**-1.9**	**-2.4**	**-3.7**
S2 – S1	Electricity	% Difference	0.0	-0.5	-0.2	-1.3	-8.3	-9.1	-11.5
S3 – S1	Electricity	% Difference	0.0	-0.3	-2.5	-2.1	-9.0	-11.4	-13.0
S4 – S1	Electricity	% Difference	0.0	-0.6	8.8	18.6	11.4	10.4	2.6
S5 – S1	Electricity	% Difference	0.0	-1.8	-9.9	-19.3	-29.0	-40.8	-55.0
S2 – S1	Industry	% Difference	0.0	0.1	0.1	-0.1	0.4	2.1	0.1
S3 – S1	Industry	% Difference	0.0	0.1	0.1	-0.1	0.3	2.2	0.2
S4 – S1	Industry	% Difference	0.0	0.1	0.2	0.0	-0.5	-0.4	-1.1
S5 – S1	Industry	% Difference	0.0	0.6	0.0	-0.3	-0.4	1.0	-1.0
S2 – S1	Residential	% Difference	0.0	-0.1	-0.1	0.1	-0.2	-0.2	-0.6
S3 – S1	Residential	% Difference	0.0	-0.1	0.0	0.1	-0.2	-0.1	-0.6
S4 – S1	Residential	% Difference	0.0	-0.1	0.3	0.6	0.4	0.1	-0.1
S5 – S1	Residential	% Difference	0.0	0.0	0.0	0.2	-0.1	0.0	-0.4
S2 – S1	Commercial	% Difference	0.0	-0.1	-0.1	0.1	-0.5	-0.5	-1.3
S3 – S1	Commercial	% Difference	0.0	-0.1	0.0	0.2	-0.5	-0.4	-1.3
S4 – S1	Commercial	% Difference	0.0	-0.1	0.6	1.2	0.8	0.2	-0.4
S5 – S1	Commercial	% Difference	0.0	0.0	0.0	0.3	-0.1	0.1	-0.6
S2 – S1	Transportation	% Difference	0.0	-0.2	0.2	-1.9	16.0	31.9	38.7
S3 – S1	Transportation	% Difference	0.0	-0.1	0.2	-1.1	17.5	33.9	42.2
S4 – S1	Transportation	% Difference	0.0	-0.1	-14.6	-24.6	-22.5	-13.6	-7.3
S5 – S1	Transportation	% Difference	0.0	-0.4	-0.9	-2.9	14.7	29.6	36.6
S2 – S1	**Total**	**% Difference**	**0.0**	**-0.2**	**0.0**	**-0.4**	**-1.1**	**0.3**	**-0.8**
S3 – S1	**Total**	**% Difference**	**0.0**	**-0.1**	**-0.7**	**-0.6**	**-1.2**	**-0.2**	**-0.9**
S4 – S1	**Total**	**% Difference**	**0.0**	**-0.2**	**2.0**	**3.4**	**1.6**	**1.8**	**-0.3**
S5 – S1	**Total**	**% Difference**	**0.0**	**-0.4**	**-2.7**	**-4.9**	**-6.6**	**-8.3**	**-12.3**

*1 Tcf in a non-leap year is equivalent to 2.74 Bcf/d

Table D-16. U.S. sectoral natural gas consumption by sector, S6 and S7, by year (Figure B-4)

Scenario	Natural Gas Volumes	Units	2020	2025	2030	2035	2040	2045	2050
S6: Energy Transition (Ref Exp)	Electricity	Tcf	11.6	12.9	8.3	5.7	5.0	5.7	6.5
S7: Energy Transition	Electricity	Tcf	11.6	12.8	8.5	5.9	5.0	5.7	6.6
S6: Energy Transition (Ref Exp)	Industry	Tcf	10.1	10.5	10.6	15.4	18.8	22.3	28.2
S7: Energy Transition	Industry	Tcf	10.1	10.5	10.6	14.7	18.4	22.0	27.8
S6: Energy Transition (Ref Exp)	Residential	Tcf	4.7	4.6	4.6	4.0	3.8	3.8	3.7
S7: Energy Transition	Residential	Tcf	4.7	4.6	4.5	4.0	3.8	3.8	3.7
S6: Energy Transition (Ref Exp)	Commercial	Tcf	3.2	3.2	3.2	2.5	2.4	2.3	2.3
S7: Energy Transition	Commercial	Tcf	3.2	3.2	3.1	2.5	2.4	2.3	2.3
S6: Energy Transition (Ref Exp)	Transportation	Tcf	0.9	0.8	0.8	0.8	0.9	1.0	1.1
S7: Energy Transition	Transportation	Tcf	0.9	0.8	0.8	0.8	0.8	1.0	1.1
S6: Energy Transition (Ref Exp)	**Total**	**Tcf**	**30.5**	**32.0**	**27.4**	**28.4**	**30.8**	**35.0**	**41.9**
S7: Energy Transition	**Total**	**Tcf**	**30.5**	**31.9**	**27.5**	**27.9**	**30.5**	**34.7**	**41.5**
S7 – S6	Electricity	Tcf	0.0	0.0	0.2	0.2	0.1	0.0	0.1
S7 – S6	Industry	Tcf	0.0	0.0	0.0	-0.6	-0.4	-0.3	-0.4
S7 – S6	Residential	Tcf	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S7 – S6	Commercial	Tcf	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S7 – S6	Transportation	Tcf	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S7 – S6	**Total**	**Tcf**	**0.0**	**0.0**	**0.1**	**-0.5**	**-0.3**	**-0.3**	**-0.3**
S7 – S6	Electricity	% Difference	0.0	-0.4	2.0	3.1	1.4	-0.1	1.4
S7 – S6	Industry	% Difference	0.0	0.0	0.1	-4.1	-2.0	-1.3	-1.4
S7 – S6	Residential	% Difference	0.0	0.0	-0.4	-0.1	-0.3	-0.2	-0.3
S7 – S6	Commercial	% Difference	0.0	0.0	-0.5	-0.4	-0.5	-0.5	-0.4
S7 – S6	Transportation	% Difference	0.0	0.4	0.1	-1.1	-0.3	-0.7	0.3
S7 – S6	**Total**	**% Difference**	**0.0**	**-0.1**	**0.5**	**-1.7**	**-1.1**	**-0.9**	**-0.8**

*1 Tcf in a non-leap year is equivalent to 2.74 Bcf/d

Table D-17. U.S. natural gas consumption for DAC, S6 and S7, by year (Figure B-5)

Scenario	Units	2020	2025	2030	2035	2040	2045	2050
S6: Energy Transition (Ref Exp)	Tcf	0.0	0.0	0.0	4.7	7.8	11.2	16.8
S7: Energy Transition	Tcf	0.0	0.0	0.0	4.1	7.5	10.7	16.2
S7 – S6	Tcf	0.0	0.0	0.0	-0.6	-0.4	-0.5	-0.7
S7 – S6	% Difference	0.0	0.0	0.0	-13.0	-4.5	-4.1	-4.0

*1 Tcf in a non-leap year is equivalent to 2.74 Bcf/dTable D-1

Table D-18. U.S. CO_2 removals by technology, S6 and S7, by year (Figure B-6)

Scenario	CO_2 Removals	Units	2020	2025	2030	2035	2040	2045	2050
S6: Energy Transition (Ref Exp)	H_2 Biomass	Gt CO_2	0.00	0.00	0.03	0.08	0.12	0.17	0.20
S6: Energy Transition (Ref Exp)	BECCS	Gt CO_2	0.00	0.00	0.02	0.03	0.04	0.04	0.04
S6: Energy Transition (Ref Exp)	DAC	Gt CO_2	0.00	0.00	0.00	0.54	0.90	1.28	1.93
S6: Energy Transition (Ref Exp)	**Total**	Gt CO_2	**0.00**	**0.00**	**0.05**	**0.65**	**1.06**	**1.49**	**2.16**
S7: Energy Transition	H_2 Biomass	Gt CO_2	0.00	0.00	0.05	0.09	0.14	0.21	0.24
S7: Energy Transition	BECCS	Gt CO_2	0.00	0.00	0.02	0.04	0.04	0.04	0.04
S7: Energy Transition	DAC	Gt CO_2	0.00	0.00	0.00	0.47	0.86	1.23	1.85
S7: Energy Transition	**Total**	Gt CO_2	**0.00**	**0.00**	**0.07**	**0.60**	**1.04**	**1.48**	**2.13**
S7 – S6	H_2 Biomass	Gt CO_2	0.00	0.00	0.02	0.01	0.02	0.03	0.04
S7 – S6	BECCS	Gt CO_2	0.00	0.00	0.00	0.00	0.01	0.01	0.01
S7 – S6	DAC	Gt CO_2	0.00	0.00	0.00	-0.07	-0.04	-0.05	-0.08
S7 – S6	**Total**	Gt CO_2	**0.00**	**0.00**	**0.02**	**-0.05**	**-0.01**	**-0.01**	**-0.03**
S7 – S6	H_2 Biomass	% Difference	0.0	-1.0	79.1	19.1	15.5	20.4	21.6
S7 – S6	BECCS	% Difference	0.0	0.0	15.0	5.5	18.7	18.4	18.8
S7 – S6	DAC	% Difference	0.0	0.0	0.0	-13.0	-4.5	-4.1	-4.0
S7 – S6	**Total**	**% Difference**	**0.0**	**-1.0**	**52.1**	**-8.3**	**-1.3**	**-0.7**	**-1.2**