U.S. Department of ENERGY | Office of Fossil Energy and Carbon Management

APPENDIX C: CONSEQUENTIAL GREENHOUSE GAS ANALYSIS OF U.S. LNG EXPORTS

October 7, 2025

On December 20, 2024, DOE published a notice of availability of its study entitled, *2024 LNG Export Study: Energy, Economic, and Environmental Assessment of U.S. LNG Exports* 2024 LNG Export Study (2024 LNG Export Study, *see* 89 Fed. Reg. 104,132 and https://fossil.energy.gov/app/docketindex/docket/index/30). DOE prepared the 2024 LNG Export Study as a comprehensive update of DOE's prior studies evaluating exports of natural gas, including liquefied natural gas (LNG), under section 3 of the Natural Gas Act (NGA), 15 U.S.C. § 717b. Since issuing the 2024 LNG Export Study and the related Response to Comments on May 19, 2025 (*see* 90 Fed. Reg. 21,912), DOE has determined that the environmental analysis in the 2024 LNG Export Study is not required for DOE's decision on applications to export LNG to non-free trade agreement (non-FTA) countries under NGA section 3(a), 15 U.S.C. § 717b(a).

Specifically, DOE found that its review of an export application under the National Environmental Policy Act of 1969 (NEPA)—in particular, under categorical exclusion B5.7, *Export of natural gas and associated transportation by marine vessel*—considers all relevant environmental effects from the proposed export of LNG to non-FTA countries. The environmental portions of the 2024 LNG Export Study were not limited to marine transport effects considered under categorical exclusion B5.7, but rather included the integration of potential upstream and downstream environmental effects, which are not reasonably foreseeable environmental impacts of DOE's export authorizations. Accordingly, on August 4, 2025, in *Venture Global Calcasieu Pass, LLC*, DOE/FECM Order No. 4346-B (Docket No. 15-25-LNG), DOE explained that its discussion of the 2024 LNG Export Study would focus only on the economic analysis in the Study, as well as DOE's related findings on energy security. DOE further explained that this position is informed by and consistent with the Supreme Court's holdings in *Dep't of Transportation v. Public Citizen*, 541 U.S. 752 (2004), and *Seven County Infrastructure Coalition v. Eagle County, Colorado*, 605 U.S. __, 145 S.Ct. 1497 (2025), which make clear that "agencies are not required to analyze the effects of projects over which they do not exercise regulatory authority." *Seven Cnty. Infrastructure Coal.,* 605 U.S. __, 145 S.Ct. at 1516.

DOE thus reiterates that, in pending and future export application proceedings under NGA section 3(a), DOE will not consider the environmental analysis in the 2024 LNG Export Study or the related Response to Comments. For more discussion, *see, e.g.*, *Venture Global Calcasieu Pass, LLC*, DOE/FECM Order No. 4346-B, at 12-13, 15-16, 36-38. We note that, on October 3, 2025, in DOE/FECM Order No. 4346-C, DOE denied rehearing of Order No. 4346-B.

December 2024

Consequential Analysis Appendix

December 2024

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ACRONYMS AND ABBREVIATIONS

°C	Degrees Celsius
AEO	Annual Energy Outlook
AgLanduse	Agricultural land use
AR5	Fifth Assessment Report
AR6	Sixth Assessment Report
AR6, 100-yr	Sixth Assessment Report, 100-year basis
AR6, 20-yr	Sixth Assessment Report, 20-year basis
Bcf, BCF	Billion cubic feet
Bcf/d	Billion cubic feet per day
BECCS	Bioenergy with carbon capture and storage
BIL	Bipartisan Infrastructure Law
BP	British Petroleum
Btu	British thermal unit
C_2F_6	Hexafluoroethane
C Asia + East Eur	Central Asia and Eastern Europe
ccf	Climate–carbon cycle Feedback
CCS	Carbon capture and storage
CCUS	Carbon capture, utilization, and storage
CDR	Carbon dioxide removal
CF_4	Tetrafluoromethane
CH_4	Methane
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
DAC	Direct air capture
DACCS	Direct air carbon capture and storage
DOE	Department of Energy
EIA	Energy Information Administration
EJ	Exajoule (10^{18} joules)
EPA	Environmental Protection Agency
EU	European Union
F-gases	Fluorinated gases
FECM	Office of Fossil Energy and Carbon Management
g	Gram
GCAM	Global Change Analysis Model
GDP	Gross domestic product
GHG	Greenhouse gas
GoM, GOM	Gulf of Mexico
Gt	Gigaton
GWP	Global warming potential
H_2	Hydrogen
HFC	Hydrofluorocarbons
HHV	Higher heating value
HMM	Hydrogen Market Module
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IRA	Inflation Reduction Act
ITC	Investment tax credit
LAC	Latin American countries
LCA	Life cycle analysis
LHV	Lower heating value
LNG	Liquefied natural gas
LUC	Land use change
LULUCF	Land use, land use change, and forestry
LC-GHG	Market adjustment factor
MAM	Macroeconomic Activity Module
Mcf	Million cubic feet
MJ	Megajoule

MMBtu	Million British thermal units
MMscf	Million standard cubic feet
N_2O	Nitrous oxide
NA	Not available/applicable
NEMS	National Energy Modeling System
NERA	NERA Economic Consulting
NETL	National Energy Technology Laboratory
NG	Natural gas
NGA	Natural Gas Act
NGP	Natural gas processing
NZ	New Zealand
O&M	Operating and Maintenance
OGSM	Oil and Gas Supply Module
PNNL	Pacific Northwest National Laboratory
PTC	Production tax credit
ROW	Rest of the World
SC-GHG	Social cost of greenhouse gas emissions
SF_6	Sulfur hexafluoride
Tcf, TCF	Trillion cubic feet
Tg	Teragram (10^{12} grams)
U.S., USA	United States
yr	Year

FOREWORD

This multi-volume study of U.S. LNG exports serves to provide an updated understanding of the potential effects of U.S. LNG exports on the domestic economy, U.S. households and consumers; communities that live near locations where natural gas is produced or exported; domestic and international energy security, including effects on U.S. trading partners; and the environment and climate. Prior to this study, Department of Energy's (DOE's) most recent economic and environmental analyses of U.S. LNG exports were published in 2018 and 2019, respectively. At that time, U.S. LNG exports were just getting underway and our export capacity was 4 billion cubic feet per day (Bcf/d), less than one-third of what it is today. Since then, our world and the global natural gas sector have changed significantly: the U.S. has become the top global exporter of LNG; Russia has invaded Ukraine and used energy as a weapon to undermine European and global security; the impacts and costs of extreme weather and natural disasters fueled by climate change have increased dramatically; and the pace of the energy transition and technological innovation has itself accelerated.

These developments and others factor into a global energy system that is changing rapidly. The pace of change creates inherent uncertainty in projecting the potential pathways for U.S. LNG through 2050. Accordingly, several considerations should be borne in mind when interpreting this study and its results.

- Given the global scope and timeframe examined in this study, there should be recognition of the inherent uncertainty in conclusions, especially given their size relative to the overall global economy and energy system.
- This study is not intended to serve as a forecast of U.S. LNG exports and impacts. Rather, it is an exercise exploring alternative conditional scenarios of future U.S. LNG exports and examining their implications for global and U.S. energy systems, economic systems, and greenhouse gas (GHG) emissions. This type of scenario analysis is a well-established analytical approach for exploring complex relationships across a range of variables.
- The scenarios explored in this study span a range of U.S. LNG export outcomes. Each scenario relies on input assumptions regarding many domestic, international, economic, and non-economic factors, such as future socioeconomic development, technology and resource availability, technological advancement, and institutional change. A full uncertainty analysis encompassing all underlying factors is beyond the scope of this study.
- For the portions of this study that have modeled results, the study does not attach probabilities to any of the scenarios examined.

EXECUTIVE SUMMARY

The U.S. Department of Energy (DOE) is responsible for authorizing exports of domestically produced natural gas, including liquefied natural gas (LNG), to foreign countries under section 3 of the Natural Gas Act (NGA), 15 U.S.C. § 717b. An application to export domestically produced natural gas to countries that have a free trade agreement (FTA) with the United States must be granted without delay or modification and is deemed to be consistent with the public interest by statute. For applications to export domestic natural gas to non-FTA countries, DOE must grant the application unless it finds that the proposed exportation will not be consistent with the public interest.

Since 2012, to inform its public interest determination, DOE's Office of Fossil Energy and Carbon Management (FECM) has commissioned multiple studies to help assess the various facets of the public interest that are affected by U.S. LNG exports. The purpose of the current study is to provide a comprehensive update to our understanding of how varying levels of U.S. LNG exports impact all these facets.

This appendix provides a consequential analysis and focuses on i) the current baseline GHG intensity of U.S. upstream natural gas and liquefaction processes, and ii) the global emissions impacts from changes in U.S. LNG exports through 2050 as provided in the Global Analysis (Appendix A). This analysis uses results from the Global Change Analysis Model (GCAM) and explores scenario comparisons of GHG emissions, level of U.S. LNG exports, and levels of global services provided. Global services are defined as those products of the global economy that provide services to consumers, such as energy, commodities, fertilizers, etc.

Key findings of this Appendix are:

1. Differences in volumes of U.S. LNG exports lead to different levels both of GHG emissions and of global services provided. When compared to scenarios that assume export levels based on existing and under construction facilities (*Existing/FID*), higher levels of U.S. LNG exports lead to higher global GHG emissions (ranging from 21 Tg CO_2e to 1,452 Tg CO_2e or about 0.002% to 0.1%), as well as higher levels of global services provided (ranging from 0.006% to about 0.1%).
2. The GCAM upstream GHG intensity values for all scenarios are within 1% of the values in the latest NETL Natural Gas baseline study (representative of the base year of this study, 2020) on an IPCC AR6, 100-yr basis.
   a. Per MJ of natural gas scaled to account for liquefaction losses, the production through transmission (upstream) GHG intensity is 9.2 g CO_2e/MJ exported on an IPCC AR6, 100-yr GWP, LHV basis and 15.7 g CO_2e/MJ exported on an IPCC AR6, 20-yr GWP, LHV basis.
   b. Overall, adjustments to align to NETL national average performance data for GHG intensity added about 20 Tg CO_2e emissions per model year, an increase of less than 0.05% on an AR6, 100-yr basis, and subtracted about 100 Tg CO_2e emissions per model year, a decrease of less than 0.2% on an AR6, 20-yr basis.
3. The national average GHG intensity for liquefaction operations in the base year is modeled using government reported data and expanded to provide representative life cycle system boundaries, resulting in a GHG emissions intensity of 5.3 g CO_2e/MJ of natural gas ready for export, reported on an IPCC AR6, 100-yr lower heating value (LHV) basis, and 5.6 g CO_2e/MJ on an IPCC AR6, 20-yr lower heating value (LHV) basis.
4. This analysis defines the upstream natural gas and liquefaction processes as project direct emissions, the direct emissions from export and use of the natural gas and direct and indirect market effects as project non-direct emissions, and the sum of them to be the consequential GHG intensity of U.S. LNG exports. Given the upstream natural gas and

liquefaction values estimated above, the average U.S. project direct emissions for 2020, the baseline year for this study, is 9.2 + 5.3 = 14.5 g CO_2e/MJ (AR6, 100-yr), and 21.3 g CO_2e/MJ (AR6, 20-yr).

5. The consequential GHG intensity is the effect (inclusive of both direct and indirect emissions) of U.S. LNG on global emissions per unit of U.S. LNG exported. The consequential GHG intensity is defined as the difference in GHG emissions between the scenarios divided by the difference in U.S. LNG exports. For instance, for one of the scenario comparisons assessed (*Defined Polices: Model Resolved*) the consequential GHG intensity is +6.3 g CO_2e/MJ (on both an AR6, 100-yr and AR6, 20-yr basis), indicating that the overall global effect of producing and exporting U.S. LNG leads to an increase in global GHG emissions resulting from consequential market effects.
   a. Analysis of the results shows that direct and indirect market substitutions result in a decrease in global GHG emissions intensity when compared on an equivalent global services basis. The increased availability of U.S. LNG on the global market enables increased demand for energy to be met with a lower cost energy supply option that often displaces more or equally GHG emissions-intensive fuels (e.g., coal and oil) within the model over the thirty-year study period.
   b. Results also show that increasing the availability of U.S. LNG on the global market (increased global energy supply) results in increased consumption of global services when compared to the baseline scenario (e.g., *Defined Policies: Existing/FID*). The consequential effect of increased global consumption of energy and services directly contributes to increased global GHG emissions.
   c. The net result of these two market effects is an increase in global GHG emissions of +6.3 g CO_2e/MJ of NG exported from the U.S. Across all scenarios, this GHG intensity figure ranges from 1.2 g CO_2e/MJ to 12.6 g CO_2e/MJ (AR6, 100-yr basis), and from -1.4 g CO_2e/MJ to 11.2 g CO_2e/MJ (AR6, 20-yr basis).
   d. The increase in global GHG emissions between the *Defined Policies: Model Resolved* and *Defined Policies: Existing/FID* scenarios is estimated to result in a cumulative SC-GHG impact of $74 billion using a discount rate of 2.5%, $130 billion using a discount rate of 2.0%, and $220 billion using a discount rate of 1.5% (all 2020$). Per MJ, this equates to a range of 0.02 cents/MJ to 0.15 cents/MJ (2.5%). The cumulative SC-GHG of the increase in global emissions across the study scenarios ranged from $3 billion to $150 billion (2.5%) to $12 billion to $450 billion (1.5%) in 2020$.
6. Estimated consequential GHG impacts and SC-GHG values for an individual U.S. export project can be calculated by using individual project values in place of the default of U.S. average values modeled in the study.
   a. For example, on an AR6, 100-yr basis, given the NETL average liquefaction emissions for a project of 5.3 g CO_2e/MJ, if an individual project has a liquefaction process with emissions that are half of the average (2.65 g CO_2e /MJ), the individual project consequential GHG intensity could be adjusted down by 2.65 g CO_2e/MJ (calculated as the difference between the average of 5.3 g CO_2e/MJ and the individual project emissions intensity of 2.65 g CO_2e/MJ). If the average U.S. consequential GHG intensity is 6.3 g CO_2e /MJ, the individual project consequential intensity would be 3.65 g CO_2e /MJ.
   b. Total lifetime social costs of the project direct and project non-direct greenhouse gas emissions from a 1 Bcf/d facility operating for 30 years are estimated to be $8 billion to $23 billion ($2020) for a facility with default average intensity values (varying across assumed discount rates). A similar facility with half the liquefaction emissions would have social costs of greenhouse gases estimated to be $4.6 billion to $13 billion ($2020).

BACKGROUND

This portion of the study utilizes the global greenhouse gas (GHG) emissions and U.S. liquefied natural gas (LNG) export volumes determined from the Global Change Analysis Model (GCAM) (detailed in Appendix A with a description of its application to this analysis in Appendix C-2) for each scenario considered within the study to determine the consequential life cycle GHG emissions on a per unit (Megajoule [MJ]) of U.S LNG exported. The life cycle analysis (LCA) modeling approach used in this study is referred to as a "consequential LCA".[1,2,3] This type of LCA accounts for the direct emissions from production, delivery, and use of the U.S. exported natural gas and the indirect emissions from changes in market behavior. Market behavior includes consequences from the decision to use U.S. exported natural gas to meet demands for provision of global services (e.g., energy, commodities, fertilizers, etc.), including fuel substitution and changes in demand for services.

The consequential LCA approach used in this study differs from past DOE LNG LCA modeling approaches. Prior DOE LNG LCA studies conducted by the National Energy Technology Laboratory (NETL)[4] and used to evaluate LNG project applications[5] directly compared the life cycle GHG emissions for producing and consuming a megawatt-hour (MWh) of baseload electricity in European and Asian markets using: (1) U.S. LNG exported from the Gulf Coast of the U.S.; (2) LNG exported from Oran, Algeria; (3) pipeline natural gas from Yamal, Russia; and (4) regionally-sourced coal. This type of LCA is referred to as an "attributional LCA".

An attributional LCA directly compares the environmental performance of each supply chain (e.g., LNG, pipeline natural gas, coal) to produce an equivalent service to society (e.g., 1 MWh of electricity)[6]. An attributional LCA modeling approach does not account for changes in market behavior in response to fuel availability. Comparing attributional LCA results provides information about the difference in environmental performance to provide an equivalent service to society. The comparative difference is the result of one form of energy completely replacing another form in the market, often referred to as direct market substitution. Attributional LCA results do not seek to provide information about the potential indirect market effects from changes in supply and price resulting from a decision to use one form of energy over the other, nor do they provide information

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[1] Ekvall, T. (2002). Cleaner production tools: LCA and beyond. Integrating Greener Product Development Perspectives, 10(5), 403–406. https://doi.org/10.1016/S0959-6526(02)00026-4

[2] Brandão, M., Weidema, B. P., Martin, M., Cowie, A., Hamelin, L., & Zamagni, A. (2024). Consequential Life Cycle Assessment: What, Why and How? In M. A. Abraham (Ed.), Encyclopedia of Sustainable Technologies (Second Edition) (pp. 181–189). Elsevier. https://doi.org/10.1016/B978-0-323-90386-8.00001-2

[3] UNEP SETAC. (2011). Global guidance principles for life cycle assessment databases: a basis for greener processes and products. United Nations Environment Programme. https://www.lifecycle initiative.org/ wp-content/ uploads/2012/12/2011%20-%20Global%20Guidance%20Principles.pdf

[4] Khutal, H., et al. Life Cycle Analysis of Natural Gas Extraction and Power Generation: U.S. 2020 Emissions Profile. National Energy Technology Laboratory, Pittsburgh, December 2024. https://www.netl.doe.gov/energy-analysis/details?id=546d4009-c43b-43f5-bcc9-64d5e63fc8d5

[5] 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. NETL, Pittsburgh, September 12, 2019.

[6] An attributional Life Cycle Assessment (LCA) comparison is done for systems that provide equivalent services to society, i.e., an equivalent function (e.g., the 1 MWh mentioned above). In this study, the boundary is far larger than that of a typical LCA, and thus the total of all services provided globally, and annually over a 30-year study period, is considered. This study will show how the level of global services change across scenarios to help to assess whether equivalent services are being provided.

about how supply or demand for global services could change resulting from changes in supply and price.

DOE has acknowledged that prior attributional LNG LCA results did not account for potential direct or indirect market effects. This study, by contrast, does consider reasonably foreseeable market effects using an integrated multisector model, GCAM, to better understand the market substitution (both direct and indirect) and changes in levels of global services provided (e.g., change in global energy or commodity consumption) that results from the increased availability of U.S. LNG on the global market. The GCAM model includes all GHG emissions from extraction, liquefaction, and use of the LNG, as well as all GHG emissions associated with global services produced. Consequential LCA results are reported with information about the change in global services to illuminate these differences when comparing results.

A trade-off of the consequential modeling approach used in this study is a reduction in attribution for specific source-to-consumption pathways, as previously modeled and used by DOE. Therefore, as a result of the consequential life cycle modeling approach, this study does not present comparative results of natural gas compared to coal for production of a MWh of electricity, or other direct source-to-consumption pathways.

CONSEQUENTIAL LCA MODELING APPROACH FOR ASSESSING GHG EMISSIONS FROM INCREASED U.S. LNG EXPORTS

The objective of the consequential LCA component of this study is to estimate the direct and indirect market effects of additional U.S. LNG exports to better understand their effect on global GHG emissions.

Two metrics are used to assess the consequential GHG emissions effects of increased U.S. LNG exports: (1) GHG intensity in carbon dioxide equivalents (CO_2e) using International Panel on Climate Change (IPCC) Sixth Assessment Report (AR6) global warming potentials (GWPs) - on 100-year (AR6, 100-yr) and 20-year (AR6, 20-yr) time frames; and (2) social cost of greenhouse gas emissions (SC-GHG) using the estimates and methodology developed by the U.S. Environmental Protection Agency (EPA) in the regulatory analysis of its December 2023 Final Rule, "Standards of Performance for New, Reconstructed, and Modified Sources and Emissions Guidelines for Existing Sources: Oil and Natural Gas Sector Climate Review," (2023 SC-GHG estimates).[7]

This analysis establishes a GHG intensity performance of U.S. natural gas production and delivery to liquefaction plants and U.S. average liquefaction plant GHG emissions intensity performance in 2020 as a reference benchmark. The reference year of 2020 aligns with the start of the study period for market consequences derived from the GCAM model.

A second objective of the LCA study is to determine the market drivers of the change in global GHG emissions with respect to changes in U.S. LNG export GHG intensity when providing an equivalent service to society (excluding increases in global services).

The consequential LCA modeling approach consists of ten data conversion and interpretation steps, each of which is described in more detail below:

1. Obtain study scenario GHG emissions and U.S. LNG export volumes from GCAM.
2. Obtain national average life cycle GHG performance data for U.S. natural gas (from NETL natural gas baseline).
3. Model national average life cycle GHG performance for U.S. liquefaction plants (developed as part of this study).
4. Align GCAM natural gas production and pipeline transport to U.S. national average GHG performance in the baseline year.
5. Calculate GCAM-NETL-aligned global GHG emissions results (for modeled years 2020-2050)
6. Interpolate GCAM-aligned global GHG emissions and U.S. LNG export volumes from 5-year GCAM modeled time steps to annual values for the study period of 2020 to 2050.
7. Calculate GCAM-NETL-aligned consequential GHG intensity per unit of U.S. LNG export (normalized over the study period of 2020 to 2050).
8. Subtract the U.S. national average upstream natural gas and liquefaction plant performance to determine the project non-direct emissions intensity.

[7] DOE has preliminarily determined that the updated 2023 SC-GHG estimates, including the approach to discounting, represent a significant improvement in estimating the SC-GHG through incorporating the most recent advancements in the scientific literature and by addressing recommendations on prior methodologies. DOE explained the basis for its determination and made it available for public comment in a July 2024 NODA for consumer gas-fired instantaneous water heaters, 89 FR 59693, 59700. As DOE explained in the July 2024 NODA, the 2023 SC-GHG estimates represent a significant improvement because the 2023 SC-GHG estimates implement the key recommendations of the National Academies, and they incorporate the extensive scientific findings and methodological advances that have occurred since the last IWG substantive updates in 2013, 2015, and 2016.

9. Add the project direct emissions intensity (U.S. LNG project upstream natural gas supply and liquefaction plant GHG performance) to the project non-direct emissions intensity to determine individual project GHG emissions intensity inclusive of consequential market effects.
10. Demonstrate estimation of consequential GHG intensity and SC-GHG for an individual U.S. LNG project.

The sections below describe one potential modeling approach that shows initial example results using a consistent and specific set of scenarios within one global climate policy generated by the GCAM model for this study. Complete results for each scenario comparison are provided in the Results section and detailed tables in Appendix C-4.

Step 1: Obtain Study Scenario GCAM GHG Emissions and U.S. LNG Export Results from GCAM

This consequential analysis considers scenarios designed for this study with varying assumptions about future climate policy ambition, technology availability, and level of U.S. LNG exports (summarized in Table 1 and further defined in Appendix A). This study does not attach probabilities to any of the scenarios, and no inference about the relative likelihood of these scenarios occurring should be made.

Table 1. Scenario design and summary

Key Assumptions			Scenario full name	Scenario abbreviation
Global climate policies	**Technology availability[a]**	**U.S. LNG export levels**		
Defined Policies		Model Resolved	*Defined Policies: Model Resolved*	*DP: MR*
		Existing/FID Exports[c]	*Defined Policies: Existing/FID Exports*	*DP: ExFID*
		High Exports	*Defined Policies: High Exports*	*DP: Hi Exp*
Commitments	High CCS	Model Resolved	*Commitments (High CCS): Model Resolved*	*C (High CCS): MR*
		Existing/FID Exports	*Commitments (High CCS): Existing/FID Exports*	*C (High CCS): ExFID*
		High Exports	*Commitments (High CCS): High Exports*	*C (High CCS): Hi Exp*
	Moderate CCS	Model Resolved	*Commitments (Moderate CCS): Model Resolved*	*C (Mod CCS): MR*
		Existing/FID Exports	*Commitments (Moderate CCS): Existing/FID Exports*	*C (Mod CCS): ExFID*
		High Exports	*Commitments (Moderate CCS): High Exports*	*C (Mod CCS): Hi Exp*
Net Zero 2050	High CCS	Model Resolved	*Net Zero 2050 (High CCS): Model Resolved*	*NZ (High CCS): MR*
		Existing/FID Exports	*Net Zero 2050 (High CCS): Existing/FID Exports*	*NZ (High CCS): ExFID*
		High Exports	*Net Zero 2050 (High CCS): High Exports*	*NZ (High CCS): Hi Exp*
	Moderate CCS[b]	Model Resolved	*Net Zero 2050 (Moderate CCS): Model Resolved*	*NZ (Mod CCS): MR*
		High Exports	*Net Zero 2050 (Moderate CCS): High Exports*	*NZ (Mod CCS): Hi Exp*

Notes:

[a] Technology availability assumptions (*High CCS* and *Moderate CCS*) are combined only with *Commitments* and *Net Zero 2050* climate policy ambition assumptions.

[b] In the *Net Zero 2050 (Moderate CCS): Model Resolved* scenario, U.S. LNG exports fall below the existing/FID exports level. Thus, a *Net Zero 2050 (Moderate CCS): Existing/FID Exports* scenario would resolve to the same outcomes as the *Net Zero 2050 (Moderate CCS): Model Resolved* scenario and is therefore not shown (and not used in this consequential analysis).

[c] Existing/FID exports refer to LNG capacity of currently operational LNG projects or LNG projects with export authorizations from DOE that have reached final investment decisions (FID) on their projects.

In the broader study, the NEMS and GCAM models were used to represent economic and environmental changes associated with the defined changes in U.S. LNG exports. The NEMS modeling focused on domestic changes that would be expected to occur in the scenarios modeled, but results from NEMS were not used as a part of this consequential analysis.[8]

Additional sensitivity scenarios on levels of domestic and rest of world natural gas production for the *Defined Policies* scenarios are listed in Table 2.

Table 2. Additional sensitivity scenarios in this study

Global climate policies	Natural gas resources	U.S. LNG export levels	Sensitivity scenarios full name	Sensitivity scenario abbreviation
Defined Policies	High U.S. Supply	Model Resolved	*DP High U.S. Supply: Model Resolved*	*DP Hi US Sup: MR*
	High U.S. Supply	Existing/FID Exports	*DP High U.S. Supply: Existing/FID Exports*	*DP Hi US Sup: ExFID*
	Low U.S. Supply	Model Resolved	*DP Low U.S. Supply: Model Resolved*	*DP Lo US Sup: MR*
	Low U.S. Supply	Existing/FID Exports	*DP Low U.S. Supply: Existing/FID Exports*	*DP Lo US Sup: ExFID*
	High Middle East Supply	Model Resolved	*DP High Middle East Supply: Model Resolved*	*DP Hi ME Sup: MR*
	High Middle East Supply	Existing/FID Exports	*DP High Middle East Supply: Existing/FID Exports*	*DP Hi ME Sup: ExFID*

Results from all scenarios in Table 1 and Table 2 were provided to NETL as output files with results for each model year (i.e., in five-year increments from 2020-2050). Across all years and scenarios, GCAM has about 100 discrete sectors, hundreds of discrete technologies, and many sector-technology pairs that can vary depending on the model configuration. However, only a subset of these sectors is relevant to this analysis (i.e., to the natural gas sectors). Detailed discussion of the formats and structures of received GCAM files is included in Appendix C-2.

Table 3 summarizes cumulative data for model year (2020-2050) including GHG emissions, U.S. LNG export volumes, and summary measures of global services from GCAM for the scenarios in Table 1. By default, GHG values in this study are shown using IPCC AR6, 100-year GWP values.

[8] NETL reviewed the NEMS data to evaluate the magnitude of changes to the regional production mix of natural gas over time to assess whether the GHG intensity of U.S. natural gas produced would change as a result of production mix changes. No significant change in intensity was found (see Appendix C-1 for details).

Where noted, IPCC AR6, 20-yr GWP values are also provided.[9] Shown here are GHG emissions in Teragrams of CO_2-equivalents (Tg CO_2e). The global services index is an aggregate weighted metric that summarizes the total services provided to global society as a result of the economic activity modeled in the scenarios over the 2020-2050 period where, by assumption, the *ExFID* scenario has a value of 1.00 within each Global Climate Policy set of scenarios (see Appendix C-2 for details).

Table 3. Summary of cumulative model year (every five years, 2020-2050) U.S. LNG exports, GHG emissions, and global services from GCAM

Scenario	Geographical Scope / Global Service Type							Global Weighted Index
	Global	U.S.	Global	Global Industrial		Global Transportation		
	GHG Emissions (AR6, 100-yr) (Tg CO_2e)	LNG Export Volumes (EJ)	Energy Services (EJ)	Commodity Products (Mt)	Nitrogen Fertilizer (Mt)	Freight, Million Ton-Kilometers (Mt-km)	Passenger, Million Passenger-Kilometers (Mp-km)	
DP: Hi Exp	351,607	95	2,376	39,752	1,144	1.53E+09	1.78E+09	1.0015
DP: MR	351,444	77	2,374	39,740	1,144	1.53E+09	1.78E+09	1.0008
DP: ExFID	351,286	50	2,372	39,725	1,145	1.52E+09	1.78E+09	1.0000
DP: Hi ME Sup: MR	352,433	74	2,382	39,801	1,143	1.53E+09	1.78E+09	1.00047
DP: Hi ME Sup: ExFID	352,356	50	2,381	39,792	1,143	1.53E+09	1.78E+09	1.0000
DP Hi US Sup: MR	351,649	88	2,376	39,750	1,144	1.53E+09	1.78E+09	1.00127
DP Hi US Sup: ExFID	351,377	50	2,372	39,727	1,145	1.53E+09	1.78E+09	1.0000
DP Lo US Sup: MR	350,692	53	2,370	39,720	1,145	1.52E+09	1.77E+09	1.00010
DP Lo US Sup: ExFID	350,683	49	2,369	39,717	1,145	1.52E+09	1.77E+09	1.0000
C (High CCS): Hi Exp	283,821	74	2,289	37,152	1,157	1.43E+09	1.76E+09	1.0009
C (High CCS): MR	283,677	56	2,287	37,137	1,157	1.43E+09	1.76E+09	1.0002
C (High CCS): ExFID	283,657	49	2,287	37,133	1,158	1.43E+09	1.76E+09	1.0000
C (Mod CCS): Hi Exp	270,432	69	2,254	35,460	1,131	1.38E+09	1.76E+09	1.0008
C (Mod CCS): MR	270,432	51	2,252	35,454	1,131	1.38E+09	1.76E+09	1.0001
C (Mod CCS): ExFID	270,189	48	2,252	35,453	1,131	1.38E+09	1.76E+09	1.0000
NZ (High CCS): Hi Exp	240,973	70	2,237	35,611	1,158	1.37E+09	1.76E+09	1.0008
NZ (High CCS): MR	240,923	52	2,236	35,594	1,158	1.37E+09	1.76E+09	1.0001
NZ (High CCS): ExFID	240,919	48	2,235	35,592	1,158	1.37E+09	1.76E+09	1.0000

[9] The use of GWP values converts emissions of distinct greenhouse gases into a single index of carbon dioxide equivalents to represent the global warming impact of the varied gases. The IPCC AR6, 100-yr GWP values (units kg CO_2e/kg gas) used are: fossil CH_4 (29.8), non-fossil CH_4 (27.2), and N_2O (273). See Appendix C-2 for GWP values used for other greenhouse gases (e.g., F-gases) and IPCC reports.

Scenario	Geographical Scope / Global Service Type							Global Weighted Index
	Global	U.S.	Global	Global Industrial		Global Transportation		
	GHG Emissions (AR6, 100-yr) (Tg CO_2e)	LNG Export Volumes (EJ)	Energy Services (EJ)	Commodity Products (Mt)	Nitrogen Fertilizer (Mt)	Freight, Million Ton-Kilometers (Mt-km)	Passenger, Million Passenger-Kilometers (Mp-km)	
NZ (Mod CCS): Hi Exp	224,035	61	2,195	33,244	1,119	1.30E+09	1.76E+09	1.0005
NZ (Mod CCS): MR	224,035	43	2,194	33,244	1,119	1.30E+09	1.76E+09	1.0000
NZ (Mod CCS): ExFID	223,831	43	2,194	33,244	1,119	1.30E+09	1.76E+09	1.0000

Notes:

- The values in this table reflect the sums of the 5-year interval data provided by the GCAM output for the years 2020-2050.
- Global energy services include: agricultural energy use, commercial cooking, commercial cooling, commercial heating, commercial hot water, commercial non-building, commercial office, commercial other, commercial others, commercial refrigeration, residential computers, residential cooking, residential cooling, residential freezers, residential furnace fans, residential heating, residential hot water, residential other, residential others, residential refrigerators, residential televisions, chemical energy use, chemical feedstocks, construction energy use, construction feedstocks, mining energy use, other industrial energy use, other industrial feedstocks, process heat cement
- Conversion of annual values from EJ/year to Bcf/d is 1:2.7759
- Global commodities products include production of aluminum, alumina, cement, and iron & steel.
- Freight transportation includes freight and international shipping.
- Passenger transportation includes ground and aviation.
- The weighted index is not provided in the GCAM results but was created in collaboration with the GCAM modeling team and is included here to summarize the global services results.

Step 2: Obtain U.S. Natural Gas National Average Life Cycle GHG Performance (from NETL Natural Gas Baseline)

The 2024 NETL natural gas baseline study[10] describes the GHG emissions due to production, gathering and boosting, processing, transmission, storage, and distribution of domestic U.S. natural gas to consumers and is representative of the year 2020, which aligns with the temporal representation of upstream natural gas processes of this study period (2020-2050). These natural gas supply chain stages (or industry segments) generally align with categories used in other federal efforts, such as EPA's Greenhouse Gas Reporting Program (GHGRP)[11] and Greenhouse Gas Inventory.[12] Results of this study are provided for two main scopes: production through transmission (end users after transmission typically include industrial and power sectors that receive natural gas via transmission pipeline directly), and production through distribution (end users after distribution typically include a combination of residential, commercial, industrial, and power sectors, where natural gas is delivered through the distribution pipeline network).

Quantitatively, the NETL natural gas baseline reports estimated ranges of GHG emissions intensities for each species (i.e., type of gas molecule) of GHG emission and for each stage of the domestic natural gas supply chain following the principles of attributional LCA. For the scope

[10] Khutal, H., et al. Life Cycle Analysis of Natural Gas Extraction and Power Generation: U.S. 2020 Emissions Profile. National Energy Technology Laboratory, Pittsburgh, December 2024. https://www.netl.doe.gov/energy-analysis/details?id=546d4009-c43b-43f5-bcc9-64d5e63fc8d5

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

[12] U.S. 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.

of domestic natural gas production through the transmission stage, the U.S. average GHG emissions intensity is estimated at 7.79 grams (g) CO_2e/megajoule (MJ) (with a 95 percent mean confidence interval of 4.6–11.1 g CO_2e/MJ, using IPCC AR6, 100-yr GWP values, higher heating value [HHV] basis) or about 8.63 g CO_2e/MJ (with a 95 percent mean confidence interval of 5.4 g CO_2e/MJ –12.8 g CO_2e/MJ, using the IPCC AR6, 100-yr GWP values, lower heating value [LHV] basis).[13,14]

The production through transmission boundary represents emissions associated with natural gas delivered to liquefaction plants (plant input). However, due to natural gas consumption and losses at the liquefaction stage, the amount of natural gas delivered to a liquefaction plant is higher than the amount of natural gas throughput/exported (plant output). Adjusting from a "per MJ of NG delivered to liquefaction plant" (plant input) to "per MJ of NG through liquefaction plant" (plant output) basis, results in a higher upstream GHG emissions intensity value. As a result, the production through transmission (upstream) GHG intensity on a per MJ NG throughput from liquefaction plant basis is 9.2 g CO_2e/MJ Exported (IPCC AR6, 100-yr GWP, LHV basis).[15]

Step 3: Model U.S. Liquefaction Plant National Average Life Cycle GHG Performance

As part of this study, a new national average life cycle GHG performance for U.S. liquefaction operations in the year 2020 was modeled to align the temporal representation of the liquefication data to the study period (2020-2050) and the U.S. national average for upstream natural gas production and delivery described in Step 2. U.S. Environmental Protection Agency's GHGRP data representative of year 2020 emissions were used as the basis with adjustments to account for certain missing emission sources in GHGRP that are discussed in more detail below, while ensuring alignment with combustion emission factors modeled in the NETL natural gas baseline LCA.

The resulting national average liquefaction process GHG emissions intensity for the year 2020 is 5.27 (or 5.3) g CO_2e/MJ (LHV) and is referred to as the 2024 NETL estimate throughout the rest of this section.

Six facilities reported to GHGRP for the 2020 data year and exported natural gas, as shown in Table 4. For the data tables and calculations shown for calculating the 2024 NETL estimate, only data from these six export facilities are used. These export volumes were also used to weight the calculated or reported facility-level GHG emissions.

[13] The rest of this report expresses GHG emissions intensity values on a lower heating value (LHV) basis (unless explicitly specified otherwise) to ensure alignment with the energy content basis used by the Global Change Analysis Model (GCAM).

[14] The higher heating value (HHV) of a fuel includes the heat released if all of the water vapor in the combustion products were condensed, while the lower heating value (LHV) is the heat released if all of the water vapor remained as vapor. A conversion factor of 1.108 MJ higher (HHV) basis per MJ lower (LHV) basis was used throughout the steps of this analysis.

[15] As per the updated NETL liquefaction stage modeling, around 1.07 kg of NG is delivered to the liquefaction plant per 1 kg of NG throughput from the plant.

Table 4. 2020 LNG facility export volumes as reported in GHGRP Subpart W[16]

LNG Facility Name	Quantity Exported (MMcf)
SLNG Elba Island Terminal	36,272
Sabine Pass LNG Terminal	926,901
Cove Point LNG Facility	233,227
Freeport	421,381
Corpus Christi Liquefaction	395,716
Cameron LNG LLC	385,662

Facility-level GHG emissions are summarized by GHGRP, allowing a direct calculation of carbon intensity for all facilities, shown in Table 5.

The speciated, summary emissions for each facility reported by GHGRP are shown in the AR4, 100-yr columns in the table. These are then converted to AR6, 100-yr to match this study (see Appendix C-2 for GWP values). LNG production is reported to GHGRP in terms of thousand cubic feet of gas, which is converted here to mass of LNG. The annual emissions and LNG production are used to calculate the speciated, AR6, 100-yr emission intensities, followed by the total in the last column. The production-weighted intensities are calculated in the bottom row based on the facility-specific information.

GHGRP data have known data gaps with regards to natural gas liquefaction facilities, including not accounting for GHG emissions from acid gas removal units (AGRU) and electricity consumption for compressors (as indicated by the low 2020 GHGRP GHG emissions intensity of the electric-driven Freeport LNG plant in Table 5).

Table 5. 2020 LNG facility GHG emissions as summarized in GHGRP[17]

	AR4, 100-yr, as-reported (Mt CO_2e/yr)			AR6, 100-yr, converted (Mt CO_2e/yr)			LNG Production, converted (Mt)	Emission Intensity, calculated AR6, 100-yr (kg CO_2e/kg LNG)			AR6, 100-yr Emissions Intensity (kg CO_2e/ kg LNG)
U.S. LNG Facility Name	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O		CO_2	CH_4	N_2O	Total
SLNG Elba Island Terminal	77,054	4,471	41	77,054	5,329	38	730,500	0.105	7.29E-03	5.19E-05	0.113
Sabine Pass LNG Terminal	4,127,013	29,905	2,314	4,127,013	35,647	2,120	18,667,328	0.221	1.91E-03	1.14E-04	0.223
Cove Point LNG Facility	1,120,158	4,616	614	1,120,158	5,502	562	4,697,068	0.238	1.17E-03	1.20E-04	0.240
Freeport	52,688	5,664	27	52,688	6,752	25	8,486,405	0.006	7.96E-04	2.90E-06	0.007
Corpus Christi Liquefaction	1,774,907	20,083	997	1,774,907	23,938	913	7,969,529	0.223	3.00E-03	1.15E-04	0.226
Cameron LNG LLC	3,092,913	46,931	1,729	3,092,913	55,942	1,584	7,767,049	0.398	7.20E-03	2.04E-04	0.406
							Production Weighted Avg	0.212	9.24E-05	3.97E-07	0.215

[16] U.S. EPA Greenhouse Gas Reporting Program (2021). Subpart W Reporting Year 2020. Available at www.epa.gov/ghgreporting. Date accessed: October 15, 2024.
[17] U.S. EPA Greenhouse Gas Reporting Program (2023). Summary GHG Data 2020. https://www.epa.gov/system/files/other-files/2023-12/ghgp_data_2020.xlsx. Date accessed: October 15, 2024.

Additionally, there are minor differences in the combustion factors used in the calculation of emissions from GHGRP Subpart C[18] data and those used by NETL in its LNG modeling. To address these limitations, the following steps were taken:

- When natural gas arrives at the LNG facility, it often contains some small amount of carbon dioxide that needs to be removed using acid gas removal before the low-temperature liquefaction process. In general, the CO_2 from acid gas removal (AGR) is simply vented to the atmosphere after being removed. These AGR CO_2 venting emissions have been estimated and incorporated within the GHG emissions profile of each liquefaction facility using the appropriate regional post-processing NG compositions reported in the natural gas baseline report and assuming that all CO_2 is removed from the pipeline gas and vented. The facilities are first aligned to an appropriate production region (either southeast or southwest) from the 2024 NETL natural gas baseline study, and then the post-processing natural gas composition is used to assign the mass fraction of CO_2 in the natural gas entering AGR (southeast – 0.261 kg CO_2/kg NG and southwest – 0.405 kg CO_2/kg NG[19]). The mass of CO_2 removed is then calculated as:

$$mass\ CO_2\ removed = \frac{mass\ fraction_{CO_2} \cdot mass\ fraction_{LNG\ export}}{1 - mass\ fraction_{CO_2}}$$

These data are summarized in Table 6, where the mass values are in metric tons (equal to Mg).

Table 6. 2020 LNG facility calculated CO_2 emissions from acid gas removal units[20]

U.S. LNG Facility Name	2024 NETL Natural Gas Baseline Study Production Region	Mass Fraction CO_2 in Gas Entering AGU Facility	LNG Mass Exported (Mt)	Mass CO_2 Removed (Mt/yr)
SLNG Elba Island Terminal	Southeast	0.26%	730,500	1,911
Sabine Pass LNG Terminal	Southeast	0.26%	18,667,328	48,827
Cove Point LNG Facility	Southeast	0.26%	4,697,068	12,286
Freeport	Southwest	0.40%	8,486,405	34,500
Corpus Christi Liquefaction	Southwest	0.40%	7,969,529	32,399
Cameron LNG LLC	Southeast	0.26%	7,767,049	20,316

- Emissions from electricity consumption for Freeport LNG terminal's electric drive turbines (the only operating U.S. export facility using this configuration) are incorporated using the Electric Reliability Council of Texas (ERCOT) electricity generation mix for 2020. The amount of electricity used by the Freeport LNG terminal is available in the company's

[18] Subpart C of the GHGRP is for General Stationary Fuel Combustion Sources. The EPA website summarizes these as "Stationary fuel combustion sources are devices that combust any solid, liquid, or gaseous fuel generally to produce electricity, steam, useful heat, or energy for industrial, commercial, or institutional use or reduce the volume of waste by removing combustible matter." For this work, the subpart C data from only the LNG facilities are considered.
[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, December 2024. https://www.netl.doe.gov/energy-analysis/details?id=546d4009-c43b-43f5-bcc9-64d5e63fc8d5
[20] U.S. EPA Greenhouse Gas Reporting Program (2021). Subpart W Reporting Year 2020. Available at www.epa.gov/ghgreporting. Date accessed: October 15, 2024.

sustainability report: 3,469,942 MWh[21]. The ERCOT greenhouse gas emissions intensity (kg CO_2e/MWh, AR6, 100-yr) is calculated using a custom generation mix in the NETL Grid Mix Explorer.[22] The generation mix was derived from the ERCOT Fuel Mix Report[23] as shown in Table 7. The end result is an additional 0.204 kg CO_2/kg LNG (AR6, 100-yr) exported for the Freeport facility.

Table 7. 2020 ERCOT generation mix[24]

Fuel type	Percent Mix	CO_2 (kg/MWh)	CH_4 (kg/MWh)	N_2O (kg/MWh)	GWP, AR6, 100-yr (kg CO_2e/MWh)
Biomass	0.09%	1.11	2.7E-04	3.4E-05	1.1
Coal	18.00%	203.57	9.3E-02	3.3E-03	207.2
Natural gas	45.66%	259.07	7.8E-01	9.9E-04	282.5
Hydro	0.17%	0.02	8.1E-05	1.0E-09	0.0
Nuclear	10.89%	1.48	1.7E-02	9.0E-05	2.0
Solar	2.30%	0.47	1.1E-03	1.6E-06	0.5
Wind	22.88%	6.23	1.4E-02	2.3E-05	6.7
				Total	500.1

- The reported facility-level emissions are separated by Subpart W[25] (Table 8 and Table 9) and Subpart C (Table 10) to allow the incorporation of the NETL combustion factors. The fuel quantities in Table 10 are multiplied by the NETL combustion factors listed in
- Table 11 to calculate the emissions for each combustion source. Combustion emissions for GHGRP are calculated using fuel use by the facility (e.g., gallons of diesel) and emissions factors (e.g., kg CO_2 per gallon diesel combusted) specified for reporting to GHGRP. NETL has developed its own emissions factors from open data sources that are used in its models. In order to make sure the liquefaction emissions used in this study would match future implementations in NETL products, NETL combustion factors are used to calculate the combustion emissions. Additionally, life cycle emissions for diesel production are included for completeness.
- Flaring CO_2 emissions are calculated from the amounts of natural gas sent to flaring reported in Table 8 by assuming a 98% mass conversion efficiency from CH_4 to CO_2 with the remaining 2% emitted as CH_4. If only these combustion-specific changes were

[21] Freeport LNG Sustainability and Community Investment Report 2020. https://freeportlng.com/files/docs/2020-Freeport-LNG-SCIR.PDF
[22] NETL Grid Mix Explorer v4.2. https://netl.doe.gov/energy-analysis/details?id=f0f94954-3627-4e9b-a5c0-c29cfe419d1c.
[23] ERCOT Fuel Mix Report: 2007-2020. https://www.ercot.com/files/docs/2021/03/10/FuelMixReport_PreviousYears.zip
[24] U.S. EPA Greenhouse Gas Reporting Program (2021). Subpart W Reporting Year 2020. Available at www.epa.gov/ghgreporting. Date accessed: October 15, 2024.
[25] Subpart W of the GHGRP is for emissions from petroleum and natural gas systems, and more specifically non-combustion emissions. The EPA website summarizes these as "Owners or operators of facilities that contain petroleum and natural gas systems and emit 25,000 metric tons or more of GHGs per year (expressed as carbon dioxide equivalents) report GHG data to EPA. Owners or operators collect GHG data; calculate GHG emissions; and follow the specified procedures for quality assurance, missing data, recordkeeping, and reporting. Subpart W consists of emission sources in ten segments of the petroleum and natural gas industry."

implemented, the 0.215 kg CO_2e/kg LNG value in Table 5 would become 0.219 kg CO_2e/kg LNG, a 2 percent increase.

Table 8. 2020 LNG facility GHGRP Subpart W LNG import and export equipment emission sources[26]

U.S. LNG Facility Name	NG Sent to Flare (MMscf)	Feed Gas Sent to Flare - CH_4 Mass Fraction	Feed Gas Sent to Flare - CO_2 Mass Fraction	Blowdown Vent Stack (tons CO_2)	Blowdown Vent Stack (tons CH_4)	Blowdown Vent Stack (tons N_2O)
SLNG Elba Island Terminal	770	0.3392	0.0234	0.1	5.1	0
Sabine Pass LNG Terminal	3,741	0.8045	0.0771	0.0	258.6	0
Cove Point LNG Facility	1,454	0.4538	0.2749	0.6	22.4	0
Freeport	854	0.9750	0.0100	0.0	0.0	0
Corpus Christi Liquefaction	4,338	0.8549	0.0039	0.0	0.0	0
Cameron LNG LLC	22,041	0.8254	0.0079	0.0	0.0	0

Table 9. 2020 LNG facility GHGRP Subpart W LNG import and export equipment emission sources (cont'd)[26]

U.S. LNG Facility Name	Equipment Leaks (tons CO_2)	Equipment Leaks (tons CH_4)	Equipment Leaks (tons N_2O)	Reciprocating Compressors (tons CO_2)	Reciprocating Compressors (tons CH_4)	Reciprocating Compressors (tons N_2O)
SLNG Elba Island Terminal	0	48.37	0	0.7	23.97	0
Sabine Pass LNG Terminal	0	224.73	0	0	0	0
Cove Point LNG Facility	0	19.88	0	2.7	93.09	0
Freeport	0	9.39	0	0	0	0
Corpus Christi Liquefaction	0	58.38	0	0	0	0
Cameron LNG LLC	1.8	68.97	0	0	0	0

[26] U.S. EPA Greenhouse Gas Reporting Program (2021). Subpart W Reporting Year 2020. Available at www.epa.gov/ghgreporting. Date accessed: October 15, 2024.

Table 10. 2020 LNG facility GHGRP Subpart C general stationary fuel combustion[26]

U.S. LNG Facility Name	Simple Cycle Combustion Turbines - NG Combusted (MMscf/yr)	Other Combustion Sources - NG Combusted (MMscf/yr)	Thermal Oxidizer Direct Fired (MMscf/yr)	Combined Cycle Combustion Turbines - NG Combusted (MMscf/yr)	Other Boiler - NG Combusted (MMscf/yr)	Process Heater - NG Combusted (MMscf/yr)	Process Heater - Propane Combusted (MMscf/yr)	Recipro-cating Internal Combustion Engine - Distillate Fuel Oil No. 2 (gal/yr)
SLNG Elba Island Terminal	0	1,050	0	0	0	0	0	0
Sabine Pass LNG Terminal	74,721	0	1,587	0	0	0	0	0
Cove Point LNG Facility	2,897	0	0	14,492	2,516	290	0.358	0
Freeport	0	0	0	0	0	0	0	0
Corpus Christi Liquefaction	25,805	798	0	2,084	0	0	0	25,856
Cameron LNG LLC	0	33,009	641	639	0	0	0	0

Table 11. NETL stationary combustion emission factors and distillate fuel life cycle emissions

Fuel	CO_2	CH_4	N_2O	Units
Distillate Fuel Oil No. 2[1]	3.20	1.28E-04	2.51E-05	kg/kg diesel
Distillate Fuel Oil No. 2 (Upstream)[2]	0.638	4.82E-03	2.82E-05	kg/kg diesel production
Natural Gas Reciprocating Compressor[3]	2.83	3.31E-02	0	kg/kg natural gas
Natural Gas Centrifugal Compressor[3]	2.66	2.08E-04	7.24E-05	kg/kg natural gas
Natural Gas Combustion[2]	2.83	5.42E-05	0	kg/kg natural gas
Propane[4]	0.155	0	0	kg/scf

Notes:

[1] NETL (2014). NETL Life Cycle Inventory Data – Unit Process: Combustion of Diesel. U.S. Department of Energy, National Energy Technology Laboratory. Last Updated: January 2015 (version 02). www.netl.doe.gov/LCA

[2] NETL (2008). Development of Baseline Data and Analysis of Life Cycle Greenhouse Gas Emissions of Petroleum-Based Fuels.

[3] NETL (2015). NETL Life Cycle Inventory Data – Unit Process: Combustion of Natural Gas. U.S. Department of Energy, National Energy Technology Laboratory. Last Updated: January 2015 (version 01). www.netl.doe.gov/LCA

[4] Propane emission factor is from Table C-1 to Subpart C – Default CO_2 Emission Factors and High Heat Values for Various Types of Fuel. https://www.ecfr.gov/current/title-40/chapter-I/subchapter-C/part-98/subpart-C/appendix-Table%20C-1%20to%20Subpart%20C%20of%20Part%2098

Table 12 summarizes the total for each species of GHG emissions (i.e., "speciated emissions") as calculated after the above adjustments and re-calculates the GHG intensity for each LNG facility (following the same columns/steps as used to create Table 5). These results show that accounting for the additional emissions increases the production-weighted average emissions intensity from 0.215 (Table 5) to 0.258 kg CO_2e/kg LNG. Additional unit conversion present results on a g CO_2e/MJ basis, including a conversion to LHV to align with GCAM.[27]

[27] The higher heating and lower heating values for these conversions are 54.3 MJ/kg LNG and 49.0 MJ/kg LNG, respectively, and are multiplied by the mass-based Facility GHG intensity (in kg CO_2e/kg LNG).

Table 12. NETL liquefaction estimate - speciated emissions

U.S. LNG Facility Name	CO_2 (Mg CO_2e)	CH_4 (Mg CO_2e)	N_2O (Mg CO_2e)	GWP, AR6, 100-yr (Mg CO_2e)	LNG Mass Exported (Mg)	Facility GHG Intensity (kg CO_2e/kg LNG)	Facility GHG Intensity (g CO_2e/MJ LNG HHV)	Facility GHG Intensity (g CO_2e/MJ LNG LHV)
SLNG Elba Island Terminal	76,214	5,477	0	81,691	730,500	0.112	2.06	2.28
Sabine Pass LNG Terminal	4,304,382	59,889	29,753	4,394,024	18,667,328	0.235	4.33	4.80
Cove Point LNG Facility	1,145,880	14,215	6,924	1,167,019	4,697,068	0.248	4.57	5.07
Freeport	1,717,497	103,843	4,169	1,825,509	8,486,405	0.215	3.96	4.39
Corpus Christi Liquefaction	1,770,920	49,755	11,105	1,831,780	7,969,529	0.230	4.23	4.69
Cameron LNG LLC	2,960,706	221,601	254	3,182,562	7,767,049	0.410	7.54	8.36
					Production Weighted Average	0.258	4.76	5.27

Below, the updated 2024 NETL liquefaction stage (2020 data year) GHG intensity estimates are compared to:

- U.S. EPA Greenhouse Gas Reporting Program (GHGRP) data[28,29]
- A 2021 paper that included liquefaction emissions as part of supplier-specific LCA for LNG supply chains (Roman-White et al., 2021)[30]
- An August 2024 pre-print of a paper reporting greenhouse gas emissions estimates of two liquefaction facilities based on measured emissions (Zhu et al., 2024)[31]

[28] U.S. EPA Greenhouse Gas Reporting Program (2023). Summary GHG Data 2020. https://www.epa.gov/system/files/other-files/2023-12/ghgp_data_2020.xlsx. Date accessed: October 15, 2024.
[29] U.S. EPA Greenhouse Gas Reporting Program (2023). Summary GHG Data 2022. http://www.epa.gov/ghgreporting. Date accessed: October 15, 2024. Calculations are based on emissions and exports from seven facilities for 2022.
[30] Roman-White, S. A., Littlefield, J. A., Fleury, K. G., Allen, D. T., Balcombe, P., Konschnik, K. E., Ewing, J., Ross, G. B., & George, F. (2021). LNG Supply Chains: A Supplier-Specific Life-Cycle Assessment for Improved Emission Accounting. ACS Sustainable Chemistry & Engineering, 9(32), 10857–10867. https://doi.org/10.1021/acssuschemeng.1c03307
[31] Zhu Y, Ross G, Khaliukova O, Roman-White S, George F, Hammerling D, et al. Multi-scale Measurements of Greenhouse Gas Emissions at U.S. Natural Gas Liquefaction Terminals. ChemRxiv. 2024; doi:10.26434/chemrxiv-2024-h4flq (This content is a preprint and has not been peer-reviewed).

Table 13. Comparison of NETL liquefaction stage GHG emissions intensity with other literature

Source		Liquefaction Stage Emissions Intensity				
		CO_2 (kg CO_2/kg LNG)	**CH_4 (kg CH_4/kg LNG)**	**N_2O (kg N_2O/kg LNG)**	**CO_2e, AR6, 100-yr GWP (kg CO_2e/kg LNG)**	**CO_2e, AR6, 100-yr GWP (g CO_2e/MJ LHV)**
NETL 2024 – National Average		**0.248**	**3.16E-04**	**3.96E-06**	**0.258**	**5.27**
GHGRP Reporting Year 2020		0.212	9.24E-05	3.97E-07	0.215	4.39
GHGRP Reporting Year 2022		0.202	4.79E-05	3.82E-07	0.204	4.16
Roman-White et al., 2021	Sabine Pass, 2018 data	-	5.00E-05	-	0.26	5.31
Zhu et al., 2024	Site 1	0.220	1.82E-04	-	0.225	4.59
	Site 2	0.243	2.22E-04	-	0.250 (0.211 – 0.281)	5.10

Notes:
- The 2024 NETL estimate uses 2020 GHGRP data as the reference data source and incorporates acid gas removal emissions for each facility and electricity consumption emissions for the Freeport LNG facility, while ensuring alignment with combustion emission factors modeled in the NETL natural gas baseline LCA to generate a representative national average liquefaction stage GHG intensity profile.
- Upon accounting for emissions from electricity consumption for the Freeport LNG terminal (represents 18% of NG exports in 2020), the GHG intensity of the facility rises from 0.011 kg CO_2e/kg LNG to 0.22 kg CO_2e/kg LNG (AR6, 100-year). Emissions from electricity consumption represent ~95% of the GHG emissions profile of the Freeport LNG terminal based on available data.

The higher GHG emissions intensity for the 2024 NETL liquefaction result compared to the 2020 and 2022 (20% and 26% higher, respectively) reporting year GHGRP estimates is driven by the additional AGRU CO_2 emissions, carbon intensity of the ERCOT grid to support on site electricity use and ensuring consistency with NETL modeling emissions factors. On an AR6, 100-yr basis, the 2024 NETL attributional GHG emissions intensity estimate for liquefaction generally aligns with estimates from other sources as noted below and provided in Table 13.

- Roman-White et al., 2021: 2024 NETL liquefaction stage emissions intensity is equivalent (<1% difference) to the liquefaction stage estimate reported in the Roman-White et al. study.

- Zhu et al., 2024: 2024 NETL estimate is around 3-15% higher than estimates reported by Zhu et al. However, NETL estimates are within the reported uncertainty range for site 2 as reported by Zhu et al. Also, the 2024 NETL estimate represents a national average liquefaction stage GHG emissions intensity profile for the year 2020, whereas the Zhu et al. study focuses on two specific liquefaction terminals – Sabine Pass, LA and Corpus Christi, TX.

Step 4: Align GCAM Natural Gas Production and Pipeline Transport to U.S. National Average GHG Performance

NETL compared the GCAM model results to the year 2020 national average for upstream natural gas production through delivery to a large end user as reported in the NETL Baseline Study (as described in Step 2). This was done to align the representation of U.S. natural gas production and

pipeline transport GHG emissions representation to the study start period (Year 2020) based on U.S. industry average data.

Specifically, 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 U.S. from GCAM to the NETL life cycle GHG intensity for U.S. average natural gas production and delivery to large end users (from Step 2), using a ratio of the NETL and GCAM results. Since GCAM uses lower heating value (LHV) to express energy content, the NETL model output figures were adjusted from HHV to LHV basis, resulting in a value of 8.63 g CO_2e/MJ (AR6, 100-yr, LHV basis). This comparison aggregated data only from three GCAM sectors in the USA region: *natural gas, gas pipelines,* and *other industrial energy use*[32].

The intensity values of upstream natural gas in GCAM and the 2024 NETL study were found to differ by 1.17% (with the NETL intensity of 8.63 g CO_2e/MJ being slightly higher than the GCAM value found to be 8.53 g CO_2e/MJ on an AR6, 100-yr LHV basis). See Appendix C-2 for additional details, including the alternate development of the adjustment factor on an AR6, 20-yr basis.

Step 5: Calculate GCAM-NETL-aligned Global GHG Emissions Results

Using the 1.17% adjustment factor calculated in Step 4, results for the three GCAM sectors listed in Step 4 were adjusted (increased by 1.17%) to align with NETL GHG intensity values. Non-U.S. region natural gas production and delivery GHG emissions intensity values for these same sectors were also adjusted up by 1.17% to align with NETL life cycle GHG intensity values. Note that the comparison and adjustment was done only to maintain the total CO_2e intensity value and not on a speciated emission basis. This adjustment was applied to all model years and regions for these three sectors reported by GCAM (i.e., every fifth year from 2020-2050). The *Defined Policies: Existing/FID Exports* scenario is shown in Table 14 as an example of the overall unadjusted and adjusted GCAM GHG emissions results (across all sectors) and for the three aligned sectors. The majority of the increase in adjusted emissions are in the GCAM *natural gas* sector. Overall, the adjustments to align to NETL 2020 national average performance data for GHG intensity (AR6, 100-yr basis) added about 20 Tg CO_2e emissions per model year, a net increase in overall global emissions of less than 0.05%.

Table 14. GCAM unadjusted and NETL aligned sector emissions for Defined Policies: Existing/FID Scenario (AR6, 100-yr basis)

Year	GHG Emissions (Tg CO_2e)									
	GCAM Unadjusted					GCAM-NETL Aligned				
	Natural Gas	Gas Pipeline	Other Industrial Energy Use	All Other Sectors	Total Across All GCAM Sectors	Natural Gas	Gas Pipeline	Other Industrial Energy Use	All Other Sectors	Total Across All GCAM Sectors
2020	957	185	5,146	47,463	53,751	968	188	5,152	47,462	53,770
2025	827	171	5,855	44,145	50,998	836	173	5,862	44,146	51,017
2030	868	182	6,670	41,417	49,137	878	184	6,677	41,417	49,156
2035	888	184	7,310	41,792	50,174	899	187	7,318	41,790	50,194
2040	894	189	7,856	40,428	49,367	904	191	7,864	40,429	49,388

[32] The adjustment for the other industrial energy use sector was focused only on natural gas relevant technologies, which comprises a small part of the overall sector. As such the resulting adjustment factor for that sector was about 0.1%. Appendix C-2 shows details of the adjustment for that sector.

2045	955	193	8,445	39,651	49,244	966	195	8,454	39,652	49,267
2050	1,013	195	8,936	38,471	48,615	1,025	197	8,945	38,472	48,639

Note: As detailed above, only a subset of emissions in the other industrial energy use were adjusted.

Table 15 shows how speciated emissions of CO_2 and CH_4 changed with the adjustments described above for the *Defined Policies: Existing/FID Exports* scenario. This shows that of the approximately 20 Tg CO_2e adjusted per year, it is generally evenly split between CO_2 and CH_4 on a CO_2e basis. The table also provides perspective on the contribution of the speciated emissions to the total global emissions profile.

Table 15. Model-year GCAM-NETL-aligned GHG emissions for DP: ExFID Scenario

Year	GHG Emissions (Tg CO_2e)									
	GCAM Unadjusted					GCAM-NETL Aligned				
	CO_2 Energy	CO_2 LUC[a]	CH_4 Energy	Other GHGs	Total	CO_2 Energy	CO_2 LUC	CH_4 Energy	Other GHGs	Total
2020	38,399	398	6,666	8,288	53,751	38,407	398	6,677	8,288	53,770
2025	36,091	754	5,588	8,566	50,998	36,099	754	5,598	8,566	51,017
2030	36,605	-2,679	5,785	9,425	49,137	36,615	-2,679	5,795	9,425	49,156
2035	35,737	-1,233	5,763	9,906	50,174	35,748	-1,233	5,773	9,906	50,194
2040	34,906	1,328	5,584	10,204	49,367	34,917	-1,328	5,595	10,204	49,388
2045	34,047	-992	5,617	10,573	49,244	34,058	-992	5,628	10,573	49,267
2050	32,900	-874	5,629	10,961	48,615	32,912	-874	5,641	10,961	48,639

Note: In the global analysis, CO_2 emissions from energy are subject to uncertainties in regional emission intensities of natural gas and other fossil fuels. The negative result for land use change CO_2 emissions demonstrates that more CO_2 is removed from the atmosphere than released from changes in land use systems in the modeled timeframe. In the global analysis, emissions from land-use changes are driven in part by changes in energy production, including those driven by changes in demand (e.g., global demand or LNG). These emissions are also subject to greater uncertainties largely due to uncertainties in data. A detailed exploration of these uncertainties is beyond the scope of this study.

Step 6: Interpolate GCAM-aligned Results from 5-year Time Steps to Annual Results

The results from Step 5 of every fifth-year model output (2020-2050) were interpolated to all intervening years via simple linear interpolation methods (e.g., the difference in five-year values divided by five and added as 1/5th shares to subsequent years). This interpolation was done for both GHG emissions as well as for U.S. LNG exports, with an example for *Defined Policies: Existing/FID Exports* shown in Table 16. These annual results are also summed as cumulative values over the period 2020-2050. Interpolated U.S. LNG export values are provided in Table 16.

Table 16. Modeled, interpolated, and cumulative GCAM-NETL-aligned GHG emissions for DP: ExFID Scenario

Year	CO_2 Energy	CO_2 LUC	CH_4 Energy	Other GHGs	Total	U.S. LNG Exports	
	Units (Tg CO_2e/year) (AR6, 100-yr)					EJ	Bcf/d
2020	38,407	398	6,677	8,288	53,770	2.44	6.8
2021	37,946	469	6,461	8,344	53,220	3.22	8.9
2022	37,484	540	6,245	8,399	52,669	4.00	11.1
2023	37,023	611	6,029	8,455	52,118	4.78	13.3
2024	36,561	683	5,814	8,511	51,567	5.55	15.4

Year	CO_2 Energy	CO_2 LUC	CH_4 Energy	Other GHGs	Total	U.S. LNG Exports	
	Units (Tg CO_2e/year) (AR6, 100-yr)					EJ	Bcf/d
2025	36,099	754	5,598	8,566	51,017	6.33	17.6
2026	36,202	67	5,637	8,738	50,645	6.45	17.9
2027	36,305	-619	5,677	8,910	50,273	6.58	18.3
2028	36,409	-1,306	5,716	9,082	49,901	6.70	18.6
2029	36,512	-1,992	5,755	9,254	49,529	6.83	19.0
2030	36,615	-2,679	5,795	9,425	49,157	6.95	19.3
2031	36,441	-2,389	5,791	9,522	49,364	7.27	20.2
2032	36,268	-2,100	5,786	9,618	49,572	7.59	21.1
2033	36,095	-1,811	5,782	9,714	49,779	7.90	21.9
2034	35,921	-1,522	5,777	9,810	49,987	8.22	22.8
2035	35,748	-1,233	5,773	9,906	50,194	8.54	23.7
2036	35,582	-1,252	5,738	9,966	50,033	8.54	23.7
2037	35,416	-1,271	5,702	10,025	49,872	8.54	23.7
2038	35,249	-1,290	5,666	10,085	49,711	8.54	23.7
2039	35,083	-1,309	5,631	10,144	49,550	8.54	23.7
2040	34,917	-1,328	5,595	10,204	49,388	8.54	23.7
2041	34,745	-1,261	5,602	10,278	49,364	8.54	23.7
2042	34,574	-1,194	5,608	10,352	49,340	8.54	23.7
2043	34,402	-1,127	5,615	10,425	49,315	8.54	23.7
2044	34,230	-1,059	5,621	10,499	49,291	8.54	23.7
2045	34,058	-992	5,628	10,573	49,267	8.54	23.7
2046	33,829	-969	5,631	10,651	49,141	8.54	23.7
2047	33,600	-945	5,633	10,728	49,016	8.54	23.7
2048	33,370	-922	5,636	10,806	48,890	8.54	23.7
2049	33,141	-898	5,638	10,883	48,765	8.54	23.7
2050	32,912	-874	5,641	10,961	48,639	8.54	23.7
Total	**1,101,142**	**-28,818**	**178,896**	**301,120**	**1,552,340**	**227**	**-**

Using the interpolated data for *Defined Policies: Model Resolved* and *Defined Policies: Existing/FID Exports*, Speciated emissions for all years 2020-2050, as well as total GHG emissions and U.S. LNG export volumes for all modeled scenarios are provided as data tables in Appendix C-4.

shows that while U.S. LNG export volumes (expressed as the dotted orange and blue lines) begin to appreciably change around 2030, and more than double in the modeled scenario by 2050, total global GHG emissions (shown as the solid orange and blue lines) do not begin to differ until 2040, and then by only 0.1 percent. The time effect of when the emissions differ is important and will be revisited in the discussion of subsequent steps.

Speciated emissions for all years 2020-2050, as well as total GHG emissions and U.S. LNG export volumes for all modeled scenarios are provided as data tables in Appendix C-4.

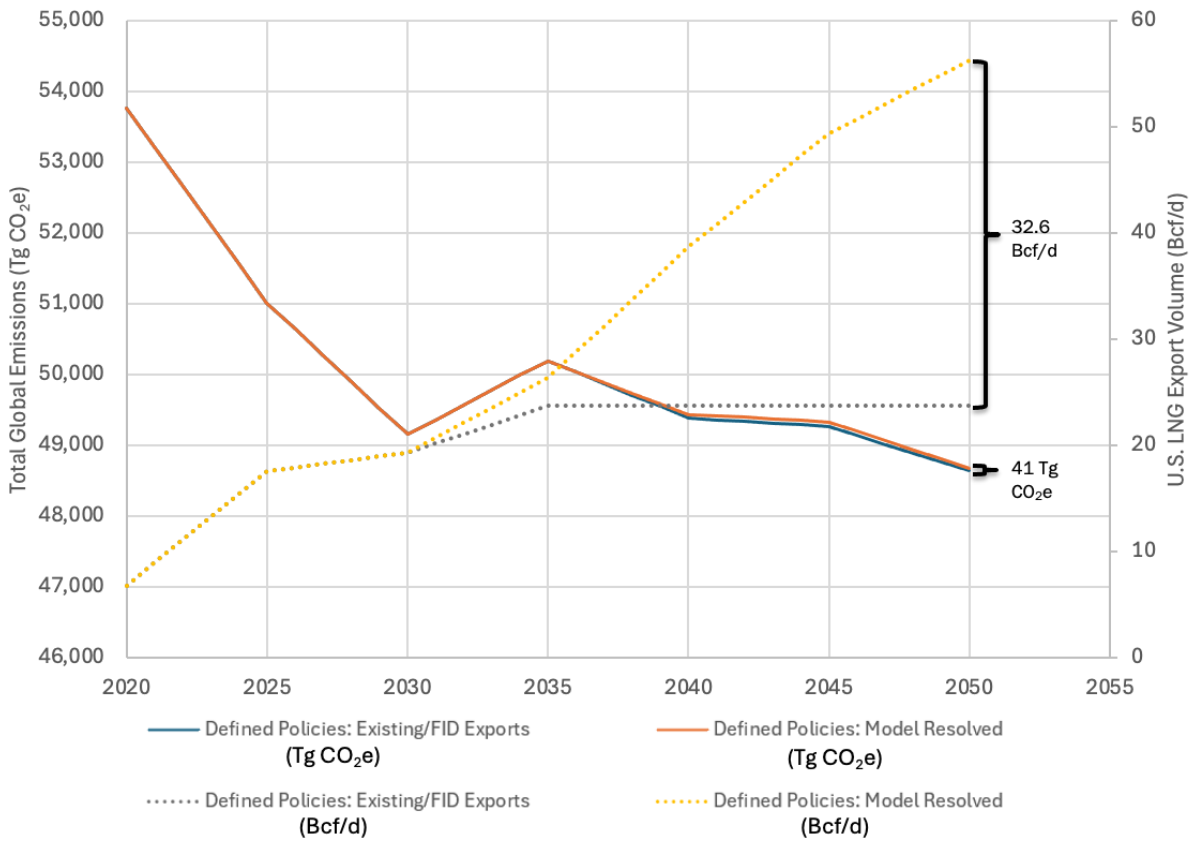

Figure 1. GHG emissions and U.S. LNG export trends for the Defined Policies: Existing/FID and Defined Policies: Model Resolved Scenarios

Step 7: Calculate GCAM-NETL-aligned Consequential GHG Intensity and SC-GHG per Unit of U.S. LNG Exports

The emissions results provided by GCAM are total global emissions, including upstream and downstream emissions (accounting for direct emissions and direct and indirect market effects, and including use/combustion of fuels). The consequential GHG intensity is the effect (inclusive of both direct and indirect emissions) of U.S. LNG on global emissions per unit of U.S. LNG exported. To quantify the consequential GHG intensity of U.S. LNG, the GCAM-NETL-aligned results were used to estimate the change in global GHG emissions per unit of U.S. LNG exported between scenarios within a global climate policy. The consequential GHG intensity of increased U.S. LNG Exports is defined as shown in Equation 1:

$$\begin{matrix} Consequential\ GHG\ Intensity \\ of\ U.S.Exports \end{matrix}_{scenario\ n} = \frac{Global\ Emissions_{scenario\ n} - Global\ Emissions_{scenario\ base}}{U.S.\ LNG\ Exports_{scenario\ n} - U.S.\ LNG\ Exports_{scenario\ base}} \quad (1)$$

This intensity value in all scenarios was estimated in comparison to the *Existing/FID* scenario baseline within a policy scenario (e.g., *Defined Policies: Model Resolved* would be compared to the *Defined Policies: Existing/FID* baseline, and this specific pairwise comparison will be used throughout this section of the report as an example). The consequential GHG intensity of increased U.S. LNG exports under this scenario can be calculated for every year (2020–2050), and with cumulative values of GHG emissions and U.S. LNG exports over the time horizon of the model.

For *Defined Policies: Model Resolved* versus *Defined Policies: Existing/FID Exports*[33] the consequential GHG intensity is the total difference in annually estimated global GHG emissions over the 2020-2050 period (711 Tg CO_2e) divided by the total difference in exported U.S. LNG over the same period (113 EJ)[34], or 6.3 g CO_2e/MJ. The consequential GHG intensity of U.S. LNG exports is estimated for all scenarios (versus their *ExFID* baseline). Cumulative consequential GHG intensity results for all scenarios are provided in Table 22. Annual consequential GHG intensity results for each scenario are provided in Appendix C-4.

Note that the study assumes that the difference in emissions between scenarios within a global climate policy is the total difference in life cycle emissions (and that the reason for the difference in emissions is the difference in U.S. LNG exported). By normalizing to the difference in U.S. LNG exports, the study assumes that the consequential GHG intensity result is showing the difference in total global emissions associated with an additional unit of U.S. LNG exported, inclusive of direct emissions and direct and indirect market effects. This leads to results on a g CO_2e/MJ of LNG exported basis (amount of GHGs emitted per unit of energy contained in LNG).[35]

The speciated GHG emissions inputs to the consequential GHG intensity can also be used with the 2023 SC-GHG methodology to monetize the impacts of the changes in GHG emissions associated with increased U.S. LNG exports. The SC-GHG, as described by the Interagency Working Group (IWG) on SC-GHG, is "the monetary value of the net harm to society associated with adding a small amount of greenhouse gases to the atmosphere in a given year."[36] Estimates of the SC-GHG "allow analysts to incorporate the net social benefits of reducing emissions of greenhouse gases, or the net social costs of increasing such emissions, in benefit-cost analysis, and when appropriate, in decision making and other contexts."[37] In short, the SC-GHG monetizes the net harm to society caused by the release of an additional ton of GHGs into the atmosphere in a given year.

The 2023 SC-GHG method uses a trio of discount rates (1.5%, 2.0% and 2.5%) to provide values of the SC-GHG for a particular base year (assumed in this study as 2024) and dollar year. The base year (which can also be considered the present value year) was chosen to be 2024 to align with the time of the study, consistent with the suggested choice aligning with a regulatory impact assessment time. The study used 2020 as the dollar year, consistent with the default year of damages provided in the framework. The monetized SC-GHG values for each of the three greenhouse gases for each of the three discount rates for each year of the study period (in year 2020 dollars) used by the method are summarized in Appendix C-3.

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[33] Recall that from Table 1, the *Defined Policies: Existing/FID Exports* scenario in GCAM represents expected future trajectories of U.S. LNG exports and GHG emissions where U.S. LNG production is constrained to volumes equal to 90% of the capacity up to or past the point of final investment decision, while the *Defined Policies: Model Resolved* scenario calculates what economically-driven levels of U.S. LNG might be supplied into the global market without that constraint. Yet, this scenario comparison is just one of the many scenarios modeled and should not be considered the primary result.

[34] Results for each year 2020-2050 and IPCC AR6 20-year time horizons are shown in Appendix C-4.

[35] The underlying GCAM data is in Tg of GHG Emissions and EJ of LNG used, a Tg/EJ is equivalent to g/MJ.

[36] Interagency Working Group on Social Cost of Greenhouse Gases, U.S. Government. (February 2021). "Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide. Interim Estimates under Executive Order 13990". https://www.whitehouse.gov/wp-content/uploads/2021/02/TechnicalSupportDocument_SocialCostofCarbonMethaneNitrousOxide.pdf

[37] U.S. EPA (November 2023). Report on the Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances. https://www.epa.gov/system/files/documents/2023-12/epa_scghg_2023_report_final.pdf

For *Defined Policies: Model Resolved* versus *Defined Policies: Existing/FID Exports*, the cumulative difference in emissions from 2020-2050 is estimated to have a cumulative SC-GHG impact of $70 billion using a discount rate of 2.5%, $130 billion using a discount rate of 2.0%, and $220 billion using a discount rate of 1.5% (all 2020$). SC-GHG estimates for all scenarios are provided in Table 23.

Normalizing SC-GHG results per MJ of change in natural gas exported leads to estimated intensities ranging from $0.0007/MJ (2.5% discount rate) to $0.002/MJ (1.5% discount rate). In other words, for this scenario, the social costs of the additional GHG emissions associated with increased U.S. LNG exports range from 0.07 cents/MJ (2.5% discount rate) to 0.2 cents/MJ (1.5% discount rate). SC-GHG estimates per unit of change in energy exported for all scenarios are provided in

Table 24. SC-GHG estimates per unit of change in energy exported for all scenarios are provided in Appendix C-2.

Step 8: Subtract National Average Upstream Natural Gas and Liquefaction Plant GHG Performance to Determine Project Non-Direct Emissions Intensity

The overall consequential GHG intensity values include all emissions from direct emissions as well as direct and indirect market effects. To facilitate an approach to evaluating environmental GHG performance of individual LNG projects that accounts for consequential market effects, these overall consequential values need to be broken down into component parts. Overall, the consequential GHG intensity of U.S. exports can be split into two primary categories, project direct emissions and project non-direct emissions, expressed in Equation 2.

Consequential GHG Intensity of US Exports = Project Direct Emissions + Project Non-Direct Emissions (2)

where:

Project direct emissions include liquefaction emissions and all upstream emissions of producing and processing the natural gas before liquefaction.

Project non-direct emissions include emissions not included in the definition of project direct emissions. This includes direct emissions from ocean shipping, regasification, importing country transport of the gas, and use (unspecified) of the exported gas, plus the direct and indirect market effects.

The project non-direct emissions factor is estimated by taking the consequential GHG intensity and subtracting the estimated project direct emissions intensity, as shown in Equation 3 (just a re-arranged version of Equation 2).

Project Non-Direct Emissions = Consequential GHG Intensity of US Exports - Project Direct Emissions. (3)

For the purposes of this study, project direct emissions values were assumed to be equal to the sum of Year 2020 U.S. average GHG emission intensity estimates for upstream natural gas production and delivery and liquefaction operations as described in Steps 2 and 3 (i.e., 9.2 and 5.3 g CO_2e/MJ, respectively, for upstream natural gas and liquefaction). The sum of project direct emissions is thus 14.5 g CO_2e/MJ.

Applying Equation 3 and the project direct emissions factor above, the project non-direct emissions factor for *Defined Policies: Model Resolved* would be +6.3 – (9.2 + 5.3), or a net of -8.2 g CO_2e/MJ. Since the project direct emissions are substantially higher than the consequential GHG intensity, it follows that the project non-direct emissions would be negative given Equations 2 and 3.

The project non-direct emissions value, which includes LNG usages across all technologies and options in global markets, represents the overall expected net global effect from ocean transport through use of the LNG plus direct and indirect market effects. The project non-direct emissions value is an interim value that enables comparison to GHG emissions from the U.S. default natural gas upstream and liquefaction values used in this study and should not be used as the basis for interpreting study findings. Table 25 summarizes the resulting project non-direct emissions values for all scenarios.

Step 9: Add Project Direct Emissions to Project Non-Direct Emissions to Determine Individual Project GHG Emissions Intensity Inclusive of Consequential Market Effects

To understand how an individual U.S. export project may differ from the U.S. average liquefaction facility values modeled in the study, the various speciated emissions values, consequential GHG intensity, and project non-direct emissions can be compared.

The default values used for individual project analyses would be the average U.S. values described in Steps 2 and 3 (9.2 g CO_2e/MJ for upstream U.S. natural gas and 5.3 g CO_2e/MJ for liquefaction).

Equations 2 and 3, defined above, are repeated here and used to help organize the consequential GHG intensities of the default facility.

Consequential GHG Intensity of US Exports = Project Direct Emissions + Project Non-Direct Emissions (2)

Project Non-Direct Emissions = Consequential GHG Intensity of US Exports - Project Direct Emissions (3)

For a default project, using the example of *Defined Policies: Model Resolved* compared against *Defined Policies: Existing/FID Exports*, the consequential GHG intensity can be organized into speciated components as shown in Table 17, with a total default U.S. average consequential GHG intensity of +6.3 g CO_2e/MJ. The values in Table 17, and its project non-direct emissions and consequential GHG intensity rows, could be used to subsequently compare individual project data.[38]

Table 17. Default values for natural gas upstream and liquefaction facility operations (example DP:MR vs. DP:ExFID)

Stage	Average Default GHG Intensity, (g CO_2e/MJ)		
	CO_2	CH_4	Total
NG Upstream	5.6	3.6	9.2
Liquefaction	5.1	0.2	5.3
Project Non-Direct Emissions (Estimated)	**-4.8**	**-3.4**	**-8.2**
Consequential Global GHG Emissions Intensity	5.8	0.5	**+6.3**

Step 10: Demonstrate Estimation of Consequential GHG Intensity and SC-GHG for an Individual U.S. LNG Project

This step demonstrates how the study results can be used, starting with the default U.S. average LNG export results (from Step 9) and hypothetical project data, to estimate the consequential GHG intensity and SC-GHG for an individual U.S. LNG project. This methodology could be used

[38] Note that for the sake of this simple demonstration, all speciated GHG emissions in the consequential model have been aligned to just CO_2 and CH_4 emissions (this includes all species of emissions shown in Step 5). CO_2 emissions have been combined with N_2O emissions, and CH_4 emissions have been combined with F-gases.

to support a side-by-side comparison of the estimated consequential GHG intensity of an individual project against the U.S. default values.

Two hypothetical projects are described below: one with higher liquefaction emissions than the U.S. default value (example 1) and one with lower liquefaction emissions than the U.S. default (example 2). Two metrics are used for comparing the GHG performance: (1) GHG intensity in CO_2e using IPCC AR6, 100-yr GWPs and (2) SC-GHG estimates.

Metric #1: Comparative Environmental GHG Performance: Consequential GHG Intensity

Table 18 represents a hypothetical LNG export project side by side with the default values from Step 9. In this hypothetical scenario, the facility liquefaction emissions are double those of the default facility; values different from the default facility are bolded.

The consequential GHG intensity per unit of LNG exported (in Table 18) is increased by 5.3 (the amount of 'doubled' liquefaction emissions estimated in Step 3) and is now +11.5 g CO_2e/MJ, which is 84% higher than the default facility (6.3 g CO_2e/MJ) from Step 9.

The second hypothetical project case assumes a project with 50% lower GHG intensity for the liquefaction stage, as shown in Table 19.

The consequential GHG intensity per unit of LNG exported (as shown in Table 19) is +3.6 g CO_2e/MJ (down 42% from +6.3 g CO_2e/MJ for the default). While both hypothetical scenarios focused on liquefaction information, the same framework could be used to evaluate emissions differences resulting from the upstream source of gas.

Table 18. Hypothetical example 1: High GHG intensity liquefaction project example (based on difference in defined policies scenarios, Market-Resolved vs. Existing/FID Exports)

Stage	Average Default GHG Intensity (g CO_2e/MJ)			Project GHG Intensity (g CO_2e/MJ)		
	CO_2	CH_4	Total	CO_2	CH_4	Total
NG Upstream	5.6	3.6	9.2	5.6	3.6	9.2 (Avg Default)
Liquefaction	5.1	0.2	5.3	**10.1**	**0.4**	**10.5 (Project)**
Project Non-Direct Emissions	-4.8	-3.4	-8.2	-4.8	-3.4	-8.2
Total Consequential Global GHG Emissions Intensity	5.8	0.4	+6.3	**10.9**	**0.6**	**+11.5**

Table 19. Hypothetical example 2: Low GHG intensity liquefaction project example (based on difference in current policies scenarios, Market-Resolved vs. Existing/FID Exports)

Stage	Average Default GHG Intensity (g CO_2e/MJ)			Project GHG Intensity (g CO_2e/MJ)		
	CO_2	CH_4	Total	CO_2	CH_4	Total
NG Upstream	5.6	3.6	9.2	5.6	3.6	9.2 (Avg Default)
Liquefaction	5.1	0.2	5.3	**2.6**	**0.1**	**2.6 (Project)**
Project Non-direct Emissions	-4.8	-3.4	-8.2	-4.8	-3.4	-8.2
Total Consequential Global LC GHG Emissions Intensity	5.8	0.4	+6.3	**3.3**	**0.3**	**+3.6**

Metric #2: Comparative Environmental Performance: Consequential Social Costs of Greenhouse Gases

The second metric uses the 2023 SC-GHG as introduced in Step 7 to identify and compare the monetized values of the damages associated with a project's direct and non-direct emissions. The "Difference" between the U.S. average (Default Facility) and the hypothetical example (Project Specific) data shows the net change in social cost of greenhouse gases when liquefaction emissions are doubled (high GHG intensity liquefaction example) and when liquefaction emissions are reduced by 50% (low GHG intensity liquefaction example). The project direct emissions associated with the default facility and this illustrative project-specific example were estimated using annual emissions estimates to calculate the SC-GHG results.

In Metric #1, the metric is in g CO_2e per MJ exported natural gas. To assess how liquefaction emissions could affect the SC-GHG, the GHG intensity in Metric #1 is used to determine the annual emissions, by species, for a hypothetical facility that exports 1 Bcf/d every year from 2020 through 2050 (equivalent to 0.36 EJ/year or 360 billion MJ/yr). These annual export volumes are multiplied by the GHG intensities in Table 18 to generate the yearly speciated greenhouse gas emissions that are used in the SC-GHG calculations.

Table 20 summarizes the SC-GHG results across the three discount rates for the first hypothetical project facility (high liquefaction) inclusive of market consequences.

Table 20. Social cost of greenhouse gases for hypothetical example 1: High GHG intensity liquefaction [base year 2024, dollar year 2020]

	Social Cost of Greenhouse Gases ($billion) for a Facility Exporting 1 Bcf/d from 2020 through 2050											
	2.5% Discount Rate				2% Discount Rate				1.5% Discount Rate			
	CO_2	CH_4	N_2O	Total	CO_2	CH_4	N_2O	Total	CO_2	CH_4	N_2O	Total
Default Facility	$7.8	$0.28	$0.00	$8.1	$13	$0.37	$0.00	$13	$22	$0.51	$0.00	$23
Project-Specific	$15	$0.40	$0.03	$15	$24	$0.53	$0.05	$25	$42	$0.73	$0.08	$43
Difference	$6.8	$0.12	$0.03	$6.9	$11	$0.16	$0.05	$11	$19	$0.22	$0.08	$19
Percent Difference	87%	44%	-0%	86%	87%	44%	-0%	86%	87%	44%	-0%	86%

The results suggest that the total lifetime social costs of the project direct and project non-direct greenhouse gas emissions from a 1 Bcf/d facility are about $8 billion to $23 billion for a facility with default average intensity values (varying across discount rates), with the large majority of social costs related to GHG emissions being attributed to emissions of CO_2. A 1 Bcf/d facility with double liquefaction emissions has a social cost of greenhouse gases that are about $15 billion to $43 billion, $7 billion to $20 billion higher than the average 1 Bcf/d facility, a difference of about 86%.

Table 21 summarizes the SC-GHG results under each of the three discount rates for the second hypothetical project facility, also assuming 1 Bcf/d capacity for the years 2020-2050, based on Table 19.

The SC-GHG results of this second example show that a hypothetical 1 Bcf/d facility with 50% lower liquefaction emissions has a SC-GHG of about $4.6 to $13 billion, $3.5 billion to $10 billion lower than the average 1 Bcf/d facility, a difference of -43%.

Table 21. Social cost of greenhouse gases for hypothetical example 2: Low GHG intensity liquefaction [base year 2024, dollar year 2020]

	Social Cost of Greenhouse Gases ($billion) for a Facility Exporting 1 Bcf/d from 2020 through 2050											
	2.5% Discount Rate				**2% Discount Rate**				**1.5% Discount Rate**			
	CO_2	**CH_4**	**N_2O**	**Total**	**CO_2**	**CH_4**	**N_2O**	**Total**	**CO_2**	**CH_4**	**N_2O**	**Total**
Default Facility	$7.8	$0.28	$0.00	$8.1	$13	$0.37	$0.00	$13	$22	$0.51	$0.00	$23
Project-Specific	$4.4	$0.22	-$0.02	$4.6	$7.3	$0.29	-$0.03	$7.6	$13	$0.39	-$0.04	$13
Difference	-$3.4	-$0.06	-$0.02	-$3.5	-$5.6	-$0.08	-$0.03	-$5.7	-$9.7	-$0.11	-$0.04	-$10
Percent Difference	-43%	-22%	-0%	-43%	-43%	-22%	-0%	-43%	-43%	-22%	-0%	-43%

CONSEQUENTIAL LCA MODELING RESULTS FOR ALL SCENARIO COMPARISONS

The sections above detailed the steps of the consequential analysis and used a single comparison set (*Defined Policies: Model Resolved* versus *Defined Policies: Existing/FID Exports*) to demonstrate example results. This section summarizes the results for all other scenarios included in the broader study. Note that due to adjustments made to the GCAM data and described in Steps 4 and 5, these results differ slightly from the GHG emissions values shown in Appendix A of the broader study.

Following the approach in Step 7, Table 22 shows the cumulative change in GHG emissions, changes in U.S. LNG Exported, and consequential GHG intensities of U.S. exports for all scenarios (baseline scenario is *Existing/FID* within each scenario). Also included is the weighted index summary change in cumulative global services, as shown in Table 3. Differences in global services are included to provide the full picture of changes resulting from the change in U.S. LNG exports. Increased U.S. LNG exports are leading to higher emissions in the non-*ExFID* scenarios as well as increased global services.

Table 22. Cumulative consequential GHG intensities of U.S. exports, LHV, AR6, 100-yr basis

Scenario	Cumulative Change in GHG Emissions, 2020-2050 (Tg CO_2e)[a]	Cumulative Change in U.S. LNG Exported, 2020-2050 (EJ)[a]	Change in Cumulative Global Services[a,b]	Consequential GHG Intensity of U.S. LNG Exports (g CO_2e/MJ)[a]
Defined Policies				
DP: Hi Exp	1,452	189	1.0015	7.7
DP: MR	711	113	1.0008	6.3
DP: Hi ME Sup: MR	363	100	1.0005	3.6
DP: Hi US Sup: MR	1,186	156	1.0013	7.6
DP: Lo US Sup: MR	32	18	1.0001	1.8
Commitments				
C (Hi CCS): Hi Exp	787	107	1.0009	7.3
C (Hi CCS): MR	97	31	1.0002	3.1
C (Mod CCS): Hi Exp	1,055	87	1.0008	12.1
C (Mod CCS): MR	67	11	1.0001	5.9
Net Zero 2050				
NZ (Hi CCS): Hi Exp	324	93	1.0008	3.5
NZ (Hi CCS): MR	21	17	1.0001	1.2
NZ (Mod CCS): Hi Exp	955	76	1.0005	12.6
NZ (Mod CCS): MR[39]	0	0	1.0000	-

Notes:
[a] Changes for all scenarios found vs. Existing/FID within each scenario.
[b] Scenarios modeled provide different levels of global services in response to changes in U.S. LNG exports. Values are indexed to the Existing/FID results within each scenario.

For the Defined Policies scenarios, the cumulative differences in U.S. LNG exported from the *Existing/FID* to other scenarios range from 18 EJ to 189 EJ over the study period. The consequential GHG intensity per unit of U.S. LNG exported values range from 1.8 to 7.7. The *Defined Policies: Model Resolved* and *Defined Policies: High Exports* scenarios provide 0.08% to 0.15% more cumulative global services than the *Defined Policies: Existing/FID Exports* scenario baseline.

For the Commitments scenarios, the cumulative differences in U.S. LNG exported from the *Existing/FID* to other scenarios range from 11 EJ to 107 EJ over the study period. As a result, the consequential GHG intensity per unit of U.S. LNG exported values range from 3.1 to 12.1. The *High CCS* and *Mod CCS* scenarios provide 0.01% to 0.09% more cumulative global services than the *Commitments Existing/FID Exports* scenario baselines.

Finally, for the Net Zero 2050 scenario, the cumulative differences in U.S. LNG exported from the *Existing/FID Exports* to other scenarios range from 0 EJ to 93 EJ. As a result, the consequential GHG intensity per unit of U.S. LNG exported values range from 1.2 to 12.6 (not including the scenario where there is no difference in exports). The *High CCS* and *Mod CCS* scenarios provide 0.01% to 0.08% more cumulative global services than the *Net Zero 2050 Existing/FID Exports* scenario baselines.

The speciated GHG emissions inputs to the consequential GHG intensity can also be used with the 2023 SC-GHG methodology to monetize the impacts of the changes in GHG emissions associated with increased U.S. LNG exports. The base year (which can also be considered the

[39] Note that the results for the Net Zero 2050 market response scenario for moderate CCS adoption leads to an extraneous result due to the GCAM model estimation of negligible changes in LNG exports and emissions.

present value year) was chosen to be 2024 to align with the time of the study, consistent with the suggested choice aligning with a regulatory impact assessment time. The study used 2020 as the dollar year, consistent with the default year of damages provided in the framework. The SC-GHG values (in year 2020 dollars) used by the method are summarized in Appendix C-3.

Cumulative results are included in Table 23. The SC-GHG values are generally highest for the High Export scenarios within a set of scenarios, and also generally highest for *Defined Policies* scenarios, followed by *Commitments* scenarios, followed by *Net Zero 2050* scenarios.

Table 23. Changes in cumulative social cost of greenhouse gases (SC-GHG), 2020$

Scenario[a]	Cumulative Change in Emissions, 2020-2050 (Tg CO_2e)[a,b]				Cumulative Change in U.S. LNG Exported, 2020-2050 (EJ)[a]	Cumulative Change in Global Services[a,c]	Cumulative Change in SC-GHG ($billion 2020)[a]		
	CO_2	CH_4	N_2O	Total			2.5%	2.0%	1.5 %
Defined Policies									
DP: Hi Exp	1,401	79	-88	1,452	189	1.0015	$150	$250	$450
DP: MR	709	17	-47	711	113	1.0008	$74	$130	$220
DP: Hi ME Sup: MR	436	-68	-25	363	100	1.0005	$42	$72	$130
DP: Hi US Sup: MR	1,135	72	-71	1,186	156	1.0013	$120	$210	$360
DP: Lo US Sup: MR	42	-8	-6	32	18	1.0001	$3	$6	$11
Commitments									
C (Hi CCS): Hi Exp	870	-95	-25	787	107	1.0009	$89	$150	$270
C (Hi CCS): MR	143	-50	-4	97	31	1.0002	$12	$22	$40
C (Mod CCS): Hi Exp	1,088	-60	0	1,055	87	1.0008	$120	$200	$360
C (Mod CCS): MR	83	-18	0	67	11	1.0001	$8	$14	$25
Net Zero 2050									
NZ (Hi CCS): Hi Exp	402	-85	-22	324	93	1.0008	$36	$63	$120
NZ (Hi CCS): MR	49	-29	-3	21	17	1.0001	$3	$6	$12
NZ (Mod CCS): Hi Exp	1,007	-59	-11	955	76	1.0005	$110	$190	$330
NZ (Mod CCS): MR	0	0	0	0	0	1.0000	$0	$0	$0

[a] Changes for all scenarios found vs. Existing/FID within each global climate policy scenario.
[b] Values shown on IPCC AR6, 100-yr basis. Total also includes F-gases (not shown in table).
[c] Scenarios modeled provide different levels of global services in response to changes in U.S. LNG exports. Values are indexed to the Existing/FID results within each scenario.

As shown in Table 23, in the Defined Policies scenarios, increasing U.S. LNG exports are generally leading to higher cumulative CO_2 and CH_4 emissions and lower N_2O emissions globally, whereas, in the Commitments and Net Zero 2050 scenarios, cumulative CO_2 emissions are generally increasing, while CH_4 and N_2O emissions are generally decreasing. Similarly, the change in methane emissions are generally a small part of the total change in GHG emissions.

The changes in SC-GHG between scenarios summarized in Table 23 were also normalized per change in MJ of U.S. LNG exported. Normalized results are included in Table 24. Overall, the normalized SC-GHG ranges between 0.02 and 0.24 cents per MJ for *Defined Policies* Scenarios, 0.04 cents per MJ and 0.41 cents per MJ for *Commitments* Scenarios, and 0.02 cents per MJ and 0.43 cents per MJ in *Net Zero 2050* Scenarios.

Table 24. Normalized changes per MJ exported in cumulative social cost of greenhouse gases

Scenario	Cumulative Change GHG Emissions 2020-2050 (Tg CO_2e)[a]	Cumulative Change in U.S. LNG Exported, 2020-2050 (EJ)[a]	Cumulative Change in Global Services[a,b]	Cumulative Change in SC-GHG per MJ (cents/MJ)[a]		
				Discount Rate		
				2.5%	2.0%	1.5%
Defined Policies						
DP: Hi Exp	1,452	189	1.0015	0.08	0.14	0.24
DP: MR	711	113	1.0008	0.07	0.11	0.20
DP: Hi ME Sup: MR	363	100	1.0005	0.04	0.07	0.12
DP: Hi US Sup: MR	1,186	156	1.0013	0.08	0.13	0.23
DP: Lo US Sup: MR	32	18	1.0001	0.02	0.03	0.06
Commitments						
C (Hi CCS): Hi Exp	787	107	1.0009	0.08	0.14	0.25
C (Hi CCS): MR	97	31	1.0002	0.04	0.07	0.13
C (Mod CCS): Hi Exp	1,055	87	1.0008	0.14	0.23	0.41
C (Mod CCS): MR	67	11	1.0001	0.07	0.13	0.23
Net Zero 2050						
NZ (Hi CCS): Hi Exp	324	93	1.0008	0.04	0.07	0.12
NZ (Hi CCS): MR	21	17	1.0001	0.02	0.04	0.07
NZ (Mod CCS): Hi Exp	955	76	1.0005	0.15	0.24	0.43
NZ (Mod CCS): MR	0	0	1.0000	N/A	N/A	N/A

Notes:
[a] Changes for all scenarios found vs. Existing/FID within each global climate policy scenario.
[b] Scenarios modeled provide different levels of global services in response to changes in U.S. LNG exports. Values are indexed to the Existing/FID results within each scenario.

Following Step 8, Table 25 summarizes the consequential GHG intensities of U.S. LNG exports and project non-direct emissions values for all scenarios in this study (compared to a baseline of the *Existing/FID Exports* scenario within their global climate policy).

Table 25. Summary of consequential GHG intensities and project non-direct emissions values for all scenarios (versus ExFID), AR6, 100-yr basis

Scenario	Cumulative Change in GHG Emissions 2020-2050 (Tg CO_2e)[a]	Cumulative Change in U.S. LNG Exported, 2020-2050 (EJ)[a]	Change in Cumulative Global Services[a,b]	Consequential GHG Intensity of U.S. LNG Exports	Project Non-Direct Emissions Factor (PNDE)[c]
				Grams of Carbon Dioxide Equivalents per Megajoule of U.S. LNG Exported[a] (g CO_2e/MJ)	
DP: Hi Exp	1,452	189	1.0015	7.7	-6.8
DP: MR	711	113	1.0008	6.3	-8.2
DP: Hi ME Sup: MR	363	100	1.0005	3.6	-10.9
DP: Hi US Sup: MR	1,186	156	1.0013	7.6	-6.9
DP: Lo US Sup: MR	32	18	1.0001	1.8	-12.7
C (Hi CCS): Hi Exp	787	107	1.0009	7.3	-7.2
C (Hi CCS): MR	97	31	1.0002	3.1	-11.4
C (Mod CCS): Hi Exp	1,055	87	1.0008	12.1	-2.4
C (Mod CCS): MR	67	11	1.0001	5.9	-8.6
NZ (Hi CCS): Hi Exp	324	93	1.0008	3.5	-11
NZ (Hi CCS): MR	21	17	1.0001	1.2	-13.3
NZ (Mod CCS): Hi Exp	955	76	1.0005	12.6	-1.9
NZ (Mod CCS): MR	0	0	1.0000	-	-

Notes:
[a] Changes for all scenarios found vs. Existing/FID within each global climate policy scenario
[b] Scenarios modeled provide different levels of global services in response to changes in U.S. LNG exports. Values are indexed to the Existing/FID results within each scenario.
[c] Assumes project direct emissions defined as including Natural Gas Upstream and Liquefaction of 14.5 g CO_2e/MJ.

The project non-direct emissions values are not specific to a receiving region and represent a result across all potential landing locations for LNG. Note that the consequential GHG intensity and project non-direct emissions results were aggregated in relation to estimated future volumes of exported LNG from the U.S. in the context of a global model. Project non-direct emissions results represent overall expected effects and not those of individual shipments of LNG. As shown in Table 25, the consequential GHG intensity and corresponding project non-direct emissions values are different for each scenario pairing. This study does not prescribe likelihood of one scenario pairing over another, but rather, presents the range of derived results for a set of potential future scenarios modeled by the study, see Table 1 and Appendix A for description of study scenarios.

Consequential analysis results using the IPCC AR6, 20-yr GWP values are summarized in Table 26. As further described in Appendix C-2, this required converting all initially received GCAM values to the AR6, 20-yr basis, and aligning them with the NETL natural gas baseline study values on an AR6, 20-yr basis. The project direct emissions, comprised of natural gas upstream and liquefaction emissions, was also recalculated on an AR6, 20-yr basis, and found to be 21.3 g CO_2e/MJ.

Table 26. Summary of consequential GHG intensities and project non-direct emissions values for all scenarios (versus ExFID), AR6, 20-yr basis

Scenario	Cumulative Change in GHG Emissions 2020-2050 (Tg CO_2e)[a]	Cumulative Change in U.S. LNG Exported, 2020-2050 (EJ)[a]	Change in Cumulative Global Services[a,b]	Consequential GHG Intensity of U.S. LNG Exports	Project Non-Direct Emissions Factor (PNDE)[c]
				Grams of Carbon Dioxide Equivalents per Megajoule of U.S. LNG Exported[a] (g CO_2e/MJ)	
DP: Hi Exp	1,533	189	1.0015	8.1	-13.1
DP: MR	718	113	1.0008	6.3	-14.9
DP: Hi ME Sup: MR	252	100	1.0005	2.5	-18.8
DP: Hi US Sup: MR	1,262	156	1.0013	8.1	-13.2
DP: Lo US Sup: MR	18	18	1.0001	1.0	-20.2
C (Hi CCS): Hi Exp	626	107	1.0009	5.8	-15.4
C (Hi CCS): MR	17	31	1.0002	0.6	-20.7
C (Mod CCS): Hi Exp	943	87	1.0008	10.8	-10.4
C (Mod CCS): MR	38	11	1.0001	3.4	-17.9
NZ (Hi CCS): Hi Exp	176	93	1.0008	1.9	-19.4
NZ (Hi CCS): MR	-24	17	1.0001	-1.4	-22.7
NZ (Mod CCS): Hi Exp	845	11.2	1.0005	11.2	-10.1
NZ (Mod CCS): MR	0	0	1.0000	-	-

Notes:
[a] Changes for all scenarios found vs. Existing/FID within each global climate policy scenario
[b] Scenarios modeled provide different levels of global services in response to changes in U.S. LNG exports. Values are indexed to the Existing/FID results within each scenario.
[c] Assumes project direct emissions defined as including Natural Gas Upstream and Liquefaction of 14.5 g CO_2e/MJ.

In the *Defined Policies* scenarios, higher LNG exports generally lead to net higher cumulative CH_4 emissions, while in Commitments and Net Zero 2050 scenarios, cumulative CH_4 emissions are decreasing. As the GWP value for CH_4 is roughly 2.7 times higher for AR6, 20-yr than AR6, 100-yr, scenarios with significant CH_4 emissions increases or decreases (as compared to their *Existing/FID* baseline) have their cumulative CH_4differences amplified as a result. In one scenario (*Net Zero 2050 (High CCS): Model Resolved*), the effect is that the amplified value of CH_4 emissions results in a net change in GHG emissions that goes from positive (in AR6, 100-yr) to negative (in AR6, 20-yr), making the consequential GHG intensity negative (-1.4 g CO_2e/MJ) instead of the previous +1.2 g CO_2e/MJ. Likewise, the project non-direct emissions values on the AR6, 20-yr basis are more negative than those in AR6, 100-yr, because the project direct emissions value is increased from the 14.5 g CO_2e/MJ used in the AR6, 100-yr basis to 21.3 g CO_2e/MJ on an AR6, 20-yr basis.

A. Individual Project Direct Emissions Breakeven GHG Performance

The project direct emissions and project non-direct emissions can be used to calculate a breakeven rate, which would be the percent change difference between an individual project's emissions and the default factors that would result in a global consequential intensity of zero (i.e., 0 g CO_2e/MJ). As defined above, the U.S. average performance values are the 9.2 g CO_2e/MJ for upstream and 5.3 g CO_2e/MJ for liquefaction (the sum of which result in an average U.S. project direct emissions of 14.5). The project non-direct emissions values from Table 25 can be used with the average project direct emissions values to estimate the breakeven percent as shown here:

$$Breakeven\ (\%) = \frac{Absolute\ Value\ of\ Project\ Nondirect\ Emissions - Average\ Project\ Direct\ Emissions}{Average\ Project\ Direct\ Emissions} \times 100$$

Table 27 shows the resulting breakeven percent changes in project direct emissions needed for all scenarios modeled (versus ExFID) on an AR6,100-yr basis.

Table 27. Breakeven percent changes (versus ExFID), AR6, 100-yr basis

Scenario[a]	Cumulative Change in GHG Emissions, 2020-2050 (Tg CO_2e)[b]	Cumulative Change in U.S. LNG Exported, 2020-2050 (EJ)[b]	Change in Global Services[b,c]	Breakeven GHG Emissions Change in Project Direct Emissions[b]
DP: Hi Exp	1,452	189	1.0015	-53%
DP: MR	711	113	1.0008	-43%
DP: Hi ME Sup: MR	363	100	1.0005	-25%
DP: Hi US Sup: MR	1,186	156	1.0013	-53%
DP: Lo US Sup: MR	32	18	1.0001	-13%
C (Hi CCS): Hi Exp	787	107	1.0009	-51%
C (Hi CCS): MR	97	31	1.0002	-21%
C (Mod CCS): Hi Exp	1,055	87	1.0008	-84%
C (Mod CCS): MR	67	11	1.0001	-40%
NZ (Hi CCS): Hi Exp	324	93	1.0008	-24%
NZ (Hi CCS): MR	21	17	1.0001	-8%
NZ (Mod CCS): Hi Exp	955	11.2	1.0005	-87%

Notes:
[a] Scenario *NZ (Mod CCS): MR* is not presented here because model-resolved LNG exports do not exceed existing/FID levels in this scenario.
[b] Changes for all scenarios found vs. Existing/FID within each global climate policy scenario.
[c] Scenarios modeled provide different levels of global services in response to changes in U.S. LNG exports. Values are indexed to the Existing/FID results within each scenario.

To illustrate a specific example for the AR6, 100-yr results, for *Defined Policies: Model Resolved*, the project direct emissions would need to be 43% lower to breakeven (the project direct emissions would have to decrease from 14.5 g CO_2e/MJ to 8.2 g CO_2e/MJ). In that scenario the project direct emissions would be 8.2 g CO_2e/MJ and would offset the project non-direct emissions of -8.2 g CO_2e/MJ, so the consequential GHG intensity would be zero. These results show that, depending on the assumed scenario, the project direct emissions would need to be reduced by at least 8% and up to 87% for U.S. LNG exports to have a zero consequential GHG intensity (i.e., to result in no net increase in global GHG emissions, holding all else equal).

Building on the breakeven analysis for *Defined Policies: Model Resolved* and its focus on the tradeoff between project direct and project non-direct emissions, the project direct upstream emissions of 9.2 g CO_2e/MJ (production through transmission) include 3.6 g CO_2e/MJ associated with methane emissions. The methane emissions correspond to an upstream methane emission rate of 0.56% (production through transmission). For example, if the upstream methane emission rate for a specific project was reported as 1.4%, the upstream methane emissions contribution to the project direct upstream emissions would increase by 5.4 g CO_2e /MJ to 9.0 g CO_2e/MJ, resulting in project direct upstream emissions of 14.6 g CO_2e/MJ. Combined with the average project direct liquefaction emissions (5.3 g CO_2e/MJ), the project direct emissions would be 19.9 g CO_2e/MJ. In order to breakeven, the project direct emissions would have to be lowered from 19.9 g CO_2e/MJ to 8.2 g CO_2e/MJ. The required project direct emission reductions (11.7 g CO_2e/MJ) are greater than the average project direct liquefaction emissions. The implication is that a project with upstream emissions of 1.4% would not breakeven even if its liquefaction

process had no emissions while the upstream natural gas methane emission rate was 1.4%. In such a case, a completely carbon neutral liquefaction facility would result in a consequential GHG emissions intensity of 6.4 g CO_2e/MJ, a 0.1 g CO_2e/MJ increase in GHG emissions per MJ of natural gas exported (i.e., Upstream Project Direct Emissions + Liquefaction Project Direct Emissions + Project Non-Direct Emissions = Consequential GHG Emissions Intensity; or 14.6 + 0 – 8.2 = 6.4).

Table 28 summarizes the breakeven analysis on an AR6, 20-yr GHG emissions basis.

Table 28 Breakeven percent changes (versus ExFID), AR6, 20-yr basis

Scenario[a]	Cumulative Change in GHG Emissions, 2020-2050 (Tg CO_2e)[b]	Cumulative Change in U.S. LNG Exported, 2020-2050 (EJ)[b]	Change in Global Services[b,c]	Breakeven GHG Emissions Change in Project Direct Emissions[b]
DP: Hi Exp	1,533	189	1.0015	-38%
DP: MR	718	113	1.0008	-30%
DP: Hi ME Sup: MR	252	100	1.0005	-12%
DP: Hi US Sup: MR	1,262	156	1.0013	-38%
DP: Lo US Sup: MR	18	18	1.0001	-5%
C (Hi CCS): Hi Exp	626	107	1.0009	-27%
C (Hi CCS): MR	17	31	1.0002	-3%
C (Mod CCS): Hi Exp	943	87	1.0008	-51%
C (Mod CCS): MR	38	11	1.0001	-16%
NZ (Hi CCS): Hi Exp	176	93	1.0008	-9%
NZ (Hi CCS): MR	-24	17	1.0001	+7%
NZ (Mod CCS): Hi Exp	845	11.2	1.0005	-53%

Notes:

[a] Scenario *NZ (Mod CCS): MR* is not presented here because model-resolved LNG exports do not exceed existing/FID levels in this scenario.

[b] Changes for all scenarios found vs. Existing/FID within each global climate policy scenario.

[c] Scenarios modeled provide different levels of global services in response to changes in U.S. LNG exports. Values are indexed to the Existing/FID results within each scenario.

To illustrate a specific example for the AR6, 20-yr results, for *Defined Policies: Model Resolved*, the project direct emissions would need to be 30% lower to breakeven (the project direct emissions would have to decrease from 21.3 g CO_2e/MJ to 14.9 g CO_2e/MJ). In that scenario the decreased project direct emissions would be 14.9 g CO_2e/MJ and would offset the project non-direct emissions of -14.9 g CO_2e/MJ, so the consequential GHG intensity would be zero. These results show that, depending on the assumed scenario, the project direct emissions would need to be reduced by up to 53%, or in one scenario increase by 7%, for U.S. LNG exports to have a zero consequential GHG.

B. Evaluation of Model Sensitivity to Key Performance Attributes

Sensitivity analyses were also conducted to evaluate the potential impact on the scenario results if key model aspects were underrepresented in the analysis. Specifically, upstream methane intensity of global natural gas production and representation of global liquefaction facility operating emissions were evaluated. In each sensitivity analysis case, GCAM results have been modified exogenously, as opposed to doing additional model runs in GCAM.

1. Sensitivity Analysis 1: Upstream Methane Emissions Intensity

This analysis considers the sensitivity of the consequential results to the assumed upstream natural gas methane emissions rates in GCAM. To accomplish this, methane emissions rates for the U.S. and the other natural gas producing regions in GCAM were adjusted using an index based on the relative change in the U.S. methane emissions rate.

To accomplish this, the GCAM-NETL-aligned U.S. upstream emissions estimates were aligned with the 2024 NETL Natural Gas Baseline on a speciated basis. As part of the alignment, U.S. upstream CH_4 emissions were scaled to match the 0.56% NETL methane emissions rate while keeping total CO_2e emissions of the natural gas sector consistent with the GCAM results. This provides a distinct and aligned estimate of upstream NG sector emissions for the sensitivity analysis.

The range of U.S. upstream natural gas sector methane emission rates in this analysis is from 0.2% (about one third of the NETL estimated rate) to 2.8% (a value at the high end of recently completed studies) and is done at increments of 0.2%. Table 29 includes the assumed U.S. methane emissions rate for the sensitivity cases and the relative level of upstream methane. The relative level of methane is the percentage applied to non-U.S. methane emissions rates to scale them for this sensitivity analysis. This approach preserves the unique country/regional methane emission rate differences within GCAM.

Table 29 summarizes the consequential GHG intensity resulting from the assumed changes in the upstream natural gas production methane emissions rates applied globally for *Defined Policies: Model Resolved* versus *Defined Policies: Existing/FID Exports*. In all other scenario pairings, the contribution of methane emissions are lower (or are decreasing with respect to increased U.S. exports) and therefore exhibit less sensitivity to changes in methane intensity of natural gas production.

Note that in this comparison while the increase in methane emissions increases overall global GHG emissions, the increase is happening in both scenarios. Since the consequential intensity is calculated based on the difference between the scenarios, the increased methane emissions have limited impact on the intensity (e.g., if the same number is added to two different linear equations, the difference between the two equations remains the same). To the extent methane emissions associated with increased U.S. LNG exports are increasing, there would be offsetting changes in the global energy system as a result of substitution of the U.S. LNG for natural gas and other sources of energy.

Table 29. Sensitivity analysis for upstream methane emissions rate (U.S. base is 0.56%), DP:MR versus DP: ExFID

U.S. Methane Emission Rate	Relative Level of Upstream Methane	Consequential GHG Intensity ($g\ CO_2e/MJ$)	Percent Change in Consequential GHG Intensity from Base
0.20%	35.7%	6.3	0%
0.40%	71.4%	6.3	0%
0.60%	107.1%	6.3	0%
0.80%	142.9%	6.3	0%
1.00%	178.6%	6.3	0%
1.20%	214.3%	6.3	0%
1.40%	250.0%	6.3	0%
1.60%	285.7%	6.3	0%
1.80%	321.4%	6.3	0%

2.00%	357.1%	6.3	0%
2.20%	392.9%	6.3	0%
2.40%	428.6%	6.4	2%
2.60%	464.3%	6.4	2%
2.80%	500.0%	6.4	2%

Note: Baseline U.S. Methane Emissions Rate is 0.56%.

2. Sensitivity Analysis 2: Liquefaction Plant Emissions Representation within GCAM

Within GCAM, GHG emissions from liquefaction are modeled in an aggregate *other industrial energy use* sector that comprises many activities. LNG-relevant processes and activities are only one of many modeled in each sector. Unlike other sectors in GCAM where activities are modeled from interactions with other sectors, growth in this sector is generally modeled as a function of exogenously defined GDP (i.e., if GDP goes up then activity and associated emissions increase comparably). As part of this study, the connections between GHG emissions and GDP growth in GCAM were compared for several regions expected to provide significant LNG supplies over time, to assess how well the sectoral results from GCAM might be modeling expected increases in LNG activities. However, this analysis was unable to estimate a specific amount by which the values are under (or over) estimated in a particular region. As a result, instead of adjusting GCAM sectoral values (e.g., as done above for upstream natural gas methane intensity), a sensitivity analysis was conducted to show the effects on model results associated with liquefaction processes.

In this sensitivity case, the U.S. average performance values referenced above for liquefaction (5.3 g CO_2e/MJ) are added exogenously for all global LNG exports for all regions, not just those exported by the U.S. This is done because the GCAM model is otherwise representing global emissions of all LNG produced, not just those exported by the U.S. While emissions are added for all LNG, the denominator for the consequential GHG intensity remains per additional unit of U.S. LNG exported. This case adds these liquefaction emissions on top of the existing baseline emissions of the modeled scenario.

Table 30 summarizes the original results from Table 22 (referred to as the base case) as well as those from the sensitivity case (accounting for additional emissions for liquefaction). While it might be expected that the consequential results simply would shift by the intensity of emissions added, (i.e., by 5.3 g CO_2e/MJ), this is not the case because while all global LNG has its emissions intensity increased, the new result is divided only by the U.S. LNG exported. As a result, the net differences are smaller than the 5.3 g CO_2e/MJ value. For example, the values for the *Defined Policies: Model Resolved* scenario are 6.3 g CO_2e/MJ in the base case, and 10 g CO_2e/MJ in the Sensitivity Case, a difference of 3.7 g CO_2e/MJ as opposed to the 5.3 g CO_2e/MJ that were added per unit of global LNG produced.

Generally, even in a worst case of adding additional full liquefaction emissions to the base case GHG emissions, the project non-direct emissions values remain negative. There are only two exceptions – the *Commitments (Moderate CCS): High Exports* and the *Net Zero 2050 (Moderate CCS): High Exports* scenarios.

Table 30. Sensitivity analysis results for additional liquefaction emissions

Scenario[a]	Cumulative Change in U.S. LNG Exported, 2020-2050 (EJ)[b]	Change in Global Services[b,c]	Base Case	Sensitivity Case: Added Liquefaction	Base Case	Sensitivity Case: Added Liquefaction
			Consequential GHG Intensity per Unit U.S. LNG Exported ($g\ CO_2e/MJ$)[b]		Project Non-Direct Emissions ($g\ CO_2e/MJ$)[b]	
Defined Policies						
DP: Hi Exp	189	1.0015	7.7	11.8	-6.8	-2.7
DP: MR	113	1.0008	6.3	9.9	-8.2	-4.6
DP: Hi ME Sup: MR	100	1.0005	3.6	6.1	-10.9	-8.5
DP: Hi US Sup: MR	156	1.0013	7.6	11.6	-6.9	-2.9
DP: Lo US Sup: MR	18	1.0001	1.8	4.1	-12.7	-10.4
Commitments						
C (Hi CCS): Hi Exp	107	1.0009	7.3	11.2	-7.2	-3.3
C (Hi CCS): MR	31	1.0002	3.1	5.9	-11.4	-8.6
C (Mod CCS): Hi Exp	87	1.0008	12.1	16.4	-2.4	+1.9
C (Mod CCS): MR	11	1.0001	5.9	8.4	-8.6	-6.1
Net Zero 2050						
NZ (Hi CCS): Hi Exp	324	1.0008	3.5	7.5	-11	-7.1
NZ (Hi CCS): MR	21	1.0001	1.2	3.7	-13.3	-10.8
NZ (Mod CCS): Hi Exp	955	1.0005	12.6	18.1	-1.9	+3.6

Notes:

[a] Scenario *NZ (Mod CCS): MR* is not presented here because model-resolved LNG exports do not exceed existing/FID levels in this scenario.

[b] Changes for all scenarios found vs. Existing/FID within each global climate policy scenario.

[c] Scenarios modeled provide different levels of global services in response to changes in U.S. LNG exports. Values are indexed to the Existing/FID results within each scenario.

C. Market Drivers for Changes in GHG Intensity of U.S. LNG Exports

NETL completed an additional analysis to evaluate the market drivers of the change in global GHG emissions in GCAM with respect to changes in U.S. LNG export GHG intensity when providing an equivalent service to society.

1. Change in Global Services

As summarized in Table 3, in addition to volumes of LNG exported and GHG emissions for each scenario, the GCAM model also provides estimated outputs of various services including energy, transportation, commodity materials, and fertilizers. The results from GCAM show that as higher levels of U.S. LNG are exported, global services increase. An abridged summary of some of the aggregated service categories (now cumulative for all years 2020-2050, not just model years) is provided in Table 31. The first row shows that the *Defined Policies: Existing/FID Exports* scenario provides 10,158 EJ of energy services globally, and the *Defined Policies: Model Resolved* and *DP:HighExp* scenarios provide higher levels of energy services, commensurate with more U.S. LNG being put into the global market.

Table 31. Summary of GCAM modeled services provided in selected defined policies scenarios

Aggregate Economic Sector	Type of Service Output (Unit)	*DP: ExFID*	*DP: MR*	*DP: High Exp*
Energy	Energy Services (EJ)	10,158	10,168	10,176
Industrial	Commodity Products Million Metric Tons (MT)	175,861	175,926	175,979
	Nitrogen Fertilizer Million Metric Tons (MT)	5,079	5,077	5,076
Transportation	Freight Transportation (Billion-Ton-Kilometers)	6,742,516	6,745,127	6,747,250
	Passenger Transportation (Billion-Passenger-Kilometers)	7,863,606	7,863,998	7,864,321
Weighted Index		1.0000	1.0008	1.001

The results presented for the consequential LCA part of the study were estimated with the values in Table 31, i.e., those that show that increased LNG leads to increased levels of services provided (and will now be referred to as “increased services” results).

2. GHG Intensity of U.S. LNG Exports per Unit of Global Services (Equivalent Unit of Service)

As a result of the identified difference in services provided between scenarios within global climate policies, an additional analysis was performed to quantify the effect of this difference on the model results. A consequential LCA, unlike an attributional LCA, does not have to maintain functional equivalence but must report the difference in the function (in this case, the services provided). In this additional analysis, the GHG emissions are compared based on the same level of global services provided. This helps explore how replacing one product or service with another affects emissions, both directly and indirectly, to offer the same service to society.

In this additional analysis, the results of the increased services scenario models were adjusted to provide equivalent levels of global services. Table 32 expands the summarized results for *Defined Policies: Model Resolved* and *Defined Policies: Existing/FID Exports*. The consequential GHG emissions per unit of U.S. LNG as derived above (for the case of increased services provided) would be +6.3 g CO_2e/MJ, due to a 113 EJ difference in cumulative LNG exported and a cumulative difference of 711 Tg CO_2e of GHG emissions between the cases. However, there is also a cumulative difference of 9.7 EJ more global energy services provided in the *Defined Policies: Model Resolved* scenario versus *Defined Policies: Existing/FID Exports*. This means that the *Defined Policies: Model Resolved* scenario is providing more global services to society as compared to the *Defined Policies: Existing/FID Exports* scenario. This was a general finding across all scenarios when compared to the ExFID scenario, and not just *Defined Policies: Model Resolved* versus *Defined Policies: Existing/FID Exports*.

Table 32. Cumulative (2020-2050) GCAM results for DP:ExFID and DP:MR (with increased services)

Scenario	U.S. LNG Exports (EJ)	Change in U.S. LNG Exports (EJ)	Global Energy Services (EJ)	Change in Global Energy Services (EJ)	GHG Emissions (Tg CO_2e)	Change in GHG Emissions (Tg CO_2e)	Consequential GHG Intensity (g CO_2e/MJ)
DP: ExFID	227.4	-	10,158	-	1,552,340	-	-
DP: MR	340.6	113.2	10,168	**9.7**	1,553,051	710.8	**6.3**

To make these two scenarios "equivalent on a functional unit basis of services delivered", since the *Defined Policies: Model Resolved* scenario provides a higher level of global services (9.7 EJ), its U.S. LNG export volume and GHG emissions values are linearly scaled to meet the lower energy service levels of *Defined Policies: Existing/FID Exports*. In doing so, the difference across all service levels is found, and by assumption, the GHG emissions were scaled down by the same difference.[40]

Using the derived weighted index value from Table 31 of 1.0008 as a scaling factor for changes in global services, results for *Defined Policies: Model Resolved* were scaled down for all service categories to meet the assumed weighted average level for *Defined Policies: Existing/FID Exports*. Global EJ of service supplied are scaled from 10,168 to 10,158 (making them equal), leading to updated estimates for *Defined Policies: Model Resolved* of 112.9 EJ of U.S. LNG exported, and 1,551,825 Tg of CO_2e emissions, as shown in Table 33.

In making these adjustments, both the numerator and denominator of the consequential GHG intensity per unit U.S. LNG are changed. The cumulative GHG emissions difference is now negative (-515 Tg, was positive before), since emissions of *Defined Policies: Model Resolved* are now less than *Defined Policies: Existing/FID Exports*, and the cumulative U.S. LNG Exported is slightly lower than before (112.9 EJ instead of 113.2 EJ). Overall, for this example, the equivalent services-adjusted consequential GHG intensity per unit of LNG is now -4.6 g CO_2e/MJ for *Defined Policies: Model Resolved*.

The most prominent effect of this scaling down of GHG emissions is that the GHG emissions of the *Defined Policies: Model Resolved* scenario is lower than the *Defined Policies: Existing/FID Exports* scenario, suggesting that when excluding increases in global services, U.S. LNG substitutions for other energy services results in a net decrease in GHG intensity. In other words, U.S. LNG substitution in foreign markets results in lower global GHG emissions when accounting for all changes in energy services.

Table 33. Summary of GCAM results for DP:ExFID and DP:MR (with equivalent services)

Scenario	U.S. LNG Exports (EJ)	Change in U.S. LNG Exports (EJ)	Global Energy Services (EJ)	Change in Global Energy Services (EJ)	GHG Emissions (Tg CO_2e)	Change in GHG Emissions (Tg CO_2e)	Consequential GHG Intensity (g CO_2e/MJ)
DP: ExFID	227.4	-	10,158	-	1,552,340	-	-
DP: MR	**340.4**	**112.9**	**10,158**	**0**	**1,551,825**	**-515.4**	**-4.6**

Table 34 shows a summary of equivalent services-adjusted consequential GHG intensity values per unit of LNG exported for all scenarios, following the method presented above.

[40] The GCAM model provides outputs of various services including energy, transportation, commodity materials, and a weighted-average metric was provided by PNNL to help consider an appropriate scaling factor encompassing all services provided, not just those provided by energy (see Appendix C-2 for details).

Table 34. Cumulative consequential GHG intensities of U.S. exports (LHV, AR6, 100-yr, equivalent services basis)

Scenario[a]	Cumulative Change in GHG Emissions, 2020-2050 (Tg CO_2e)[b]	Cumulative Change in U.S. LNG Exported, 2020-2050 (EJ)[b]	Change in Global Services[b,c]	Consequential GHG Intensity per Unit U.S. LNG Exported (g CO_2e/MJ)[b]
Defined Policies				
DP: Hi Exp	-838	188	0	-4.5
DP: MR	-515	113	0	-4.6
DP: Hi ME Sup: MR	-364	100	0	-3.6
DP: Hi US Sup: MR	-778	115	0	-5.0
DP: Lo US Sup: MR	-119	18	0	-6.8
Commitments				
C (Hi CCS): Hi Exp	-379	107	0	-3.6
C (Hi CCS): MR	-156	31	0	-5.0
C (Mod CCS): Hi Exp	114	86	0	+1.7
C (Mod CCS): MR	-3	11	0	-0.3
Net Zero 2050				
NZ (Hi CCS): Hi Exp	-489	93	0	-5.3
NZ (Hi CCS): MR	-75	17	0	-4.4
NZ (Mod CCS): Hi Exp	496	76	0	+6.6

Notes:
[a] Scenario *NZ (Mod CCS): MR* is not presented here because model-resolved LNG exports do not exceed existing/FID levels in this scenario.
[b] Changes for all scenarios found vs. Existing/FID within each global climate policy scenario.
[c] Scenarios modeled provide different levels of global services in response to changes in U.S. LNG exports. Values are indexed to the Existing/FID results within each scenario.

The consequential GHG intensity per unit LNG generally switches from positive to negative for equivalent service adjusted scenarios (except for two of them). This occurs because the GCAM model results between scenarios, especially for GHG emissions, are very similar (within 1%) and tend to only vary by small amounts, even when cumulative over the 2020-2050 period. By making the scaling adjustment, what were small positive changes in emissions values become negative change emissions values when compared to the *ExFID* baselines.

By revisiting the results for the *Defined Policies: Model Resolved* versus *Defined Policies: Existing/FID Exports* scenario analysis above, the original (increased services) results were based on a cumulative difference of 711 Tg CO_2e (*Defined Policies: Model Resolved* higher than *Defined Policies: Existing/FID Exports*). In scaling the scenario results to an equivalent services basis, it is revealed that 515 Tg of emissions were substituted for providing energy services and thus the difference (1,226 Tg) was associated with providing additional energy to society.

3. Summary of Market Drivers of Total Consequential GHG Intensity of U.S. LNG Exports

For additional comparative context, Tables 35 and 36 provide direct attributional life cycle GHG emissions and direct and indirect emissions from market effects from increased U.S. LNG exports. Attributional life cycle GHG emissions from production, export, and end use of the fuel in an Asian destination market is presented in Table 35 assuming 100% combustion of U.S. LNG exports with unabated emissions at the point of end use (i.e., no carbon capture and storage (CCS) installed at point of end use). The illustrative attributional life cycle GHG emissions profile has 76 g

CO_2e/MJ of LNG exported.[41] This attributional GHG emission profile would represent the expected contribution to global emissions if 100% of U.S. LNG exports resulted in an equivalent increase in global services, without any market substitution. To put this in the terms of exports, for 1 Bcf/d of LNG exported to an Asian destination market, the annual unabated direct life cycle GHG emissions would total up to 27 Tg CO_2e.

Multiplying the total increase in U.S. LNG export by the attributional profile from production through end use equals the total direct GHG emissions from increased U.S. LNG exports when market effects are not accounted for (i.e., an approach similar to those of past studies).[42] For example, comparing *Model Resolved* to *Existing/FID Exports* levels in the *Defined Policies* scenario, the direct life cycle GHG emissions from production, export, and end use (assuming 100% combustion without CCS) of increased U.S. LNG exports would cumulatively (2020-2050) contribute 8,588 Tg CO_2e before accounting for market effects. In 2050, direct life cycle GHG emissions from all modeled U.S. LNG exports (56.3 Bcf/d) would be approximately 1,500 Tg CO_2e before accounting for market effects.

Consequential modeling of direct and indirect market effects provided by the GCAM model determined that both market substitution and increased global services occur when the supply of U.S. LNG is increased to the global market, compared to the *Existing/FID* levels for each scenario. The section above, *GHG Intensity of U.S. LNG Exports per Unit of Global Services (Equivalent Unit of Service)*, summarized the net market effects from market substitution only (excluding increased global services). The market substitution effect is larger when representing the direct life cycle GHG emissions from increased exports and accounting for the resulting change from direct and indirect market effects. This value is reported in Tables 35 and 36 as the *Cumulative Change in Direct Attributional Emissions of Direct and Indirect Market Substitution Effects only, 2020 – 2050* and is obtained by determining the difference between the cumulative change in direct GHG emissions and the cumulative change in GHG emissions from Table 34 on an equivalent services basis (also reproduced in Table 35 and Table 36 below).

Combining the net market substitution effects with the change in GHG emissions from increased global services, the result equals the cumulative change in GHG emissions as determined in Step 7 above and reported in Table 22.

Table 36 summarizes the direct and indirect life cycle GHG emissions contributions if 100% of U.S. LNG exports were consumed at end use facilities equipped with 90% carbon capture equipment and permanent sequestration of the captured carbon dioxide to prevent release to the atmosphere. The illustrative attributional life cycle GHG emissions profile of U.S. LNG consumed in an Asian market with 90% carbon capture on end use combustion is modeled as 30 g CO_2e/MJ of LNG exported.

Tables 35 and 36 provide bounding perspectives based on the end use of U.S.LNG exported fuel being combusted without or with CCS. The consequential result determined from the GCAM model accounts for the variations in both end use destinations and end use applications. These tables are intended to help facilitate an understanding of consequential market effects in context of the attributional GHG emissions that result from production, export, and use of increased U.S. LNG exports for each scenario pairing.

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[41] The attributional values found for use in this section were calculated using the natural gas upstream and liquefaction values updated in this study for the year 2020, the end use combustion values from the 2020 NETL Natural Gas Report (Khutal et al, 2024), and the use and losses of gas and GHG emissions for ocean shipping through regasification values from the 2019 NETL LNG Update (Roman-White et al, 2019). The combustion cases are representative of F and H-class NGCC plants (without CCS and with 90% CCS) from the 2020 (Khutal et al, 2024) study. The 90% CCS case was selected to match those of the GCAM model.
[42] See, for example, Roman-White et al, 2019.

Table 35. Summary of market drivers of total consequential GHG intensity of increased U.S. LNG exports, cumulative change, 2020 - 2050 (LHV, AR6, 100-yr), direct emissions end use of U.S. LNG represented as unabated combustion (no CCS)

Scenario[a]	Cumulative Change in U.S. LNG Exported, 2020-2050 (EJ)[b,c]	Cumulative Change in Direct Attributional Emissions from Increased U.S. LNG Exports if 100% Combusted w/o CCS End Use, 2020-2050 (Tg CO_2e)[b,d]	Cumulative Change in Direct Attributional Emissions of Direct and Indirect Market Substitutions, 2020-2050 (Tg CO_2e)[b,e]	Cumulative Change in Direct and Indirect GHG Emissions Market Substitution Effects Only, 2020-2050 (Tg CO_2e)[b,f]	Cumulative Change in Indirect GHG Emissions from Increased Global Services Effects Only, 2020-2050 (Tg CO_2e)[b,g]	Cumulative Change in GHG Emissions, 2020-2050 (Tg CO_2e)[b,h,i]
Defined Policies						
DP: Hi Exp	188	14,288	-15,126	-838	2,290	1,452
DP: MR	113	8,588	-9,103	-515	1,226	711
DP: Hi ME Sup: MR	100	7,600	-7,964	-364	727	363
DP: Hi US Sup: MR	115	8,740	-9,518	-778	1,964	1,186
DP: Lo US Sup: MR	18	1,368	-1,487	-119	151	32
Commitments						
C (Hi CCS): Hi Exp	107	8,132	-8,511	-379	1,166	787
C (Hi CCS): MR	31	2,356	-2,512	-156	253	97
C (Mod CCS): Hi Exp	86	6,536	-6,422	114	1,169	1,055
C (Mod CCS): MR	11	836	-839	-3	70	67
Net Zero 2050						
NZ (Hi CCS): Hi Exp	93	7,068	-7,557	-489	813	324
NZ (Hi CCS): MR	17	1,292	-1,367	-75	96	21
NZ (Mod CCS): Hi Exp	76	5,776	-5,280	496	459	955

Notes:

[a] Scenario *NZ (Mod CCS): MR* is not presented here because model-resolved LNG exports do not exceed existing/FID levels in this scenario.

[b] Changes for all scenarios found vs. *Existing/FID* within each global climate policy scenario.

[c] Conversion of annual values from EJ/year to Bcf/d is 1:2.7759

[d] Assumes every EJ of U.S. LNG exported is combusted at end use and released to the atmosphere (no CCS). Oceans shipping was modeled as 100% to Asian Market (27,500 nautical miles, round trip). Attributional life cycle result (76 g CO_2e/MJ LHV, AR6, 100-yr) is provided to illustrate the absolute cumulative emissions to the environment from 2020 - 2050 for one example end destination and use. Consequential modeling results account for a range of end destinations and end uses with varying degrees of CCS deployment depending on the scenario.

[e] Total direct emissions from increased U.S. LNG exports plus the indirect GHG emissions from market substitution effects, excludes GHG emissions from increases in global services. Direct emissions are estimated for illustrative purposes based on direct emissions from U.S. LNG exports if 100% combusted w/o CCS end use.

[f] Results from Table 34, Cumulative Consequential GHG Intensities for U.S. Exports (LHV, AR6, 100-yr, equivalent services basis).

[g] Derived from the absolute difference between the cumulative change in GHG emissions from Table 22 (all consequences) and Table 34 (excludes change in global services).

[h] Results from Table 22. Cumulative Consequential GHG Intensities of U.S. Exports, LV, AR6,100-yr Basis.

[i] Consequential GHG Intensity of U.S. LNG Exports (g CO_2e/MJ), as reported in Table 22, can be obtained by dividing the Cumulative change in GHG Emissions, 2020 - 2050 (this column) by the Cumulative Change in U.S. LNG Exported, 2020 – 2050 (second column in the table).

Table 36. Summary of market drivers of total consequential GHG intensity of increased U.S. LNG exports, cumulative change, 2020 - 2050 (LHV, AR6, 100-yr), direct emissions end use of U.S. LNG represented as 90% CCS at end use

Scenario[a]	Cumulative Change in U.S. LNG Exported, 2020-2050 (EJ)[b,c]	Cumulative Change in Direct GHG Emissions from Increased U.S. LNG Exports if 100% Combusted with 90% CCS End Use, 2020-2050 (Tg CO_2e)[b,d]	Cumulative Change in Direct Attributional Emissions of Direct and Indirect Market Substitutions, 2020-2050 (Tg CO_2e)[b,e]	Cumulative Change in Direct and Indirect GHG Emissions Market Substitution Effects Only, 2020-2050 (Tg CO_2e)[b,f]	Cumulative Change in Indirect GHG Emissions from Increased Global Services Effects Only, 2020-2050 (Tg CO_2e)[b,g]	Cumulative Change in GHG Emissions, 2020-2050 (Tg CO_2e)[b,h,i]
Defined Policies						
DP: Hi Exp	188	5,640	-6,478	-838	2,290	1,452
DP: MR	113	3,390	-3,905	-515	1,226	711
DP: Hi ME Sup: MR	100	3,000	-3,364	-364	727	363
DP: Hi US Sup: MR	115	3,450	-4,228	-778	1,964	1,186
DP: Lo US Sup: MR	18	540	-659	-119	151	32
Commitments						
C (Hi CCS): Hi Exp	107	3,210	-3,589	-379	1,166	787
C (Hi CCS): MR	31	930	-1,086	-156	253	97
C (Mod CCS): Hi Exp	86	2,580	-2,466	114	1,169	1,055
C (Mod CCS): MR	11	330	-333	-3	70	67
Net Zero 2050						
NZ (Hi CCS): Hi Exp	93	2,790	-3,279	-489	813	324
NZ (Hi CCS): MR	17	510	-585	-75	96	21
NZ (Mod CCS): Hi Exp	76	2,280	-1,784	496	459	955

Notes:

[a] Scenario *NZ (Mod CCS): MR* is not presented here because model-resolved LNG exports do not exceed existing/FID levels in this scenario.

[b] Changes for all scenarios found vs. Existing/FID within each global climate policy scenario.

[c] Conversion of annual values from EJ/year to Bcf/d is 1:2.7759

[d] Assumes every EJ of U.S. LNG exported is combusted at end use and 90% of the end use carbon dioxide emissions are captured and sequestered from being released to the atmosphere. Oceans shipping was modeled as 100% to Asian Market (27,500 nautical miles, round trip). Attributional life cycle result (30 g CO_2e/MJ LHV, AR6, 100-yr) is provided to illustrate the absolute cumulative emissions to the environment from 2020 - 2050 for one example end destination and use. Consequential modeling results account for a range of end destinations and end uses with varying degrees of CCS deployment depending on the scenario.

[e] Total direct emissions from increased U.S. LNG exports plus the indirect GHG emissions from market substitution effects, excludes GHG emissions from increases in global services. Direct emissions are estimated for illustrative purposes based on direct emissions from U.S. LNG exports with 90% CCS at end use combustion.

[f] Results from Table 34, Cumulative Consequential GHG Intensities for U.S. Exports (LHV, AR6, 100-yr, equivalent services basis).

[g] Derived from the absolute difference between the cumulative change in GHG emissions from Table 22 (all consequences) and Table 34 (excludes change in global services).

[h] Results from Table 22. Cumulative Consequential GHG Intensities of U.S. Exports, LV, AR6,100-yr Basis.

[i] Consequential GHG Intensity of U.S. LNG Exports (g CO_2e/MJ), as reported in Table 22, can be obtained by dividing the Cumulative change in GHG Emissions, 2020 - 2050 (this column) by the Cumulative Change in U.S. LNG Exported, 2020 – 2050 (second column in the table).

D. Modeling Caveats and Limitations

The results of this study are dependent on various data sources, models, and assumptions that are highly connected. Important caveats and limitations of this analysis include:

1. For the estimation of liquefaction emissions of projects, the basis of the NETL GHG intensity estimates are current practice and data. This affects the primary result as well as the framework for the individual project analysis. As modeled within this study, the U.S.

average performance for liquefaction facilities used as the default value is a static reference aligned to year 2020 industry performance. This liquefaction facility value is not adjusted in future modeling years for potential unknown industry changes, such as implementation of carbon capture and storage, electrification, etc.

2. The upstream natural gas GHG intensity profile is currently based on the 2024 NETL Natural Gas baseline study. Measurement studies of the combined oil and gas sectors suggest methane emission rates could be higher for natural gas production than are represented in the NETL natural gas model. Sensitivity to upstream methane emissions is evaluated in the Results, Sensitivity Analysis section of this study.
3. Changes in the quantity of natural gas liquefied globally result in direct changes in emissions from liquefaction operations represented in the GCAM model. Liquefaction operations are modeled as a component of other industrial emissions within GCAM and are responsive to changes in country GDP and not directly connected to changes in country-level LNG export volumes. Therefore, sensitivity to liquefaction operating emissions representation in the GCAM model is evaluated in the Results, Sensitivity Analysis section of this study.

STUDY SUMMARY

The purpose of this study was to examine the potential global GHG emissions implications of a wide range of levels of U.S. LNG exports. Key conclusions include:

1. Differences in volumes of U.S. LNG exports lead to different levels both of GHG emissions and of global services provided. When compared to scenarios that assume export levels based on existing and under construction facilities (*Existing/FID*), higher levels of U.S. LNG exports lead to higher global GHG emissions (ranging from 21 Tg CO_2e to 1,452 Tg CO_2e or about 0.002% to 0.1%), as well as higher levels of global services provided (ranging from 0.006% to about 0.1%).
2. The GCAM upstream GHG intensity values for all scenarios are within 1% of the values in the latest NETL Natural Gas baseline study (representative of the base year of this study, 2020) on an IPCC AR6, 100-yr basis.
    a. Per MJ of natural gas scaled to account for liquefaction losses, the production through transmission (upstream) GHG intensity is 9.2 g CO_2e/MJ exported on an IPCC AR6, 100-yr GWP, LHV basis and 15.7 g CO_2e/MJ exported on an IPCC AR6, 20-yr GWP, LHV basis.
    b. Overall, adjustments to align to NETL national average performance data for GHG intensity added about 20 Tg CO_2e emissions per model year, an increase of less than 0.05% on an AR6, 100-yr basis, and subtracted about 100 Tg CO_2e emissions per model year, a decrease of less than 0.2% (AR6, 20-yr basis).
3. The national average GHG intensity for liquefaction operations in the base year is modeled using government reported data and expanded to provide representative life cycle system boundaries, resulting in a GHG emissions intensity of 5.3 g CO_2e/MJ of natural gas ready for export, reported on an IPCC AR6, 100-yr lower heating value (LHV) basis, and 5.6 g CO_2e/MJ on an IPCC AR6, 20-yr lower heating value (LHV) basis.
4. This analysis defines the upstream natural gas and liquefaction processes as project direct emissions, the direct emissions from export and use of the natural gas and direct and indirect market effects as project non-direct emissions and the sum of them to be the consequential GHG intensity of U.S. LNG Exports. Given the upstream natural gas and liquefaction values estimated above, the average U.S. project direct emissions for 2020, the baseline year for this study, is 9.2 + 5.3 = 14.5 g CO_2e/MJ (AR6, 100-yr), and 21.3 g CO_2e/MJ (AR6, 20-yr).

5. The consequential GHG intensity is the effect (inclusive of both direct and indirect emissions) of U.S. LNG on global emissions per unit of U.S. LNG exported. The consequential GHG intensity is defined as the difference in GHG emissions between the scenarios divided by the difference in U.S. LNG exports. For instance, for one of the scenario comparisons assessed (*Defined Polices: Model Resolved*) the consequential GHG intensity is +6.3 g CO_2e/MJ (on both an AR6, 100-yr and AR6, 20-yr basis), indicating that the overall global effect of producing and exporting U.S. LNG leads to an increase in global GHG emissions resulting from consequential market effects.
    a. Analysis of the results shows that direct and indirect market substitutions result in a decrease in global GHG emissions intensity when compared on an equivalent global services basis. The increased availability of U.S. LNG on the global market enables increased demand for energy to be met with a lower cost energy supply option that often displaces more or equally GHG emissions-intensive fuels (e.g., coal and oil) within the model over the thirty-year study period.
    b. Results also show that increasing the availability of U.S. LNG on the global market (increased global energy supply) results in increased consumption of global services when compared to the baseline scenario (e.g., *Defined Policies: Existing/FID*). The consequential effect of increased global consumption of energy and services directly contributes to increased global GHG emissions.
    c. The net result of these two market effects is an increase in global GHG emissions of +6.3 g CO_2e/MJ of NG exported from the U.S. Across all scenarios, this GHG intensity figure ranges from 1.2 g CO_2e/MJ to 12.6 g CO_2e/MJ (AR6, 100-yr basis), and -1.4 g CO_2e/MJ to 11.2 g CO_2e/MJ (AR6, 20-yr basis).
    d. The increase in global GHG emissions between the *Defined Policies: Model Resolved* and *Defined Policies: Existing/FID* scenarios is estimated to result in a cumulative SC-GHG impact of $74 billion using a discount rate of 2.5%, $130 billion using a discount rate of 2.0%, and $220 billion using a discount rate of 1.5% (all 2020$). Per MJ, this equates to a range of 0.02 cents/MJ to 0.15 cents/MJ (2.5%). The cumulative SC-GHG of the increase in global emissions across the study scenarios ranged from $3 billion to $150 billion (2.5%) to $12 billion to $450 billion (1.5%) in 2020$.
6. Estimated consequential GHG impacts and SC-GHG values for an individual U.S. export project can be calculated by using individual project values in place of the default of U.S. average values modeled in the study.
    a. For example, on an AR6, 100-yr basis, given the NETL average liquefaction emissions for a project of 5.3 g CO_2e/MJ, if an individual project has a liquefaction process with emissions that are half of the average (2.65 g CO_2e /MJ), the individual project consequential GHG intensity could be adjusted down by 2.65 g CO_2e/MJ (calculated as the difference between the average of 5.3 g CO_2e/MJ and the individual project emissions intensity of 2.65 g CO_2e/MJ). If the average U.S. consequential GHG intensity is 6.3 g CO_2e /MJ, the individual project consequential intensity would be 3.65 g CO_2e /MJ.
    b. Total lifetime social costs of the project direct and project non-direct greenhouse gas emissions from a 1 Bcf/d facility operating for 30 years are estimated to be $8 billion to $23 billion ($2020) for a facility with default average intensity values (varying across assumed discount rates). A similar facility with half the liquefaction emissions would have social costs of greenhouse gases estimated to be $4.6 billion to $13 billion ($2020).

APPENDICES TO THIS REPORT

Appendix C-1: NEMS and NETL LCA Model Results Comparison

Appendix C-2: Incorporation, Assessment, and Adjustments to the Global Change Analysis Model (GCAM) Results

Appendix C-3: Social Cost of Greenhouse Gases Modeling and Additional Results

Appendix C-4: Detailed Data Tables for Values Summarized in this Report

APPENDIX C-1: NEMS AND NETL LCA MODEL RESULTS COMPARISON

The NEMS modeling done in this project focused on domestic changes that would be expected to occur in the 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 NETL would have recommended adjustments to the assumed GHG intensity for U.S. natural gas in the results.

For *all scenarios*, NEMS-modeled data of dry natural gas production of "Production by OGSM District" were mapped to a state and then to an NETL natural gas model region as shown in Table C-1.1. Note that several "states" are offshore regions.

Table C-1.1. Matching NEMS (Oil and Gas Methane Partnership states) to NETL states and 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
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
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-1.2.

Table C-1.2. Regional dry production (Tcf) between 2020 and 2050, DP:MR

Region	2020	2025	2030	2035	2040	2045	2050
Southeast	4.59	6.64	6.01	6.28	7.21	8.01	8.11
Southwest	11.26	13.08	13.38	14.00	16.43	19.38	21.18
Pacific	2.69	2.08	2.09	1.98	2.19	2.61	2.78
Rocky Mountain	3.32	2.92	2.88	2.57	2.65	2.66	2.67
Northeast	10.33	11.80	11.93	12.94	14.49	15.21	15.31
Midwest	0.97	0.95	0.96	0.95	0.92	0.91	0.91

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-1.3.

Table C-1.3. Regional NG dry production shares, DP:MR

Region	2020	2025	2030	2035	2040	2045	2050
Midwest	0.139	0.177	0.161	0.162	0.164	0.164	0.159
Northeast	0.339	0.349	0.359	0.362	0.374	0.397	0.416
Pacific	0.081	0.056	0.056	0.050	0.050	0.054	0.055
Rocky Mountain	0.100	0.078	0.077	0.067	0.060	0.055	0.052
Southeast	0.311	0.315	0.320	0.335	0.330	0.312	0.300
Southwest	0.029	0.025	0.026	0.024	0.021	0.019	0.018

The regional production shares estimated based on NEMS data are disaggregated to a techno-basin level based on the proportion of regional natural gas production shares in the 2020 NETL Natural Gas model. Based on the 2020 NETL Natural Gas model, Table C-1.4 provides the techno-basin to region mapping details and Table C-1.5 reports the GHG emissions intensity results for natural gas production from all techno-basins, for the production through transmission network life cycle boundary, using U.S. average transmission network data.

Table C-1.4. Regional NG dry production shares, DP:MR

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 Coalbed Methane	Southwest
San Juan Shale	Southwest
South Oklahoma Shale	Southwest
Strawn Shale	Southwest
Uinta Conventional	Rocky Mountain
Uinta Tight	Rocky Mountain

Table C-1.5. 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
Piceance Tight	8.55E+00
San Juan Coalbed Methane	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 Natural Gas Model were converted from HHV to LHV basis for this work.

Overall, Table C-1.6 suggests that the NEMS-modeled changes in domestic natural gas production by region across the scenarios are not expected to significantly affect the projected GHG emissions intensities over time as evidenced by the 0 to 0.004 variance across the time horizon and scenarios.

Table C-1.6. Estimated U.S. average GHG intensity (g CO_2e/MJ) across NEMS scenarios, production through transmission (2020-2050)

Scenario	***2020***	***2025***	***2030***	***2035***	***2040***	***2045***	***2050***
DP: MR	*0.083*	*0.082*	*0.082*	*0.082*	*0.082*	*0.083*	*0.084*
DP: ExFID	*0.083*	*0.082*	*0.082*	*0.082*	*0.082*	*0.082*	*0.082*
DP Hi US Sup: MR	*0.083*	*0.083*	*0.084*	*0.083*	*0.084*	*0.084*	*0.084*
DP Hi US Sup: ExFID	*0.083*	*0.083*	*0.084*	*0.084*	*0.083*	*0.083*	*0.083*
DP Lo US Sup: MR	*0.083*	*0.081*	*0.081*	*0.080*	*0.080*	*0.081*	*0.081*
DP Lo US Sup: ExFID	*0.083*	*0.081*	*0.081*	*0.080*	*0.080*	*0.080*	*0.081*

APPENDIX C-2: INCORPORATION, ASSESSMENT, AND ADJUSTMENTS TO THE GLOBAL CHANGE ANALYSIS MODEL (GCAM) RESULTS

Across all years and scenarios, GCAM has over 100 discrete sectors, hundreds of 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 and years modeled were provided as described in Table C-2.1 and were processed accordingly.

Table C-2.1. Provided set of GCAM data documentation

File	Data Represented
co2_em_tech	Provides data showing CO_2 emissions in megatons per year for various sectors, energy sources or "technology" for different scenarios across each of 32 regions.
non_co2_em_tech	Provides data showing non-CO_2 emissions in gigagrams, equivalent to metric kilotons or 1,000 metric tons, for various sectors, energy sources or "technology" and different scenarios across each of 37 regions.
inputs.by.tech	Provides detailed information about energy consumption in different regions and sectors along with specific technologies and years.
outputs.by.tech	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 "Defined Policies: Existing/FID," 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 CO_2 emissions are being measured, e.g., "*agricultural energy use*," "*cement*," etc.
sub-sector	Within a sector, there may be further divisions or subcategories to specify the specific aspect of the sector being measured, e.g., by type of fuel or "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, "gas CC" and "gas steam/CT."
year	The specific year or period for which the CO_2 emissions values are provided; this ranges from 2020 to 2050.
value	Numerical values for the activity being described given combination of scenario, region, sector, subsector, technology, and year.
ghg	Refers to the GHG that is being emitted (for non-CO_2 data). It identifies the specific type of gas responsible for the emissions, e.g., CH_4, N_2O, HFC125, C_2F_6, etc.
input	The energy or other input into sector/subsector/technology.
output	The commodity or service provided by the sector/subsector/technology.

A. GCAM and NETL (2020) Emissions Intensity Comparison and Adjustment

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 three sectors in GCAM include GHG emissions relevant to the natural gas sector: *natural*

gas, *gas pipeline*, and *other industrial energy use*. In this document, these GCAM sectors are *italicized* when referred to given their colloquial use in other ways such as in describing stages of the natural gas life cycle.

Using the basis of process stages as represented in the NETL Natural Gas model, Figure C-2.1 shows the relevant GCAM sectors that have associated CO_2 and non-CO_2 emissions. While, overall, GCAM has 16 species of GHG emissions, for the three GCAM sectors above relevant to the upstream natural gas sector, only emissions of CO_2, CH_4, and N_2O were represented. Most stages of the NETL Natural Gas model framework are accounted for in these three GCAM sectors, but not all are explicitly scaled to production amounts of natural gas or derivative products. Also, the Ocean Shipping stage is included as part of *trn_shipping_intl* but the effects 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.

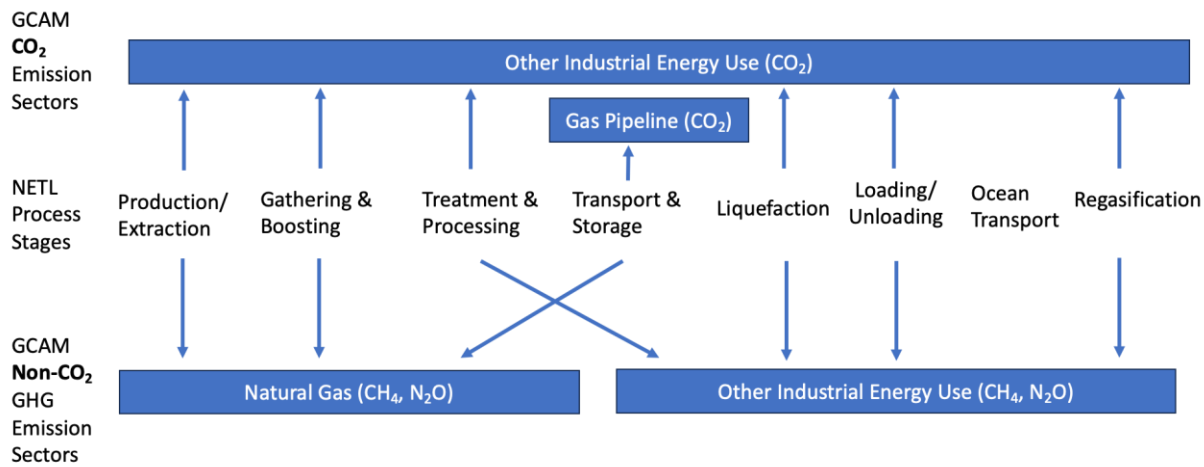

Figure C-2.1. Mapping of NETL natural gas stages to GCAM sectors

To assess the alignment of the modeling of natural gas upstream emissions in GCAM against the NETL Natural Gas model, 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 were listed and compared to NETL natural gas model results. Note, in order to compare NETL and GCAM results, NETL model results were regenerated using an LHV basis as shown below and differ from those published (as HHV by default) and listed in Step 2 of the report.

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 International Energy Agency (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-2.2.

Table C-2.2. LCA stage cross-mapping

NETL LCA Stage	IEA Energy Flow	GCAM Sector – Energy & CO_2
Extraction	Oil and Gas Extraction	other industrial energy use
Gathering and Boosting	Oil and Gas Extraction	other industrial energy use
Processing	Gas Works	other industrial energy use
Domestic Pipeline Transport	Pipeline Transport	gas pipeline
Liquefaction	LNG/Regasification Plants	other industrial energy use

Ocean Transport	International Marine Bunkers	trn_shipping_intl
Regasification	LNG/Regasification Plants	other industrial energy use
Pipeline Transport (at destination)	Pipeline Transport	gas pipeline

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 represents 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 United States), emissions from those activities are excluded from the analysis, consistent with the focus on upstream natural gas effects.

Overall, only four subsector/technology pair values of the other industrial energy use sector in GCAM were considered: gas/gas, gas/gas cogen, refined liquids/refined liquids, and refined liquids/refined liquids cogen (and are shown as aggregated to the subsector level).

The emissions intensity cells in Table C-2.3 show the underlying equation used to generate values on an AR6, 100-yr basis, where the numerator is the total emissions from GCAM for the USA region for the Defined Policies: Model Resolved scenario for the year 2020 for each of the three GHGs (if available), normalized by the total production of U.S. natural gas and oil from GCAM in 2020 (32.29 EJ and 22.32 EJ, respectively). Note that GCAM reports “production” of resources but actually maps more appropriately to “delivered product”. As such the basis of the GCAM and NETL boundaries match (all are in terms of NG delivered). Units of emissions intensity follow those internal to GCAM, which are Tg CO_2 equivalent/EJ, 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-2.3 show comparisons to those of the NETL model.

Table C-2.3. GCAM emissions intensities for sectors (DP:MR, 2020, USA region, AR6, 100-yr 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 Natural Gas model.	38.0/32.3 = 1.18	-	-
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.	-	138.3/32.3 = 4.28	.014/32.3 = 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.	92.9/32.3 = 2.88	0.06/32.3 = 0.002	0.04/32.3 = 0.001
other industrial energy use (technology = refined liquids and refined liquids cogen)[a]			10.3/(32.3+ 22.3) = 0.2	0.07/(32.3+ 22.3) = 0.001	0.39/(32.3+ 22.3) = 0.007
other industrial energy use (electricity)[a]			-	-	-
Total GCAM by gas (LHV)			**= 1.18 + 2.88 + .2 = 4.24**	**4.28**	**0.009**
Total GCAM (LHV)			**8.53**		
Subtotal from NETL Model, Processing through Transmission boundary – LHV basis			**8.63**		
Adjustment factor (LHV)			**8.63/8.53 = 1.0117**		

Overall, the estimated upstream emissions intensity for the USA region in GCAM in the year 2020 for *Defined Policies: Model Resolved* was about 8.53 g CO_2e/MJ (AR6, 100-yr, LHV basis), which is slightly lower than the GHG emissions intensity estimated by the NETL model for the production through transmission boundary (8.63 g CO_2e/MJ, AR6, 100-yr, LHV basis). Using the relationship between those estimates, emissions results in the three GCAM natural gas sectors identified above were adjusted by a factor of 8.63/8.53, or 1.0117 (a 1.17% increase) 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, and is directly applied to GHG emissions in all regions of the GCAM model results 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

CH_4 mitigation trends for each region in the underlying GCAM emissions factors for the *natural gas* sector were 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 those associated with natural gas, such as use of biomass and coal. 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 1.17% increase in emissions intensity for the sector), it avoids the outcome where that sector's emissions are reduced for all of the other activities. Specifically, as delineated above only the emissions of the gas/gas cogen and refined liquids/refined liquids cogen subsectors were increased by 1.17%, and only for the share of activity within those subsectors associated with Extraction and Gathering/Boosting activities.

These adjustments to emissions from all regions, all scenarios, and all years were applied to existing GCAM results (i.e., GCAM was not re-run based on these adjustments). As 99.5% of GHG emissions in the *other industrial energy use* sector are CO_2, only CO_2 emissions for that sector were adjusted. The net global adjustment of GHG emissions in this sector (an increase of 0.11% in 2020) has negligible effects on GHG emissions.

Table C-2.4 shows the GWP of GHG emissions estimates from GCAM that were used in conjunction with the emissions factors to derive the overall life cycle GHG intensity values.

Table C-2.4. GWP values used in this analysis

GHG	AR6, 100-yr	AR6, 20-yr
CH_4 (fossil)	29.8	82.5
CH_4 (non-fossil)	27.2	80.8
N_2O (fossil)	273	273
N_2O (non-fossil)	273	273
HFC125	3740	6740
HFC134a	1530	4140
HFC143a	5810	7840
HFC23	14600	12400
HFC32	771	2690
SF_6	24300	18200
HFC245fa	962	3170
HFC365mfc	914	2920
C_2F_6	12400	8940
CF_4	7380	5300
HFC43	1600	3960
HFC152a	164	591
HFC227ea	3600	5850
HFC236fa	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 16 GHGs and all are included in this study.

Using the same detailed approach as detailed in Table C-2.3, Table C-2.5 more succinctly summarizes the provided GCAM values and adjustments identified for the IPCC AR6, 20-yr values.

Table C-2.5. GCAM emissions intensities for sectors (S1, 2020, U.S. region, AR6, 20-yr basis)

GCAM Sector	**Estimated GCAM Emissions Intensity (Tg CO_2e/EJ, g CO_2e/MJ) [IPCC AR6, 20-yr]**		
	CO_2	**CH_4**	**N_2O**
gas pipeline	1.18	-	-
natural gas	-	11.86	4.5 E-4
other industrial energy use (technology = gas or gas cogen)	2.88	0.005	0.001
other industrial energy use (technology = refined liquids and refined liquids cogen)	0.2	0.006	0.007
Total GCAM by gas (LHV)	= 1.18 + 2.88 + .2 = 4.24	11.87	0.009
Total GCAM (LHV)	16.1		
NETL (LHV basis)	14.6		
Adjustment Factor (LHV)	0.907		

In addition to the adjustment of GCAM results, the liquefaction and upstream natural gas GHG intensity values produced in Steps 2 and 3 were also updated to the AR6, 20-yr basis. The resulting values are 15.7 g CO_2e/MJ and 5.6 g CO_2e/MJ for the for the upstream natural gas GHG intensity and liquefaction GHG intensity, respectively. The sum of these is 21.3 g CO_2e/MJ and is the estimate of project direct emissions for analysis on an AR6, 20-yr basis.

B. Method and Scaling Factors Used for Service-Equivalent Analysis

An additional analysis was done from the base set of scenarios that estimated results with increased services provided. The additional analysis normalized services delivered on an equivalent basis, as described in this section.

An output file from GCAM provided aggregated summaries of domestic and global services provided from GCAM, which include end-use energy services (e.g., space heating and cooling, passenger and freight transportation, industrial energy) and output of some major commodities (e.g., cement). Originally provided estimates of about 50 services are aggregated into about 15 categories.

A method was derived to compare and normalize the greenhouse gas emissions and U.S. LNG exports based on the changes in services provided between scenarios across the entire set of services provided.

The “outputs” data is an export of GCAM modeling that shows the quantities of outputs for various services. These account for energy services that can be quantified using appropriate exajoule units, material production (e.g., cement and iron/steel) that are more appropriately quantified by mass, and transportation that can be for materials or people with appropriate units. For any scenario pair where the end, cumulative result is an increase in U.S. LNG exports, these cumulative global services increase by different amounts along with their GHG emissions. In order to compare the carbon intensity of two scenarios, the GHG emissions and U.S. LNG exports need

to be adjusted to account for those changes in services. This is done by calculating a ratio of the service between two scenarios – for example scenario 1 cement production in million tonnes divided scenario 2 cement production in million tons. This is done for all services, resulting in a vector of multiple (50 into 15) ratios. These ratios are weighted by the amount of energy input for that service, and then summed together to provide a single weighting factor to apply to the both the global GHG emissions and U.S. LNG production.

In general, when adjusting scenarios to reach service-equivalence, the GHG intensity per unit of U.S. LNG is negative, suggesting that the global GHG intensity of services in general slightly decreases as a result of U.S. LNG exports. This is largely due to removals of enough coal, oil, and more GHG-intense natural gas from energy use globally to offset the reductions in any renewable energy use that also occur. As a result, weighted average scaling factors for the service-equivalent analysis were developed for all scenarios relative overall to the *Defined Policies: Existing/FID Exports* scenario and within each set of scenarios to the specific *ExFID* scenario, as shown in Table C-2.6.

Table C-2.6. Scaling factors used for service adjustment calculation relative to the existing/fid levels of LNG export

Scenario	Service Adjustment Scaling Factor
Defined Policies: High Exports	1.001476
Defined Policies: Model Resolved	1.00079
Defined Policies: Existing/FID Exports	1
Defined Policies: High Middle East Supply: Model Resolved	1.000467
Defined Policies: High Middle East Supply: Existing/FID Exports	1
Defined Policies: High US Supply: Model Resolved	1.001265
Defined Policies: High US Supply: Existing/FID Exports	1
Defined Policies: Low US Supply: Model Resolved	1.000098
Defined Policies: Low US Supply: Existing/FID Exports	1
Commitments (High CCS): High Exports	1.00092
Commitments (High CCS): Model Resolved	1.000199
Commitments (High CCS): Existing/FID Exports	1
Commitments (Mod CCS): High Exports	1.000755
Commitments (Mod CCS): Model Resolved	1.000058
Commitments (Mod CCS): Existing/FID Exports	1
Net Zero 2050 (High CCS): High Exports	1.000759
Net Zero 2050 (High CCS): Model Resolved	1.000089
Net Zero 2050 (High CCS): Existing/FID Exports	1
Net Zero 2050 (Mod CCS): High Exports	1.000464
Net Zero 2050 (Mod CCS): Model Resolved	1
Net Zero 2050 (Mod CCS): Existing/FID Exports	1

APPENDIX C-3: SOCIAL COST OF GREENHOUSE GASES MODELING AND ADDITIONAL RESULTS

The speciated GHG emissions inputs to the consequential GHG intensity can also be used with the 2023 SC-GHG methodology to monetize the impacts of the changes in GHG emissions associated with increased U.S. LNG exports. The social cost of greenhouse gases (SC-GHG), as described by the Interagency Working Group (IWG) on SC-GHG, is "the monetary value of the net harm to society associated with adding a small amount of greenhouse gases to the atmosphere in a given year." In short, the SC-GHG monetizes the net harm to society caused by the release of an additional ton of GHGs into the atmosphere in a given year.

The 2023 SC-GHG method uses a trio of constant discount rates (1.5%, 2.0% and 2.5%) to provide estimate the SC-GHG for a particular base year (assumed in this study as 2024) and dollar year. The base year (which can also be considered the present value year) was chosen to be 2024 to align with the time of the study, consistent with the suggested choice aligning with a regulatory impact assessment time. The study used 2020 and 2022 as the dollar year, consistent with the default year of damages provided in the framework[43]. The SC-GHG for a given quantity of emissions estimate the net social benefits in dollar values of reducing those emissions, or the net social costs of increasing emissions by that quantity. It also provides a common metric (social costs, in dollars) for identifying the effects of changes in inputs or assumptions on the final result.

Using the 2023 SC-GHG guidance and analysis documents in this study requires only the input of annual speciated GHG emissions of carbon dioxide, methane, and nitrous oxide, which came from the NETL-aligned GCAM results. Table C-3.1 summarizes the monetized SC-GHG estimates in the 2023 SC-GHG method used in the study in 2020 dollars per metric ton of emissions by species, which are defined as having been set using near-term Ramsey discount rates. A GDP deflator is used to convert these values as needed for the 2022-dollar year basis.

Table C-3.1. Annual Unrounded Values in 2023 SC-GHG Estimates, 2020-2080 (2020$ per metric ton of emissions)

Gas	CO_2	CO_2	CO_2	CH_4	CH_4	CH_4	N_2O	N_2O	N_2O
Near-term Ramsey Discount Rate	**2.50%**	**2.00%**	**1.50%**	**2.50%**	**2.00%**	**1.50%**	**2.50%**	**2.00%**	**1.50%**
2020	117	193	337	1,257	1,648	2,305	35,232	54,139	87,284
2021	119	197	341	1,324	1,723	2,391	36,180	55,364	88,869
2022	122	200	346	1,390	1,799	2,478	37,128	56,590	90,454
2023	125	204	351	1,457	1,874	2,564	38,076	57,816	92,040
2024	128	208	356	1,524	1,950	2,650	39,024	59,041	93,625
2025	130	212	360	1,590	2,025	2,737	39,972	60,267	95,210
2026	133	215	365	1,657	2,101	2,823	40,920	61,492	96,796
2027	136	219	370	1,724	2,176	2,910	41,868	62,718	98,381
2028	139	223	375	1,791	2,252	2,996	42,816	63,944	99,966
2029	141	226	380	1,857	2,327	3,083	43,764	65,169	101,552
2030	144	230	384	1,924	2,403	3,169	44,712	66,395	103,137

[43] Generally, this Appendix refers to 2020-dollar year results, while the Summary report refers to 2022 dollar year results.

2031	147	234	389	2,002	2,490	3,270	45,693	67,645	104,727
2032	150	237	394	2,080	2,578	3,371	46,674	68,895	106,316
2033	153	241	398	2,157	2,666	3,471	47,655	70,145	107,906
2034	155	245	403	2,235	2,754	3,572	48,636	71,394	109,495
2035	158	248	408	2,313	2,842	3,673	49,617	72,644	111,085
2036	161	252	412	2,391	2,929	3,774	50,598	73,894	112,674
2037	164	256	417	2,468	3,017	3,875	51,578	75,144	114,264
2038	167	259	422	2,546	3,105	3,975	52,559	76,394	115,853
2039	170	263	426	2,624	3,193	4,076	53,540	77,644	117,443
2040	173	267	431	2,702	3,280	4,177	54,521	78,894	119,032
2041	176	271	436	2,786	3,375	4,285	55,632	80,304	120,809
2042	179	275	441	2,871	3,471	4,394	56,744	81,714	122,586
2043	182	279	446	2,955	3,566	4,502	57,855	83,124	124,362
2044	186	283	451	3,040	3,661	4,610	58,966	84,535	126,139
2045	189	287	456	3,124	3,756	4,718	60,078	85,945	127,916
2046	192	291	462	3,209	3,851	4,827	61,189	87,355	129,693
2047	195	296	467	3,293	3,946	4,935	62,301	88,765	131,469
2048	199	300	472	3,378	4,041	5,043	63,412	90,176	133,246
2049	202	304	477	3,462	4,136	5,151	64,523	91,586	135,023
2050	205	308	482	3,547	4,231	5,260	65,635	92,996	136,799

Results from the SC-GHG analyses for the 2020-dollar year basis are summarized in Table C-3.2 through Table C-3.4. Note that unlike the consequential intensity and project non-direct emissions results shown earlier, these social costs of greenhouse gases are those associated with all global emissions over the 2020-2050 period for the scenarios, and not just those associated with U.S. LNG exports.

Table C-3.2. Social cost of greenhouse gases results for Defined Policies (base year 2024, trillion 2020$)

		Discount Rate		
Scenario	**Gas**	**2.50%**	**2.00%**	**1.50%**
Defined Policies: High Exports	CO_2	$129.06	$213.68	$370.63
	CH_4	$19.39	$25.34	$34.86
	N_2O	$14.31	$22.18	$35.93
	Total	**$162.76**	**$261.20**	**$441.42**
Defined Policies: Model Resolved	CO_2	$128.98	$213.54	$370.40
	CH_4	$19.38	$25.34	$34.85
	N_2O	$14.31	$22.19	$35.94
	Total	**$162.68**	**$261.07**	**$441.19**
Defined Policies: Existing/FID Exports	CO_2	$128.90	$213.41	$370.16
	CH_4	$19.38	$25.33	$34.85
	N_2O	$14.32	$22.20	$35.96
	Total	**$162.60**	**$260.95**	**$440.97**

Defined Policies: High Middle East Supply: Model Resolved	CO_2	$129.36	$214.19	$371.52
	CH_4	$19.44	$25.41	$34.96
	N_2O	$14.30	$22.17	$35.90
	Total	**$163.11**	**$261.77**	**$442.39**
Defined Policies: High Middle East Supply: Existing/FID Exports	CO_2	$129.31	$214.10	$371.38
	CH_4	$19.45	$25.42	$34.97
	N_2O	$14.30	$22.17	$35.91
	Total	**$163.06**	**$261.70**	**$442.26**
Defined Policies: High US Supply: Model Resolved	CO_2	$129.07	$213.69	$370.66
	CH_4	$19.39	$25.34	$34.86
	N_2O	$14.31	$22.19	$35.93
	Total	**$162.77**	**$261.22**	**$441.45**
Defined Policies: High US Supply: Existing/FID Exports	CO_2	$128.94	$213.48	$370.28
	CH_4	$19.39	$25.34	$34.86
	N_2O	$14.32	$22.20	$35.96
	Total	**$162.65**	**$261.01**	**$441.09**
Defined Policies: Low US Supply: Model Resolved	CO_2	$128.63	$212.95	$369.36
	CH_4	$19.37	$25.32	$34.83
	N_2O	$14.32	$22.20	$35.95
	Total	**$162.32**	**$260.47**	**$440.14**
Defined Policies: Low US Supply: Existing/FID Exports	CO_2	$128.62	$212.94	$369.35
	CH_4	$19.37	$25.32	$34.83
	N_2O	$14.32	$22.20	$35.95
	Total	**$162.31**	**$260.46**	**$440.13**

Table C-3.3. Social cost of greenhouse gases results for Commitments (base year 2024, trillion 2020$)

		Discount Rate		
Scenario	**Gas**	**2.50%**	**2.00%**	**1.50%**
Commitments (High CCS): High Exports	CO_2	$100.51	$165.67	$286.26
	CH_4	$17.98	$23.47	$32.26
	N_2O	$13.68	$21.19	$34.29
	Total	**$132.16**	**$210.33**	**$352.81**
Commitments (High CCS): Model Resolved	CO_2	$100.43	$165.53	$286.02
	CH_4	$17.98	$23.47	$32.27
	N_2O	$13.68	$21.19	$34.30
	Total	**$132.09**	**$210.20**	**$352.58**
Commitments (High CCS): Existing/FID Exports	CO_2	$100.41	$165.51	$285.97
	CH_4	$17.98	$23.48	$32.27
	N_2O	$13.68	$21.19	$34.30
	Total	**$132.07**	**$210.17**	**$352.54**
	CO_2	$95.51	$157.29	$271.59

Commitments (Mod CCS): High Exports	CH_4	$17.14	$22.37	$30.74
	N_2O	$13.29	$20.58	$33.30
	Total	**$125.94**	**$200.24**	**$335.64**
Commitments (Mod CCS): Model Resolved	CO_2	$95.39	$157.10	$271.25
	CH_4	$17.14	$22.37	$30.75
	N_2O	$13.29	$20.58	$33.30
	Total	**$125.82**	**$200.05**	**$335.30**
Commitments (Mod CCS): Existing/FID Exports	CO_2	$95.38	$157.08	$271.22
	CH_4	$17.14	$22.37	$30.75
	N_2O	$13.29	$20.58	$33.30
	Total	**$125.82**	**$200.04**	**$335.28**

Table C-3.4. Social cost of greenhouse gases results for Net Zero 2050 (base year 2024, trillion 2020$)

		Discount Rate		
Scenario	**Gas**	**2.50%**	**2.00%**	**1.50%**
Net Zero 2050 (High CCS): High Exports	CO_2	$79.78	$131.11	$225.96
	CH_4	$17.06	$22.26	$30.60
	N_2O	$13.30	$20.60	$33.33
	Total	**$110.14**	**$173.97**	**$289.90**
Net Zero 2050 (High CCS): Model Resolved	CO_2	$79.75	$131.04	$225.85
	CH_4	$17.06	$22.27	$30.61
	N_2O	$13.30	$20.60	$33.34
	Total	**$110.11**	**$173.91**	**$289.79**
Net Zero 2050 (High CCS): Existing/FID Exports	CO_2	$79.74	$131.03	$225.83
	CH_4	$17.06	$22.27	$30.61
	N_2O	$13.30	$20.60	$33.34
	Total	**$110.11**	**$173.91**	**$289.78**
Net Zero 2050 (Mod CCS): High Exports	CO_2	$72.93	$119.68	$206.02
	CH_4	$16.01	$20.89	$28.70
	N_2O	$12.80	$19.82	$32.06
	Total	**$101.74**	**$160.38**	**$266.78**
Net Zero 2050 (Mod CCS): Model Resolved	CO_2	$72.82	$119.48	$205.68
	CH_4	$16.01	$20.89	$28.71
	N_2O	$12.80	$19.82	$32.06
	Total	**$101.63**	**$160.19**	**$266.45**
Net Zero 2050 (Mod CCS): Existing/FID Exports	CO_2	$72.82	$119.48	$205.68
	CH_4	$16.01	$20.89	$28.71
	N_2O	$12.80	$19.82	$32.06
	Total	**$101.63**	**$160.19**	**$266.45**

Similarly, Table C-3.5 through Table C-3.7 show SC-GHG results for all scenarios for the 2022-dollar year basis.

Table C-3.5. Social cost of greenhouse gases results for Defined Policies (base year 2024, trillion 2022$)

		Discount Rate		
Scenario	**Gas**	**2.50%**	**2.00%**	**1.50%**
Defined Policies: High Exports	CO_2	$144.48	$239.21	$414.92
	CH_4	$21.71	$28.37	$39.03
	N_2O	$16.02	$24.83	$40.22
	Total	**$182.20**	**$292.41**	**$494.16**
Defined Policies: Model Resolved	CO_2	$144.39	$239.06	$414.66
	CH_4	$21.70	$28.36	$39.02
	N_2O	$16.02	$24.84	$40.23
	Total	**$182.12**	**$292.27**	**$493.91**
Defined Policies: Existing/FID Exports	CO_2	$144.30	$238.91	$414.39
	CH_4	$21.70	$28.36	$39.02
	N_2O	$16.03	$24.85	$40.25
	Total	**$182.03**	**$292.13**	**$493.66**
Defined Policies: High Middle East Supply: Model Resolved	CO_2	$144.82	$239.78	$415.92
	CH_4	$21.77	$28.45	$39.14
	N_2O	$16.01	$24.82	$40.19
	Total	**$182.60**	**$293.05**	**$495.25**
Defined Policies: High Middle East Supply: Existing/FID Exports	CO_2	$144.77	$239.69	$415.75
	CH_4	$21.77	$28.46	$39.15
	N_2O	$16.01	$24.82	$40.20
	Total	**$182.55**	**$292.97**	**$495.10**
Defined Policies: High US Supply: Model Resolved	CO_2	$144.49	$239.23	$414.95
	CH_4	$21.71	$28.37	$39.03
	N_2O	$16.02	$24.84	$40.23
	Total	**$182.22**	**$292.43**	**$494.20**
Defined Policies: High US Supply: Existing/FID Exports	CO_2	$144.35	$238.98	$414.52
	CH_4	$21.70	$28.36	$39.02
	N_2O	$16.03	$24.85	$40.25
	Total	**$182.08**	**$292.20**	**$493.79**
Defined Policies: Low US Supply: Model Resolved	CO_2	$144.00	$238.40	$413.49
	CH_4	$21.69	$28.34	$38.99
	N_2O	$16.03	$24.85	$40.25
	Total	**$181.71**	**$291.59**	**$492.73**
Defined Policies: Low US Supply: Existing/FID Exports	CO_2	$143.99	$238.39	$413.48
	CH_4	$21.69	$28.34	$38.99
	N_2O	$16.03	$24.85	$40.25
	Total	**$181.71**	**$291.59**	**$492.72**

Table C-3.6. Social cost of greenhouse gases results for Commitments (base year 2024, trillion 2022$)

		Discount Rate		
Scenario	**Gas**	**2.50%**	**2.00%**	**1.50%**
Commitments (High CCS): High Exports	CO_2	$112.52	$185.47	$320.47
	CH_4	$20.12	$26.27	$36.12
	N_2O	$15.31	$23.72	$38.39
	Total	**$147.96**	**$235.46**	**$394.97**
Commitments (High CCS): Model Resolved	CO_2	$112.43	$185.31	$320.19
	CH_4	$20.13	$26.28	$36.12
	N_2O	$15.31	$23.72	$38.39
	Total	**$147.87**	**$235.31**	**$394.71**
Commitments (High CCS): Existing/FID Exports	CO_2	$112.41	$185.28	$320.14
	CH_4	$20.13	$26.28	$36.13
	N_2O	$15.31	$23.72	$38.40
	Total	**$147.86**	**$235.29**	**$394.67**
Commitments (Mod CCS): High Exports	CO_2	$106.92	$176.09	$304.04
	CH_4	$19.19	$25.04	$34.42
	N_2O	$14.88	$23.04	$37.28
	Total	**$140.99**	**$224.17**	**$375.74**
Commitments (Mod CCS): Model Resolved	CO_2	$106.79	$175.87	$303.66
	CH_4	$19.19	$25.04	$34.42
	N_2O	$14.88	$23.04	$37.28
	Total	**$140.86**	**$223.96**	**$375.37**
Commitments (Mod CCS): Existing/FID Exports	CO_2	$106.78	$175.85	$303.63
	CH_4	$19.19	$25.05	$34.42
	N_2O	$14.88	$23.04	$37.28
	Total	**$140.85**	**$223.94**	**$375.34**

Table C-3.7. Social cost of greenhouse gases results for Net Zero 2050 (base year 2024, trillion 2022$)

		Discount Rate		
Scenario	**Gas**	**2.50%**	**2.00%**	**1.50%**
Net Zero 2050 (High CCS): High Exports	CO_2	$89.32	$146.77	$252.96
	CH_4	$19.09	$24.92	$34.26
	N_2O	$14.89	$23.06	$37.32
	Total	**$123.30**	**$194.76**	**$324.54**
Net Zero 2050 (High CCS): Model Resolved	CO_2	$89.27	$146.70	$252.83
	CH_4	$19.10	$24.93	$34.27
	N_2O	$14.89	$23.07	$37.32
	Total	**$123.27**	**$194.69**	**$324.42**
	CO_2	$89.27	$146.69	$252.81

Net Zero 2050 (High CCS): Existing/FID Exports	CH_4	$19.10	$24.93	$34.27
	N_2O	$14.89	$23.07	$37.32
	Total	**$123.26**	**$194.69**	**$324.41**
Net Zero 2050 (Mod CCS): High Exports	CO_2	$81.65	$133.98	$230.63
	CH_4	$17.92	$23.38	$32.13
	N_2O	$14.33	$22.19	$35.89
	Total	**$113.90**	**$179.54**	**$298.65**
Net Zero 2050 (Mod CCS): Model Resolved	CO_2	$81.52	$133.76	$230.25
	CH_4	$17.92	$23.39	$32.14
	N_2O	$14.33	$22.19	$35.89
	Total	**$113.77**	**$179.34**	**$298.29**
Net Zero 2050 (Mod CCS): Existing/FID Exports	CO_2	$81.52	$133.76	$230.25
	CH_4	$17.92	$23.39	$32.14
	N_2O	$14.33	$22.19	$35.89
	Total	**$113.77**	**$179.34**	**$298.29**

APPENDIX C-4: DETAILED DATA TABLES FOR VALUES SUMMARIZED IN THIS REPORT

The first set of tables provided in this Appendix are archives of the speciated GHG emissions data for all scenarios used in the analysis, representing the GCAM-NETL-aligned values described in the Consequential Appendix. Values are provided on both AR6-100 and AR6-20 basis.

The second set of tables provided in this Appendix summarize annual and cumulative values of GHG emissions, U.S. LNG exports, and the consequential GHG intensity and project non-direct emissions, for all scenarios.

Table C-4.1. Global Emissions Summary for Defined Policies: Model Resolved (GCAM-NETL-Aligned, AR6-100 Basis)

Year	CO_2 Energy	CO_2 LUC	CH_4 Energy	CH_4 Ag	N_2O Energy	N_2O Ag	F Gases	Total
	Units (Tg CO_2e/year) (AR6, 100-year)							
2020	38,407	398	6,677	3,929	887	2,123	1,349	53,770
2021	37,946	469	6,461	3,946	877	2,151	1,370	53,219
2022	37,484	540	6,245	3,964	867	2,179	1,390	52,669
2023	37,022	611	6,029	3,981	857	2,206	1,410	52,118
2024	36,561	683	5,813	3,999	847	2,234	1,431	51,567
2025	36,099	754	5,598	4,016	837	2,262	1,451	51,017
2026	36,202	67	5,637	4,081	845	2,294	1,518	50,645
2027	36,305	-619	5,677	4,145	853	2,326	1,586	50,273
2028	36,409	-1,306	5,716	4,210	860	2,358	1,653	49,901
2029	36,512	-1,992	5,755	4,274	868	2,390	1,721	49,529
2030	36,615	-2,679	5,795	4,339	876	2,423	1,788	49,156
2031	36,441	-2,389	5,791	4,399	869	2,448	1,806	49,364
2032	36,268	-2,100	5,786	4,460	863	2,472	1,823	49,572
2033	36,094	-1,811	5,782	4,520	857	2,497	1,840	49,779
2034	35,921	-1,522	5,777	4,580	851	2,522	1,857	49,987
2035	35,748	-1,233	5,773	4,640	844	2,547	1,874	50,194
2036	35,582	-1,252	5,737	4,694	833	2,571	1,868	50,033
2037	35,415	-1,271	5,702	4,747	822	2,595	1,861	49,872
2038	35,249	-1,290	5,666	4,800	812	2,619	1,855	49,711
2039	35,083	-1,309	5,631	4,853	801	2,643	1,848	49,549
2040	34,917	-1,328	5,595	4,906	790	2,667	1,841	49,388
2041	34,745	-1,261	5,602	4,962	791	2,698	1,827	49,364
2042	34,574	-1,194	5,608	5,017	792	2,730	1,812	49,340
2043	34,402	-1,127	5,615	5,073	793	2,761	1,797	49,315
2044	34,230	-1,059	5,621	5,129	794	2,793	1,783	49,291
2045	34,058	-992	5,628	5,185	796	2,824	1,768	49,267
2046	33,829	-969	5,630	5,235	796	2,855	1,764	49,141
2047	33,600	-945	5,633	5,286	797	2,885	1,759	49,016
2048	33,370	-922	5,636	5,337	798	2,916	1,755	48,890
2049	33,141	-898	5,638	5,388	798	2,946	1,751	48,765
2050	32,912	-874	5,641	5,439	799	2,977	1,746	48,639
Total	**1,101,142**	**-28,818**	**178,895**	**143,533**	**25,770**	**78,914**	**52,903**	**1,552,340**

Note: Emissions shown have been interpolated for non-model years.

Table C-4.2. Global Emissions Summary for Defined Policies: Model Resolved (GCAM-NETL-Aligned, AR6-100 Basis)

Year	CO_2 Energy	CO_2 LUC	CH_4 Energy	CH_4 Ag	N_2O Energy	N_2O Ag	F Gases	Total
	Units (Tg CO_2e/year) (AR6, 20-year)							
2020	38,407	398	6,677	3,929	887	2,123	1,349	53,770
2021	37,946	469	6,461	3,946	877	2,151	1,370	53,219
2022	37,484	540	6,245	3,964	867	2,179	1,390	52,669
2023	37,022	611	6,029	3,981	857	2,206	1,410	52,118
2024	36,561	683	5,813	3,999	847	2,234	1,431	51,567
2025	36,099	754	5,598	4,016	837	2,262	1,451	51,017
2026	36,202	67	5,637	4,081	845	2,294	1,518	50,645
2027	36,305	-619	5,677	4,145	853	2,326	1,586	50,273
2028	36,409	-1,306	5,716	4,210	860	2,358	1,653	49,901
2029	36,512	-1,992	5,755	4,274	868	2,390	1,721	49,529
2030	36,615	-2,679	5,795	4,339	876	2,423	1,788	49,156
2031	36,449	-2,397	5,791	4,399	869	2,447	1,806	49,365
2032	36,282	-2,115	5,788	4,460	863	2,472	1,823	49,573
2033	36,116	-1,833	5,784	4,520	857	2,497	1,840	49,781
2034	35,950	-1,551	5,780	4,580	850	2,522	1,858	49,989
2035	35,783	-1,269	5,777	4,640	844	2,546	1,875	50,197
2036	35,631	-1,293	5,742	4,694	833	2,570	1,869	50,046
2037	35,479	-1,317	5,707	4,747	822	2,594	1,863	49,894
2038	35,327	-1,341	5,672	4,800	811	2,618	1,856	49,743
2039	35,175	-1,364	5,637	4,853	800	2,641	1,850	49,592
2040	35,023	-1,388	5,602	4,906	789	2,665	1,844	49,440
2041	34,849	-1,315	5,607	4,962	790	2,696	1,829	49,418
2042	34,674	-1,241	5,612	5,017	791	2,728	1,814	49,396
2043	34,500	-1,167	5,617	5,073	792	2,759	1,800	49,374
2044	34,325	-1,093	5,621	5,129	794	2,791	1,785	49,352
2045	34,151	-1,020	5,626	5,185	795	2,822	1,770	49,329
2046	33,913	-990	5,627	5,235	795	2,853	1,766	49,200
2047	33,675	-960	5,628	5,286	796	2,883	1,761	49,070
2048	33,437	-930	5,629	5,337	797	2,914	1,757	48,940
2049	33,198	-900	5,630	5,388	797	2,944	1,752	48,810
2050	32,960	-871	5,631	5,439	798	2,975	1,748	48,680
Total	**1,102,460**	**-29,427**	**178,912**	**143,533**	**25,756**	**78,881**	**52,936**	**1,553,051**

Note: Emissions shown have been interpolated for non-model years.

Table C-4.3. Global Emissions Summary for Defined Policies: High Exports (GCAM-NETL-Aligned, AR6-100 Basis)

Year	CO_2 Energy	CO_2 LUC	CH_4 Energy	CH_4 Ag	N_2O Energy	N_2O Ag	F Gases	Total
	Units (Tg CO_2e/year) (AR6, 20-year)							
2020	38,407	398	6,677	3,929	887	2,123	1,349	53,770
2021	37,946	469	6,461	3,946	877	2,151	1,370	53,219
2022	37,484	540	6,245	3,964	867	2,179	1,390	52,669
2023	37,022	611	6,029	3,981	857	2,206	1,410	52,118
2024	36,561	683	5,813	3,999	847	2,234	1,431	51,567
2025	36,099	754	5,598	4,016	837	2,262	1,451	51,017
2026	36,202	67	5,637	4,081	845	2,294	1,518	50,645
2027	36,305	-619	5,677	4,145	853	2,326	1,586	50,273
2028	36,409	-1,306	5,716	4,210	860	2,358	1,653	49,901
2029	36,512	-1,992	5,755	4,274	868	2,390	1,721	49,529
2030	36,615	-2,679	5,795	4,339	876	2,423	1,788	49,156
2031	36,462	-2,410	5,792	4,399	869	2,447	1,806	49,365
2032	36,309	-2,142	5,790	4,460	863	2,472	1,824	49,574
2033	36,156	-1,873	5,788	4,520	856	2,496	1,841	49,783
2034	36,003	-1,605	5,785	4,580	850	2,520	1,859	49,992
2035	35,850	-1,337	5,783	4,640	843	2,545	1,876	50,201
2036	35,699	-1,349	5,748	4,694	832	2,569	1,870	50,062
2037	35,549	-1,362	5,713	4,747	821	2,592	1,864	49,924
2038	35,398	-1,375	5,678	4,800	810	2,616	1,858	49,785
2039	35,248	-1,388	5,643	4,853	799	2,640	1,852	49,647
2040	35,097	-1,400	5,608	4,906	788	2,663	1,846	49,508
2041	34,921	-1,326	5,612	4,962	789	2,695	1,831	49,483
2042	34,745	-1,252	5,616	5,017	791	2,726	1,816	49,458
2043	34,568	-1,179	5,620	5,073	792	2,758	1,801	49,433
2044	34,392	-1,105	5,624	5,129	793	2,789	1,787	49,409
2045	34,215	-1,031	5,628	5,185	794	2,820	1,772	49,384
2046	33,972	-999	5,628	5,235	795	2,851	1,767	49,250
2047	33,730	-967	5,629	5,286	795	2,881	1,763	49,117
2048	33,487	-935	5,629	5,337	796	2,912	1,758	48,984
2049	33,244	-903	5,629	5,388	796	2,942	1,754	48,851
2050	33,001	-872	5,629	5,439	797	2,973	1,749	48,717
Total	**1,103,609**	**-29,883**	**178,974**	**143,533**	**25,744**	**78,852**	**52,963**	**1,553,792**

Note: Emissions shown have been interpolated for non-model years.

Table C-4.4. Global Emissions Summary for Defined Policies: High Middle East Supply: Existing/FID Exports (GCAM_NETL-Aligned, AR6-100 Basis)

Year	CO_2 Energy	CO_2 LUC	CH_4 Energy	CH_4 Ag	N_2O Energy	N_2O Ag	F Gases	Total
	Units (Tg CO_2e/year) (AR6, 20-year)							
2020	38,416	397	6,678	3,929	887	2,123	1,350	53,780
2021	37,955	468	6,462	3,946	877	2,151	1,370	53,230
2022	37,495	540	6,247	3,964	867	2,179	1,390	52,681
2023	37,035	611	6,031	3,981	857	2,206	1,411	52,131
2024	36,574	682	5,815	3,999	847	2,234	1,431	51,582
2025	36,114	753	5,599	4,016	837	2,262	1,451	51,032
2026	36,227	56	5,640	4,081	845	2,294	1,519	50,662
2027	36,340	-640	5,681	4,145	853	2,326	1,586	50,291
2028	36,454	-1,336	5,722	4,210	860	2,358	1,654	49,921
2029	36,567	-2,033	5,763	4,274	868	2,390	1,722	49,551
2030	36,680	-2,729	5,804	4,339	875	2,422	1,789	49,180
2031	36,529	-2,452	5,803	4,399	869	2,446	1,807	49,401
2032	36,378	-2,175	5,803	4,460	863	2,471	1,825	49,623
2033	36,227	-1,898	5,802	4,520	856	2,495	1,842	49,844
2034	36,075	-1,621	5,802	4,580	850	2,520	1,860	50,065
2035	35,924	-1,345	5,801	4,640	843	2,544	1,878	50,286
2036	35,786	-1,363	5,771	4,694	832	2,568	1,872	50,158
2037	35,647	-1,382	5,740	4,747	821	2,591	1,866	50,030
2038	35,509	-1,400	5,710	4,800	810	2,615	1,860	49,903
2039	35,370	-1,419	5,680	4,853	799	2,638	1,854	49,775
2040	35,232	-1,438	5,650	4,906	788	2,662	1,848	49,647
2041	35,073	-1,374	5,659	4,962	789	2,693	1,833	49,635
2042	34,915	-1,311	5,668	5,017	790	2,724	1,818	49,623
2043	34,757	-1,248	5,678	5,073	792	2,755	1,804	49,610
2044	34,598	-1,184	5,687	5,129	793	2,786	1,789	49,598
2045	34,440	-1,121	5,696	5,185	794	2,817	1,775	49,586
2046	34,218	-1,100	5,702	5,236	794	2,847	1,771	49,468
2047	33,997	-1,078	5,707	5,286	795	2,877	1,766	49,350
2048	33,775	-1,057	5,712	5,337	796	2,907	1,762	49,232
2049	33,553	-1,035	5,717	5,388	796	2,937	1,758	49,114
2050	33,331	-1,014	5,722	5,439	797	2,967	1,753	48,996
Total	**1,107,190**	**-31,246**	**179,951**	**143,534**	**25,741**	**78,803**	**53,012**	**1,556,984**

Note: Emissions shown have been interpolated for non-model years.

Table C-4.5. Global Emissions Summary for Defined Policies: High Middle East Supply: Model Resolved (GCAM-NETL-Aligned, AR6-100 Basis)

Year	CO_2 Energy	CO_2 LUC	CH_4 Energy	CH_4 Ag	N_2O Energy	N_2O Ag	F Gases	Total
	Units (Tg CO_2e/year) (AR6, 20-year)							
2020	38,416	397	6,678	3,929	887	2,123	1,350	53,780
2021	37,955	468	6,462	3,946	877	2,151	1,370	53,230
2022	37,495	540	6,247	3,964	867	2,179	1,390	52,681
2023	37,035	611	6,031	3,981	857	2,206	1,411	52,131
2024	36,574	682	5,815	3,999	847	2,234	1,431	51,582
2025	36,114	753	5,599	4,016	837	2,262	1,451	51,032
2026	36,227	56	5,640	4,081	845	2,294	1,519	50,662
2027	36,340	-640	5,681	4,145	853	2,326	1,586	50,291
2028	36,454	-1,336	5,722	4,210	860	2,358	1,654	49,921
2029	36,567	-2,033	5,763	4,274	868	2,390	1,722	49,551
2030	36,680	-2,729	5,804	4,339	875	2,422	1,789	49,180
2031	36,535	-2,458	5,804	4,399	869	2,446	1,807	49,402
2032	36,389	-2,186	5,803	4,460	862	2,470	1,825	49,624
2033	36,243	-1,915	5,803	4,520	856	2,495	1,843	49,845
2034	36,098	-1,643	5,803	4,580	850	2,519	1,861	50,067
2035	35,952	-1,372	5,803	4,640	843	2,543	1,878	50,288
2036	35,819	-1,390	5,772	4,694	832	2,567	1,872	50,166
2037	35,686	-1,408	5,741	4,747	821	2,590	1,867	50,044
2038	35,553	-1,426	5,710	4,800	810	2,614	1,861	49,922
2039	35,420	-1,444	5,680	4,853	799	2,637	1,855	49,799
2040	35,287	-1,462	5,649	4,906	788	2,661	1,849	49,677
2041	35,126	-1,394	5,657	4,962	789	2,692	1,834	49,666
2042	34,966	-1,327	5,665	5,017	790	2,723	1,820	49,654
2043	34,806	-1,259	5,673	5,073	791	2,754	1,805	49,643
2044	34,645	-1,192	5,681	5,129	792	2,785	1,791	49,632
2045	34,485	-1,124	5,689	5,185	793	2,816	1,776	49,620
2046	34,260	-1,103	5,693	5,236	794	2,846	1,772	49,497
2047	34,035	-1,082	5,697	5,286	795	2,876	1,767	49,375
2048	33,810	-1,061	5,701	5,337	795	2,906	1,763	49,252
2049	33,585	-1,040	5,706	5,388	796	2,936	1,759	49,129
2050	33,360	-1,019	5,710	5,439	797	2,966	1,754	49,006
Total	**1,107,917**	**-31,537**	**179,882**	**143,534**	**25,734**	**78,785**	**53,032**	**1,557,347**

Note: Emissions shown have been interpolated for non-model years.

Table C-4.6. Global Emissions Summary for Defined Policies: High U.S. Supply: Existing/FID Exports (GCAM-NETL-Aligned, AR6-100 Basis)

Year	CO_2 Energy	CO_2 LUC	CH_4 Energy	CH_4 Ag	N_2O Energy	N_2O Ag	F Gases	Total
	Units (Tg CO_2e/year) (AR6, 20-year)							
2020	38,403	398	6,677	3,929	887	2,123	1,349	53,766
2021	37,943	469	6,461	3,946	877	2,151	1,370	53,216
2022	37,483	539	6,245	3,964	867	2,179	1,390	52,667
2023	37,023	610	6,029	3,981	857	2,206	1,410	52,117
2024	36,563	681	5,814	3,999	847	2,234	1,431	51,568
2025	36,103	751	5,598	4,016	837	2,262	1,451	51,019
2026	36,207	64	5,637	4,081	845	2,294	1,519	50,647
2027	36,312	-623	5,677	4,145	853	2,326	1,586	50,276
2028	36,416	-1,310	5,717	4,210	860	2,358	1,653	49,905
2029	36,520	-1,997	5,756	4,274	868	2,390	1,721	49,534
2030	36,625	-2,684	5,796	4,339	876	2,423	1,788	49,162
2031	36,451	-2,393	5,791	4,399	869	2,447	1,806	49,371
2032	36,276	-2,102	5,787	4,460	863	2,472	1,823	49,580
2033	36,102	-1,811	5,782	4,520	857	2,497	1,840	49,788
2034	35,928	-1,520	5,778	4,580	851	2,522	1,857	49,997
2035	35,754	-1,229	5,773	4,640	844	2,547	1,874	50,205
2036	35,589	-1,249	5,738	4,694	833	2,571	1,868	50,044
2037	35,425	-1,270	5,702	4,747	823	2,595	1,861	49,883
2038	35,260	-1,290	5,667	4,800	812	2,619	1,855	49,722
2039	35,095	-1,311	5,631	4,853	801	2,643	1,848	49,560
2040	34,931	-1,331	5,596	4,906	790	2,667	1,841	49,399
2041	34,763	-1,266	5,602	4,962	791	2,698	1,827	49,377
2042	34,595	-1,200	5,609	5,017	792	2,730	1,812	49,356
2043	34,427	-1,135	5,616	5,073	793	2,761	1,798	49,334
2044	34,259	-1,069	5,623	5,129	795	2,793	1,783	49,312
2045	34,091	-1,004	5,630	5,185	796	2,824	1,768	49,290
2046	33,866	-981	5,633	5,235	797	2,855	1,764	49,168
2047	33,642	-959	5,635	5,286	797	2,885	1,760	49,047
2048	33,417	-937	5,638	5,337	798	2,916	1,755	48,925
2049	33,193	-914	5,641	5,388	799	2,946	1,751	48,803
2050	32,968	-892	5,644	5,439	800	2,977	1,747	48,681
Total	**1,101,631**	**-28,959**	**178,923**	**143,533**	**25,773**	**78,913**	**52,906**	**1,552,720**

Note: Emissions shown have been interpolated for non-model years.

Table C-4.7. Global Emissions Summary for Defined Policies: High U.S. Supply: Model Resolved (GCAM-NETL-Aligned, AR6-100 Basis)

Year	CO_2 Energy	CO_2 LUC	CH_4 Energy	CH_4 Ag	N_2O Energy	N_2O Ag	F Gases	Total
	Units (Tg CO_2e/year) (AR6, 20-year)							
2020	38,403	398	6,677	3,929	887	2,123	1,349	53,766
2021	37,943	469	6,461	3,946	877	2,151	1,370	53,216
2022	37,483	539	6,245	3,964	867	2,179	1,390	52,667
2023	37,023	610	6,029	3,981	857	2,206	1,410	52,117
2024	36,563	681	5,814	3,999	847	2,234	1,431	51,568
2025	36,103	751	5,598	4,016	837	2,262	1,451	51,019
2026	36,207	64	5,637	4,081	845	2,294	1,519	50,647
2027	36,312	-623	5,677	4,145	853	2,326	1,586	50,276
2028	36,416	-1,310	5,717	4,210	860	2,358	1,653	49,905
2029	36,520	-1,997	5,756	4,274	868	2,390	1,721	49,534
2030	36,625	-2,684	5,796	4,339	876	2,423	1,788	49,162
2031	36,462	-2,404	5,792	4,399	869	2,447	1,806	49,372
2032	36,299	-2,125	5,789	4,460	863	2,472	1,823	49,581
2033	36,137	-1,846	5,786	4,520	857	2,497	1,841	49,791
2034	35,974	-1,566	5,782	4,580	850	2,521	1,858	50,000
2035	35,812	-1,287	5,779	4,640	844	2,546	1,876	50,209
2036	35,665	-1,312	5,745	4,694	833	2,570	1,869	50,064
2037	35,519	-1,336	5,710	4,747	822	2,593	1,863	49,918
2038	35,373	-1,361	5,675	4,800	811	2,617	1,857	49,772
2039	35,227	-1,385	5,641	4,853	800	2,641	1,851	49,627
2040	35,081	-1,410	5,606	4,906	789	2,664	1,845	49,481
2041	34,915	-1,341	5,611	4,962	790	2,696	1,830	49,463
2042	34,749	-1,272	5,616	5,017	791	2,727	1,816	49,444
2043	34,582	-1,203	5,622	5,073	792	2,758	1,801	49,425
2044	34,416	-1,134	5,627	5,129	793	2,789	1,786	49,407
2045	34,250	-1,065	5,632	5,185	794	2,821	1,772	49,388
2046	34,020	-1,037	5,633	5,235	795	2,851	1,767	49,265
2047	33,790	-1,009	5,634	5,286	796	2,881	1,763	49,141
2048	33,559	-981	5,635	5,337	797	2,912	1,758	49,017
2049	33,329	-953	5,636	5,388	797	2,942	1,754	48,894
2050	33,099	-925	5,637	5,439	798	2,972	1,750	48,770
Total	**1,103,858**	**-30,051**	**178,994**	**143,533**	**25,753**	**78,862**	**52,956**	**1,553,906**

Note: Emissions shown have been interpolated for non-model years.

Table C-4.8. Global Emissions Summary for Defined Policies: Low U.S. Supply: Existing/FID Exports (GCAM-NETL-Aligned, AR6-100 Basis)

Year	CO_2 Energy	CO_2 LUC	CH_4 Energy	CH_4 Ag	N_2O Energy	N_2O Ag	F Gases	Total
	Units (Tg CO_2e/year) (AR6, 20-year)							
2020	38,431	396	6,678	3,929	887	2,123	1,350	53,794
2021	37,958	472	6,462	3,946	877	2,151	1,370	53,236
2022	37,484	548	6,245	3,964	867	2,179	1,390	52,678
2023	37,011	625	6,029	3,981	857	2,206	1,410	52,119
2024	36,538	701	5,812	3,999	847	2,234	1,431	51,561
2025	36,065	777	5,595	4,016	837	2,261	1,451	51,003
2026	36,159	93	5,634	4,081	845	2,294	1,518	50,624
2027	36,254	-591	5,673	4,145	852	2,326	1,586	50,245
2028	36,348	-1,275	5,712	4,210	860	2,358	1,653	49,866
2029	36,443	-1,959	5,751	4,274	868	2,391	1,720	49,487
2030	36,537	-2,643	5,790	4,339	875	2,423	1,788	49,108
2031	36,359	-2,357	5,785	4,399	869	2,448	1,805	49,308
2032	36,181	-2,071	5,780	4,460	863	2,473	1,822	49,508
2033	36,004	-1,785	5,775	4,520	856	2,498	1,839	49,708
2034	35,826	-1,498	5,770	4,580	850	2,523	1,856	49,907
2035	35,648	-1,212	5,766	4,640	844	2,548	1,873	50,107
2036	35,477	-1,232	5,730	4,694	833	2,571	1,867	49,940
2037	35,306	-1,251	5,695	4,747	822	2,595	1,860	49,773
2038	35,134	-1,271	5,659	4,800	811	2,619	1,854	49,606
2039	34,963	-1,290	5,624	4,853	800	2,643	1,847	49,439
2040	34,791	-1,310	5,588	4,906	789	2,667	1,841	49,273
2041	34,602	-1,230	5,594	4,962	790	2,699	1,826	49,243
2042	34,412	-1,149	5,600	5,017	791	2,730	1,811	49,213
2043	34,222	-1,068	5,605	5,073	792	2,762	1,797	49,183
2044	34,032	-988	5,611	5,129	794	2,793	1,782	49,153
2045	33,842	-907	5,616	5,185	795	2,825	1,767	49,123
2046	33,618	-904	5,619	5,235	795	2,856	1,763	48,982
2047	33,394	-901	5,621	5,286	796	2,886	1,759	48,841
2048	33,171	-898	5,624	5,337	796	2,917	1,754	48,701
2049	32,947	-895	5,627	5,388	797	2,947	1,750	48,560
2050	32,723	-892	5,629	5,438	798	2,978	1,746	48,419
Total	**1,097,878**	**-27,967**	**178,699**	**143,533**	**25,755**	**78,923**	**52,887**	**1,549,708**

Note: Emissions shown have been interpolated for non-model years.

Table C-4.9. Global Emissions Summary for Defined Policies: Low U.S. Supply: Model Resolved (GCAM-NETL-Aligned, AR6-100 Basis)

Year	CO_2 Energy	CO_2 LUC	CH_4 Energy	CH_4 Ag	N_2O Energy	N_2O Ag	F Gases	Total
	Units (Tg CO_2e/year) (AR6, 20-year)							
2020	38,431	396	6,678	3,929	887	2,123	1,350	53,794
2021	37,958	472	6,462	3,946	877	2,151	1,370	53,236
2022	37,484	548	6,245	3,964	867	2,179	1,390	52,678
2023	37,011	625	6,029	3,981	857	2,206	1,410	52,119
2024	36,538	701	5,812	3,999	847	2,234	1,431	51,561
2025	36,065	777	5,595	4,016	837	2,261	1,451	51,003
2026	36,159	93	5,634	4,081	845	2,294	1,518	50,624
2027	36,254	-591	5,673	4,145	852	2,326	1,586	50,245
2028	36,348	-1,275	5,712	4,210	860	2,358	1,653	49,866
2029	36,443	-1,959	5,751	4,274	868	2,391	1,720	49,487
2030	36,537	-2,643	5,790	4,339	875	2,423	1,788	49,108
2031	36,359	-2,357	5,785	4,399	869	2,448	1,805	49,308
2032	36,181	-2,071	5,780	4,460	863	2,473	1,822	49,508
2033	36,004	-1,785	5,775	4,520	856	2,498	1,839	49,708
2034	35,826	-1,498	5,770	4,580	850	2,523	1,856	49,907
2035	35,648	-1,212	5,766	4,640	844	2,548	1,873	50,107
2036	35,478	-1,232	5,730	4,694	833	2,571	1,867	49,940
2037	35,307	-1,252	5,695	4,747	822	2,595	1,860	49,774
2038	35,136	-1,273	5,659	4,800	811	2,619	1,854	49,607
2039	34,966	-1,293	5,624	4,853	800	2,643	1,847	49,440
2040	34,795	-1,313	5,589	4,906	789	2,667	1,841	49,274
2041	34,607	-1,234	5,594	4,962	790	2,698	1,826	49,244
2042	34,420	-1,156	5,599	5,017	791	2,730	1,812	49,214
2043	34,232	-1,077	5,605	5,073	792	2,762	1,797	49,184
2044	34,045	-999	5,610	5,129	794	2,793	1,782	49,154
2045	33,857	-920	5,615	5,185	795	2,825	1,768	49,124
2046	33,636	-918	5,618	5,235	795	2,855	1,763	48,984
2047	33,414	-916	5,620	5,286	796	2,886	1,759	48,845
2048	33,193	-914	5,623	5,337	796	2,916	1,755	48,705
2049	32,971	-912	5,625	5,388	797	2,947	1,751	48,566
2050	32,750	-910	5,627	5,438	797	2,977	1,746	48,426
Total	**1,098,051**	**-28,098**	**178,691**	**143,533**	**25,753**	**78,919**	**52,891**	**1,549,740**

Note: Emissions shown have been interpolated for non-model years.

Table C-4.10. Global Emissions Summary for Commitments (High CCS): Existing/FID Exports (GCAM-NETL-Aligned, AR6-100 Basis)

Year	CO_2 Energy	CO_2 LUC	CH_4 Energy	CH_4 Ag	N_2O Energy	N_2O Ag	F Gases	Total
	Units (Tg CO_2e/year) (AR6, 20-year)							
2020	38,407	532	6,674	3,928	886	2,126	1,349	53,903
2021	37,781	616	6,430	3,944	872	2,151	1,366	53,160
2022	37,155	700	6,185	3,959	857	2,177	1,384	52,417
2023	36,529	784	5,940	3,975	843	2,202	1,401	51,674
2024	35,903	868	5,696	3,990	829	2,227	1,418	50,931
2025	35,278	952	5,451	4,005	815	2,252	1,435	50,188
2026	35,132	732	5,483	4,071	825	2,277	1,497	50,016
2027	34,987	511	5,515	4,137	834	2,301	1,560	49,845
2028	34,841	291	5,548	4,202	844	2,326	1,622	49,674
2029	34,696	70	5,580	4,268	853	2,350	1,685	49,502
2030	34,550	-150	5,612	4,334	863	2,374	1,747	49,331
2031	33,222	-124	5,524	4,381	842	2,401	1,744	47,989
2032	31,893	-98	5,435	4,428	820	2,428	1,741	46,648
2033	30,565	-72	5,346	4,476	799	2,455	1,738	45,306
2034	29,237	-46	5,257	4,523	777	2,482	1,735	43,965
2035	27,908	-20	5,169	4,570	756	2,509	1,732	42,623
2036	26,604	180	5,107	4,618	747	2,530	1,723	41,510
2037	25,300	380	5,046	4,666	738	2,551	1,715	40,396
2038	23,995	580	4,985	4,714	729	2,572	1,706	39,282
2039	22,691	781	4,923	4,762	720	2,594	1,698	38,168
2040	21,387	981	4,862	4,810	711	2,615	1,689	37,054
2041	20,078	871	4,749	4,851	694	2,627	1,623	35,492
2042	18,769	762	4,636	4,891	677	2,638	1,556	33,930
2043	17,460	652	4,523	4,932	660	2,650	1,490	32,368
2044	16,152	542	4,411	4,972	643	2,662	1,424	30,805
2045	14,843	433	4,298	5,013	626	2,674	1,357	29,243
2046	13,554	250	4,208	5,058	610	2,686	1,317	27,683
2047	12,265	67	4,119	5,104	594	2,698	1,276	26,122
2048	10,976	-116	4,029	5,149	578	2,710	1,236	24,561
2049	9,687	-299	3,940	5,194	562	2,722	1,196	23,001
2050	8,397	-481	3,850	5,240	545	2,734	1,155	21,440
Total	**810,240**	**11,127**	**158,531**	**141,167**	**23,148**	**76,699**	**47,315**	**1,268,227**

Note: Emissions shown have been interpolated for non-model years.

Table C-4.11. Global Emissions Summary for Commitments (High CCS): Model Resolved (GCAM-NETL-Aligned, AR6-100 Basis)

Year	CO_2 Energy	CO_2 LUC	CH_4 Energy	CH_4 Ag	N_2O Energy	N_2O Ag	F Gases	Total
	Units (Tg CO_2e/year) (AR6, 20-year)							
2020	38,407	532	6,674	3,928	886	2,126	1,349	53,903
2021	37,781	616	6,430	3,944	872	2,151	1,366	53,160
2022	37,155	700	6,185	3,959	857	2,177	1,384	52,417
2023	36,529	784	5,940	3,975	843	2,202	1,401	51,674
2024	35,903	868	5,696	3,990	829	2,227	1,418	50,931
2025	35,278	952	5,451	4,005	815	2,252	1,435	50,188
2026	35,132	732	5,483	4,071	825	2,277	1,497	50,016
2027	34,987	511	5,515	4,137	834	2,301	1,560	49,845
2028	34,841	291	5,548	4,202	844	2,326	1,622	49,674
2029	34,696	70	5,580	4,268	853	2,350	1,685	49,502
2030	34,550	-150	5,612	4,334	863	2,374	1,747	49,331
2031	33,222	-124	5,524	4,381	842	2,401	1,744	47,989
2032	31,893	-98	5,435	4,428	820	2,428	1,741	46,648
2033	30,565	-72	5,346	4,476	799	2,455	1,738	45,306
2034	29,237	-46	5,257	4,523	777	2,482	1,735	43,965
2035	27,908	-20	5,169	4,570	756	2,509	1,732	42,623
2036	26,609	172	5,107	4,618	747	2,530	1,724	41,507
2037	25,309	365	5,046	4,666	738	2,551	1,715	40,390
2038	24,010	557	4,985	4,714	729	2,572	1,707	39,273
2039	22,710	750	4,923	4,762	719	2,594	1,698	38,157
2040	21,411	942	4,862	4,810	710	2,615	1,690	37,040
2041	20,100	845	4,748	4,851	693	2,626	1,624	35,487
2042	18,789	747	4,634	4,891	677	2,638	1,557	33,934
2043	17,478	650	4,520	4,932	660	2,650	1,491	32,381
2044	16,168	552	4,407	4,972	643	2,662	1,424	30,828
2045	14,857	455	4,293	5,013	626	2,673	1,358	29,274
2046	13,566	269	4,202	5,058	610	2,685	1,317	27,708
2047	12,275	84	4,112	5,104	594	2,697	1,277	26,142
2048	10,984	-102	4,022	5,149	578	2,709	1,236	24,576
2049	9,693	-287	3,932	5,194	562	2,721	1,196	23,010
2050	8,402	-473	3,842	5,240	545	2,733	1,155	21,444
Total	**810,441**	**11,069**	**158,481**	**141,167**	**23,147**	**76,696**	**47,323**	**1,268,324**

Note: Emissions shown have been interpolated for non-model years.

Table C-4.12. Global Emissions Summary for Commitments (High CCS): High Exports (GCAM-NETL-Aligned, AR6-100 Basis)

Year	CO_2 Energy	CO_2 LUC	CH_4 Energy	CH_4 Ag	N_2O Energy	N_2O Ag	F Gases	Total
	Units (Tg CO_2e/year) (AR6, 20-year)							
2020	38,407	532	6,674	3,928	886	2,126	1,349	53,903
2021	37,781	616	6,430	3,944	872	2,151	1,366	53,160
2022	37,155	700	6,185	3,959	857	2,177	1,384	52,417
2023	36,529	784	5,940	3,975	843	2,202	1,401	51,674
2024	35,903	868	5,696	3,990	829	2,227	1,418	50,931
2025	35,278	952	5,451	4,005	815	2,252	1,435	50,188
2026	35,132	732	5,483	4,071	825	2,277	1,497	50,016
2027	34,987	511	5,515	4,137	834	2,301	1,560	49,845
2028	34,841	291	5,548	4,202	844	2,326	1,622	49,674
2029	34,696	70	5,580	4,268	853	2,350	1,685	49,502
2030	34,550	-150	5,612	4,334	863	2,374	1,747	49,331
2031	33,239	-141	5,525	4,381	842	2,401	1,745	47,991
2032	31,928	-132	5,438	4,428	820	2,428	1,742	46,651
2033	30,617	-123	5,350	4,476	799	2,454	1,739	45,311
2034	29,306	-114	5,263	4,523	777	2,481	1,737	43,971
2035	27,994	-105	5,175	4,570	755	2,507	1,734	42,631
2036	26,688	104	5,113	4,618	746	2,529	1,725	41,524
2037	25,382	313	5,050	4,666	737	2,550	1,717	40,416
2038	24,076	522	4,987	4,714	728	2,571	1,709	39,308
2039	22,770	731	4,925	4,762	719	2,592	1,700	38,201
2040	21,465	941	4,862	4,810	710	2,614	1,692	37,093
2041	20,149	852	4,747	4,851	693	2,626	1,625	35,543
2042	18,834	764	4,631	4,891	677	2,637	1,559	33,993
2043	17,518	675	4,516	4,932	660	2,649	1,492	32,443
2044	16,203	587	4,401	4,972	643	2,661	1,426	30,893
2045	14,888	499	4,285	5,013	626	2,673	1,359	29,343
2046	13,595	305	4,194	5,058	610	2,685	1,319	27,766
2047	12,303	112	4,102	5,104	594	2,697	1,278	26,189
2048	11,010	-81	4,011	5,149	578	2,709	1,237	24,612
2049	9,718	-275	3,919	5,195	561	2,721	1,197	23,036
2050	8,425	-468	3,828	5,240	545	2,733	1,156	21,459
Total	**811,367**	**10,870**	**158,436**	**141,167**	**23,143**	**76,678**	**47,352**	**1,269,014**

Note: Emissions shown have been interpolated for non-model years.

Table C-4.13. Global Emissions Summary for Commitments (Moderate CCS): Existing/FID Exports (GCAM-NETL-Aligned, AR6-100 Basis)

Year	CO_2 Energy	CO_2 LUC	CH_4 Energy	CH_4 Ag	N_2O Energy	N_2O Ag	F Gases	Total
	Units (Tg CO_2e/year) (AR6, 20-year)							
2020	38,407	532	6,674	3,928	886	2,126	1,349	53,903
2021	37,778	571	6,397	3,937	867	2,149	1,361	53,061
2022	37,150	610	6,120	3,946	848	2,172	1,373	52,220
2023	36,522	650	5,842	3,955	829	2,195	1,385	51,378
2024	35,894	689	5,565	3,963	811	2,218	1,397	50,536
2025	35,266	728	5,287	3,972	792	2,241	1,408	49,694
2026	35,123	503	5,319	4,040	804	2,266	1,472	49,527
2027	34,980	279	5,350	4,108	815	2,291	1,535	49,359
2028	34,838	55	5,381	4,175	827	2,317	1,598	49,191
2029	34,695	-169	5,412	4,243	838	2,342	1,662	49,024
2030	34,552	-393	5,444	4,311	850	2,367	1,725	48,856
2031	33,267	-563	5,299	4,347	824	2,385	1,706	47,265
2032	31,982	-732	5,155	4,383	797	2,402	1,687	45,674
2033	30,696	-902	5,011	4,419	771	2,420	1,668	44,084
2034	29,411	-1,071	4,867	4,456	745	2,438	1,648	42,493
2035	28,126	-1,241	4,723	4,492	718	2,455	1,629	40,902
2036	26,822	-1,576	4,617	4,532	702	2,466	1,607	39,170
2037	25,518	-1,911	4,512	4,572	685	2,477	1,584	37,437
2038	24,214	-2,246	4,406	4,611	669	2,488	1,562	35,704
2039	22,910	-2,582	4,301	4,651	653	2,499	1,539	33,971
2040	21,606	-2,917	4,196	4,691	636	2,511	1,517	32,239
2041	20,283	-2,775	4,094	4,739	621	2,520	1,471	30,953
2042	18,960	-2,633	3,993	4,786	606	2,530	1,425	29,668
2043	17,638	-2,491	3,891	4,834	591	2,540	1,379	28,382
2044	16,315	-2,349	3,789	4,881	576	2,550	1,333	27,097
2045	14,992	-2,206	3,688	4,929	561	2,560	1,287	25,811
2046	13,678	-2,224	3,612	4,979	553	2,575	1,256	24,429
2047	12,364	-2,241	3,536	5,029	545	2,589	1,224	23,047
2048	11,051	-2,258	3,460	5,079	536	2,603	1,193	21,664
2049	9,737	-2,275	3,384	5,129	528	2,618	1,162	20,282
2050	8,423	-2,293	3,308	5,180	520	2,632	1,131	18,900
Total	**813,197**	**-35,428**	**146,632**	**139,298**	**22,005**	**74,944**	**45,271**	**1,205,919**

Note: Emissions shown have been interpolated for non-model years.

Table C-4.14. Global Emissions Summary for Commitments (Moderate CCS): Model Resolved (GCAM-NETL-Aligned, AR6-100 Basis)

Year	CO_2 Energy	CO_2 LUC	CH_4 Energy	CH_4 Ag	N_2O Energy	N_2O Ag	F Gases	Total
	Units (Tg CO_2e/year) (AR6, 20-year)							
2020	38,407	532	6,674	3,928	886	2,126	1,349	53,903
2021	37,778	571	6,397	3,937	867	2,149	1,361	53,061
2022	37,150	610	6,120	3,946	848	2,172	1,373	52,220
2023	36,522	650	5,842	3,955	829	2,195	1,385	51,378
2024	35,894	689	5,565	3,963	811	2,218	1,397	50,536
2025	35,266	728	5,287	3,972	792	2,241	1,408	49,694
2026	35,123	503	5,319	4,040	804	2,266	1,472	49,527
2027	34,980	279	5,350	4,108	815	2,291	1,535	49,359
2028	34,838	55	5,381	4,175	827	2,317	1,598	49,191
2029	34,695	-169	5,412	4,243	838	2,342	1,662	49,024
2030	34,552	-393	5,444	4,311	850	2,367	1,725	48,856
2031	33,267	-563	5,299	4,347	824	2,385	1,706	47,265
2032	31,982	-732	5,155	4,383	797	2,402	1,687	45,674
2033	30,696	-902	5,011	4,419	771	2,420	1,668	44,084
2034	29,411	-1,071	4,867	4,456	745	2,438	1,648	42,493
2035	28,126	-1,241	4,723	4,492	718	2,455	1,629	40,902
2036	26,823	-1,576	4,617	4,532	702	2,466	1,607	39,171
2037	25,520	-1,911	4,512	4,572	685	2,477	1,584	37,440
2038	24,217	-2,246	4,406	4,611	669	2,488	1,562	35,709
2039	22,914	-2,581	4,301	4,651	653	2,500	1,539	33,978
2040	21,612	-2,916	4,196	4,691	636	2,511	1,517	32,246
2041	20,289	-2,774	4,094	4,739	621	2,520	1,471	30,960
2042	18,967	-2,632	3,992	4,786	606	2,530	1,425	29,675
2043	17,644	-2,489	3,890	4,834	591	2,540	1,379	28,389
2044	16,321	-2,347	3,788	4,881	576	2,550	1,333	27,103
2045	14,999	-2,205	3,686	4,929	561	2,560	1,287	25,817
2046	13,684	-2,223	3,610	4,979	553	2,575	1,256	24,433
2047	12,370	-2,241	3,533	5,029	545	2,589	1,224	23,050
2048	11,055	-2,258	3,457	5,079	536	2,603	1,193	21,666
2049	9,741	-2,276	3,381	5,129	528	2,618	1,162	20,283
2050	8,426	-2,294	3,305	5,180	520	2,632	1,131	18,899
Total	**813,270**	**-35,419**	**146,614**	**139,299**	**22,005**	**74,944**	**45,273**	**1,205,985**

Note: Emissions shown have been interpolated for non-model years.

Table C-4.15. Global Emissions Summary for Commitments (Moderate CCS): High Exports (GCAM-NETL-Aligned, AR6-100 Basis)

Year	CO_2 Energy	CO_2 LUC	CH_4 Energy	CH_4 Ag	N_2O Energy	N_2O Ag	F Gases	Total
	Units (Tg CO_2e/year) (AR6, 20-year)							
2020	38,407	532	6,674	3,928	886	2,126	1,349	53,903
2021	37,778	571	6,397	3,937	867	2,149	1,361	53,061
2022	37,150	610	6,120	3,946	848	2,172	1,373	52,220
2023	36,522	650	5,842	3,955	829	2,195	1,385	51,378
2024	35,894	689	5,565	3,963	811	2,218	1,397	50,536
2025	35,266	728	5,287	3,972	792	2,241	1,408	49,694
2026	35,123	503	5,319	4,040	804	2,266	1,472	49,527
2027	34,980	279	5,350	4,108	815	2,291	1,535	49,359
2028	34,838	55	5,381	4,175	827	2,317	1,598	49,191
2029	34,695	-169	5,412	4,243	838	2,342	1,662	49,024
2030	34,552	-393	5,444	4,311	850	2,367	1,725	48,856
2031	33,276	-560	5,301	4,347	824	2,385	1,706	47,278
2032	32,000	-728	5,157	4,383	797	2,402	1,687	45,700
2033	30,724	-895	5,014	4,419	771	2,420	1,669	44,122
2034	29,448	-1,063	4,871	4,456	745	2,438	1,650	42,545
2035	28,172	-1,230	4,728	4,492	719	2,455	1,631	40,967
2036	26,866	-1,566	4,621	4,532	702	2,467	1,609	39,230
2037	25,561	-1,903	4,514	4,572	686	2,478	1,586	37,493
2038	24,255	-2,239	4,407	4,611	669	2,489	1,563	35,756
2039	22,950	-2,575	4,300	4,651	653	2,500	1,541	34,019
2040	21,644	-2,912	4,193	4,691	636	2,511	1,518	32,282
2041	20,325	-2,770	4,091	4,739	621	2,520	1,472	30,999
2042	19,007	-2,628	3,988	4,786	606	2,530	1,426	29,716
2043	17,688	-2,486	3,885	4,834	591	2,540	1,380	28,433
2044	16,369	-2,344	3,782	4,882	576	2,550	1,334	27,149
2045	15,050	-2,201	3,679	4,929	561	2,560	1,288	25,866
2046	13,743	-2,220	3,602	4,979	553	2,574	1,257	24,489
2047	12,436	-2,239	3,526	5,029	545	2,589	1,226	23,111
2048	11,129	-2,257	3,449	5,080	536	2,603	1,194	21,734
2049	9,822	-2,276	3,373	5,130	528	2,617	1,163	20,357
2050	8,515	-2,295	3,296	5,180	519	2,632	1,132	18,979
Total	**814,186**	**-35,330**	**146,569**	**139,301**	**22,006**	**74,943**	**45,298**	**1,206,973**

Note: Emissions shown have been interpolated for non-model years.

Table C-4.16. Global Emissions Summary for Net Zero 2050 (High CCS): Existing/FID Exports (GCAM-NETL-Aligned, AR6-100 Basis)

Year	CO_2 Energy	CO_2 LUC	CH_4 Energy	CH_4 Ag	N_2O Energy	N_2O Ag	F Gases	Total
	Units (Tg CO_2e/year) (AR6, 20-year)							
2020	38,407	532	6,674	3,928	886	2,126	1,349	53,903
2021	37,781	616	6,430	3,944	872	2,151	1,366	53,160
2022	37,155	700	6,185	3,959	857	2,177	1,384	52,417
2023	36,529	784	5,940	3,975	843	2,202	1,401	51,674
2024	35,903	868	5,696	3,990	829	2,227	1,418	50,931
2025	35,278	952	5,451	4,005	815	2,252	1,435	50,188
2026	33,803	423	5,351	4,051	798	2,275	1,471	48,171
2027	32,329	-107	5,251	4,096	781	2,297	1,508	46,155
2028	30,854	-636	5,151	4,141	764	2,319	1,545	44,138
2029	29,380	-1,166	5,051	4,187	746	2,341	1,582	42,121
2030	27,905	-1,695	4,951	4,232	729	2,364	1,618	40,105
2031	26,454	-1,180	4,903	4,284	723	2,391	1,619	39,193
2032	25,003	-666	4,854	4,336	717	2,418	1,619	38,281
2033	23,552	-151	4,806	4,388	710	2,445	1,619	37,370
2034	22,101	364	4,758	4,440	704	2,472	1,619	36,458
2035	20,649	878	4,709	4,492	698	2,499	1,620	35,546
2036	19,293	727	4,597	4,532	679	2,512	1,593	33,933
2037	17,936	577	4,485	4,572	660	2,524	1,567	32,321
2038	16,580	426	4,373	4,612	640	2,537	1,541	30,708
2039	15,223	275	4,261	4,651	621	2,549	1,514	29,095
2040	13,866	125	4,149	4,691	602	2,562	1,488	27,483
2041	12,508	178	4,077	4,743	591	2,574	1,444	26,115
2042	11,150	231	4,005	4,795	581	2,586	1,400	24,746
2043	9,792	284	3,933	4,846	570	2,598	1,355	23,378
2044	8,434	337	3,861	4,898	559	2,610	1,311	22,010
2045	7,076	389	3,789	4,950	549	2,622	1,267	20,642
2046	5,680	360	3,693	5,004	541	2,633	1,236	19,147
2047	4,283	330	3,597	5,058	533	2,645	1,206	17,653
2048	2,887	301	3,501	5,112	526	2,657	1,175	16,158
2049	1,490	271	3,405	5,167	518	2,669	1,144	14,664
2050	94	242	3,308	5,221	510	2,680	1,114	13,169
Total	**639,377**	**5,568**	**145,193**	**139,301**	**21,153**	**75,913**	**44,528**	**1,071,033**

Note: Emissions shown have been interpolated for non-model years.

Table C-4.17. Global Emissions Summary for Net Zero 2050 (High CCS): Model Resolved (GCAM-NETL-Aligned, AR6-100 Basis)

Year	CO_2 Energy	CO_2 LUC	CH_4 Energy	CH_4 Ag	N_2O Energy	N_2O Ag	F Gases	Total
	Units (Tg CO_2e/year) (AR6, 20-year)							
2020	38,407	532	6,674	3,928	886	2,126	1,349	53,903
2021	37,781	616	6,430	3,944	872	2,151	1,366	53,160
2022	37,155	700	6,185	3,959	857	2,177	1,384	52,417
2023	36,529	784	5,940	3,975	843	2,202	1,401	51,674
2024	35,903	868	5,696	3,990	829	2,227	1,418	50,931
2025	35,278	952	5,451	4,005	815	2,252	1,435	50,188
2026	33,803	423	5,351	4,051	798	2,275	1,471	48,171
2027	32,329	-107	5,251	4,096	781	2,297	1,508	46,155
2028	30,854	-636	5,151	4,141	764	2,319	1,545	44,138
2029	29,380	-1,166	5,051	4,187	746	2,341	1,582	42,121
2030	27,905	-1,695	4,951	4,232	729	2,364	1,618	40,105
2031	26,454	-1,181	4,903	4,284	723	2,391	1,619	39,193
2032	25,003	-666	4,854	4,336	717	2,418	1,619	38,281
2033	23,551	-151	4,806	4,388	710	2,445	1,619	37,369
2034	22,100	363	4,758	4,440	704	2,472	1,619	36,457
2035	20,649	878	4,709	4,492	698	2,499	1,620	35,546
2036	19,295	723	4,597	4,532	679	2,512	1,593	33,931
2037	17,941	567	4,485	4,572	660	2,524	1,567	32,316
2038	16,586	412	4,373	4,612	640	2,537	1,541	30,701
2039	15,232	257	4,261	4,651	621	2,549	1,515	29,086
2040	13,878	101	4,148	4,691	602	2,561	1,488	27,471
2041	12,518	162	4,076	4,743	591	2,573	1,444	26,108
2042	11,159	224	4,003	4,794	581	2,585	1,400	24,746
2043	9,799	285	3,931	4,846	570	2,597	1,356	23,384
2044	8,439	346	3,858	4,898	559	2,609	1,311	22,022
2045	7,080	407	3,786	4,950	549	2,621	1,267	20,660
2046	5,683	374	3,690	5,004	541	2,633	1,237	19,161
2047	4,286	341	3,593	5,058	533	2,645	1,206	17,663
2048	2,889	308	3,497	5,112	526	2,657	1,175	16,164
2049	1,492	275	3,401	5,167	518	2,668	1,144	14,666
2050	95	242	3,305	5,221	510	2,680	1,114	13,167
Total	**639,453**	**5,540**	**145,165**	**139,301**	**21,152**	**75,911**	**44,531**	**1,071,054**

Note: Emissions shown have been interpolated for non-model years.

Table C-4.18. Global Emissions Summary for Net Zero 2050 (High CCS): High Exports (GCAM-NETL-Aligned, AR6-100 Basis)

Year	CO_2 Energy	CO_2 LUC	CH_4 Energy	CH_4 Ag	N_2O Energy	N_2O Ag	F Gases	Total
	Units (Tg CO_2e/year) (AR6, 20-year)							
2020	38,407	532	6,674	3,928	886	2,126	1,349	53,903
2021	37,781	616	6,430	3,944	872	2,151	1,366	53,160
2022	37,155	700	6,185	3,959	857	2,177	1,384	52,417
2023	36,529	784	5,940	3,975	843	2,202	1,401	51,674
2024	35,903	868	5,696	3,990	829	2,227	1,418	50,931
2025	35,278	952	5,451	4,005	815	2,252	1,435	50,188
2026	33,803	423	5,351	4,051	798	2,275	1,471	48,171
2027	32,329	-107	5,251	4,096	781	2,297	1,508	46,155
2028	30,854	-636	5,151	4,141	764	2,319	1,545	44,138
2029	29,380	-1,166	5,051	4,187	746	2,341	1,582	42,121
2030	27,905	-1,695	4,951	4,232	729	2,364	1,618	40,105
2031	26,462	-1,196	4,904	4,284	723	2,391	1,619	39,187
2032	25,020	-697	4,856	4,336	716	2,418	1,620	38,270
2033	23,577	-197	4,809	4,388	710	2,445	1,620	37,352
2034	22,134	302	4,761	4,440	704	2,472	1,621	36,434
2035	20,692	801	4,714	4,492	697	2,499	1,622	35,517
2036	19,337	662	4,601	4,532	678	2,511	1,595	33,916
2037	17,982	522	4,487	4,572	659	2,523	1,569	32,315
2038	16,628	382	4,374	4,611	640	2,536	1,543	30,714
2039	15,273	243	4,261	4,651	621	2,548	1,516	29,113
2040	13,919	103	4,147	4,691	602	2,560	1,490	27,512
2041	12,556	173	4,073	4,743	591	2,573	1,446	26,154
2042	11,193	243	3,999	4,794	581	2,585	1,401	24,796
2043	9,830	313	3,926	4,846	570	2,597	1,357	23,438
2044	8,467	383	3,852	4,898	560	2,609	1,313	22,080
2045	7,104	453	3,778	4,950	549	2,621	1,268	20,722
2046	5,704	407	3,681	5,004	541	2,632	1,237	19,207
2047	4,304	360	3,584	5,058	533	2,644	1,207	17,691
2048	2,904	313	3,487	5,113	525	2,656	1,176	16,175
2049	1,504	267	3,390	5,167	518	2,668	1,145	14,659
2050	104	220	3,293	5,221	510	2,679	1,114	13,143
Total	**640,017**	**5,330**	**145,109**	**139,300**	**21,148**	**75,896**	**44,556**	**1,071,356**

Note: Emissions shown have been interpolated for non-model years.

Table C-4.19. Global Emissions Summary for Net Zero 2050 (Moderate CCS): Existing/FID Exports (GCAM-NETL-Aligned, AR6-100 Basis)

Year	CO_2 Energy	CO_2 LUC	CH_4 Energy	CH_4 Ag	N_2O Energy	N_2O Ag	F Gases	Total
	Units (Tg CO_2e/year) (AR6, 20-year)							
2020	38,407	532	6,674	3,928	886	2,126	1,349	53,903
2021	37,778	571	6,397	3,937	867	2,149	1,361	53,061
2022	37,150	610	6,120	3,946	848	2,172	1,373	52,220
2023	36,522	650	5,842	3,955	829	2,195	1,385	51,378
2024	35,894	689	5,565	3,963	811	2,218	1,397	50,536
2025	35,266	728	5,287	3,972	792	2,241	1,408	49,694
2026	33,806	76	5,140	4,007	774	2,258	1,436	47,497
2027	32,347	-576	4,992	4,042	757	2,276	1,463	45,300
2028	30,888	-1,227	4,844	4,077	739	2,293	1,491	43,103
2029	29,428	-1,879	4,696	4,112	721	2,310	1,518	40,906
2030	27,969	-2,531	4,548	4,147	703	2,328	1,546	38,710
2031	26,585	-2,788	4,429	4,189	685	2,338	1,535	36,973
2032	25,201	-3,046	4,309	4,232	668	2,348	1,525	35,236
2033	23,817	-3,304	4,189	4,275	650	2,358	1,514	33,499
2034	22,433	-3,561	4,070	4,317	632	2,368	1,504	31,763
2035	21,049	-3,819	3,950	4,360	614	2,378	1,493	30,026
2036	19,668	-3,575	3,875	4,412	601	2,391	1,481	28,853
2037	18,286	-3,331	3,799	4,463	588	2,404	1,470	27,679
2038	16,904	-3,088	3,724	4,515	575	2,417	1,458	26,505
2039	15,522	-2,844	3,649	4,567	562	2,430	1,446	25,332
2040	14,140	-2,600	3,573	4,619	549	2,442	1,435	24,158
2041	12,778	-2,738	3,468	4,670	541	2,449	1,396	22,563
2042	11,416	-2,876	3,362	4,720	533	2,456	1,356	20,968
2043	10,054	-3,014	3,256	4,771	524	2,463	1,317	19,372
2044	8,692	-3,152	3,150	4,822	516	2,470	1,278	17,777
2045	7,330	-3,290	3,044	4,873	508	2,477	1,239	16,181
2046	5,916	-2,831	2,967	4,930	504	2,494	1,218	15,196
2047	4,501	-2,373	2,890	4,987	500	2,510	1,196	14,212
2048	3,086	-1,914	2,813	5,044	496	2,527	1,175	13,227
2049	1,672	-1,455	2,735	5,101	492	2,544	1,154	12,242
2050	257	-996	2,658	5,158	488	2,561	1,132	11,257
Total	**644,762**	**-58,952**	**130,012**	**137,111**	**19,953**	**73,393**	**43,049**	**989,329**

Note: Emissions shown have been interpolated for non-model years.

Table C-4.20. Global Emissions Summary for Net Zero 2050 (Moderate CCS): Model Resolved (GCAM-NETL-Aligned, AR6-100 Basis)

Year	CO_2 Energy	CO_2 LUC	CH_4 Energy	CH_4 Ag	N_2O Energy	N_2O Ag	F Gases	Total
	Units (Tg CO_2e/year) (AR6, 20-year)							
2020	38,407	532	6,674	3,928	886	2,126	1,349	53,903
2021	37,778	571	6,397	3,937	867	2,149	1,361	53,061
2022	37,150	610	6,120	3,946	848	2,172	1,373	52,220
2023	36,522	650	5,842	3,955	829	2,195	1,385	51,378
2024	35,894	689	5,565	3,963	811	2,218	1,397	50,536
2025	35,266	728	5,287	3,972	792	2,241	1,408	49,694
2026	33,806	76	5,140	4,007	774	2,258	1,436	47,497
2027	32,347	-576	4,992	4,042	757	2,276	1,463	45,300
2028	30,888	-1,227	4,844	4,077	739	2,293	1,491	43,103
2029	29,428	-1,879	4,696	4,112	721	2,310	1,518	40,906
2030	27,969	-2,531	4,548	4,147	703	2,328	1,546	38,710
2031	26,585	-2,788	4,429	4,189	685	2,338	1,535	36,973
2032	25,201	-3,046	4,309	4,232	668	2,348	1,525	35,236
2033	23,817	-3,304	4,189	4,275	650	2,358	1,514	33,499
2034	22,433	-3,561	4,070	4,317	632	2,368	1,504	31,763
2035	21,049	-3,819	3,950	4,360	614	2,378	1,493	30,026
2036	19,668	-3,575	3,875	4,412	601	2,391	1,481	28,853
2037	18,286	-3,331	3,799	4,463	588	2,404	1,470	27,679
2038	16,904	-3,088	3,724	4,515	575	2,417	1,458	26,505
2039	15,522	-2,844	3,649	4,567	562	2,430	1,446	25,332
2040	14,140	-2,600	3,573	4,619	549	2,442	1,435	24,158
2041	12,778	-2,738	3,468	4,670	541	2,449	1,396	22,563
2042	11,416	-2,876	3,362	4,720	533	2,456	1,356	20,968
2043	10,054	-3,014	3,256	4,771	524	2,463	1,317	19,372
2044	8,692	-3,152	3,150	4,822	516	2,470	1,278	17,777
2045	7,330	-3,290	3,044	4,873	508	2,477	1,239	16,181
2046	5,916	-2,831	2,967	4,930	504	2,494	1,218	15,196
2047	4,501	-2,373	2,890	4,987	500	2,510	1,196	14,212
2048	3,086	-1,914	2,813	5,044	496	2,527	1,175	13,227
2049	1,672	-1,455	2,735	5,101	492	2,544	1,154	12,242
2050	257	-996	2,658	5,158	488	2,561	1,132	11,257
Total	**644,762**	**-58,952**	**130,012**	**137,111**	**19,953**	**73,393**	**43,049**	**989,329**

Note: Emissions shown have been interpolated for non-model years.

Table C-4.21.Global Emissions Summary for Net Zero 2050 (Moderate CCS): High Exports (GCAM-NETL-Aligned, AR6-100 Basis)

Year	CO_2 Energy	CO_2 LUC	CH_4 Energy	CH_4 Ag	N_2O Energy	N_2O Ag	F Gases	Total
	Units (Tg CO_2e/year) (AR6, 20-year)							
2020	38,407	532	6,674	3,928	886	2,126	1,349	53,903
2021	37,778	571	6,397	3,937	867	2,149	1,361	53,061
2022	37,150	610	6,120	3,946	848	2,172	1,373	52,220
2023	36,522	650	5,842	3,955	829	2,195	1,385	51,378
2024	35,894	689	5,565	3,963	811	2,218	1,397	50,536
2025	35,266	728	5,287	3,972	792	2,241	1,408	49,694
2026	33,806	76	5,140	4,007	774	2,258	1,436	47,497
2027	32,347	-576	4,992	4,042	757	2,276	1,463	45,300
2028	30,888	-1,227	4,844	4,077	739	2,293	1,491	43,103
2029	29,428	-1,879	4,696	4,112	721	2,310	1,518	40,906
2030	27,969	-2,531	4,548	4,147	703	2,328	1,546	38,710
2031	26,596	-2,796	4,429	4,189	685	2,338	1,535	36,978
2032	25,223	-3,060	4,311	4,232	668	2,348	1,525	35,245
2033	23,850	-3,325	4,192	4,275	650	2,358	1,515	33,513
2034	22,477	-3,590	4,073	4,317	632	2,368	1,505	31,781
2035	21,104	-3,855	3,954	4,360	614	2,378	1,495	30,049
2036	19,727	-3,604	3,878	4,412	601	2,391	1,483	28,887
2037	18,349	-3,354	3,802	4,463	588	2,404	1,471	27,724
2038	16,972	-3,103	3,726	4,515	575	2,416	1,460	26,561
2039	15,594	-2,852	3,650	4,567	562	2,429	1,448	25,399
2040	14,217	-2,601	3,574	4,618	549	2,442	1,436	24,236
2041	12,857	-2,740	3,467	4,669	541	2,449	1,397	22,639
2042	11,497	-2,879	3,359	4,720	532	2,456	1,358	21,043
2043	10,137	-3,018	3,251	4,771	524	2,463	1,318	19,446
2044	8,777	-3,158	3,144	4,822	516	2,470	1,279	17,849
2045	7,417	-3,297	3,036	4,873	508	2,477	1,239	16,253
2046	6,010	-2,853	2,958	4,930	504	2,493	1,218	15,260
2047	4,604	-2,410	2,880	4,987	500	2,510	1,197	14,267
2048	3,198	-1,966	2,802	5,043	496	2,527	1,175	13,274
2049	1,792	-1,523	2,723	5,100	491	2,543	1,154	12,282
2050	386	-1,079	2,645	5,157	487	2,560	1,132	11,289
Total	**646,236**	**-59,419**	**129,959**	**137,105**	**19,949**	**73,386**	**43,066**	**990,283**

Note: Emissions shown have been interpolated for non-model years.

Table C-4.22. Global Emissions Summary for Defined Policies: Existing/FID Exports (GCAM-NETL-Aligned, AR6-20 Basis)

Year	CO_2 Energy	CO_2 LUC	CH_4 Energy	CH_4 Ag	N_2O Energy	N_2O Ag	F Gases	Total
	Units (Tg CO_2e/year) (AR6, 20-year)							
2020	38,334	398	18,207	11,671	887	2,123	2,244	73,863
2021	37,872	469	17,617	11,723	877	2,151	2,265	72,973
2022	37,409	540	17,027	11,775	867	2,179	2,287	72,083
2023	36,947	611	16,437	11,827	857	2,206	2,308	71,193
2024	36,484	683	15,847	11,879	847	2,234	2,330	70,303
2025	36,022	754	15,257	11,930	837	2,262	2,351	69,413
2026	36,123	67	15,363	12,122	845	2,294	2,456	69,271
2027	36,225	-619	15,470	12,314	853	2,326	2,561	69,129
2028	36,326	-1,306	15,577	12,506	860	2,358	2,665	68,987
2029	36,428	-1,992	15,684	12,697	868	2,390	2,770	68,845
2030	36,529	-2,679	15,791	12,889	876	2,423	2,875	68,703
2031	36,355	-2,389	15,778	13,068	869	2,448	2,898	69,025
2032	36,180	-2,100	15,764	13,248	863	2,472	2,921	69,348
2033	36,005	-1,811	15,751	13,427	857	2,497	2,944	69,670
2034	35,831	-1,522	15,738	13,606	851	2,522	2,967	69,992
2035	35,656	-1,233	15,725	13,785	844	2,547	2,990	70,314
2036	35,489	-1,252	15,626	13,943	833	2,571	2,975	70,185
2037	35,322	-1,271	15,527	14,100	822	2,595	2,960	70,056
2038	35,155	-1,290	15,428	14,258	811	2,619	2,945	69,927
2039	34,988	-1,309	15,329	14,416	801	2,643	2,931	69,798
2040	34,821	-1,328	15,230	14,574	790	2,667	2,916	69,669
2041	34,648	-1,261	15,245	14,739	791	2,698	2,884	69,744
2042	34,475	-1,194	15,259	14,905	792	2,730	2,853	69,820
2043	34,302	-1,127	15,274	15,070	793	2,761	2,821	69,896
2044	34,130	-1,059	15,289	15,236	794	2,793	2,789	69,971
2045	33,957	-992	15,303	15,401	796	2,824	2,758	70,047
2046	33,727	-969	15,307	15,552	796	2,855	2,747	70,016
2047	33,497	-945	15,311	15,703	797	2,885	2,737	69,985
2048	33,267	-922	15,315	15,854	798	2,916	2,726	69,954
2049	33,037	-898	15,318	16,005	798	2,946	2,716	69,923
2050	32,807	-874	15,322	16,156	799	2,977	2,705	69,892
Total	**1,098,346**	**-28,818**	**487,115**	**426,377**	**25,770**	**78,914**	**84,293**	**2,171,997**

Note: Emissions shown have been interpolated for non-model years.

Table C-4.23. Global Emissions Summary for Defined Policies: Model Resolved (GCAM-NETL-Aligned, AR6-20 Basis)

Year	CO_2 Energy	CO_2 LUC	CH_4 Energy	CH_4 Ag	N_2O Energy	N_2O Ag	F Gases	Total
	Units (Tg CO_2e/year) (AR6, 100-year)							
2020	38,334	398	18,207	11,671	887	2,123	2,244	73,863
2021	37,872	469	17,617	11,723	877	2,151	2,265	72,973
2022	37,409	540	17,027	11,775	867	2,179	2,287	72,083
2023	36,947	611	16,437	11,827	857	2,206	2,308	71,193
2024	36,484	683	15,847	11,879	847	2,234	2,330	70,303
2025	36,022	754	15,257	11,930	837	2,262	2,351	69,413
2026	36,123	67	15,363	12,122	845	2,294	2,456	69,271
2027	36,225	-619	15,470	12,314	853	2,326	2,561	69,129
2028	36,326	-1,306	15,577	12,506	860	2,358	2,665	68,987
2029	36,428	-1,992	15,684	12,697	868	2,390	2,770	68,845
2030	36,529	-2,679	15,791	12,889	876	2,423	2,875	68,703
2031	36,362	-2,397	15,779	13,068	869	2,447	2,898	69,027
2032	36,194	-2,115	15,768	13,247	863	2,472	2,921	69,351
2033	36,027	-1,833	15,757	13,427	857	2,497	2,944	69,675
2034	35,859	-1,551	15,745	13,606	850	2,522	2,968	69,999
2035	35,692	-1,269	15,734	13,785	844	2,546	2,991	70,323
2036	35,538	-1,293	15,636	13,943	833	2,570	2,977	70,204
2037	35,385	-1,317	15,539	14,100	822	2,594	2,962	70,086
2038	35,232	-1,341	15,442	14,258	811	2,618	2,948	69,967
2039	35,079	-1,364	15,344	14,416	800	2,641	2,934	69,849
2040	34,925	-1,388	15,247	14,574	789	2,665	2,919	69,731
2041	34,750	-1,315	15,257	14,739	790	2,696	2,888	69,806
2042	34,575	-1,241	15,267	14,905	791	2,728	2,856	69,881
2043	34,399	-1,167	15,278	15,070	792	2,759	2,824	69,956
2044	34,224	-1,093	15,288	15,236	794	2,791	2,793	70,031
2045	34,048	-1,020	15,298	15,402	795	2,822	2,761	70,106
2046	33,810	-990	15,298	15,552	795	2,853	2,750	70,068
2047	33,571	-960	15,297	15,703	796	2,883	2,740	70,030
2048	33,332	-930	15,297	15,854	797	2,914	2,729	69,992
2049	33,093	-900	15,296	16,005	797	2,944	2,718	69,954
2050	32,855	-871	15,296	16,156	798	2,975	2,708	69,916
Total	**1,099,646**	**-29,427**	**487,141**	**426,378**	**25,755**	**78,881**	**84,340**	**2,172,715**

Note: Emissions shown have been interpolated for non-model years.

Table C-4.24. Global Emissions Summary for Defined Policies: High Exports (GCAM-NETL-Aligned, AR6-20 Basis)

Year	CO_2 Energy	CO_2 LUC	CH_4 Energy	CH_4 Ag	N_2O Energy	N_2O Ag	F Gases	Total
	Units (Tg CO_2e/year) (AR6, 20-year)							
2020	38,334	398	18,207	11,671	887	2,123	2,244	73,863
2021	37,872	469	17,617	11,723	877	2,151	2,265	72,973
2022	37,409	540	17,027	11,775	867	2,179	2,287	72,083
2023	36,947	611	16,437	11,827	857	2,206	2,308	71,193
2024	36,484	683	15,847	11,879	847	2,234	2,330	70,303
2025	36,022	754	15,257	11,930	837	2,262	2,351	69,413
2026	36,123	67	15,363	12,122	845	2,294	2,456	69,271
2027	36,225	-619	15,470	12,314	853	2,326	2,561	69,129
2028	36,326	-1,306	15,577	12,506	860	2,358	2,665	68,987
2029	36,428	-1,992	15,684	12,697	868	2,390	2,770	68,845
2030	36,529	-2,679	15,791	12,889	876	2,423	2,875	68,703
2031	36,375	-2,410	15,782	13,068	869	2,447	2,898	69,029
2032	36,220	-2,142	15,773	13,247	863	2,472	2,922	69,356
2033	36,066	-1,873	15,765	13,427	856	2,496	2,946	69,682
2034	35,912	-1,605	15,756	13,606	850	2,520	2,969	70,008
2035	35,757	-1,337	15,747	13,785	843	2,545	2,993	70,334
2036	35,606	-1,349	15,650	13,943	832	2,569	2,979	70,228
2037	35,454	-1,362	15,552	14,100	821	2,592	2,965	70,123
2038	35,302	-1,375	15,455	14,258	810	2,616	2,950	70,017
2039	35,151	-1,388	15,357	14,416	799	2,640	2,936	69,911
2040	34,999	-1,400	15,260	14,574	788	2,663	2,922	69,806
2041	34,821	-1,326	15,268	14,739	789	2,695	2,890	69,877
2042	34,644	-1,252	15,277	14,905	791	2,726	2,858	69,948
2043	34,466	-1,179	15,285	15,070	792	2,758	2,827	70,020
2044	34,289	-1,105	15,294	15,236	793	2,789	2,795	70,091
2045	34,111	-1,031	15,302	15,402	794	2,820	2,763	70,162
2046	33,868	-999	15,300	15,552	795	2,851	2,753	70,120
2047	33,625	-967	15,298	15,703	795	2,881	2,742	70,077
2048	33,381	-935	15,296	15,854	796	2,912	2,731	70,035
2049	33,138	-903	15,294	16,005	796	2,942	2,720	69,993
2050	32,894	-872	15,292	16,156	797	2,973	2,710	69,950
Total	**1,100,779**	**-29,883**	**487,281**	**426,378**	**25,744**	**78,852**	**84,380**	**2,173,530**

Note: Emissions shown have been interpolated for non-model years.

Table C-4.25. Global Emissions Summary for Defined Policies: High Middle East Supply: Existing/FID Exports (GCAM_NETL-Aligned, AR6-20 Basis)

Year	CO_2 Energy	CO_2 LUC	CH_4 Energy	CH_4 Ag	N_2O Energy	N_2O Ag	F Gases	Total
	Units (Tg CO_2e/year) (AR6, 20-year)							
2020	38,342	397	18,209	11,671	887	2,123	2,244	73,874
2021	37,881	468	17,620	11,723	877	2,151	2,266	72,985
2022	37,420	540	17,030	11,775	867	2,179	2,287	72,097
2023	36,959	611	16,440	11,827	857	2,206	2,309	71,208
2024	36,497	682	15,850	11,879	847	2,234	2,330	70,319
2025	36,036	753	15,261	11,930	837	2,262	2,351	69,431
2026	36,148	56	15,371	12,122	845	2,294	2,456	69,292
2027	36,259	-640	15,481	12,314	853	2,326	2,561	69,154
2028	36,371	-1,336	15,591	12,506	860	2,358	2,666	69,016
2029	36,483	-2,033	15,701	12,697	868	2,390	2,771	68,877
2030	36,594	-2,729	15,812	12,889	875	2,422	2,876	68,739
2031	36,442	-2,452	15,808	13,068	869	2,446	2,900	69,080
2032	36,289	-2,175	15,804	13,247	863	2,471	2,923	69,421
2033	36,136	-1,898	15,800	13,427	856	2,495	2,947	69,762
2034	35,984	-1,621	15,796	13,606	850	2,520	2,971	70,104
2035	35,831	-1,345	15,792	13,785	843	2,544	2,995	70,445
2036	35,691	-1,363	15,706	13,943	832	2,568	2,981	70,357
2037	35,551	-1,382	15,620	14,100	821	2,591	2,967	70,269
2038	35,411	-1,400	15,534	14,258	810	2,615	2,953	70,181
2039	35,272	-1,419	15,448	14,416	799	2,638	2,938	70,093
2040	35,132	-1,438	15,362	14,574	788	2,662	2,924	70,005
2041	34,972	-1,374	15,384	14,739	789	2,693	2,893	70,096
2042	34,813	-1,311	15,405	14,905	790	2,724	2,862	70,188
2043	34,653	-1,248	15,426	15,070	791	2,755	2,830	70,279
2044	34,493	-1,184	15,448	15,236	793	2,786	2,799	70,370
2045	34,334	-1,121	15,469	15,402	794	2,817	2,767	70,462
2046	34,111	-1,100	15,479	15,553	794	2,847	2,757	70,442
2047	33,889	-1,078	15,489	15,703	795	2,877	2,746	70,422
2048	33,666	-1,057	15,499	15,854	796	2,907	2,736	70,402
2049	33,444	-1,035	15,509	16,005	796	2,937	2,726	70,382
2050	33,221	-1,014	15,519	16,156	797	2,967	2,715	70,362
Total	**1,104,327**	**-31,246**	**489,663**	**426,379**	**25,741**	**78,803**	**84,447**	**2,178,114**

Note: Emissions shown have been interpolated for non-model years.

Table C-4.26. Global Emissions Summary for Defined Policies: High Middle East Supply: Model Resolved (GCAM-NETL-Aligned, AR6-20 Basis)

Year	CO_2 Energy	CO_2 LUC	CH_4 Energy	CH_4 Ag	N_2O Energy	N_2O Ag	F Gases	Total
	Units (Tg CO_2e/year) (AR6, 20-year)							
2020	38,342	397	18,209	11,671	887	2,123	2,244	73,874
2021	37,881	468	17,620	11,723	877	2,151	2,266	72,985
2022	37,420	540	17,030	11,775	867	2,179	2,287	72,097
2023	36,959	611	16,440	11,827	857	2,206	2,309	71,208
2024	36,497	682	15,850	11,879	847	2,234	2,330	70,319
2025	36,036	753	15,261	11,930	837	2,262	2,351	69,431
2026	36,148	56	15,371	12,122	845	2,294	2,456	69,292
2027	36,259	-640	15,481	12,314	853	2,326	2,561	69,154
2028	36,371	-1,336	15,591	12,506	860	2,358	2,666	69,016
2029	36,483	-2,033	15,701	12,697	868	2,390	2,771	68,877
2030	36,594	-2,729	15,812	12,889	875	2,422	2,876	68,739
2031	36,447	-2,458	15,809	13,068	869	2,446	2,900	69,081
2032	36,300	-2,186	15,806	13,247	862	2,470	2,924	69,423
2033	36,153	-1,915	15,802	13,426	856	2,495	2,948	69,766
2034	36,006	-1,643	15,799	13,606	850	2,519	2,972	70,108
2035	35,859	-1,372	15,796	13,785	843	2,543	2,996	70,450
2036	35,724	-1,390	15,709	13,943	832	2,567	2,982	70,367
2037	35,590	-1,408	15,622	14,100	821	2,590	2,968	70,283
2038	35,455	-1,426	15,535	14,258	810	2,614	2,954	70,200
2039	35,321	-1,444	15,447	14,416	799	2,637	2,940	70,116
2040	35,186	-1,462	15,360	14,574	788	2,661	2,927	70,033
2041	35,025	-1,394	15,378	14,739	789	2,692	2,895	70,123
2042	34,863	-1,327	15,396	14,905	790	2,723	2,864	70,214
2043	34,701	-1,259	15,414	15,070	791	2,754	2,832	70,304
2044	34,540	-1,192	15,433	15,236	792	2,785	2,801	70,395
2045	34,378	-1,124	15,451	15,402	793	2,816	2,769	70,485
2046	34,152	-1,103	15,458	15,553	794	2,846	2,759	70,458
2047	33,926	-1,082	15,465	15,704	795	2,876	2,748	70,432
2048	33,700	-1,061	15,473	15,854	795	2,906	2,738	70,405
2049	33,475	-1,040	15,480	16,005	796	2,936	2,727	70,379
2050	33,249	-1,019	15,487	16,156	797	2,966	2,717	70,352
Total	**1,105,043**	**-31,537**	**489,486**	**426,379**	**25,734**	**78,785**	**84,476**	**2,178,366**

Note: Emissions shown have been interpolated for non-model years.

Table C-4.27. Global Emissions Summary for Defined Policies: High U.S. Supply: Existing/FID Exports (GCAM-NETL-Aligned, AR6-20 Basis)

Year	CO_2 Energy	CO_2 LUC	CH_4 Energy	CH_4 Ag	N_2O Energy	N_2O Ag	F Gases	Total
	Units (Tg CO_2e/year) (AR6, 20-year)							
2020	38,330	398	18,207	11,671	887	2,123	2,243	73,858
2021	37,869	469	17,617	11,723	877	2,151	2,265	72,970
2022	37,408	539	17,027	11,775	867	2,179	2,287	72,081
2023	36,947	610	16,437	11,827	857	2,206	2,308	71,192
2024	36,486	681	15,847	11,879	847	2,234	2,330	70,304
2025	36,026	751	15,257	11,930	837	2,262	2,351	69,415
2026	36,128	64	15,364	12,122	845	2,294	2,456	69,274
2027	36,231	-623	15,471	12,314	853	2,326	2,561	69,133
2028	36,334	-1,310	15,578	12,506	860	2,358	2,665	68,992
2029	36,436	-1,997	15,686	12,697	868	2,390	2,770	68,851
2030	36,539	-2,684	15,793	12,889	876	2,423	2,875	68,710
2031	36,364	-2,393	15,779	13,068	869	2,447	2,898	69,033
2032	36,188	-2,102	15,766	13,248	863	2,472	2,921	69,356
2033	36,013	-1,811	15,752	13,427	857	2,497	2,944	69,680
2034	35,838	-1,520	15,739	13,606	851	2,522	2,967	70,003
2035	35,662	-1,229	15,725	13,785	844	2,547	2,990	70,326
2036	35,497	-1,249	15,627	13,943	833	2,571	2,975	70,197
2037	35,331	-1,270	15,528	14,100	823	2,595	2,960	70,068
2038	35,165	-1,290	15,429	14,258	812	2,619	2,946	69,939
2039	35,000	-1,311	15,330	14,416	801	2,643	2,931	69,810
2040	34,834	-1,331	15,232	14,574	790	2,667	2,916	69,681
2041	34,665	-1,266	15,247	14,739	791	2,698	2,884	69,759
2042	34,496	-1,200	15,262	14,905	792	2,730	2,853	69,837
2043	34,327	-1,135	15,277	15,070	793	2,761	2,821	69,916
2044	34,158	-1,069	15,292	15,236	795	2,793	2,790	69,994
2045	33,989	-1,004	15,307	15,401	796	2,824	2,758	70,073
2046	33,764	-981	15,312	15,552	797	2,855	2,748	70,046
2047	33,539	-959	15,316	15,703	797	2,885	2,737	70,019
2048	33,313	-937	15,321	15,854	798	2,916	2,726	69,992
2049	33,088	-914	15,325	16,005	799	2,946	2,716	69,965
2050	32,863	-892	15,330	16,156	800	2,977	2,705	69,938
Total	**1,098,830**	**-28,959**	**487,179**	**426,377**	**25,773**	**78,913**	**84,297**	**2,172,411**

Note: Emissions shown have been interpolated for non-model years.

Table C-4.28. Global Emissions Summary for Defined Policies: High U.S. Supply: Model Resolved (GCAM-NETL-Aligned, AR6-20 Basis)

Year	CO_2 Energy	CO_2 LUC	CH_4 Energy	CH_4 Ag	N_2O Energy	N_2O Ag	F Gases	Total
	Units (Tg CO_2e/year) (AR6, 20-year)							
2020	38,330	398	18,207	11,671	887	2,123	2,243	73,858
2021	37,869	469	17,617	11,723	877	2,151	2,265	72,970
2022	37,408	539	17,027	11,775	867	2,179	2,287	72,081
2023	36,947	610	16,437	11,827	857	2,206	2,308	71,192
2024	36,486	681	15,847	11,879	847	2,234	2,330	70,304
2025	36,026	751	15,257	11,930	837	2,262	2,351	69,415
2026	36,128	64	15,364	12,122	845	2,294	2,456	69,274
2027	36,231	-623	15,471	12,314	853	2,326	2,561	69,133
2028	36,334	-1,310	15,578	12,506	860	2,358	2,665	68,992
2029	36,436	-1,997	15,686	12,697	868	2,390	2,770	68,851
2030	36,539	-2,684	15,793	12,889	876	2,423	2,875	68,710
2031	36,375	-2,404	15,782	13,068	869	2,447	2,898	69,036
2032	36,211	-2,125	15,771	13,247	863	2,472	2,922	69,361
2033	36,047	-1,846	15,760	13,427	857	2,497	2,945	69,687
2034	35,883	-1,566	15,750	13,606	850	2,521	2,968	70,012
2035	35,719	-1,287	15,739	13,785	844	2,546	2,992	70,338
2036	35,572	-1,312	15,642	13,943	833	2,570	2,978	70,226
2037	35,425	-1,336	15,546	14,100	822	2,593	2,963	70,113
2038	35,277	-1,361	15,450	14,258	811	2,617	2,949	70,001
2039	35,130	-1,385	15,353	14,416	800	2,641	2,935	69,889
2040	34,983	-1,410	15,257	14,574	789	2,664	2,921	69,777
2041	34,815	-1,341	15,268	14,739	790	2,696	2,889	69,856
2042	34,648	-1,272	15,278	14,905	791	2,727	2,858	69,935
2043	34,481	-1,203	15,289	15,070	792	2,758	2,826	70,014
2044	34,314	-1,134	15,300	15,236	793	2,789	2,795	70,093
2045	34,146	-1,065	15,311	15,402	794	2,821	2,763	70,172
2046	33,915	-1,037	15,311	15,552	795	2,851	2,752	70,140
2047	33,684	-1,009	15,310	15,703	796	2,881	2,742	70,108
2048	33,453	-981	15,310	15,854	797	2,912	2,731	70,077
2049	33,222	-953	15,310	16,005	797	2,942	2,721	70,045
2050	32,991	-925	15,310	16,156	798	2,972	2,710	70,013
Total	**1,101,029**	**-30,051**	**487,331**	**426,379**	**25,753**	**78,862**	**84,370**	**2,173,673**

Note: Emissions shown have been interpolated for non-model years.

Table C-4.29. Global Emissions Summary for Defined Policies: Low U.S. Supply: Existing/FID Exports (GCAM-NETL-Aligned, AR6-20 Basis)

Year	CO_2 Energy	CO_2 LUC	CH_4 Energy	CH_4 Ag	N_2O Energy	N_2O Ag	F Gases	Total
	Units (Tg CO_2e/year) (AR6, 20-year)							
2020	38,357	396	18,210	11,671	887	2,123	2,244	73,889
2021	37,883	472	17,618	11,723	877	2,151	2,266	72,990
2022	37,409	548	17,027	11,775	867	2,179	2,287	72,092
2023	36,935	625	16,435	11,827	857	2,206	2,308	71,193
2024	36,461	701	15,843	11,878	847	2,234	2,330	70,295
2025	35,987	777	15,252	11,930	837	2,261	2,351	69,396
2026	36,080	93	15,357	12,122	845	2,294	2,456	69,246
2027	36,173	-591	15,462	12,314	852	2,326	2,560	69,097
2028	36,266	-1,275	15,568	12,506	860	2,358	2,665	68,947
2029	36,359	-1,959	15,673	12,697	868	2,391	2,769	68,797
2030	36,452	-2,643	15,778	12,889	875	2,423	2,873	68,648
2031	36,273	-2,357	15,764	13,068	869	2,448	2,896	68,962
2032	36,094	-2,071	15,750	13,248	863	2,473	2,919	69,276
2033	35,915	-1,785	15,736	13,427	856	2,498	2,943	69,590
2034	35,736	-1,498	15,722	13,606	850	2,523	2,966	69,904
2035	35,557	-1,212	15,707	13,785	844	2,548	2,989	70,218
2036	35,385	-1,232	15,609	13,943	833	2,571	2,974	70,083
2037	35,213	-1,251	15,510	14,100	822	2,595	2,959	69,949
2038	35,041	-1,271	15,412	14,258	811	2,619	2,944	69,814
2039	34,869	-1,290	15,313	14,416	800	2,643	2,930	69,680
2040	34,696	-1,310	15,215	14,574	789	2,667	2,915	69,546
2041	34,506	-1,230	15,227	14,739	790	2,699	2,883	69,615
2042	34,315	-1,149	15,240	14,905	791	2,730	2,851	69,683
2043	34,124	-1,068	15,252	15,070	792	2,762	2,820	69,752
2044	33,934	-988	15,265	15,236	794	2,793	2,788	69,821
2045	33,743	-907	15,277	15,401	795	2,825	2,756	69,890
2046	33,518	-904	15,281	15,552	795	2,856	2,746	69,844
2047	33,294	-901	15,284	15,703	796	2,886	2,735	69,798
2048	33,070	-898	15,288	15,854	796	2,917	2,725	69,751
2049	32,845	-895	15,292	16,005	797	2,947	2,715	69,705
2050	32,621	-892	15,295	16,155	798	2,978	2,704	69,659
Total	**1,095,112**	**-27,967**	**486,663**	**426,377**	**25,755**	**78,923**	**84,267**	**2,169,129**

Note: Emissions shown have been interpolated for non-model years.

Table C-4.30. Global Emissions Summary for Defined Policies: Low U.S. Supply: Model Resolved (GCAM-NETL-Aligned, AR6-20 Basis)

Year	CO_2 Energy	CO_2 LUC	CH_4 Energy	CH_4 Ag	N_2O Energy	N_2O Ag	F Gases	Total
	Units (Tg CO_2e/year) (AR6, 20-year)							
2020	38,357	396	18,210	11,671	887	2,123	2,244	73,889
2021	37,883	472	17,618	11,723	877	2,151	2,266	72,990
2022	37,409	548	17,027	11,775	867	2,179	2,287	72,092
2023	36,935	625	16,435	11,827	857	2,206	2,308	71,193
2024	36,461	701	15,843	11,878	847	2,234	2,330	70,295
2025	35,987	777	15,252	11,930	837	2,261	2,351	69,396
2026	36,080	93	15,357	12,122	845	2,294	2,456	69,246
2027	36,173	-591	15,462	12,314	852	2,326	2,560	69,097
2028	36,266	-1,275	15,568	12,506	860	2,358	2,665	68,947
2029	36,359	-1,959	15,673	12,697	868	2,391	2,769	68,797
2030	36,452	-2,643	15,778	12,889	875	2,423	2,873	68,648
2031	36,273	-2,357	15,764	13,068	869	2,448	2,896	68,962
2032	36,094	-2,071	15,750	13,248	863	2,473	2,919	69,276
2033	35,915	-1,785	15,736	13,427	856	2,498	2,943	69,590
2034	35,736	-1,498	15,722	13,606	850	2,523	2,966	69,904
2035	35,557	-1,212	15,707	13,785	844	2,548	2,989	70,218
2036	35,386	-1,232	15,609	13,943	833	2,571	2,974	70,084
2037	35,214	-1,252	15,511	14,100	822	2,595	2,959	69,949
2038	35,043	-1,273	15,412	14,258	811	2,619	2,944	69,815
2039	34,871	-1,293	15,314	14,416	800	2,643	2,930	69,681
2040	34,700	-1,313	15,216	14,574	789	2,667	2,915	69,547
2041	34,511	-1,234	15,227	14,739	790	2,698	2,883	69,616
2042	34,323	-1,156	15,239	14,905	791	2,730	2,852	69,684
2043	34,135	-1,077	15,251	15,070	792	2,762	2,820	69,753
2044	33,946	-999	15,263	15,236	794	2,793	2,788	69,821
2045	33,758	-920	15,275	15,401	795	2,825	2,757	69,890
2046	33,536	-918	15,278	15,552	795	2,855	2,746	69,844
2047	33,314	-916	15,281	15,703	796	2,886	2,736	69,799
2048	33,091	-914	15,284	15,854	796	2,916	2,726	69,754
2049	32,869	-912	15,288	16,005	797	2,947	2,715	69,708
2050	32,647	-910	15,291	16,156	797	2,977	2,705	69,663
Total	**1,095,283**	**-28,098**	**486,640**	**426,377**	**25,753**	**78,919**	**84,273**	**2,169,147**

Note: Emissions shown have been interpolated for non-model years.

Table C-4.31. Global Emissions Summary for Commitments (High CCS): Existing/FID Exports (GCAM-NETL-Aligned, AR6-20 Basis)

Year	CO_2 Energy	CO_2 LUC	CH_4 Energy	CH_4 Ag	N_2O Energy	N_2O Ag	F Gases	Total
	Units (Tg CO_2e/year) (AR6, 20-year)							
2020	38,333	532	18,199	11,670	886	2,126	2,244	73,991
2021	37,707	616	17,531	11,716	872	2,151	2,260	72,853
2022	37,080	700	16,863	11,761	857	2,177	2,277	71,716
2023	36,454	784	16,195	11,807	843	2,202	2,294	70,579
2024	35,827	868	15,527	11,852	829	2,227	2,311	69,441
2025	35,200	952	14,859	11,898	815	2,252	2,327	68,304
2026	35,054	732	14,948	12,093	825	2,277	2,424	68,351
2027	34,907	511	15,036	12,288	834	2,301	2,521	68,399
2028	34,760	291	15,125	12,484	844	2,326	2,618	68,446
2029	34,613	70	15,214	12,679	853	2,350	2,714	68,493
2030	34,466	-150	15,303	12,874	863	2,374	2,811	68,541
2031	33,137	-124	15,060	13,014	842	2,401	2,802	67,133
2032	31,809	-98	14,817	13,155	820	2,428	2,794	65,725
2033	30,480	-72	14,575	13,295	799	2,455	2,786	64,317
2034	29,152	-46	14,332	13,436	777	2,482	2,777	62,909
2035	27,823	-20	14,089	13,576	756	2,509	2,769	61,501
2036	26,519	180	13,921	13,719	747	2,530	2,749	60,365
2037	25,215	380	13,753	13,862	738	2,551	2,730	59,228
2038	23,910	580	13,584	14,004	729	2,572	2,711	58,091
2039	22,606	781	13,416	14,147	720	2,594	2,691	56,954
2040	21,302	981	13,248	14,289	711	2,615	2,672	55,817
2041	19,994	871	12,937	14,410	694	2,627	2,547	54,079
2042	18,685	762	12,626	14,530	677	2,638	2,422	52,340
2043	17,377	652	12,315	14,650	660	2,650	2,297	50,601
2044	16,069	542	12,004	14,771	643	2,662	2,172	48,863
2045	14,760	433	11,693	14,891	626	2,674	2,047	47,124
2046	13,473	250	11,448	15,026	610	2,686	1,971	45,463
2047	12,186	67	11,202	15,161	594	2,698	1,894	43,802
2048	10,898	-116	10,957	15,296	578	2,710	1,818	42,141
2049	9,611	-299	10,712	15,430	562	2,722	1,742	40,479
2050	8,324	-481	10,466	15,565	545	2,734	1,665	38,818
Total	**807,730**	**11,127**	**431,956**	**419,349**	**23,148**	**76,699**	**74,856**	**1,844,865**

Note: Emissions shown have been interpolated for non-model years.

Table C-4.32. Global Emissions Summary for Commitments (High CCS): Model Resolved (GCAM-NETL-Aligned, AR6-20 Basis)

Year	CO_2 Energy	CO_2 LUC	CH_4 Energy	CH_4 Ag	N_2O Energy	N_2O Ag	F Gases	Total
	Units (Tg CO_2e/year) (AR6, 20-year)							
2020	38,333	532	18,199	11,670	886	2,126	2,244	73,991
2021	37,707	616	17,531	11,716	872	2,151	2,260	72,853
2022	37,080	700	16,863	11,761	857	2,177	2,277	71,716
2023	36,454	784	16,195	11,807	843	2,202	2,294	70,579
2024	35,827	868	15,527	11,852	829	2,227	2,311	69,441
2025	35,200	952	14,859	11,898	815	2,252	2,327	68,304
2026	35,054	732	14,948	12,093	825	2,277	2,424	68,351
2027	34,907	511	15,036	12,288	834	2,301	2,521	68,399
2028	34,760	291	15,125	12,484	844	2,326	2,618	68,446
2029	34,613	70	15,214	12,679	853	2,350	2,714	68,493
2030	34,466	-150	15,303	12,874	863	2,374	2,811	68,541
2031	33,137	-124	15,060	13,014	842	2,401	2,802	67,133
2032	31,809	-98	14,817	13,155	820	2,428	2,794	65,725
2033	30,480	-72	14,575	13,295	799	2,455	2,786	64,317
2034	29,152	-46	14,332	13,436	777	2,482	2,777	62,909
2035	27,823	-20	14,089	13,576	756	2,509	2,769	61,501
2036	26,524	172	13,921	13,719	747	2,530	2,750	60,362
2037	25,224	365	13,753	13,861	738	2,551	2,730	59,222
2038	23,925	557	13,584	14,004	729	2,572	2,711	58,082
2039	22,625	750	13,416	14,147	719	2,594	2,692	56,943
2040	21,326	942	13,248	14,289	710	2,615	2,673	55,803
2041	20,015	845	12,935	14,410	693	2,626	2,548	54,072
2042	18,705	747	12,621	14,530	677	2,638	2,423	52,341
2043	17,395	650	12,307	14,650	660	2,650	2,298	50,610
2044	16,084	552	11,994	14,771	643	2,662	2,173	48,879
2045	14,774	455	11,680	14,891	626	2,673	2,048	47,147
2046	13,485	269	11,433	15,026	610	2,685	1,971	45,480
2047	12,195	84	11,186	15,161	594	2,697	1,895	43,812
2048	10,906	-102	10,939	15,296	578	2,709	1,818	42,144
2049	9,617	-287	10,692	15,431	562	2,721	1,742	40,477
2050	8,328	-473	10,445	15,565	545	2,733	1,666	38,809
Total	**807,928**	**11,069**	**431,827**	**419,349**	**23,147**	**76,696**	**74,867**	**1,844,882**

Note: Emissions shown have been interpolated for non-model years.

Table C-4.33. Global Emissions Summary for Commitments (High CCS): High Exports (GCAM-NETL-Aligned, AR6-20 Basis)

Year	CO_2 Energy	CO_2 LUC	CH_4 Energy	CH_4 Ag	N_2O Energy	N_2O Ag	F Gases	Total
	Units (Tg CO_2e/year) (AR6, 20-year)							
2020	38,333	532	18,199	11,670	886	2,126	2,244	73,991
2021	37,707	616	17,531	11,716	872	2,151	2,260	72,853
2022	37,080	700	16,863	11,761	857	2,177	2,277	71,716
2023	36,454	784	16,195	11,807	843	2,202	2,294	70,579
2024	35,827	868	15,527	11,852	829	2,227	2,311	69,441
2025	35,200	952	14,859	11,898	815	2,252	2,327	68,304
2026	35,054	732	14,948	12,093	825	2,277	2,424	68,351
2027	34,907	511	15,036	12,288	834	2,301	2,521	68,399
2028	34,760	291	15,125	12,484	844	2,326	2,618	68,446
2029	34,613	70	15,214	12,679	853	2,350	2,714	68,493
2030	34,466	-150	15,303	12,874	863	2,374	2,811	68,541
2031	33,155	-141	15,063	13,014	842	2,401	2,803	67,136
2032	31,843	-132	14,824	13,155	820	2,428	2,795	65,732
2033	30,532	-123	14,584	13,295	799	2,454	2,787	64,327
2034	29,220	-114	14,345	13,436	777	2,481	2,779	62,923
2035	27,909	-105	14,105	13,576	755	2,507	2,771	61,518
2036	26,603	104	13,934	13,719	746	2,529	2,752	60,386
2037	25,297	313	13,762	13,861	737	2,550	2,733	59,253
2038	23,991	522	13,591	14,004	728	2,571	2,714	58,121
2039	22,685	731	13,420	14,146	719	2,592	2,695	56,988
2040	21,379	941	13,248	14,289	710	2,614	2,676	55,856
2041	20,064	852	12,931	14,409	693	2,626	2,550	54,125
2042	18,749	764	12,614	14,530	677	2,637	2,425	52,395
2043	17,434	675	12,296	14,650	660	2,649	2,300	50,665
2044	16,119	587	11,979	14,771	643	2,661	2,175	48,934
2045	14,804	499	11,662	14,891	626	2,673	2,049	47,204
2046	13,513	305	11,411	15,026	610	2,685	1,973	45,523
2047	12,222	112	11,161	15,161	594	2,697	1,896	43,843
2048	10,932	-81	10,910	15,296	578	2,709	1,820	42,162
2049	9,641	-275	10,659	15,431	561	2,721	1,743	40,482
2050	8,350	-468	10,409	15,566	545	2,733	1,667	38,801
Total	**808,839**	**10,870**	**431,707**	**419,348**	**23,143**	**76,678**	**74,905**	**1,845,490**

Note: Emissions shown have been interpolated for non-model years.

Table C-4.34. Global Emissions Summary for Commitments (Moderate CCS): Existing/FID Exports (GCAM-NETL-Aligned, AR6-20 Basis)

Year	CO_2 Energy	CO_2 LUC	CH_4 Energy	CH_4 Ag	N_2O Energy	N_2O Ag	F Gases	Total
	Units (Tg CO_2e/year) (AR6, 20-year)							
2020	38,333	532	18,199	11,670	886	2,126	2,244	73,991
2021	37,705	571	17,443	11,696	867	2,149	2,252	72,682
2022	37,076	610	16,686	11,722	848	2,172	2,260	71,374
2023	36,447	650	15,929	11,747	829	2,195	2,268	70,065
2024	35,818	689	15,172	11,773	811	2,218	2,276	68,756
2025	35,190	728	14,415	11,799	792	2,241	2,284	67,448
2026	35,046	503	14,501	12,000	804	2,266	2,381	67,501
2027	34,902	279	14,587	12,202	815	2,291	2,478	67,554
2028	34,758	55	14,673	12,403	827	2,317	2,575	67,608
2029	34,613	-169	14,759	12,605	838	2,342	2,673	67,661
2030	34,469	-393	14,845	12,806	850	2,367	2,770	67,714
2031	33,184	-563	14,451	12,914	824	2,385	2,734	65,928
2032	31,899	-732	14,058	13,021	797	2,402	2,697	64,143
2033	30,614	-902	13,664	13,128	771	2,420	2,661	62,357
2034	29,328	-1,071	13,271	13,236	745	2,438	2,625	60,571
2035	28,043	-1,241	12,877	13,343	718	2,455	2,589	58,785
2036	26,739	-1,576	12,588	13,462	702	2,466	2,545	56,926
2037	25,436	-1,911	12,299	13,580	685	2,477	2,501	55,068
2038	24,132	-2,246	12,010	13,699	669	2,488	2,457	53,209
2039	22,829	-2,582	11,721	13,817	653	2,499	2,413	51,350
2040	21,525	-2,917	11,432	13,935	636	2,511	2,369	49,492
2041	20,204	-2,775	11,156	14,077	621	2,520	2,281	48,084
2042	18,882	-2,633	10,880	14,218	606	2,530	2,192	46,676
2043	17,561	-2,491	10,603	14,359	591	2,540	2,104	45,269
2044	16,240	-2,349	10,327	14,501	576	2,550	2,015	43,861
2045	14,918	-2,206	10,051	14,642	561	2,560	1,927	42,453
2046	13,607	-2,224	9,846	14,791	553	2,575	1,869	41,017
2047	12,295	-2,241	9,642	14,940	545	2,589	1,812	39,581
2048	10,984	-2,258	9,437	15,089	536	2,603	1,754	38,145
2049	9,673	-2,275	9,232	15,237	528	2,618	1,697	36,709
2050	8,361	-2,293	9,027	15,386	520	2,632	1,639	35,273
Total	**810,811**	**-35,428**	**399,778**	**413,798**	**22,005**	**74,944**	**71,342**	**1,757,251**

Note: Emissions shown have been interpolated for non-model years.

Table C-4.35. Global Emissions Summary for Commitments (Moderate CCS): Model Resolved (GCAM-NETL-Aligned, AR6-20 Basis)

Year	CO_2 Energy	CO_2 LUC	CH_4 Energy	CH_4 Ag	N_2O Energy	N_2O Ag	F Gases	Total
	Units (Tg CO_2e/year) (AR6, 20-year)							
2020	38,333	532	18,199	11,670	886	2,126	2,244	73,991
2021	37,705	571	17,443	11,696	867	2,149	2,252	72,682
2022	37,076	610	16,686	11,722	848	2,172	2,260	71,374
2023	36,447	650	15,929	11,747	829	2,195	2,268	70,065
2024	35,818	689	15,172	11,773	811	2,218	2,276	68,756
2025	35,190	728	14,415	11,799	792	2,241	2,284	67,448
2026	35,046	503	14,501	12,000	804	2,266	2,381	67,501
2027	34,902	279	14,587	12,202	815	2,291	2,478	67,554
2028	34,758	55	14,673	12,403	827	2,317	2,575	67,608
2029	34,613	-169	14,759	12,605	838	2,342	2,673	67,661
2030	34,469	-393	14,845	12,806	850	2,367	2,770	67,714
2031	33,184	-563	14,451	12,914	824	2,385	2,734	65,928
2032	31,899	-732	14,058	13,021	797	2,402	2,697	64,143
2033	30,614	-902	13,664	13,128	771	2,420	2,661	62,357
2034	29,328	-1,071	13,271	13,236	745	2,438	2,625	60,571
2035	28,043	-1,241	12,877	13,343	718	2,455	2,589	58,785
2036	26,741	-1,576	12,588	13,462	702	2,466	2,545	56,928
2037	25,438	-1,911	12,299	13,580	685	2,477	2,501	55,071
2038	24,136	-2,246	12,010	13,699	669	2,488	2,457	53,214
2039	22,834	-2,581	11,721	13,817	653	2,500	2,414	51,357
2040	21,531	-2,916	11,432	13,936	636	2,511	2,370	49,500
2041	20,210	-2,774	11,155	14,077	621	2,520	2,281	48,091
2042	18,889	-2,632	10,878	14,218	606	2,530	2,193	46,682
2043	17,567	-2,489	10,600	14,359	591	2,540	2,104	45,273
2044	16,246	-2,347	10,323	14,501	576	2,550	2,016	43,864
2045	14,925	-2,205	10,046	14,642	561	2,560	1,927	42,456
2046	13,613	-2,223	9,841	14,791	553	2,575	1,870	41,018
2047	12,301	-2,241	9,636	14,940	545	2,589	1,812	39,581
2048	10,989	-2,258	9,430	15,089	536	2,603	1,754	38,143
2049	9,677	-2,276	9,225	15,238	528	2,618	1,697	36,706
2050	8,365	-2,294	9,020	15,386	520	2,632	1,639	35,268
Total	**810,883**	**-35,419**	**399,732**	**413,799**	**22,005**	**74,944**	**71,345**	**1,757,289**

Note: Emissions shown have been interpolated for non-model years.

Table C-4.36. Global Emissions Summary for Commitments (Moderate CCS): High Exports (GCAM-NETL-Aligned, AR6-20 Basis)

Year	CO_2 Energy	CO_2 LUC	CH_4 Energy	CH_4 Ag	N_2O Energy	N_2O Ag	F Gases	Total
	Units (Tg CO_2e/year) (AR6, 20-year)							
2020	38,333	532	18,199	11,670	886	2,126	2,244	73,991
2021	37,705	571	17,443	11,696	867	2,149	2,252	72,682
2022	37,076	610	16,686	11,722	848	2,172	2,260	71,374
2023	36,447	650	15,929	11,747	829	2,195	2,268	70,065
2024	35,818	689	15,172	11,773	811	2,218	2,276	68,756
2025	35,190	728	14,415	11,799	792	2,241	2,284	67,448
2026	35,046	503	14,501	12,000	804	2,266	2,381	67,501
2027	34,902	279	14,587	12,202	815	2,291	2,478	67,554
2028	34,758	55	14,673	12,403	827	2,317	2,575	67,608
2029	34,613	-169	14,759	12,605	838	2,342	2,673	67,661
2030	34,469	-393	14,845	12,806	850	2,367	2,770	67,714
2031	33,193	-560	14,454	12,914	824	2,385	2,734	65,943
2032	31,917	-728	14,063	13,021	797	2,402	2,698	64,171
2033	30,641	-895	13,672	13,128	771	2,420	2,662	62,400
2034	29,365	-1,063	13,282	13,236	745	2,438	2,627	60,629
2035	28,088	-1,230	12,891	13,343	719	2,455	2,591	58,857
2036	26,783	-1,566	12,598	13,462	702	2,467	2,547	56,992
2037	25,478	-1,903	12,305	13,580	686	2,478	2,503	55,127
2038	24,173	-2,239	12,012	13,699	669	2,489	2,459	53,262
2039	22,868	-2,575	11,719	13,817	653	2,500	2,415	51,396
2040	21,563	-2,912	11,426	13,936	636	2,511	2,372	49,531
2041	20,245	-2,770	11,146	14,077	621	2,520	2,283	48,124
2042	18,928	-2,628	10,866	14,218	606	2,530	2,194	46,716
2043	17,610	-2,486	10,587	14,360	591	2,540	2,106	45,308
2044	16,293	-2,344	10,307	14,501	576	2,550	2,017	43,901
2045	14,975	-2,201	10,028	14,642	561	2,560	1,928	42,493
2046	13,670	-2,220	9,822	14,791	553	2,574	1,871	41,061
2047	12,366	-2,239	9,616	14,940	544	2,589	1,813	39,630
2048	11,061	-2,257	9,410	15,089	536	2,603	1,756	38,198
2049	9,757	-2,276	9,204	15,238	528	2,617	1,698	36,766
2050	8,452	-2,295	8,998	15,387	519	2,632	1,641	35,334
Total	**811,784**	**-35,330**	**399,610**	**413,805**	**22,006**	**74,943**	**71,375**	**1,758,194**

Note: Emissions shown have been interpolated for non-model years.

Table C-4.37. Global Emissions Summary for Net Zero 2050 (High CCS): Existing/FID Exports (GCAM-NETL-Aligned, AR6-20 Basis)

Year	CO_2 Energy	CO_2 LUC	CH_4 Energy	CH_4 Ag	N_2O Energy	N_2O Ag	F Gases	Total
	Units (Tg CO_2e/year) (AR6, 20-year)							
2020	38,333	532	18,199	11,670	886	2,126	2,244	73,991
2021	37,707	616	17,531	11,716	872	2,151	2,260	72,853
2022	37,080	700	16,863	11,761	857	2,177	2,277	71,716
2023	36,454	784	16,195	11,807	843	2,202	2,294	70,579
2024	35,827	868	15,527	11,852	829	2,227	2,311	69,441
2025	35,200	952	14,859	11,898	815	2,252	2,327	68,304
2026	33,725	423	14,586	12,033	798	2,275	2,384	66,223
2027	32,250	-107	14,313	12,168	781	2,297	2,441	64,143
2028	30,775	-636	14,041	12,303	764	2,319	2,498	62,063
2029	29,300	-1,166	13,768	12,437	746	2,341	2,555	59,982
2030	27,825	-1,695	13,495	12,572	729	2,364	2,611	57,902
2031	26,373	-1,180	13,363	12,727	723	2,391	2,606	57,002
2032	24,922	-666	13,231	12,881	717	2,418	2,600	56,103
2033	23,471	-151	13,099	13,036	710	2,445	2,594	55,204
2034	22,020	364	12,967	13,190	704	2,472	2,588	54,305
2035	20,568	878	12,835	13,344	698	2,499	2,582	53,405
2036	19,212	727	12,527	13,463	679	2,512	2,530	51,650
2037	17,856	577	12,218	13,581	660	2,524	2,479	49,895
2038	16,500	426	11,910	13,699	640	2,537	2,427	48,139
2039	15,143	275	11,602	13,817	621	2,549	2,375	46,384
2040	13,787	125	11,294	13,936	602	2,562	2,323	44,629
2041	12,431	178	11,098	14,089	591	2,574	2,240	43,200
2042	11,074	231	10,902	14,243	581	2,586	2,156	41,772
2043	9,717	284	10,707	14,396	570	2,598	2,073	40,344
2044	8,360	337	10,511	14,550	559	2,610	1,989	38,916
2045	7,004	389	10,315	14,703	549	2,622	1,906	37,488
2046	5,611	360	10,054	14,864	541	2,633	1,848	35,912
2047	4,218	330	9,793	15,026	533	2,645	1,791	34,336
2048	2,824	301	9,532	15,187	526	2,657	1,733	32,760
2049	1,431	271	9,271	15,348	518	2,669	1,676	31,184
2050	38	242	9,010	15,510	510	2,680	1,619	29,609
Total	**637,037**	**5,568**	**395,621**	**413,805**	**21,153**	**75,913**	**70,336**	**1,619,433**

Note: Emissions shown have been interpolated for non-model years.

Table C-4.38. Global Emissions Summary for Net Zero 2050 (High CCS): Model Resolved (GCAM-NETL-Aligned, AR6-20 Basis)

Year	CO_2 Energy	CO_2 LUC	CH_4 Energy	CH_4 Ag	N_2O Energy	N_2O Ag	F Gases	Total
	Units (Tg CO_2e/year) (AR6, 20-year)							
2020	38,333	532	18,199	11,670	886	2,126	2,244	73,991
2021	37,707	616	17,531	11,716	872	2,151	2,260	72,853
2022	37,080	700	16,863	11,761	857	2,177	2,277	71,716
2023	36,454	784	16,195	11,807	843	2,202	2,294	70,579
2024	35,827	868	15,527	11,852	829	2,227	2,311	69,441
2025	35,200	952	14,859	11,898	815	2,252	2,327	68,304
2026	33,725	423	14,586	12,033	798	2,275	2,384	66,223
2027	32,250	-107	14,313	12,168	781	2,297	2,441	64,143
2028	30,775	-636	14,041	12,303	764	2,319	2,498	62,063
2029	29,300	-1,166	13,768	12,437	746	2,341	2,555	59,982
2030	27,825	-1,695	13,495	12,572	729	2,364	2,611	57,902
2031	26,373	-1,181	13,363	12,727	723	2,391	2,606	57,002
2032	24,922	-666	13,231	12,881	717	2,418	2,600	56,103
2033	23,471	-151	13,099	13,036	710	2,445	2,594	55,204
2034	22,019	363	12,967	13,190	704	2,472	2,588	54,304
2035	20,568	878	12,835	13,344	698	2,499	2,582	53,405
2036	19,214	723	12,526	13,463	679	2,512	2,531	51,647
2037	17,860	567	12,218	13,581	660	2,524	2,479	49,889
2038	16,506	412	11,910	13,699	640	2,537	2,427	48,131
2039	15,152	257	11,601	13,817	621	2,549	2,376	46,373
2040	13,799	101	11,293	13,935	602	2,561	2,324	44,615
2041	12,440	162	11,096	14,089	591	2,573	2,240	43,193
2042	11,082	224	10,899	14,242	581	2,585	2,157	41,770
2043	9,724	285	10,702	14,396	570	2,597	2,073	40,347
2044	8,365	346	10,505	14,550	559	2,609	1,989	38,924
2045	7,007	407	10,308	14,703	549	2,621	1,906	37,501
2046	5,614	374	10,046	14,864	541	2,633	1,848	35,921
2047	4,220	341	9,785	15,026	533	2,645	1,791	34,341
2048	2,826	308	9,523	15,187	526	2,657	1,734	32,761
2049	1,433	275	9,262	15,348	518	2,668	1,676	31,181
2050	39	242	9,000	15,510	510	2,680	1,619	29,601
Total	**637,113**	**5,540**	**395,547**	**413,805**	**21,152**	**75,911**	**70,340**	**1,619,408**

Note: Emissions shown have been interpolated for non-model years.

Table C-4.39. Global Emissions Summary for Net Zero 2050 (High CCS): High Exports (GCAM-NETL-Aligned, AR6-20 Basis)

Year	CO_2 Energy	CO_2 LUC	CH_4 Energy	CH_4 Ag	N_2O Energy	N_2O Ag	F Gases	Total
	Units (Tg CO_2e/year) (AR6, 20-year)							
2020	38,333	532	18,199	11,670	886	2,126	2,244	73,991
2021	37,707	616	17,531	11,716	872	2,151	2,260	72,853
2022	37,080	700	16,863	11,761	857	2,177	2,277	71,716
2023	36,454	784	16,195	11,807	843	2,202	2,294	70,579
2024	35,827	868	15,527	11,852	829	2,227	2,311	69,441
2025	35,200	952	14,859	11,898	815	2,252	2,327	68,304
2026	33,725	423	14,586	12,033	798	2,275	2,384	66,223
2027	32,250	-107	14,313	12,168	781	2,297	2,441	64,143
2028	30,775	-636	14,041	12,303	764	2,319	2,498	62,063
2029	29,300	-1,166	13,768	12,437	746	2,341	2,555	59,982
2030	27,825	-1,695	13,495	12,572	729	2,364	2,611	57,902
2031	26,382	-1,196	13,366	12,727	723	2,391	2,606	56,998
2032	24,939	-697	13,236	12,881	716	2,418	2,601	56,094
2033	23,496	-197	13,106	13,035	710	2,445	2,595	55,190
2034	22,053	302	12,976	13,190	704	2,472	2,590	54,286
2035	20,610	801	12,846	13,344	697	2,499	2,585	53,382
2036	19,256	662	12,535	13,462	678	2,511	2,533	51,636
2037	17,901	522	12,223	13,580	659	2,523	2,481	49,891
2038	16,547	382	11,912	13,699	640	2,536	2,430	48,145
2039	15,193	243	11,601	13,817	621	2,548	2,378	46,400
2040	13,839	103	11,289	13,935	602	2,560	2,326	44,654
2041	12,477	173	11,089	14,089	591	2,573	2,242	43,234
2042	11,115	243	10,888	14,242	581	2,585	2,159	41,813
2043	9,754	313	10,688	14,396	570	2,597	2,075	40,392
2044	8,392	383	10,487	14,550	560	2,609	1,991	38,971
2045	7,030	453	10,287	14,703	549	2,621	1,907	37,551
2046	5,634	407	10,024	14,865	541	2,632	1,850	35,952
2047	4,237	360	9,761	15,026	533	2,644	1,792	34,354
2048	2,841	313	9,497	15,187	525	2,656	1,735	32,755
2049	1,444	267	9,234	15,349	518	2,668	1,677	31,157
2050	48	220	8,971	15,510	510	2,679	1,620	29,558
Total	**637,664**	**5,330**	**395,394**	**413,802**	**21,148**	**75,896**	**70,374**	**1,619,609**

Note: Emissions shown have been interpolated for non-model years.

Table C-4.40. Global Emissions Summary for Net Zero 2050 (Moderate CCS): Existing/FID Exports (GCAM-NETL-Aligned, AR6-20 Basis)

Year	CO_2 Energy	CO_2 LUC	CH_4 Energy	CH_4 Ag	N_2O Energy	N_2O Ag	F Gases	Total
	Units (Tg CO_2e/year) (AR6, 20-year)							
2020	38,333	532	18,199	11,670	886	2,126	2,244	73,991
2021	37,705	571	17,443	11,696	867	2,149	2,252	72,682
2022	37,076	610	16,686	11,722	848	2,172	2,260	71,374
2023	36,447	650	15,929	11,747	829	2,195	2,268	70,065
2024	35,818	689	15,172	11,773	811	2,218	2,276	68,756
2025	35,190	728	14,415	11,799	792	2,241	2,284	67,448
2026	33,730	76	14,012	11,903	774	2,258	2,324	65,077
2027	32,270	-576	13,609	12,007	757	2,276	2,364	62,706
2028	30,810	-1,227	13,206	12,110	739	2,293	2,404	60,335
2029	29,350	-1,879	12,802	12,214	721	2,310	2,444	57,963
2030	27,890	-2,531	12,399	12,318	703	2,328	2,484	55,592
2031	26,507	-2,788	12,074	12,445	685	2,338	2,461	53,721
2032	25,124	-3,046	11,748	12,572	668	2,348	2,437	51,850
2033	23,741	-3,304	11,422	12,698	650	2,358	2,414	49,979
2034	22,357	-3,561	11,097	12,825	632	2,368	2,390	48,108
2035	20,974	-3,819	10,771	12,952	614	2,378	2,367	46,237
2036	19,593	-3,575	10,567	13,106	601	2,391	2,341	45,024
2037	18,213	-3,331	10,362	13,259	588	2,404	2,316	43,811
2038	16,832	-3,088	10,158	13,413	575	2,417	2,290	42,597
2039	15,451	-2,844	9,954	13,566	562	2,430	2,264	41,384
2040	14,071	-2,600	9,750	13,720	549	2,442	2,239	40,171
2041	12,712	-2,738	9,466	13,871	541	2,449	2,165	38,466
2042	11,352	-2,876	9,182	14,022	533	2,456	2,091	36,760
2043	9,993	-3,014	8,898	14,174	524	2,463	2,017	35,055
2044	8,634	-3,152	8,614	14,325	516	2,470	1,943	33,350
2045	7,275	-3,290	8,330	14,476	508	2,477	1,869	31,645
2046	5,865	-2,831	8,122	14,645	504	2,494	1,823	30,621
2047	4,455	-2,373	7,914	14,814	500	2,510	1,776	29,597
2048	3,045	-1,914	7,706	14,984	496	2,527	1,730	28,573
2049	1,635	-1,455	7,498	15,153	492	2,544	1,683	27,549
2050	225	-996	7,290	15,322	488	2,561	1,636	26,525
Total	**642,673**	**-58,952**	**354,789**	**407,301**	**19,953**	**73,393**	**67,855**	**1,507,012**

Note: Emissions shown have been interpolated for non-model years.

Table C-4.41. Global Emissions Summary for Net Zero 2050 (Moderate CCS): Model Resolved (GCAM-NETL-Aligned, AR6-20 Basis)

Year	CO_2 Energy	CO_2 LUC	CH_4 Energy	CH_4 Ag	N_2O Energy	N_2O Ag	F Gases	Total
	Units (Tg CO_2e/year) (AR6, 20-year)							
2020	38,333	532	18,199	11,670	886	2,126	2,244	73,991
2021	37,705	571	17,443	11,696	867	2,149	2,252	72,682
2022	37,076	610	16,686	11,722	848	2,172	2,260	71,374
2023	36,447	650	15,929	11,747	829	2,195	2,268	70,065
2024	35,818	689	15,172	11,773	811	2,218	2,276	68,756
2025	35,190	728	14,415	11,799	792	2,241	2,284	67,448
2026	33,730	76	14,012	11,903	774	2,258	2,324	65,077
2027	32,270	-576	13,609	12,007	757	2,276	2,364	62,706
2028	30,810	-1,227	13,206	12,110	739	2,293	2,404	60,335
2029	29,350	-1,879	12,802	12,214	721	2,310	2,444	57,963
2030	27,890	-2,531	12,399	12,318	703	2,328	2,484	55,592
2031	26,507	-2,788	12,074	12,445	685	2,338	2,461	53,721
2032	25,124	-3,046	11,748	12,572	668	2,348	2,437	51,850
2033	23,741	-3,304	11,422	12,698	650	2,358	2,414	49,979
2034	22,357	-3,561	11,097	12,825	632	2,368	2,390	48,108
2035	20,974	-3,819	10,771	12,952	614	2,378	2,367	46,237
2036	19,593	-3,575	10,567	13,106	601	2,391	2,341	45,024
2037	18,213	-3,331	10,362	13,259	588	2,404	2,316	43,811
2038	16,832	-3,088	10,158	13,413	575	2,417	2,290	42,597
2039	15,451	-2,844	9,954	13,566	562	2,430	2,264	41,384
2040	14,071	-2,600	9,750	13,720	549	2,442	2,239	40,171
2041	12,712	-2,738	9,466	13,871	541	2,449	2,165	38,466
2042	11,352	-2,876	9,182	14,022	533	2,456	2,091	36,760
2043	9,993	-3,014	8,898	14,174	524	2,463	2,017	35,055
2044	8,634	-3,152	8,614	14,325	516	2,470	1,943	33,350
2045	7,275	-3,290	8,330	14,476	508	2,477	1,869	31,645
2046	5,865	-2,831	8,122	14,645	504	2,494	1,823	30,621
2047	4,455	-2,373	7,914	14,814	500	2,510	1,776	29,597
2048	3,045	-1,914	7,706	14,984	496	2,527	1,730	28,573
2049	1,635	-1,455	7,498	15,153	492	2,544	1,683	27,549
2050	225	-996	7,290	15,322	488	2,561	1,636	26,525
Total	**642,673**	**-58,952**	**354,789**	**407,301**	**19,953**	**73,393**	**67,855**	**1,507,012**

Note: Emissions shown have been interpolated for non-model years.

Table C-4.42. Global Emissions Summary for Net Zero 2050 (Moderate CCS): High Exports (GCAM-NETL-Aligned, AR6-20 Basis)

Year	CO_2 Energy	CO_2 LUC	CH_4 Energy	CH_4 Ag	N_2O Energy	N_2O Ag	F Gases	Total
	Units (Tg CO_2e/year) (AR6, 20-year)							
2020	38,333	532	18,199	11,670	886	2,126	2,244	73,991
2021	37,705	571	17,443	11,696	867	2,149	2,252	72,682
2022	37,076	610	16,686	11,722	848	2,172	2,260	71,374
2023	36,447	650	15,929	11,747	829	2,195	2,268	70,065
2024	35,818	689	15,172	11,773	811	2,218	2,276	68,756
2025	35,190	728	14,415	11,799	792	2,241	2,284	67,448
2026	33,730	76	14,012	11,903	774	2,258	2,324	65,077
2027	32,270	-576	13,609	12,007	757	2,276	2,364	62,706
2028	30,810	-1,227	13,206	12,110	739	2,293	2,404	60,335
2029	29,350	-1,879	12,802	12,214	721	2,310	2,444	57,963
2030	27,890	-2,531	12,399	12,318	703	2,328	2,484	55,592
2031	26,518	-2,796	12,076	12,445	685	2,338	2,461	53,727
2032	25,145	-3,060	11,752	12,571	668	2,348	2,438	51,862
2033	23,773	-3,325	11,428	12,698	650	2,358	2,415	49,996
2034	22,401	-3,590	11,105	12,825	632	2,368	2,392	48,131
2035	21,028	-3,855	10,781	12,951	614	2,378	2,369	46,266
2036	19,652	-3,604	10,575	13,105	601	2,391	2,343	45,062
2037	18,275	-3,354	10,369	13,259	588	2,404	2,317	43,859
2038	16,899	-3,103	10,164	13,412	575	2,416	2,292	42,656
2039	15,523	-2,852	9,958	13,566	562	2,429	2,266	41,452
2040	14,146	-2,601	9,752	13,720	549	2,442	2,241	40,249
2041	12,789	-2,740	9,464	13,871	541	2,449	2,167	38,539
2042	11,432	-2,879	9,175	14,022	532	2,456	2,092	36,830
2043	10,075	-3,018	8,887	14,173	524	2,463	2,018	35,121
2044	8,717	-3,158	8,598	14,324	516	2,470	1,944	33,412
2045	7,360	-3,297	8,310	14,475	508	2,477	1,870	31,702
2046	5,959	-2,853	8,099	14,644	504	2,493	1,823	30,669
2047	4,557	-2,410	7,888	14,813	500	2,510	1,776	29,635
2048	3,156	-1,966	7,678	14,982	496	2,527	1,730	28,601
2049	1,754	-1,523	7,467	15,151	491	2,543	1,683	27,567
2050	353	-1,079	7,256	15,320	487	2,560	1,636	26,534
Total	**644,132**	**-59,419**	**354,650**	**407,283**	**19,949**	**73,386**	**67,876**	**1,507,858**

Note: Emissions shown have been interpolated for non-model years.

C. Summary Consequential Result Tables

The remaining tables summarize values of U.S. LNG Exports and GHG emissions used for calculating the consequential GHG intensity and PNDE factors on an annual and cumulative basis for all scenarios (including sensitivity scenarios) in the Consequential Analysis Appendix.

Note: U.S. LNG export and GHG emissions values were interpolated for non-model years. Also, consequential and PNDE results have been removed from these tables for years with zero or near-zero changes in GHG emissions or U.S. LNG exports that lead to extraneous annual results.

Table C-4.43. Annual and Cumulative Emissions, U.S. LNG Exports, and Consequential Analysis of Defined Policies Scenarios (AR6-100 Basis)

Year	*DP: ExFID*		*DP: MR*		*DP: MR vs ExFID*				*DP: Hi Exp*		*DP: Hi Exp vs ExFID*			
	US LNG EJ	GHG Tg CO_2e	US LNG EJ	GHG Tg CO_2e	Δ LNG EJ	Δ GHG Tg CO_2e	Cons GHG g CO_2e/MJ	PNDE g CO_2e/MJ	US LNG EJ	GHG Tg CO_2e	Δ LNG EJ	Δ GHG Tg CO_2e	Cons GHG g CO_2e/MJ	PNDE g CO_2e/MJ
2020	2.4	53,770	2.4	53,770	0.0	0.0			2.4	53,770	0.0	0.0		
2021	3.2	53,219	3.2	53,219	0.0	0.0			3.2	53,219	0.0	0.0		
2022	4.0	52,669	4.0	52,669	0.0	0.0			4.0	52,669	0.0	0.0		
2023	4.8	52,118	4.8	52,118	0.0	0.0			4.8	52,118	0.0	0.0		
2024	5.6	51,567	5.6	51,567	0.0	0.0			5.6	51,567	0.0	0.0		
2025	6.3	51,017	6.3	51,017	0.0	0.0			6.3	51,017	0.0	0.0		
2026	6.5	50,645	6.5	50,645	0.0	0.0			6.5	50,645	0.0	0.0		
2027	6.6	50,273	6.6	50,273	0.0	0.0			6.6	50,273	0.0	0.0		
2028	6.7	49,901	6.7	49,901	0.0	0.0			6.7	49,901	0.0	0.0		
2029	6.8	49,529	6.8	49,529	0.0	0.0			6.8	49,529	0.0	0.0		
2030	7.0	49,156	7.0	49,156	0.0	0.0			7.0	49,156	0.0	0.0		
2031	7.3	49,364	7.5	49,365	0.2	0.6	3.1	-11.4	7.8	49,365	0.6	1.3	2.4	-12.1
2032	7.6	49,572	8.0	49,573	0.4	1.2	3.1	-11.4	8.7	49,574	1.1	2.7	2.4	-12.1
2033	7.9	49,779	8.5	49,781	0.6	1.8	3.1	-11.4	9.6	49,783	1.7	4.0	2.4	-12.1
2034	8.2	49,987	9.0	49,989	0.8	2.3	3.1	-11.4	10.4	49,992	2.2	5.3	2.4	-12.1
2035	8.5	50,194	9.5	50,197	1.0	2.9	3.1	-11.4	11.3	50,201	2.8	6.7	2.4	-12.1
2036	8.5	50,033	10.4	50,046	1.8	12.7	6.9	-7.6	12.5	50,062	4.0	29.3	7.3	-7.2
2037	8.5	49,872	11.3	49,894	2.7	22.6	8.3	-6.3	13.8	49,924	5.3	51.8	9.9	-4.6
2038	8.5	49,711	12.2	49,743	3.6	32.4	8.9	-5.6	15.0	49,785	6.5	74.4	11.5	-3.1
2039	8.5	49,549	13.0	49,592	4.5	42.2	9.4	-5.2	16.3	49,647	7.7	97.0	12.5	-2.0
2040	8.5	49,388	13.9	49,440	5.4	52.0	9.6	-4.9	17.5	49,508	9.0	119.6	13.3	-1.2
2041	8.5	49,364	14.7	49,418	6.2	54.1	8.8	-5.7	18.7	49,483	10.1	119.1	11.8	-2.8
2042	8.5	49,340	15.5	49,396	6.9	56.3	8.1	-6.4	19.8	49,458	11.3	118.6	10.5	-4.0
2043	8.5	49,315	16.3	49,374	7.7	58.5	7.6	-6.9	20.9	49,433	12.4	118.1	9.5	-5.0
2044	8.5	49,291	17.0	49,352	8.5	60.6	7.1	-7.4	22.1	49,409	13.5	117.6	8.7	-5.8
2045	8.5	49,267	17.8	49,329	9.3	62.8	6.8	-7.7	23.2	49,384	14.7	117.1	8.0	-6.5
2046	8.5	49,141	18.3	49,200	9.8	58.4	6.0	-8.5	24.1	49,250	15.5	109.3	7.0	-7.5
2047	8.5	49,016	18.8	49,070	10.2	54.0	5.3	-9.3	24.9	49,117	16.4	101.5	6.2	-8.3
2048	8.5	48,890	19.3	48,940	10.7	49.6	4.6	-9.9	25.8	48,984	17.2	93.8	5.4	-9.1
2049	8.5	48,765	19.8	48,810	11.2	45.2	4.0	-10.5	26.6	48,851	18.1	86.0	4.8	-9.8
2050	8.5	48,639	20.3	48,680	11.7	40.8	3.5	-11.0	27.5	48,717	18.9	78.2	4.1	-10.4
Cum.	**227**	**1,552,340**	**341**	**1,553,051**	**113**	**711**	**6.3**	**-8.2**	**416**	**1,553,792**	**189**	**1,452**	**7.7**	**-6.8**

Table C-4.44. Annual and Cumulative Emissions, U.S. LNG Exports, and Consequential Analysis of DP High Middle East Supply Scenarios (AR6-100 Basis)

Year	DP Hi ME Sup: ExFID			DP Hi ME Sup: MR		DP Hi ME Sup: MR vs ExFID			
	US LNG EJ	GHG Tg CO_2e		US LNG EJ	GHG Tg CO_2e	D LNG EJ	D GHG Tg CO_2e	Cons GHG g CO_2e/MJ	PNDE g CO_2e/MJ
2020	2.4	53,780		2.4	53,780	0.0	0.0		
2021	3.2	53,230		3.2	53,230	0.0	0.0		
2022	4.0	52,681		4.0	52,681	0.0	0.0		
2023	4.8	52,131		4.8	52,131	0.0	0.0		
2024	5.6	51,582		5.6	51,582	0.0	0.0		
2025	6.3	51,032		6.3	51,032	0.0	0.0		
2026	6.5	50,662		6.5	50,662	0.0	0.0		
2027	6.6	50,291		6.6	50,291	0.0	0.0		
2028	6.8	49,921		6.8	49,921	0.0	0.0		
2029	6.9	49,551		6.9	49,551	0.0	0.0		
2030	7.1	49,180		7.1	49,180	0.0	0.0		
2031	7.4	49,401		7.6	49,402	0.2	0.5	2.2	-12.3
2032	7.7	49,623		8.1	49,624	0.4	1.0	2.2	-12.3
2033	8.0	49,844		8.6	49,845	0.7	1.5	2.2	-12.3
2034	8.2	50,065		9.1	50,067	0.9	2.0	2.2	-12.3
2035	8.5	50,286		9.7	50,288	1.1	2.5	2.2	-12.3
2036	8.5	50,158		10.4	50,166	1.9	8.0	4.2	-10.3
2037	8.5	50,030		11.2	50,044	2.6	13.4	5.1	-9.4
2038	8.5	49,903		11.9	49,922	3.4	18.9	5.6	-9.0
2039	8.5	49,775		12.7	49,799	4.1	24.3	5.9	-8.7
2040	8.5	49,647		13.4	49,677	4.9	29.8	6.1	-8.4
2041	8.5	49,635		14.1	49,666	5.5	30.8	5.6	-9.0
2042	8.5	49,623		14.7	49,654	6.1	31.7	5.2	-9.4
2043	8.5	49,610		15.3	49,643	6.8	32.7	4.8	-9.7
2044	8.5	49,598		15.9	49,632	7.4	33.7	4.6	-10.0
2045	8.5	49,586		16.5	49,620	8.0	34.7	4.3	-10.2
2046	8.5	49,468		17.0	49,497	8.4	29.6	3.5	-11.0
2047	8.5	49,350		17.4	49,375	8.8	24.5	2.8	-11.7
2048	8.5	49,232		17.8	49,252	9.3	19.5	2.1	-12.4
2049	8.5	49,114		18.2	49,129	9.7	14.4	1.5	-13.0
2050	8.5	48,996		18.6	49,006	10.1	9.3	0.9	-13.6
Cum.	**228**	**1,556,984**		**329**	**1,557,347**	**100**	**363**	**3.6**	**-10.9**

Table C-4.45. Annual and Cumulative Emissions, U.S. LNG Exports, and Consequential Analysis of DP High U.S. Supply Scenarios (AR6-100 Basis)

Year	*DP Hi US Sup: ExFID*			*DP Hi US Sup: MR*		*DP Hi US Sup: MR vs ExFID*			
	US LNG EJ	GHG Tg CO_2e		US LNG EJ	GHG Tg CO_2e	D LNG EJ	D GHG Tg CO_2e	Cons GHG g CO_2e/MJ	PNDE g CO_2e/MJ
2020	2.4	53,766		2.4	53,766	0.0	0.0		
2021	3.2	53,216		3.2	53,216	0.0	0.0		
2022	4.0	52,667		4.0	52,667	0.0	0.0		
2023	4.8	52,117		4.8	52,117	0.0	0.0		
2024	5.6	51,568		5.6	51,568	0.0	0.0		
2025	6.3	51,019		6.3	51,019	0.0	0.0		
2026	6.5	50,647		6.5	50,647	0.0	0.0		
2027	6.6	50,276		6.6	50,276	0.0	0.0		
2028	6.8	49,905		6.8	49,905	0.0	0.0		
2029	6.9	49,534		6.9	49,534	0.0	0.0		
2030	7.0	49,162		7.0	49,162	0.0	0.0		
2031	7.3	49,371		7.6	49,372	0.3	0.8	2.8	-11.7
2032	7.6	49,580		8.2	49,581	0.6	1.6	2.8	-11.7
2033	7.9	49,788		8.8	49,791	0.9	2.4	2.8	-11.7
2034	8.2	49,997		9.4	50,000	1.2	3.3	2.8	-11.7
2035	8.5	50,205		10.0	50,209	1.5	4.1	2.8	-11.7
2036	8.5	50,044		11.1	50,064	2.6	19.6	7.6	-6.9
2037	8.5	49,883		12.2	49,918	3.7	35.2	9.5	-5.0
2038	8.5	49,722		13.3	49,772	4.8	50.7	10.5	-4.0
2039	8.5	49,560		14.5	49,627	5.9	66.2	11.2	-3.3
2040	8.5	49,399		15.6	49,481	7.0	81.8	11.6	-2.9
2041	8.5	49,377		16.7	49,463	8.2	85.1	10.4	-4.1
2042	8.5	49,356		17.8	49,444	9.3	88.4	9.5	-5.0
2043	8.5	49,334		18.9	49,425	10.4	91.7	8.8	-5.7
2044	8.5	49,312		20.0	49,407	11.5	95.1	8.3	-6.3
2045	8.5	49,290		21.1	49,388	12.6	98.4	7.8	-6.7
2046	8.5	49,168		22.0	49,265	13.4	96.4	7.2	-7.3
2047	8.5	49,047		22.8	49,141	14.2	94.4	6.6	-7.9
2048	8.5	48,925		23.6	49,017	15.1	92.3	6.1	-8.4
2049	8.5	48,803		24.4	48,894	15.9	90.3	5.7	-8.8
2050	8.5	48,681		25.2	48,770	16.7	88.3	5.3	-9.2
Cum.	**228**	**1,552,720**		**383**	**1,553,906**	**156**	**1,186**	**7.6**	**-6.9**

Table C-4.46. Annual and Cumulative Emissions, U.S. LNG Exports, and Consequential Analysis of DP Low U.S. Supply Scenarios (AR6-100 Basis)

Year	DP Lo US Sup: ExFID			DP Lo US Sup: MR			DP Lo US Sup: MR vs ExFID		
	US LNG EJ	GHG Tg CO_2e		US LNG EJ	GHG Tg CO_2e	D LNG EJ	D GHG Tg CO_2e	Cons GHG g CO_2e/MJ	PNDE g CO_2e/MJ
2020	2.4	53,794		2.4	53,794	0.0	0.0		
2021	3.2	53,236		3.2	53,236	0.0	0.0		
2022	4.0	52,678		4.0	52,678	0.0	0.0		
2023	4.8	52,119		4.8	52,119	0.0	0.0		
2024	5.5	51,561		5.5	51,561	0.0	0.0		
2025	6.3	51,003		6.3	51,003	0.0	0.0		
2026	6.4	50,624		6.4	50,624	0.0	0.0		
2027	6.4	50,245		6.4	50,245	0.0	0.0		
2028	6.5	49,866		6.5	49,866	0.0	0.0		
2029	6.5	49,487		6.5	49,487	0.0	0.0		
2030	6.6	49,108		6.6	49,108	0.0	0.0		
2031	6.8	49,308		6.8	49,308	0.0	0.0		
2032	7.0	49,508		7.0	49,508	0.0	0.0		
2033	7.2	49,708		7.2	49,708	0.0	0.0		
2034	7.4	49,907		7.4	49,907	0.0	0.0		
2035	7.6	50,107		7.6	50,107	0.0	0.0		
2036	7.8	49,940		7.8	49,940	0.1	0.2	3.2	-11.3
2037	8.0	49,773		8.1	49,774	0.1	0.5	3.2	-11.3
2038	8.1	49,606		8.4	49,607	0.2	0.7	3.2	-11.3
2039	8.3	49,439		8.6	49,440	0.3	1.0	3.2	-11.3
2040	8.5	49,273		8.9	49,274	0.4	1.2	3.2	-11.3
2041	8.5	49,243		9.1	49,244	0.6	1.2	2.0	-12.5
2042	8.5	49,213		9.3	49,214	0.8	1.2	1.5	-13.1
2043	8.5	49,183		9.6	49,184	1.0	1.2	1.1	-13.4
2044	8.5	49,153		9.8	49,154	1.2	1.2	0.9	-13.6
2045	8.5	49,123		10.0	49,124	1.5	1.2	0.8	-13.7
2046	8.5	48,982		10.3	48,984	1.7	2.3	1.3	-13.2
2047	8.5	48,841		10.5	48,845	2.0	3.4	1.7	-12.8
2048	8.5	48,701		10.8	48,705	2.3	4.6	2.0	-12.5
2049	8.5	48,560		11.1	48,566	2.5	5.7	2.3	-12.3
2050	8.5	48,419		11.3	48,426	2.8	6.9	2.5	-12.1
Cum.	**221**	**1,549,708**		**238**	**1,549,740**	**18**	**32**	**1.8**	**-12.7**

Table C-4.47. Annual and Cumulative Emissions, U.S. LNG Exports, and Consequential Analysis of Commitments (High CCS) Scenarios (AR6-100 Basis)

Year	C (High CCS): ExFID		C (High CCS): MR		C (High CCS): MR vs ExFID				C (High CCS): Hi Exp		C (High CCS): Hi Exp vs ExFID			
	US LNG EJ	GHG Tg CO_2e	US LNG EJ	GHG Tg CO_2e	D LNG EJ	D GHG Tg CO_2e	Cons GHG g CO_2e/MJ	PNDE g CO_2e/MJ	US LNG EJ	GHG Tg CO_2e	D LNG EJ	D GHG Tg CO_2e	Cons GHG g CO_2e/MJ	PNDE g CO_2e/MJ
2020	2.4	53,903	2.4	53,903	0.0	0.0			2.4	53,903	0.0	0.0		
2021	3.2	53,160	3.2	53,160	0.0	0.0			3.2	53,160	0.0	0.0		
2022	4.0	52,417	4.0	52,417	0.0	0.0			4.0	52,417	0.0	0.0		
2023	4.8	51,674	4.8	51,674	0.0	0.0			4.8	51,674	0.0	0.0		
2024	5.6	50,931	5.6	50,931	0.0	0.0			5.6	50,931	0.0	0.0		
2025	6.3	50,188	6.3	50,188	0.0	0.0			6.3	50,188	0.0	0.0		
2026	6.4	50,016	6.4	50,016	0.0	0.0			6.4	50,016	0.0	0.0		
2027	6.5	49,845	6.5	49,845	0.0	0.0			6.5	49,845	0.0	0.0		
2028	6.5	49,674	6.5	49,674	0.0	0.0			6.5	49,674	0.0	0.0		
2029	6.6	49,502	6.6	49,502	0.0	0.0			6.6	49,502	0.0	0.0		
2030	6.7	49,331	6.7	49,331	0.0	0.0			6.7	49,331	0.0	0.0		
2031	6.9	47,989	6.9	47,989	0.0	0.0			7.3	47,991	0.4	1.6	4.4	-10.2
2032	7.1	46,648	7.1	46,648	0.0	0.0			7.8	46,651	0.7	3.1	4.4	-10.2
2033	7.3	45,306	7.3	45,306	0.0	0.0			8.4	45,311	1.1	4.7	4.4	-10.2
2034	7.5	43,965	7.5	43,965	0.0	0.0			9.0	43,971	1.4	6.3	4.4	-10.2
2035	7.8	42,623	7.8	42,623	0.0	0.0			9.6	42,631	1.8	7.8	4.4	-10.2
2036	7.9	41,510	8.2	41,507	0.3	-2.8	-10.5	-25.0	10.3	41,524	2.4	14.1	5.8	-8.7
2037	8.1	40,396	8.6	40,390	0.5	-5.7	-10.5	-25.0	11.1	40,416	3.1	20.3	6.6	-7.9
2038	8.2	39,282	9.0	39,273	0.8	-8.5	-10.5	-25.0	11.9	39,308	3.7	26.5	7.2	-7.4
2039	8.4	38,168	9.5	38,157	1.1	-11.4	-10.5	-25.0	12.7	38,201	4.3	32.7	7.6	-7.0
2040	8.5	37,054	9.9	37,040	1.4	-14.2	-10.5	-25.0	13.5	37,093	5.0	38.9	7.8	-6.7
2041	8.5	35,492	10.2	35,487	1.7	-5.1	-3.1	-17.6	14.2	35,543	5.6	51.0	9.1	-5.4
2042	8.5	33,930	10.5	33,934	2.0	4.0	2.0	-12.5	14.8	33,993	6.3	63.2	10.0	-4.5
2043	8.5	32,368	10.8	32,381	2.3	13.0	5.7	-8.8	15.5	32,443	7.0	75.3	10.8	-3.7
2044	8.5	30,805	11.1	30,828	2.6	22.1	8.5	-6.0	16.2	30,893	7.6	87.4	11.5	-3.1
2045	8.5	29,243	11.4	29,274	2.9	31.2	10.8	-3.7	16.8	29,343	8.3	99.5	12.0	-2.5
2046	8.5	27,683	11.5	27,708	3.0	25.7	8.6	-5.9	17.3	27,766	8.8	83.3	9.5	-5.0
2047	8.5	26,122	11.6	26,142	3.1	20.3	6.5	-8.0	17.8	26,189	9.2	67.1	7.3	-7.2
2048	8.5	24,561	11.7	24,576	3.2	14.8	4.6	-9.9	18.2	24,612	9.7	50.9	5.3	-9.3
2049	8.5	23,001	11.8	23,010	3.3	9.3	2.8	-11.7	18.7	23,036	10.1	34.6	3.4	-11.1
2050	8.5	21,440	11.9	21,444	3.4	3.8	1.1	-13.4	19.1	21,459	10.6	18.4	1.7	-12.8
Cum.	**222**	**1,268,227**	**254**	**1,268,324**	**31**	**97**	**3.1**	**-11.4**	**329**	**1,269,014**	**107**	**787**	**7.3**	**-7.2**

Table C-4.48. Annual and Cumulative Emissions, U.S. LNG Exports, and Consequential Analysis of Commitments (Moderate CCS) Scenarios (AR6-100 Basis)

Year	C (Mod CCS): ExFID		C (Mod CCS): MR		C (Mod CCS): MR vs ExFID				C (Mod CCS): Hi Exp		C (Mod CCS): Hi Exp vs ExFID			
	US LNG EJ	GHG Tg CO_2e	US LNG EJ	GHG Tg CO_2e	Δ LNG EJ	Δ GHG Tg CO_2e	Cons GHG g CO_2e/MJ	PNDE g CO_2e/MJ	US LNG EJ	GHG Tg CO_2e	Δ LNG EJ	Δ GHG Tg CO_2e	Cons GHG g CO_2e/MJ	PNDE g CO_2e/MJ
2020	2.4	53,903	2.4	53,903	0.0	0.0			2.4	53,903	0.0	0.0		
2021	3.2	53,061	3.2	53,061	0.0	0.0			3.2	53,061	0.0	0.0		
2022	4.0	52,220	4.0	52,220	0.0	0.0			4.0	52,220	0.0	0.0		
2023	4.8	51,378	4.8	51,378	0.0	0.0			4.8	51,378	0.0	0.0		
2024	5.6	50,536	5.6	50,536	0.0	0.0			5.6	50,536	0.0	0.0		
2025	6.3	49,694	6.3	49,694	0.0	0.0			6.3	49,694	0.0	0.0		
2026	6.4	49,527	6.4	49,527	0.0	0.0			6.4	49,527	0.0	0.0		
2027	6.4	49,359	6.4	49,359	0.0	0.0			6.4	49,359	0.0	0.0		
2028	6.5	49,191	6.5	49,191	0.0	0.0			6.5	49,191	0.0	0.0		
2029	6.6	49,024	6.6	49,024	0.0	0.0			6.6	49,024	0.0	0.0		
2030	6.6	48,856	6.6	48,856	0.0	0.0			6.6	48,856	0.0	0.0		
2031	6.8	47,265	6.8	47,265	0.0	0.0			7.1	47,278	0.4	12.9	35.8	21.3
2032	6.9	45,674	6.9	45,674	0.0	0.0			7.6	45,700	0.7	25.8	35.8	21.2
2033	7.1	44,084	7.1	44,084	0.0	0.0			8.2	44,122	1.1	38.7	35.8	21.2
2034	7.2	42,493	7.2	42,493	0.0	0.0			8.7	42,545	1.4	51.5	35.8	21.2
2035	7.4	40,902	7.4	40,902	0.0	0.0			9.2	40,967	1.8	64.4	35.8	21.2
2036	7.6	39,170	7.7	39,171	0.1	1.6	16.1	1.6	9.9	39,230	2.3	60.3	26.7	12.2
2037	7.8	37,437	8.0	37,440	0.2	3.1	16.1	1.6	10.5	37,493	2.7	56.2	20.7	6.2
2038	8.1	35,704	8.4	35,709	0.3	4.7	16.1	1.6	11.2	35,756	3.2	52.0	16.4	1.9
2039	8.3	33,971	8.7	33,978	0.4	6.3	16.1	1.6	11.9	34,019	3.6	47.9	13.2	-1.3
2040	8.5	32,239	9.0	32,246	0.5	7.8	16.2	1.6	12.6	32,282	4.1	43.7	10.7	-3.8
2041	8.5	30,953	9.1	30,960	0.6	7.4	12.1	-2.4	13.1	30,999	4.6	46.0	10.1	-4.5
2042	8.5	29,668	9.3	29,675	0.7	7.0	9.5	-5.0	13.6	29,716	5.1	48.2	9.5	-5.0
2043	8.5	28,382	9.4	28,389	0.9	6.5	7.6	-6.9	14.1	28,433	5.5	50.5	9.1	-5.4
2044	8.5	27,097	9.5	27,103	1.0	6.1	6.2	-8.3	14.6	27,149	6.0	52.7	8.7	-5.8
2045	8.5	25,811	9.6	25,817	1.1	5.6	5.1	-9.4	15.0	25,866	6.5	54.9	8.4	-6.1
2046	8.5	24,429	9.6	24,433	1.1	4.5	4.0	-10.5	15.4	24,489	6.9	59.9	8.7	-5.8
2047	8.5	23,047	9.7	23,050	1.1	3.3	2.9	-11.6	15.8	23,111	7.2	64.9	9.0	-5.6
2048	8.5	21,664	9.7	21,666	1.1	2.1	1.9	-12.6	16.1	21,734	7.6	69.8	9.2	-5.3
2049	8.5	20,282	9.7	20,283	1.1	0.9	0.8	-13.7	16.5	20,357	8.0	74.8	9.4	-5.1
2050	8.5	18,900	9.7	18,899	1.1	-0.2	-0.2	-14.7	16.9	18,979	8.3	79.7	9.6	-5.0
Cum.	**220**	**1,205,919**	**231**	**1,205,985**	**11**	**67**	**5.9**	**-8.6**	**307**	**1,206,973**	**87**	**1,055**	**12.1**	**-2.4**

Table C-4.49. Annual and Cumulative Emissions, U.S. LNG Exports, and Consequential Analysis of Net Zero 2050 (High CCS) Scenarios (AR6-100 Basis)

Year	NZ (Hi CCS): ExFID		NZ (High CCS): MR		NZ (High CCS): MR vs ExFID				NZ (High CCS): Hi Exp		NZ (High CCS): Hi Exp vs ExFID			
	US LNG EJ	GHG Tg CO_2e	US LNG EJ	GHG Tg CO_2e	Δ LNG EJ	Δ GHG Tg CO_2e	Cons GHG g CO_2e/MJ	PNDE g CO_2e/MJ	US LNG EJ	GHG Tg CO_2e	Δ LNG EJ	Δ GHG Tg CO_2e	Cons GHG g CO_2e/MJ	PNDE g CO_2e/MJ
2020	2.4	53,903	2.4	53,903	0.0	0.0			2.4	53,903	0.0	0.0		
2021	3.2	53,160	3.2	53,160	0.0	0.0			3.2	53,160	0.0	0.0		
2022	4.0	52,417	4.0	52,417	0.0	0.0			4.0	52,417	0.0	0.0		
2023	4.8	51,674	4.8	51,674	0.0	0.0			4.8	51,674	0.0	0.0		
2024	5.6	50,931	5.6	50,931	0.0	0.0			5.6	50,931	0.0	0.0		
2025	6.3	50,188	6.3	50,188	0.0	0.0			6.3	50,188	0.0	0.0		
2026	6.4	48,171	6.4	48,171	0.0	0.0			6.4	48,171	0.0	0.0		
2027	6.4	46,155	6.4	46,155	0.0	0.0			6.4	46,155	0.0	0.0		
2028	6.4	44,138	6.4	44,138	0.0	0.0			6.4	44,138	0.0	0.0		
2029	6.5	42,121	6.5	42,121	0.0	0.0			6.5	42,121	0.0	0.0		
2030	6.5	40,105	6.5	40,105	0.0	0.0			6.5	40,105	0.0	0.0		
2031	6.7	39,193	6.7	39,193	0.0	-0.1			7.0	39,187	0.4	-5.9	-16.4	-30.9
2032	6.8	38,281	6.8	38,281	0.0	-0.2			7.6	38,270	0.7	-11.8	-16.4	-30.9
2033	7.0	37,370	7.0	37,369	0.0	-0.3			8.1	37,352	1.1	-17.7	-16.4	-30.9
2034	7.2	36,458	7.2	36,457	0.0	-0.4			8.6	36,434	1.4	-23.6	-16.4	-30.9
2035	7.4	35,546	7.4	35,546	0.0	-0.5			9.2	35,517	1.8	-29.5	-16.4	-30.9
2036	7.6	33,933	7.7	33,931	0.2	-2.8	-18.6	-33.1	9.9	33,916	2.3	-17.7	-7.7	-22.2
2037	7.8	32,321	8.1	32,316	0.3	-5.2	-17.1	-31.6	10.7	32,315	2.8	-5.9	-2.1	-16.6
2038	8.1	30,708	8.5	30,701	0.5	-7.6	-16.6	-31.1	11.4	30,714	3.3	5.8	1.8	-12.8
2039	8.3	29,095	8.9	29,086	0.6	-9.9	-16.3	-30.8	12.2	29,113	3.8	17.6	4.6	-9.9
2040	8.5	27,483	9.3	27,471	0.8	-12.3	-16.2	-30.7	12.9	27,512	4.4	29.4	6.7	-7.8
2041	8.5	26,115	9.5	26,108	0.9	-6.2	-6.7	-21.2	13.4	26,154	4.9	39.6	8.1	-6.4
2042	8.5	24,746	9.6	24,746	1.1	-0.1	-0.1	-14.6	14.0	24,796	5.4	49.9	9.2	-5.3
2043	8.5	23,378	9.8	23,384	1.3	5.9	4.6	-9.9	14.5	23,438	6.0	60.2	10.1	-4.4
2044	8.5	22,010	10.0	22,022	1.5	12.0	8.3	-6.2	15.0	22,080	6.5	70.4	10.8	-3.7
2045	8.5	20,642	10.2	20,660	1.6	18.1	11.1	-3.4	15.6	20,722	7.0	80.7	11.5	-3.0
2046	8.5	19,147	10.2	19,161	1.6	14.1	8.5	-6.0	16.0	19,207	7.4	59.3	8.0	-6.5
2047	8.5	17,653	10.2	17,663	1.7	10.1	6.0	-8.5	16.3	17,691	7.8	37.8	4.9	-9.7
2048	8.5	16,158	10.2	16,164	1.7	6.0	3.6	-11.0	16.7	16,175	8.2	16.4	2.0	-12.5
2049	8.5	14,664	10.3	14,666	1.7	2.0	1.2	-13.3	17.1	14,659	8.6	-5.0	-0.6	-15.1
2050	8.5	13,169	10.3	13,167	1.7	-2.0	-1.1	-15.7	17.5	13,143	8.9	-26.4	-3.0	-17.5
Cum.	**219**	**1,071,033**	**236**	**1,071,054**	**17**	**21**	**1.2**	**-13.3**	**312**	**1,071,356**	**93**	**324**	**3.5**	**-11.0**

Table C-4.50. Annual and Cumulative Emissions, U.S. LNG Exports, and Consequential Analysis of Net Zero 2050 (Moderate CCS) Scenarios (AR6-100 Basis)

Year	NZ (Mod CCS):ExFID		NZ (Mod CCS): MR		NZ (Mod CCS): MR vs ExFID				NZ (Mod CCS): Hi Exp		NZ (Mod CCS): Hi Exp vs ExFID			
	US LNG EJ	GHG Tg CO_2e	US LNG EJ	GHG Tg CO_2e	Δ LNG EJ	Δ GHG Tg CO_2e	Cons GHG g CO_2e/MJ	PNDE g CO_2e/MJ	US LNG EJ	GHG Tg CO_2e	Δ LNG EJ	Δ GHG Tg CO_2e	Cons GHG g CO_2e/MJ	PNDE g CO_2e/MJ
2020	2.4	53,903	2.4	53,903	0.0	0.0			2.4	53,903	0.0	0.0		
2021	3.2	53,061	3.2	53,061	0.0	0.0			3.2	53,061	0.0	0.0		
2022	4.0	52,220	4.0	52,220	0.0	0.0			4.0	52,220	0.0	0.0		
2023	4.8	51,378	4.8	51,378	0.0	0.0			4.8	51,378	0.0	0.0		
2024	5.6	50,536	5.6	50,536	0.0	0.0			5.6	50,536	0.0	0.0		
2025	6.3	49,694	6.3	49,694	0.0	0.0			6.3	49,694	0.0	0.0		
2026	6.3	47,497	6.3	47,497	0.0	0.0			6.3	47,497	0.0	0.0		
2027	6.4	45,300	6.4	45,300	0.0	0.0			6.4	45,300	0.0	0.0		
2028	6.4	43,103	6.4	43,103	0.0	0.0			6.4	43,103	0.0	0.0		
2029	6.4	40,906	6.4	40,906	0.0	0.0			6.4	40,906	0.0	0.0		
2030	6.4	38,710	6.4	38,710	0.0	0.0			6.4	38,710	0.0	0.0		
2031	6.5	36,973	6.5	36,973	0.0	0.0			6.9	36,978	0.4	4.7	12.9	-1.6
2032	6.6	35,236	6.6	35,236	0.0	0.0			7.3	35,245	0.7	9.3	12.9	-1.6
2033	6.7	33,499	6.7	33,499	0.0	0.0			7.7	33,513	1.1	14.0	12.9	-1.6
2034	6.7	31,763	6.7	31,763	0.0	0.0			8.2	31,781	1.4	18.6	12.9	-1.6
2035	6.8	30,026	6.8	30,026	0.0	0.0			8.6	30,049	1.8	23.3	12.9	-1.6
2036	6.9	28,853	6.9	28,853	0.0	0.0			9.1	28,887	2.2	34.1	15.8	1.3
2037	7.0	27,679	7.0	27,679	0.0	0.0			9.6	27,724	2.5	44.9	17.8	3.3
2038	7.2	26,505	7.2	26,505	0.0	0.0			10.0	26,561	2.9	55.7	19.3	4.8
2039	7.3	25,332	7.3	25,332	0.0	0.0			10.5	25,399	3.2	66.5	20.5	6.0
2040	7.4	24,158	7.4	24,158	0.0	0.0			11.0	24,236	3.6	77.4	21.5	7.0
2041	7.3	22,563	7.3	22,563	0.0	0.0			11.3	22,639	4.0	76.1	19.2	4.7
2042	7.2	20,968	7.2	20,968	0.0	0.0			11.5	21,043	4.3	74.9	17.3	2.8
2043	7.1	19,372	7.1	19,372	0.0	0.0			11.8	19,446	4.7	73.7	15.7	1.2
2044	7.1	17,777	7.1	17,777	0.0	0.0			12.1	17,849	5.0	72.5	14.4	-0.1
2045	7.0	16,181	7.0	16,181	0.0	0.0			12.4	16,253	5.4	71.3	13.2	-1.3
2046	6.8	15,196	6.8	15,196	0.0	0.0			12.6	15,260	5.8	63.4	11.0	-3.5
2047	6.7	14,212	6.7	14,212	0.0	0.0			12.8	14,267	6.1	55.5	9.1	-5.5
2048	6.5	13,227	6.5	13,227	0.0	0.0			13.0	13,274	6.5	47.5	7.3	-7.2
2049	6.3	12,242	6.3	12,242	0.0	0.0			13.2	12,282	6.8	39.6	5.8	-8.7
2050	6.2	11,257	6.2	11,257	0.0	0.0			13.4	11,289	7.2	31.7	4.4	-10.1
Cum.	**195**	**989,329**	**195**	**989,329**	**0**	**0**	**N/A**	**N/A**	**271**	**990,283**	**76**	**955**	**12.6**	**-1.9**

Table C-4.51. Annual and Cumulative Emissions, U.S. LNG Exports, and Consequential Analysis of Defined Policies Scenarios (AR6-20 Basis)

Year	DP: ExFID		DP: MR		DP: MR vs ExFID				DP: Hi Exp		DP: Hi Exp vs ExFID			
	US LNG EJ	GHG Tg CO_2e	US LNG EJ	GHG Tg CO_2e	Δ LNG EJ	Δ GHG Tg CO_2e	Cons GHG g CO_2e/MJ	PNDE g CO_2e/MJ	US LNG EJ	GHG Tg CO_2e	Δ LNG EJ	Δ GHG Tg CO_2e	Cons GHG g CO_2e/MJ	PNDE g CO_2e/MJ
2020	2.4	73,863	2.4	73,863	0.0	0.0			2.4	73,863	0.0	0.0		
2021	3.2	72,973	3.2	72,973	0.0	0.0			3.2	72,973	0.0	0.0		
2022	4.0	72,083	4.0	72,083	0.0	0.0			4.0	72,083	0.0	0.0		
2023	4.8	71,193	4.8	71,193	0.0	0.0			4.8	71,193	0.0	0.0		
2024	5.6	70,303	5.6	70,303	0.0	0.0			5.6	70,303	0.0	0.0		
2025	6.3	69,413	6.3	69,413	0.0	0.0			6.3	69,413	0.0	0.0		
2026	6.5	69,271	6.5	69,271	0.0	0.0			6.5	69,271	0.0	0.0		
2027	6.6	69,129	6.6	69,129	0.0	0.0			6.6	69,129	0.0	0.0		
2028	6.7	68,987	6.7	68,987	0.0	0.0			6.7	68,987	0.0	0.0		
2029	6.8	68,845	6.8	68,845	0.0	0.0			6.8	68,845	0.0	0.0		
2030	7.0	68,703	7.0	68,703	0.0	0.0			7.0	68,703	0.0	0.0		
2031	7.3	69,025	7.5	69,027	0.2	1.6	8.6	-12.7	7.8	69,029	0.6	3.9	7.2	-14.1
2032	7.6	69,348	8.0	69,351	0.4	3.3	8.6	-12.7	8.7	69,356	1.1	7.9	7.2	-14.1
2033	7.9	69,670	8.5	69,675	0.6	4.9	8.6	-12.7	9.6	69,682	1.7	11.8	7.2	-14.1
2034	8.2	69,992	9.0	69,999	0.8	6.5	8.6	-12.7	10.4	70,008	2.2	15.8	7.2	-14.1
2035	8.5	70,314	9.5	70,323	1.0	8.2	8.6	-12.7	11.3	70,334	2.8	19.7	7.2	-14.1
2036	8.5	70,185	10.4	70,204	1.8	18.9	10.3	-11.0	12.5	70,228	4.0	43.2	10.8	-10.5
2037	8.5	70,056	11.3	70,086	2.7	29.7	10.9	-10.4	13.8	70,123	5.3	66.6	12.7	-8.6
2038	8.5	69,927	12.2	69,967	3.6	40.4	11.2	-10.1	15.0	70,017	6.5	90.1	13.9	-7.4
2039	8.5	69,798	13.0	69,849	4.5	51.2	11.4	-9.9	16.3	69,911	7.7	113.5	14.7	-6.6
2040	8.5	69,669	13.9	69,731	5.4	61.9	11.5	-9.8	17.5	69,806	9.0	137.0	15.2	-6.0
2041	8.5	69,744	14.7	69,806	6.2	61.3	9.9	-11.3	18.7	69,877	10.1	132.6	13.1	-8.2
2042	8.5	69,820	15.5	69,881	6.9	60.7	8.8	-12.5	19.8	69,948	11.3	128.2	11.4	-9.9
2043	8.5	69,896	16.3	69,956	7.7	60.1	7.8	-13.5	20.9	70,020	12.4	123.8	10.0	-11.3
2044	8.5	69,971	17.0	70,031	8.5	59.5	7.0	-14.3	22.1	70,091	13.5	119.4	8.8	-12.4
2045	8.5	70,047	17.8	70,106	9.3	58.9	6.4	-14.9	23.2	70,162	14.7	114.9	7.8	-13.4
2046	8.5	70,016	18.3	70,068	9.8	52.0	5.3	-15.9	24.1	70,120	15.5	103.6	6.7	-14.6
2047	8.5	69,985	18.8	70,030	10.2	45.0	4.4	-16.9	24.9	70,077	16.4	92.3	5.6	-15.6
2048	8.5	69,954	19.3	69,992	10.7	38.1	3.5	-17.7	25.8	70,035	17.2	81.0	4.7	-16.6
2049	8.5	69,923	19.8	69,954	11.2	31.1	2.8	-18.5	26.6	69,993	18.1	69.6	3.9	-17.4
2050	8.5	69,892	20.3	69,916	11.7	24.2	2.1	-19.2	27.5	69,950	18.9	58.3	3.1	-18.2
Cum.	**227**	**2,171,997**	**341**	**2,172,715**	**113**	**718**	**6.3**	**-14.9**	**416**	**2,173,530**	**189**	**1,533**	**8.1**	**-13.1**

Table C-4.52. Annual and Cumulative Emissions, U.S. LNG Exports, and Consequential Analysis of DP High Middle East Supply Scenarios (AR6-20 Basis)

Year	*DP Hi ME Sup: ExFID*		*DP Hi ME Sup: MR*		*DP Hi ME Sup: MR vs ExFID*			
	US LNG EJ	GHG Tg CO_2e	US LNG EJ	GHG Tg CO_2e	D LNG EJ	D GHG Tg CO_2e	Cons GHG g CO_2e/MJ	PNDE g CO_2e/MJ
2020	2.4	73,874	2.4	73,874	0.0	0.0		
2021	3.2	72,985	3.2	72,985	0.0	0.0		
2022	4.0	72,097	4.0	72,097	0.0	0.0		
2023	4.8	71,208	4.8	71,208	0.0	0.0		
2024	5.6	70,319	5.6	70,319	0.0	0.0		
2025	6.3	69,431	6.3	69,431	0.0	0.0		
2026	6.5	69,292	6.5	69,292	0.0	0.0		
2027	6.6	69,154	6.6	69,154	0.0	0.0		
2028	6.8	69,016	6.8	69,016	0.0	0.0		
2029	6.9	68,877	6.9	68,877	0.0	0.0		
2030	7.1	68,739	7.1	68,739	0.0	0.0		
2031	7.4	69,080	7.6	69,081	0.2	1.0	4.6	-16.7
2032	7.7	69,421	8.1	69,423	0.4	2.1	4.6	-16.7
2033	8.0	69,762	8.6	69,766	0.7	3.1	4.6	-16.7
2034	8.2	70,104	9.1	70,108	0.9	4.2	4.6	-16.7
2035	8.5	70,445	9.7	70,450	1.1	5.2	4.6	-16.7
2036	8.5	70,357	10.4	70,367	1.9	9.8	5.2	-16.1
2037	8.5	70,269	11.2	70,283	2.6	14.4	5.5	-15.8
2038	8.5	70,181	11.9	70,200	3.4	19.0	5.6	-15.7
2039	8.5	70,093	12.7	70,116	4.1	23.6	5.7	-15.6
2040	8.5	70,005	13.4	70,033	4.9	28.2	5.7	-15.5
2041	8.5	70,096	14.1	70,123	5.5	27.2	4.9	-16.3
2042	8.5	70,188	14.7	70,214	6.1	26.2	4.3	-17.0
2043	8.5	70,279	15.3	70,304	6.8	25.2	3.7	-17.5
2044	8.5	70,370	15.9	70,395	7.4	24.2	3.3	-18.0
2045	8.5	70,462	16.5	70,485	8.0	23.2	2.9	-18.4
2046	8.5	70,442	17.0	70,458	8.4	16.5	2.0	-19.3
2047	8.5	70,422	17.4	70,432	8.8	9.8	1.1	-20.2
2048	8.5	70,402	17.8	70,405	9.3	3.1	0.3	-20.9
2049	8.5	70,382	18.2	70,379	9.7	-3.6	-0.4	-21.6
2050	8.5	70,362	18.6	70,352	10.1	-10.3	-1.0	-22.3
Cum.	**228**	**2,178,114**	**329**	**2,178,366**	**100**	**252**	**2.5**	**-18.8**

Table C-4.53. Annual and Cumulative Emissions, U.S. LNG Exports, and Consequential Analysis of DP High U.S. Supply Scenarios (AR6-20 Basis)

Year	DP Hi US Sup: ExFID			DP Hi US Sup: MR		DP Hi US Sup: MR vs ExFID			
	US LNG EJ	GHG Tg CO_2e		US LNG EJ	GHG Tg CO_2e	D LNG EJ	D GHG Tg CO_2e	Cons GHG g CO_2e/MJ	PNDE g CO_2e/MJ
2020	2.4	73,858		2.4	73,858	0.0	0.0		
2021	3.2	72,970		3.2	72,970	0.0	0.0		
2022	4.0	72,081		4.0	72,081	0.0	0.0		
2023	4.8	71,192		4.8	71,192	0.0	0.0		
2024	5.6	70,304		5.6	70,304	0.0	0.0		
2025	6.3	69,415		6.3	69,415	0.0	0.0		
2026	6.5	69,274		6.5	69,274	0.0	0.0		
2027	6.6	69,133		6.6	69,133	0.0	0.0		
2028	6.8	68,992		6.8	68,992	0.0	0.0		
2029	6.9	68,851		6.9	68,851	0.0	0.0		
2030	7.0	68,710		7.0	68,710	0.0	0.0		
2031	7.3	69,033		7.6	69,036	0.3	2.4	8.1	-13.1
2032	7.6	69,356		8.2	69,361	0.6	4.7	8.1	-13.1
2033	7.9	69,680		8.8	69,687	0.9	7.1	8.1	-13.1
2034	8.2	70,003		9.4	70,012	1.2	9.5	8.1	-13.1
2035	8.5	70,326		10.0	70,338	1.5	11.9	8.1	-13.1
2036	8.5	70,197		11.1	70,226	2.6	28.8	11.2	-10.1
2037	8.5	70,068		12.2	70,113	3.7	45.7	12.4	-8.9
2038	8.5	69,939		13.3	70,001	4.8	62.7	13.0	-8.2
2039	8.5	69,810		14.5	69,889	5.9	79.6	13.4	-7.8
2040	8.5	69,681		15.6	69,777	7.0	96.5	13.7	-7.6
2041	8.5	69,759		16.7	69,856	8.2	97.0	11.9	-9.4
2042	8.5	69,837		17.8	69,935	9.3	97.5	10.5	-10.7
2043	8.5	69,916		18.9	70,014	10.4	98.1	9.4	-11.8
2044	8.5	69,994		20.0	70,093	11.5	98.6	8.6	-12.7
2045	8.5	70,073		21.1	70,172	12.6	99.1	7.9	-13.4
2046	8.5	70,046		22.0	70,140	13.4	94.3	7.0	-14.2
2047	8.5	70,019		22.8	70,108	14.2	89.4	6.3	-15.0
2048	8.5	69,992		23.6	70,077	15.1	84.6	5.6	-15.6
2049	8.5	69,965		24.4	70,045	15.9	79.8	5.0	-16.2
2050	8.5	69,938		25.2	70,013	16.7	75.0	4.5	-16.8
Cum.	**228**	**2,172,411**		**383**	**2,173,673**	**156**	**1,262**	**8.1**	**-13.2**

Table C-4.54. Annual and Cumulative Emissions, U.S. LNG Exports, and Consequential Analysis of DP Low U.S. Supply Scenarios (AR6-20 Basis)

Year	DP Lo US Sup: ExFID			DP Lo US Sup: MR		DP Lo US Sup: MR vs ExFID			
	US LNG EJ	GHG Tg CO_2e		US LNG EJ	GHG Tg CO_2e	D LNG EJ	D GHG Tg CO_2e	Cons GHG g CO_2e/MJ	PNDE g CO_2e/MJ
2020	2.4	73,889		2.4	73,889	0.0	0.0		
2021	3.2	72,990		3.2	72,990	0.0	0.0		
2022	4.0	72,092		4.0	72,092	0.0	0.0		
2023	4.8	71,193		4.8	71,193	0.0	0.0		
2024	5.5	70,295		5.5	70,295	0.0	0.0		
2025	6.3	69,396		6.3	69,396	0.0	0.0		
2026	6.4	69,246		6.4	69,246	0.0	0.0		
2027	6.4	69,097		6.4	69,097	0.0	0.0		
2028	6.5	68,947		6.5	68,947	0.0	0.0		
2029	6.5	68,797		6.5	68,797	0.0	0.0		
2030	6.6	68,648		6.6	68,648	0.0	0.0		
2031	6.8	68,962		6.8	68,962	0.0	0.0		
2032	7.0	69,276		7.0	69,276	0.0	0.0		
2033	7.2	69,590		7.2	69,590	0.0	0.0		
2034	7.4	69,904		7.4	69,904	0.0	0.0		
2035	7.6	70,218		7.6	70,218	0.0	0.0		
2036	7.8	70,083		7.8	70,084	0.1	0.3	4.2	-17.0
2037	8.0	69,949		8.1	69,949	0.1	0.6	4.2	-17.0
2038	8.1	69,814		8.4	69,815	0.2	0.9	4.3	-17.0
2039	8.3	69,680		8.6	69,681	0.3	1.3	4.3	-17.0
2040	8.5	69,546		8.9	69,547	0.4	1.6	4.3	-17.0
2041	8.5	69,615		9.1	69,616	0.6	1.2	2.0	-19.3
2042	8.5	69,683		9.3	69,684	0.8	0.8	1.0	-20.3
2043	8.5	69,752		9.6	69,753	1.0	0.4	0.4	-20.9
2044	8.5	69,821		9.8	69,821	1.2	0.0	0.0	-21.3
2045	8.5	69,890		10.0	69,890	1.5	-0.4	-0.3	-21.5
2046	8.5	69,844		10.3	69,844	1.7	0.5	0.3	-21.0
2047	8.5	69,798		10.5	69,799	2.0	1.4	0.7	-20.6
2048	8.5	69,751		10.8	69,754	2.3	2.3	1.0	-20.2
2049	8.5	69,705		11.1	69,708	2.5	3.2	1.3	-20.0
2050	8.5	69,659		11.3	69,663	2.8	4.1	1.5	-19.8
Cum.	**221**	**2,169,129**		**238**	**2,169,147**	**18**	**18**	**1.0**	**-20.2**

Table C-4.55. Annual and Cumulative Emissions, U.S. LNG Exports, and Consequential Analysis of Commitments (High CCS) Scenarios (AR6-20 Basis)

Year	C (High CCS): ExFID		C (High CCS): MR		C (High CCS): MR vs ExFID				C (High CCS): Hi Exp		C (High CCS): Hi Exp vs ExFID			
	US LNG EJ	GHG Tg CO_2e	US LNG EJ	GHG Tg CO_2e	D LNG EJ	D GHG Tg CO_2e	Cons GHG g CO_2e/MJ	PNDE g CO_2e/MJ	US LNG EJ	GHG Tg CO_2e	D LNG EJ	D GHG Tg CO_2e	Cons GHG g CO_2e/MJ	PNDE g CO_2e/MJ
2020	2.4	73,991	2.4	73,991	0.0	0.0			2.4	73,991	0.0	0.0		
2021	3.2	72,853	3.2	72,853	0.0	0.0			3.2	72,853	0.0	0.0		
2022	4.0	71,716	4.0	71,716	0.0	0.0			4.0	71,716	0.0	0.0		
2023	4.8	70,579	4.8	70,579	0.0	0.0			4.8	70,579	0.0	0.0		
2024	5.6	69,441	5.6	69,441	0.0	0.0			5.6	69,441	0.0	0.0		
2025	6.3	68,304	6.3	68,304	0.0	0.0			6.3	68,304	0.0	0.0		
2026	6.4	68,351	6.4	68,351	0.0	0.0			6.4	68,351	0.0	0.0		
2027	6.5	68,399	6.5	68,399	0.0	0.0			6.5	68,399	0.0	0.0		
2028	6.5	68,446	6.5	68,446	0.0	0.0			6.5	68,446	0.0	0.0		
2029	6.6	68,493	6.6	68,493	0.0	0.0			6.6	68,493	0.0	0.0		
2030	6.7	68,541	6.7	68,541	0.0	0.0			6.7	68,541	0.0	0.0		
2031	6.9	67,133	6.9	67,133	0.0	0.0			7.3	67,136	0.4	3.4	9.5	-11.7
2032	7.1	65,725	7.1	65,725	0.0	0.0			7.8	65,732	0.7	6.9	9.5	-11.7
2033	7.3	64,317	7.3	64,317	0.0	0.0			8.4	64,327	1.1	10.3	9.5	-11.7
2034	7.5	62,909	7.5	62,909	0.0	0.0			9.0	62,923	1.4	13.7	9.5	-11.7
2035	7.8	61,501	7.8	61,501	0.0	0.0			9.6	61,518	1.8	17.1	9.5	-11.7
2036	7.9	60,365	8.2	60,362	0.3	-2.9	-10.6	-31.8	10.3	60,386	2.4	21.4	8.8	-12.5
2037	8.1	59,228	8.6	59,222	0.5	-5.7	-10.6	-31.8	11.1	59,253	3.1	25.6	8.3	-12.9
2038	8.2	58,091	9.0	58,082	0.8	-8.6	-10.6	-31.8	11.9	58,121	3.7	29.8	8.1	-13.2
2039	8.4	56,954	9.5	56,943	1.1	-11.5	-10.6	-31.8	12.7	56,988	4.3	34.0	7.9	-13.4
2040	8.5	55,817	9.9	55,803	1.4	-14.3	-10.6	-31.8	13.5	55,856	5.0	38.2	7.7	-13.6
2041	8.5	54,079	10.2	54,072	1.7	-6.8	-4.1	-25.4	14.2	54,125	5.6	46.6	8.3	-13.0
2042	8.5	52,340	10.5	52,341	2.0	0.7	0.4	-20.9	14.8	52,395	6.3	54.9	8.7	-12.5
2043	8.5	50,601	10.8	50,610	2.3	8.3	3.6	-17.6	15.5	50,665	7.0	63.3	9.1	-12.2
2044	8.5	48,863	11.1	48,879	2.6	15.8	6.1	-15.1	16.2	48,934	7.6	71.6	9.4	-11.9
2045	8.5	47,124	11.4	47,147	2.9	23.4	8.1	-13.2	16.8	47,204	8.3	80.0	9.6	-11.6
2046	8.5	45,463	11.5	45,480	3.0	16.8	5.6	-15.6	17.3	45,523	8.8	60.6	6.9	-14.4
2047	8.5	43,802	11.6	43,812	3.1	10.3	3.3	-17.9	17.8	43,843	9.2	41.2	4.5	-16.8
2048	8.5	42,141	11.7	42,144	3.2	3.8	1.2	-20.1	18.2	42,162	9.7	21.8	2.3	-19.0
2049	8.5	40,479	11.8	40,477	3.3	-2.8	-0.8	-22.1	18.7	40,482	10.1	2.4	0.2	-21.0
2050	8.5	38,818	11.9	38,809	3.4	-9.3	-2.7	-24.0	19.1	38,801	10.6	-17.0	-1.6	-22.9
Cum.	**222**	**1,844,865**	**254**	**1,844,882**	**31**	**17**	**0.6**	**-20.7**	**329**	**1,845,490**	**107**	**626**	**5.8**	**-15.4**

Table C-4.56. Annual and Cumulative Emissions, U.S. LNG Exports, and Consequential Analysis of Commitments (Moderate CCS) Scenarios (AR6-20 Basis)

Year	C (Mod CCS): ExFID		C (Mod CCS): MR		C (Mod CCS): MR vs ExFID				C (Mod CCS): Hi Exp		C (Mod CCS): Hi Exp vs ExFID			
	US LNG EJ	GHG Tg CO_2e	US LNG EJ	GHG Tg CO_2e	D LNG EJ	D GHG Tg CO_2e	Cons GHG g CO_2e/MJ	PNDE g CO_2e/MJ	US LNG EJ	GHG Tg CO_2e	D LNG EJ	D GHG Tg CO_2e	Cons GHG g CO_2e/MJ	PNDE g CO_2e/MJ
2020	2.4	73,991	2.4	73,991	0.0	0.0			2.4	73,991	0.0	0.0		
2021	3.2	72,682	3.2	72,682	0.0	0.0			3.2	72,682	0.0	0.0		
2022	4.0	71,374	4.0	71,374	0.0	0.0			4.0	71,374	0.0	0.0		
2023	4.8	70,065	4.8	70,065	0.0	0.0			4.8	70,065	0.0	0.0		
2024	5.6	68,756	5.6	68,756	0.0	0.0			5.6	68,756	0.0	0.0		
2025	6.3	67,448	6.3	67,448	0.0	0.0			6.3	67,448	0.0	0.0		
2026	6.4	67,501	6.4	67,501	0.0	0.0			6.4	67,501	0.0	0.0		
2027	6.4	67,554	6.4	67,554	0.0	0.0			6.4	67,554	0.0	0.0		
2028	6.5	67,608	6.5	67,608	0.0	0.0			6.5	67,608	0.0	0.0		
2029	6.6	67,661	6.6	67,661	0.0	0.0			6.6	67,661	0.0	0.0		
2030	6.6	67,714	6.6	67,714	0.0	0.0			6.6	67,714	0.0	0.0		
2031	6.8	65,928	6.8	65,928	0.0	0.0			7.1	65,943	0.4	14.5	40.2	18.9
2032	6.9	64,143	6.9	64,143	0.0	0.0			7.6	64,171	0.7	28.9	40.1	18.9
2033	7.1	62,357	7.1	62,357	0.0	0.0			8.2	62,400	1.1	43.4	40.1	18.9
2034	7.2	60,571	7.2	60,571	0.0	0.0			8.7	60,629	1.4	57.8	40.1	18.9
2035	7.4	58,785	7.4	58,785	0.0	0.0			9.2	58,857	1.8	72.3	40.1	18.9
2036	7.6	56,926	7.7	56,928	0.1	1.6	16.2	-5.0	9.9	56,992	2.3	65.8	29.1	7.8
2037	7.8	55,068	8.0	55,071	0.2	3.2	16.3	-5.0	10.5	55,127	2.7	59.2	21.8	0.5
2038	8.1	53,209	8.4	53,214	0.3	4.7	16.3	-5.0	11.2	53,262	3.2	52.6	16.6	-4.7
2039	8.3	51,350	8.7	51,357	0.4	6.3	16.3	-5.0	11.9	51,396	3.6	46.1	12.7	-8.6
2040	8.5	49,492	9.0	49,500	0.5	7.9	16.3	-5.0	12.6	49,531	4.1	39.5	9.7	-11.6
2041	8.5	48,084	9.1	48,091	0.6	6.8	11.2	-10.1	13.1	48,124	4.6	39.6	8.7	-12.6
2042	8.5	46,676	9.3	46,682	0.7	5.7	7.8	-13.5	13.6	46,716	5.1	39.7	7.9	-13.4
2043	8.5	45,269	9.4	45,273	0.9	4.6	5.4	-15.9	14.1	45,308	5.5	39.8	7.2	-14.1
2044	8.5	43,861	9.5	43,864	1.0	3.5	3.6	-17.7	14.6	43,901	6.0	39.9	6.6	-14.7
2045	8.5	42,453	9.6	42,456	1.1	2.4	2.2	-19.1	15.0	42,493	6.5	40.0	6.1	-15.1
2046	8.5	41,017	9.6	41,018	1.1	1.0	0.9	-20.3	15.4	41,061	6.9	44.2	6.4	-14.8
2047	8.5	39,581	9.7	39,581	1.1	-0.3	-0.3	-21.6	15.8	39,630	7.2	48.4	6.7	-14.6
2048	8.5	38,145	9.7	38,143	1.1	-1.7	-1.5	-22.8	16.1	38,198	7.6	52.7	6.9	-14.3
2049	8.5	36,709	9.7	36,706	1.1	-3.0	-2.7	-24.0	16.5	36,766	8.0	56.9	7.1	-14.1
2050	8.5	35,273	9.7	35,268	1.1	-4.4	-3.9	-25.2	16.9	35,334	8.3	61.2	7.3	-13.9
Cum.	**220**	**1,757,251**	**231**	**1,757,289**	**11**	**38**	**3.4**	**-17.9**	**307**	**1,758,194**	**87**	**943**	**10.8**	**-10.4**

Table C-4.57.Annual and Cumulative Emissions, U.S. LNG Exports, and Consequential Analysis of Net Zero 2050 (High CCS) Scenarios (AR6-20 Basis)

Year	NZ (Hi CCS): ExFID		NZ (High CCS): MR		NZ (High CCS): MR vs ExFID				NZ (High CCS): Hi Exp		NZ (High CCS): Hi Exp vs ExFID			
	US LNG EJ	GHG Tg CO_2e	US LNG EJ	GHG Tg CO_2e	D LNG EJ	D GHG Tg CO_2e	Cons GHG g CO_2e/MJ	PNDE g CO_2e/MJ	US LNG EJ	GHG Tg CO_2e	D LNG EJ	D GHG Tg CO_2e	Cons GHG g CO_2e/MJ	PNDE g CO_2e/MJ
2020	2.4	73,991	2.4	73,991	0.0	0.0			2.4	73,991	0.0	0.0		
2021	3.2	72,853	3.2	72,853	0.0	0.0			3.2	72,853	0.0	0.0		
2022	4.0	71,716	4.0	71,716	0.0	0.0			4.0	71,716	0.0	0.0		
2023	4.8	70,579	4.8	70,579	0.0	0.0			4.8	70,579	0.0	0.0		
2024	5.6	69,441	5.6	69,441	0.0	0.0			5.6	69,441	0.0	0.0		
2025	6.3	68,304	6.3	68,304	0.0	0.0			6.3	68,304	0.0	0.0		
2026	6.4	66,223	6.4	66,223	0.0	0.0			6.4	66,223	0.0	0.0		
2027	6.4	64,143	6.4	64,143	0.0	0.0			6.4	64,143	0.0	0.0		
2028	6.4	62,063	6.4	62,063	0.0	0.0			6.4	62,063	0.0	0.0		
2029	6.5	59,982	6.5	59,982	0.0	0.0			6.5	59,982	0.0	0.0		
2030	6.5	57,902	6.5	57,902	0.0	0.0			6.5	57,902	0.0	0.0		
2031	6.7	57,002	6.7	57,002	0.0	-0.1			7.0	56,998	0.4	-4.7	-13.0	-34.3
2032	6.8	56,103	6.8	56,103	0.0	-0.2			7.6	56,094	0.7	-9.4	-13.0	-34.3
2033	7.0	55,204	7.0	55,204	0.0	-0.3			8.1	55,190	1.1	-14.1	-13.0	-34.3
2034	7.2	54,305	7.2	54,304	0.0	-0.4			8.6	54,286	1.4	-18.8	-13.0	-34.3
2035	7.4	53,405	7.4	53,405	0.0	-0.5			9.2	53,382	1.8	-23.5	-13.0	-34.3
2036	7.6	51,650	7.7	51,647	0.2	-3.0	-19.7	-41.0	9.9	51,636	2.3	-13.6	-5.9	-27.1
2037	7.8	49,895	8.1	49,889	0.3	-5.5	-18.2	-39.4	10.7	49,891	2.8	-3.7	-1.3	-22.6
2038	8.1	48,139	8.5	48,131	0.5	-8.0	-17.7	-38.9	11.4	48,145	3.3	6.1	1.8	-19.4
2039	8.3	46,384	8.9	46,373	0.6	-10.6	-17.4	-38.7	12.2	46,400	3.8	16.0	4.1	-17.1
2040	8.5	44,629	9.3	44,615	0.8	-13.1	-17.3	-38.5	12.9	44,654	4.4	25.8	5.9	-15.3
2041	8.5	43,200	9.5	43,193	0.9	-7.8	-8.3	-29.6	13.4	43,234	4.9	33.3	6.8	-14.5
2042	8.5	41,772	9.6	41,770	1.1	-2.4	-2.2	-23.5	14.0	41,813	5.4	40.8	7.5	-13.8
2043	8.5	40,344	9.8	40,347	1.3	2.9	2.3	-19.0	14.5	40,392	6.0	48.3	8.1	-13.2
2044	8.5	38,916	10.0	38,924	1.5	8.2	5.6	-15.6	15.0	38,971	6.5	55.7	8.6	-12.7
2045	8.5	37,488	10.2	37,501	1.6	13.5	8.3	-12.9	15.6	37,551	7.0	63.2	9.0	-12.3
2046	8.5	35,912	10.2	35,921	1.6	9.2	5.6	-15.7	16.0	35,952	7.4	40.4	5.5	-15.8
2047	8.5	34,336	10.2	34,341	1.7	4.9	2.9	-18.3	16.3	34,354	7.8	17.7	2.3	-19.0
2048	8.5	32,760	10.2	32,761	1.7	0.6	0.4	-20.9	16.7	32,755	8.2	-5.1	-0.6	-21.9
2049	8.5	31,184	10.3	31,181	1.7	-3.7	-2.1	-23.4	17.1	31,157	8.6	-27.9	-3.3	-24.5
2050	8.5	29,609	10.3	29,601	1.7	-8.0	-4.6	-25.8	17.5	29,558	8.9	-50.6	-5.7	-26.9
Cum.	**219**	**1,619,433**	**236**	**1,619,408**	**17**	**-24**	**-1.4**	**-22.7**	**312**	**1,619,609**	**93**	**176**	**1.9**	**-19.4**

Table C-4.58. Annual and Cumulative Emissions, U.S. LNG Exports, and Consequential Analysis of Net Zero 2050 (Moderate CCS) Scenarios (AR6-20 Basis)

Year	NZ (Mod CCS):ExFID		NZ (Mod CCS): MR		NZ (Mod CCS): MR vs ExFID				NZ (Mod CCS): Hi Exp		NZ (Mod CCS): Hi Exp vs ExFID			
	US LNG EJ	GHG Tg CO_2e	US LNG EJ	GHG Tg CO_2e	D LNG EJ	D GHG Tg CO_2e	Cons GHG g CO_2e/MJ	PNDE g CO_2e/MJ	US LNG EJ	GHG Tg CO_2e	D LNG EJ	D GHG Tg CO_2e	Cons GHG g CO_2e/MJ	PNDE g CO_2e/MJ
2020	2.4	73,991	2.4	73,991	0.0	0.0			2.4	73,991	0.0	0.0		
2021	3.2	72,682	3.2	72,682	0.0	0.0			3.2	72,682	0.0	0.0		
2022	4.0	71,374	4.0	71,374	0.0	0.0			4.0	71,374	0.0	0.0		
2023	4.8	70,065	4.8	70,065	0.0	0.0			4.8	70,065	0.0	0.0		
2024	5.6	68,756	5.6	68,756	0.0	0.0			5.6	68,756	0.0	0.0		
2025	6.3	67,448	6.3	67,448	0.0	0.0			6.3	67,448	0.0	0.0		
2026	6.3	65,077	6.3	65,077	0.0	0.0			6.3	65,077	0.0	0.0		
2027	6.4	62,706	6.4	62,706	0.0	0.0			6.4	62,706	0.0	0.0		
2028	6.4	60,335	6.4	60,335	0.0	0.0			6.4	60,335	0.0	0.0		
2029	6.4	57,963	6.4	57,963	0.0	0.0			6.4	57,963	0.0	0.0		
2030	6.4	55,592	6.4	55,592	0.0	0.0			6.4	55,592	0.0	0.0		
2031	6.5	53,721	6.5	53,721	0.0	0.0			6.9	53,727	0.4	5.7	15.9	-5.4
2032	6.6	51,850	6.6	51,850	0.0	0.0			7.3	51,862	0.7	11.4	15.9	-5.4
2033	6.7	49,979	6.7	49,979	0.0	0.0			7.7	49,996	1.1	17.1	15.9	-5.4
2034	6.7	48,108	6.7	48,108	0.0	0.0			8.2	48,131	1.4	22.9	15.9	-5.4
2035	6.8	46,237	6.8	46,237	0.0	0.0			8.6	46,266	1.8	28.6	15.9	-5.4
2036	6.9	45,024	6.9	45,024	0.0	0.0			9.1	45,062	2.2	38.4	17.8	-3.5
2037	7.0	43,811	7.0	43,811	0.0	0.0			9.6	43,859	2.5	48.2	19.1	-2.1
2038	7.2	42,597	7.2	42,597	0.0	0.0			10.0	42,656	2.9	58.1	20.2	-1.1
2039	7.3	41,384	7.3	41,384	0.0	0.0			10.5	41,452	3.2	67.9	21.0	-0.3
2040	7.4	40,171	7.4	40,171	0.0	0.0			11.0	40,249	3.6	77.8	21.6	0.3
2041	7.3	38,466	7.3	38,466	0.0	0.0			11.3	38,539	4.0	73.8	18.6	-2.7
2042	7.2	36,760	7.2	36,760	0.0	0.0			11.5	36,830	4.3	69.8	16.1	-5.1
2043	7.1	35,055	7.1	35,055	0.0	0.0			11.8	35,121	4.7	65.8	14.0	-7.2
2044	7.1	33,350	7.1	33,350	0.0	0.0			12.1	33,412	5.0	61.8	12.3	-9.0
2045	7.0	31,645	7.0	31,645	0.0	0.0			12.4	31,702	5.4	57.8	10.7	-10.6
2046	6.8	30,621	6.8	30,621	0.0	0.0			12.6	30,669	5.8	47.9	8.3	-13.0
2047	6.7	29,597	6.7	29,597	0.0	0.0			12.8	29,635	6.1	38.0	6.2	-15.1
2048	6.5	28,573	6.5	28,573	0.0	0.0			13.0	28,601	6.5	28.0	4.3	-16.9
2049	6.3	27,549	6.3	27,549	0.0	0.0			13.2	27,567	6.8	18.1	2.6	-18.6
2050	6.2	26,525	6.2	26,525	0.0	0.0			13.4	26,534	7.2	8.2	1.1	-20.1
Cum.	**195**	**1,507,012**	**195**	**1,507,012**	**0**	**0**	**N/A**	**N/A**	**271**	**1,507,858**	**76**	**845**	**11.2**	**-10.1**