NATIONAL PETROLEUM COUNCIL

APPROVED 4/23/2024 SUBJECT TO FINAL EDITING

CHARTING THE COURSE

Reducing GHG Emissions from the U.S. Natural Gas Supply Chain

Volume 1, Report Summary

April 23, 2024

Notes

- THE FIGURES/GRAPHICS INCLUDED ARE PRELIMINARY AND WILL BE REVISED AND COMPLETED DURING THE REPORT DRAFTING PROCESS.
- REFERENCES AND CITATIONS WILL BE FULLY COMPLETED ACCORDING TO THE CHICAGO MANUAL OF STYLE BEFORE PUBLICATION.

Preface

NATIONAL PETROLEUM COUNCIL

The National Petroleum Council (NPC) is an organization whose sole purpose is to provide advice to the federal government. After successful cooperation during World War II, President Harry Truman requested this federally chartered and privately funded advisory group to be established by the Secretary of the Interior to represent the oil and natural gas industry's views to the federal government by advising, informing, and recommending policy options. Today, the NPC is chartered by the Secretary of Energy under the Federal Advisory Committee Act of 1972, and the views represented are broader than those of the oil and natural gas industry.

Council members, about 200 in number, are appointed by the Energy Secretary to assure well-balanced representation from all segments of the oil and natural gas industry, from all sections of the country, and from large and small companies. Members are also appointed from outside the oil and natural gas industry, representing related interests such as large consumers, states, Native Americans, and academic, financial, research, and public-interest organizations and institutions. The council promotes informed dialogue on issues involving energy, security, the economy, and the environment of an ever-changing world.

STUDY REQUEST AND OBJECTIVES

By a letter dated April 22, 2022, Secretary of Energy Jennifer Granholm formally requested the NPC to undertake a study that defines pathways and prioritizes options for greenhouse gas (GHG) emissions reduction across the U.S. natural gas supply chain (Appendix A). The request placed particular emphasis on those having the potential to contribute to the achievement of the Global Methane Pledge and U.S. emissions reduction targets.

The Secretary requested the council's advice on six key topics:

1. Characterization of the state of GHG emissions and emissions reduction plans and programs across the U.S. natural gas value chain, including extraction, processing, transport, storage, liquefaction, and distribution.

2. Identification of the highest-emitting value chain segments and initiatives that can offer impactful, cost-effective, and achievable GHG reduction opportunities.

3. Exploration of options on how detection of GHG emissions from U.S.-produced natural gas can be characterized by employing both direct detection via terrestrial, airborne, and space-based monitoring, and indirect detection via emissions coefficients and proxy values, to provide useful information for public- and private-sector decision-makers, as well as other stakeholders, recognizing variability due to different technologies, sources of supply, and end uses.

4. Discussion of modeling frameworks that are utilized for life cycle emissions analysis and can provide results of consequences regarding the impacts of natural gas relative to other energy sources, both domestically and internationally.

5. Discussion of potential trade-offs of low- and no-emissions natural gas, including energy and economic security, environmental justice, the carbon intensity of the products resulting from its use—e.g., heat, power, and chemicals—and other environmental impacts.

6. Evaluation of the feasibility and effectiveness of different approaches to reduce and/or offset GHG emissions across the existing and evolving natural gas value chain. Approaches may include technology investments, market mechanisms, and policy and regulatory measures.

Appendix A contains the Secretary's request letter and more details on the NPC.

STUDY CONTEXT

In 2011, the NPC produced a report for the Secretary of Energy titled *Prudent Development: Realizing the Potential of North America's Abundant Natural Gas and Oil Resources*. The report essentially concluded that the prudent development of oil and gas resources can be "potentially transformative for the American economy, energy security, and the environment." Since its publication, the shale revolution has provided reliable and affordable energy domestically while also seeing reductions in overall GHG emissions primarily afforded by fuel switching in the power sector as further described in Chapter 1. More recently, methane regulations have emerged at the state and national levels. During this period, the United States has also embarked on exporting natural gas internationally, providing a secure, reliable, and environmentally competitive energy source as other countries also address the need for energy security, affordability, and environmental considerations.

The natural gas industry has several opportunities to contribute to the GHG emissions reduction targets both domestically and abroad. Since the publication of the 2011 report, there has been significant public focus on GHG emissions from the natural gas supply chain, and advancement on quantification and monitoring of GHG emissions. Methane emissions from the natural gas supply chain reduce benefits of natural gas relative to higher-GHG-intensive fossil fuels. Over the past decade, scientists, policymakers, and operators have gained better understanding of emissions profiles of the natural gas supply chain, deployment of monitoring technologies and analytical methods, and implementation of voluntary and regulatory programs. Reducing emissions across the natural gas supply chain will require a mix of investments, changes to infrastructure design and operations, regulations at both new and existing facilities, advancement of monitoring technologies, alignment of reporting principles and practices, and the export of these technologies and experiences abroad.

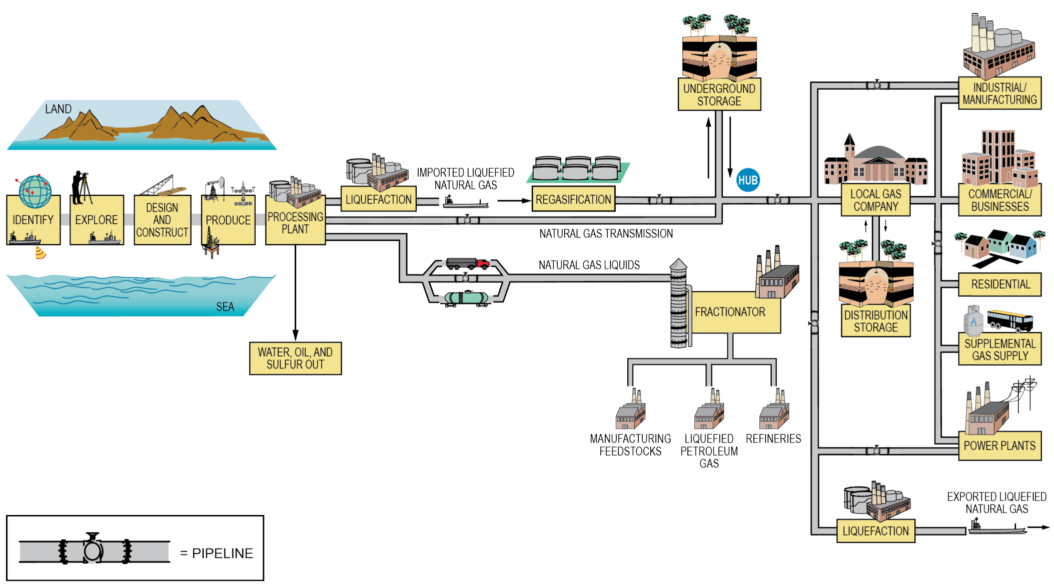
The NPC delivers findings and recommendations for the U.S. Department of Energy (DOE), as well as suggestions for policy, regulatory, and legislative actions, further research needs, and potential actions to be taken by natural gas supply chain entities.

STUDY SCOPE AND PROCESS

The study leadership developed a proposed workplan that defined the study scope, organization, and timeline at the onset of the study in late 2022 to ensure alignment on deliverables and to submit the final report to the Secretary by April 2024. Study topics on methane and GHG emissions are dynamic, with new articles, papers, regulations, and announcements occurring daily. The study's findings and recommendations are based on information available through the end of 2023; any 2024 information used will be noted as such.

The objective of this study was to assess GHG emissions reduction plans and potential across the U.S.[1] natural gas supply chain and provide recommendations for government, petroleum industry, research community, and nongovernmental organizations (NGO) actions. The focus of the study is to examine opportunities to minimize the GHG emissions attributable to the production, transmission, and delivery for domestic use or export of U.S. natural gas. While emphasis was on U.S. emissions reduction targets, the study incorporated learnings from international initiatives and other countries.

This study addressed the U.S. natural gas supply chain from extraction, processing, transport, storage, liquefaction, and distribution until the end user's[2] meter, plus liquefied natural gas (LNG) shipping to destination ports. Orphan/abandoned wells are also in scope. Per the Secretary's request to study the natural gas value chain, end-user emissions are excluded from the study scope. Unless specifically addressing the Secretary's letter, the more common term "supply chain" will be used instead of "value chain." Figure P-1 shows the supply chain components.



Source: American Petroleum Institute, *Oil and Natural Gas Industry Preparedness Handbook*, October 2013.

Figure P-1. Illustrative Diagram of the U.S. Natural Gas Supply Chain

1 U.S. includes 50 states, D.C., and U.S. territories.

2 End-user is defined for three different gates within the study but generally is to the customer (power, commercial, residential, or regas facility) meter.

The study scope focuses on emissions reduction from wellhead to end-user receipt (the natural gas supply chain), thus excluding end-user consumption and end-use combustion emissions, frequently referred to as "Scope 3," from the study. The reason is threefold: (1) The NPC extensively studied carbon capture and storage, a primary mitigation of end-use combustion emissions, in the NPC's 2019 report *Meeting the Dual Challenge.*[3] (2) Regulatory and technological mechanisms for limiting end-use combustion emissions affect primarily the customers of the natural gas supply chain and would require different study team inclusive of Power, Industrial, and other end users. (3) A robust study of end-use emissions reduction would undoubtedly involve an evaluation of fuel switching between natural gas and other primary energy sources (e.g., oil, wind, solar, hydro, and nuclear), a subject that has been extensively studied. Consequently, NPC chose to respond to the Secretary's request by focusing on the pathways for reducing GHG emissions along the natural gas supply chain, such that reduced carbon intensity of U.S. natural gas becomes a contributor to the U.S. goals as stated in the Secretary's request letter.

Oil and natural gas are produced in many environments, including offshore (primarily Gulf of Mexico) and the Arctic (Alaska). These two areas have unique operating challenges including enclosed facilities and proximity to living quarters that have always required heightened detection and monitoring. Therefore, discussion of these two operating areas is limited.

This study will be useful in assisting readers with an understanding of the magnitude of emissions associated with the natural gas supply chain, and opportunities to reduce those emissions, but will not address the question of how natural gas use compares to alternatives, such as end-use electrification.[4] It is understood that the success of natural gas GHG emissions reductions at scale requires economic and operational integration across industries, harmonized and durable local/tribal/state/federal policy, a strong health and safety record, and addressing social considerations and impacts across its supply chain while taking into consideration energy demand and U.S. energy security. The study focuses on existing initiatives, energy and economic security, detection technology to rapidly respond to unexpected emissions and potentially quantify emissions, life cycle assessments (LCAs) to understand emissions intensity, cross-organizational integration, regulation, and policy options. The creation of a streamlined LCA model is one of the unique aspects of this study. This model was developed to encourage identification of and reduction opportunities for GHG emissions reduction and informing decisions in public and private sectors.

Consistent with NPC's mission and as part of community outreach and to ensure perspectives from smaller operators was included in this study, four workshops were hosted throughout the United States to solicit feedback on potential emissions reductions pathways.

The *Harnessing Hydrogen: A Key Element of the U.S. Energy Future* NPC study was completed simultaneously with this study. The two studies collaborated to ensure that the carbon

3 Meeting the Dual Challenge -Report Downloads (npc.org), https://dualchallenge.npc.org/.
4 The NPC addressed mitigation of end-user combustion carbon dioxide in the 2019 "Meeting the Dual Challenge" study on Carbon Capture, Use, and Storage (CCUS), https://dualchallenge.npc.org/downloads.php.

intensity of natural gas used to reform hydrogen was aligned. The two studies also collaborated on framing of the societal considerations and impacts (SCI).

The SCI topic represents a significant development for the NPC itself as it, together with the concurrent *Harnessing Hydrogen* study's safety, societal considerations, and impacts Chapter 7, is the first time NPC studies have undertaken a dedicated SCI review of issues related to a study topic. While both studies' SCI treatments are an important step forward, more work needs to be done to thoroughly understand the social, community, and environmental justice (EJ) issues involved in energy systems and energy infrastructure.

INSET

Definition of Environmental Justice

The Secretary of Energy's letter asked the National Petroleum Council to discuss "environmental justice." The Secretary did not provide a definition of the rapidly evolving term; however, both NPC studies have referenced some widely used definitions of EJ and associated terminology that is utilized by government agencies and others. These definitions are not representative of the entire compendium of definitions or views on these issues. The Societal Considerations and Impacts title was chosen based on guidance and engagements with the Department of Energy as an appropriate descriptor for a wide range of external community and environmental concerns across the United States. Other terminology used by EJ researchers and advocates with definitions of some of those terms can be found in the Chapter 2 appendix.

END INSET

The GHG study drew on available analysis from a variety of sources such as reports and studies from: DOE, national labs, U.S. Environmental Protection Agency (EPA), East Daley Analytics, U.S. Energy Information Administration (EIA), International Energy Agency (IEA), and data from demonstration and commercial-scale projects. It also followed the approach used in previous NPC studies, such as those on *Prudent Development*, *Dynamic Delivery*, and *Meeting the Dual Challenge*.

This NPC study was conducted in full compliance with applicable laws and regulations, including antitrust laws and the Federal Advisory Committee Act. To ensure antitrust compliance, for example, the study did not include evaluations of any forward-looking commodity prices despite the role these can play in encouraging the research and technology investments required for widespread GHG emissions reduction.

STUDY GROUP ORGANIZATION

In response to the Secretary's requests, the NPC established a Committee on Natural Gas GHG Emissions composed of more than 60 members of the council. The committee's purpose was to conduct a study on this topic and to supervise the preparation of a draft report for the council's consideration. This study committee was led by a steering committee consisting of the committee's chair, government representative, and 11 members representing a cross section of the committee. The steering committee provided timely guidance and resolution of issues during the study.

A coordinating subcommittee and five task groups were also established to assist the committee in conducting the study. These study groups were aided by multiple subgroups focused on specific subject areas, supplemented by workshops and other outreach. Figure P-2 provides an organization chart for the groups that conducted the study's analyses.

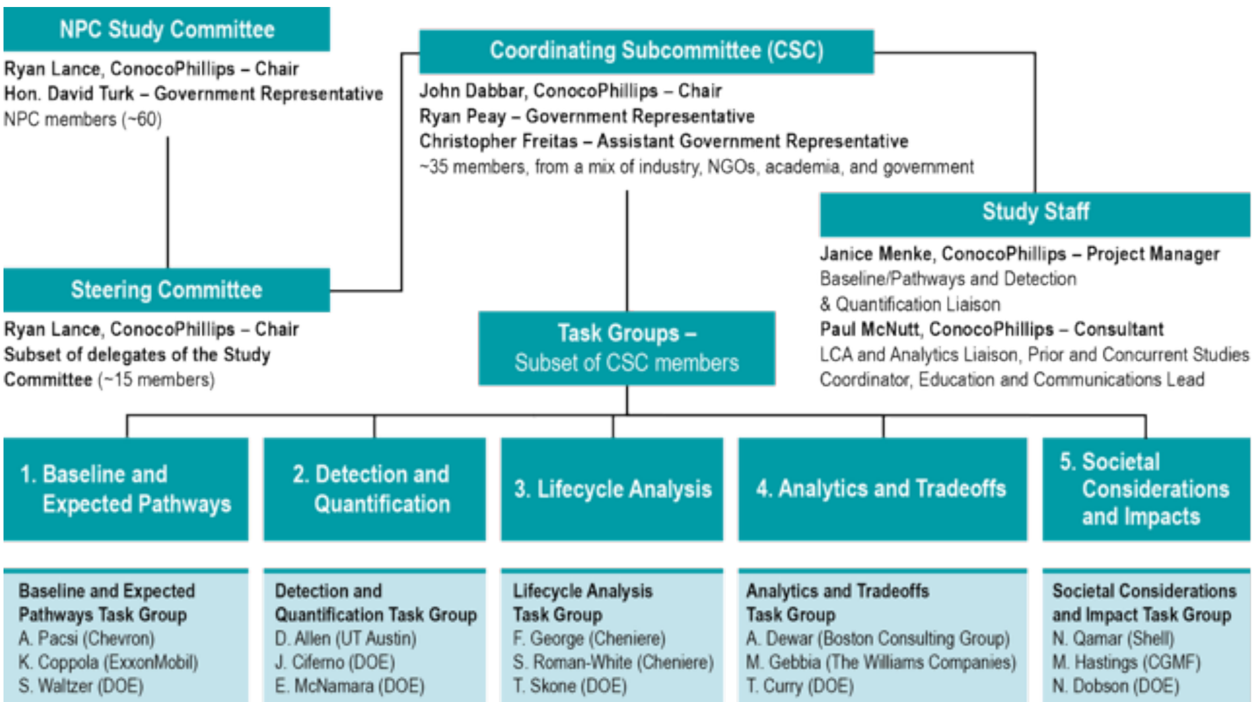


Figure P-2. GHG Study Organization

The following task groups were created based on the six questions in the letter from the Secretary of Energy:

- **Baseline and Expected Pathways**: Characterize the state of GHG emissions and emissions reduction plans and programs and identification of the highest-emitting supply chain segments
- **Detection and Quantification**: Provide options for detection and measurement
- **Life Cycle Analysis**: Model and analyze life cycle emissions
- **Analytics and Trade-offs**: Examine GHG emissions reduction opportunities, trade-offs, and carbon intensity

- **Societal Considerations and Impacts**: Provide insights to avoid or mitigate adverse impacts on communities, particularly the disadvantaged, while maximizing the effectiveness of community benefits that can flow from GHG emissions reduction projects, activities, and policy

The members of the various study groups were drawn from NPC members' organizations as well as from many other industries, federal, state, and Tribal agencies, NGOs, other public-interest groups, financial institutions, consultancies, academia, and research groups. More than 200 people served on the study's committee, subcommittee, task groups, and subgroups. While all have relevant expertise for the study, about half the study members are from the oil and natural gas industry. Figure P-3 shows the study leadership. Figure P-4 shows the diversity of participation in the study process, and Appendix B contains rosters of participants in each study group. This broad participation was an integral part of the study with the goal of soliciting input from an informed range of interested parties.

Participants in this study contributed in a variety of ways, ranging from work in all study areas, to involvement in a specific topic, to reviewing proposed materials, to participating in technical workshops. Involvement in these activities should not be construed as a participant's or their organization's endorsement or agreement with all the statements, findings, and recommendations in this report. Additionally, while U.S. government participants provided significant assistance in the identification and compilation of data and other information, they did not take positions on the study's recommendations.

As a federally appointed and chartered advisory committee, the NPC is solely responsible for the final advice provided to the Secretary of Energy. The council believes that the broad and diverse participation has informed and enhanced its study and advice. The council appreciates the commitment and contributions from all who participated in the process.

NPC COMMITTEE ON GHG EMISSIONS

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Chairman and Chief Executive Officer
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Marilu Hastings
Executive Vice President
Director, Mitchell Innovation Lab
The Cynthia and George Mitchell Foundation

Vicki A. Hollub
President and Chief Executive Officer
Occidental Petroleum Corporation

James Y. Kerr II
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Southern Company Gas

Mark K. Miller
President
Merlin Energy, Inc.

Donald L. Paul
Executive Director
USC Energy Institute
Professor and William M. Keck Chair
of Energy Resources
Viterbi School of Engineering
University of Southern California

Scott D. Sheffield
Special Advisor to the Chief Executive Officer
Pioneer Natural Resources Company

Lorenzo Simonelli
Chairman and Chief Executive Officer
Baker Hughes Company

J. Robinson West
Chairman Emeritus
Center for Energy Impact
The Boston Consulting Group

Darren W. Woods
Chairman, President and Chief Executive Officer
Exxon Mobil Corporation

COORDINATING SUBCOMMITTEE

CHAIR
John M. Dabbar
Managing Director
Low Carbon Technologies
ConocoPhillips Company

GOVERNMENT COCHAIR
Ryan Peay
Deputy Assistant Secretary
Office of Resource Sustainability
Office of Fossil Energy and Carbon Management
U.S. Department of Energy

ALTERNATE GOVERNMENT COCHAIR
Christopher J. Freitas
Senior Program Manager for Methane Mitigation R&D
Office of Resource Sustainability
Office of Fossil Energy and Carbon Management
U.S. Department of Energy

PROJECT MANAGER
Janice Y. Menke
NPC GHG Project Manager, Low Carbon Technologies
ConocoPhillips Company

PROJECT INTEGRATION
Paul B. McNutt
Consultant, Low Carbon Technologies
ConocoPhillips Company

COCHAIRS – BASELINE AND EXPECTED PATHWAYS TASK GROUP

Kelly K. Coppola
Upstream Unconventional Issues & Advocacy Manager
Exxon Mobil Corporation

Adam P. Pacsi
Methane Policy Advisor
Chevron Corporation

CHAIR – DETECTION AND QUANTIFICATION TASK GROUP

David T. Allen
Melvin H. Gertz Regents Chair in Chemical Engineering
Cockrell School of Engineering, University of Texas

CHAIR – LIFECYCLE ANALYSIS TASK GROUP
Fiji C. George
Senior Director, Climate & Sustainability
Cheniere Energy, Inc.

ASSISTANT CHAIR – LIFECYCLE ANALYSIS TASK GROUP
Selina A. Roman-White
Supervisor, Climate
Cheniere Energy, Inc.

COCHAIRS – ANALYTICS AND TRADEOFFS TASK GROUP

Alex Dewar
Managing Director & Partner
The Boston Consulting Group

Mark A. Gebbia
VP Environmental and Permitting
The Williams Companies

COCHAIRS – SOCIETAL CONSIDERATIONS & IMPACTS TASK GROUP

Marilu Hastings
Executive Vice President
Director, Mitchell Innovation Lab
The Cynthia and George Mitchell Foundation

Natasha R. Qamar
U.S. Climate Policy & Advocacy Advisor
Shell USA Inc.

Figure P-3. GHG Study Leaders

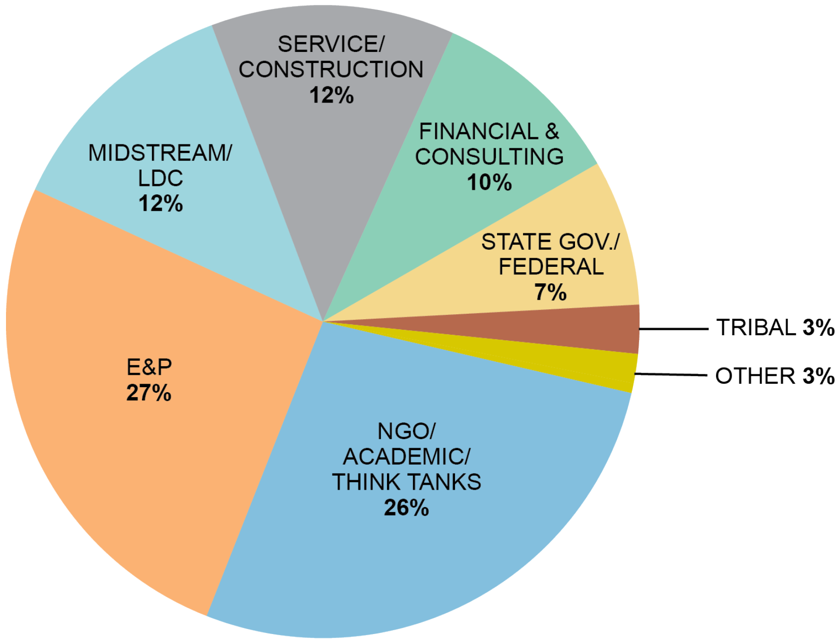

Figure P-4. GHG Study Participation Diversity

REPORT STRUCTURE

In the interest of transparency, and to help readers better understand this study, the NPC is making the study results available through the website to all interested parties. To provide interested parties with the ability to review this report and supporting materials in various levels of detail, the report is organized in multiple layers as follows.

Report Summary includes the report transmittal letter, outline of the entire report, preface, executive summary, a list of the recommendations of the study, and appendices providing the study request letter, NPC roster, and study group rosters. This volume provides two levels of summarization:

- **Report Transmittal Letter** is the first level that submits the report to the Secretary of Energy as the council's response to her request for advice on GHG emissions reductions across the U.S. natural gas supply chain. It provides a very brief, high-level overview of the report's key messages.

Executive Summary is the second level and provides an overview of the study's findings and recommendations for reducing GHG emissions in the natural gas supply chain. It is organized into the following themes that the Secretary of Energy's requested:

1. *The role of natural gas*: Characterization of the state of GHG emissions and emissions reduction plans and programs across the U.S. natural gas supply chain.

2. *Greenhouse gas emissions solutions and challenges*: Identification of the highest-emitting parts of the supply chain and initiatives that offer impactful, cost-effective, and achievable GHG reduction opportunities.

3. *Addressing the Secretary's three goals*: 1) A 50 to 52% reduction in GHG emissions from 2005 levels by 2030; 2) Net zero emissions economy-wide by 2050; 3) the Global Methane Pledge to collectively reduce global methane emissions by 30% from 2020 levels by 2030.

4. *Societal considerations and impacts*: Analysis of issues associated with environmental justice; community engagement; and trade-offs, impacts, and benefits.

5. *Detection and measurement*: Exploration of options on how detection of GHG emissions from U.S. natural gas can be characterized.

6. *Life cycle assessments*: Discussion of modeling frameworks that are utilized for life cycle emissions assessments and can provide results of consequences regarding the impacts of natural gas relative to other energy sources, both domestically and internationally.

7. *Integrated analytics and trade-offs*: Discussion of potential trade-offs of low- and no-emissions natural gas. Evaluation of the feasibility and effectiveness of different approaches, individually and in combination, to reduce and/or offset GHG emissions across the existing and evolving natural gas supply chain.

The executive summary, report chapters, appendices, and topic papers may be individually downloaded from the NPC website at: www.npc.org. The public is welcome and encouraged to visit the site to download the entire report or individual sections for free. Printed copies of the report can be purchased.

Executive Summary

INTRODUCTION

National Petroleum Council studies are requested by the Secretary of the Department of Energy (DOE) to advise on policy, technology, and related topics. *Charting the Course* was initiated by the DOE on April 22, 2022, to evaluate how to assess and reduce the greenhouse gas (GHG) emissions along the natural gas supply chain (NGSC). The study's release is timely as a new Environmental Protection Agency (EPA) methane rule applicable to the oil and natural gas industry and a "pause" on the approval of liquefied natural gas (LNG) export terminals are current topics in policy debates. The study calls on government, nongovernment, industry, and research organizations to work together to implement the recommendations and reduce the NGSC GHG emissions, starting with methane and then building to address carbon dioxide.

In total, petroleum and natural gas systems account for 33% of methane emissions,[5] 5% of CO_2 emissions, and 8% of total U.S. GHG emissions. *Charting the Course* focuses on reducing NGSC GHG emissions. The scope does not include future fuel switching or supply and demand scenarios. GHG emissions analysis is based on the Energy Information Administration (EIA) Reference Case, noting that EIA does not create scenarios intentionally aligned with a net zero goal. International Energy Agency (IEA) scenarios are also shown. The study team did not analyze the likelihood, precision, or accuracy of any scenario, outlook, or forecast, nor does it endorse the use of any scenario over others. The study's goal is to identify ways to reduce the NGSC GHG emissions at the source-level for all future supply and demand scenarios.

This study is the result of collaboration by service firms, financial firms, consulting firms, state government, non-governmental organizations, academic institutions, tribal groups, and oil and gas industry companies. The study concludes that if these organizations implement the Existing Policies (EP) Pathway[6] defined as the combination of existing policies, regulatory and voluntary actions, technology advancements, and market mechanisms, a 50% reduction in methane emissions can be achieved by 2050, with most of that occurring before 2030. However, a 25% increase in carbon dioxide emissions would result given EIA Reference Case production through 2050.[7]

The NPC defines another pathway that is representative of a future with increased policies and regulation, increased voluntary commitments, advancing technologies, and implementing market mechanisms. Under this pathway, named Technology, Innovation, and Policy (TIP), methane emissions decrease by 70% and carbon dioxide emissions reduce by 33% through 2050

5 While petroleum and natural gas are a major source of, agriculture is the largest source (38%), with key contributions from livestock and rice cultivation. Waste (20%), which includes landfills and wastewater treatment, and coal mining (7%) are also key contributors to national methane emissions estimates.
6 Pathway is defined for the study as a combination of policies, regulatory and voluntary actions, technology advancements, and market mechanisms working together.
7 Existing Policies, EIA Reference Case Production.

again using the EIA Reference case for production. The assumptions and actions in the TIP Pathway would typically manifest in natural gas supply and demand scenarios that are much lower than the EIA Reference Case. A combination of lower emissions intensity and lower natural gas production would further reduce total NGSC GHG emissions but is not modeled in this study.

The TIP Pathway would require a large infrastructure buildout for emissions reduction projects, including electrification, carbon capture and storage, and potentially low carbon intensity hydrogen. Permit reform and community engagement are enablers for such a pathway. The oil and gas industry has a long history of engaging with the communities where they operate. The consistent application of community engagement best practices can be improved, and additional community input should be sought out. In this study, the NPC has highlighted societal considerations and impacts (SCI). Chapter 2 is dedicated to SCI and SCI is embedded throughout the study.

All study pathways include the EPA's rule to reduce methane emissions from the oil and gas sector which was announced in December 2023. The NPC engaged with dozens of smaller operators (designated Less Capitalized Operators or LCOs) to better understand the challenges the rule presents. LCOs are concerned about understanding and meeting the new regulatory requirements and the potential impact on marginal wells. The EPA Regulatory Impact Assessment indicated added regulatory costs could decrease U.S. oil production by 113,000 Bo/d (barrels of oil per day) and decrease natural gas production by 434 Mmcf/d (million cubic feet per day) in 2038.[8] Not only could U.S. oil and gas supply be impacted, but there could be a disproportionate impact on marginal wells and LCOs.

Another LCO concern is the cost of compliance, including detection, measurement, and quantification of methane emissions. From satellites, planes, drones, ground-based lasers, and optical gas imaging cameras to operators walking sites and using their senses to detect emissions, the new regulations will require incremental cost. Detection and quantification are discussed in Chapter 3. Some of the LCOs have proactively adopted detection and repair protocols and provided examples of programs of cost-effective GHG emission reduction programs.

In January 2024, the DOE announced a temporary pause on authorizations for pending applications for LNG export projects to non-Free Trade Agreement countries as DOE conducts a public interest assessment.[9] Due to timing, this policy announcement was not fully analyzed by the NPC, although some of the insights from this report should be germane to the public interest assessment process. Some important considerations, like unintended global supply and demand balance consequences and investment certainty for projects in the U.S., are outside the scope of

[8] Regulatory Impact Analysis of the Standards of Performance for New, Reconstructed, and Modified Sources and Emissions Guidelines for Existing Sources: Oil and Natural Gas Sector Climate Review (epa.gov)

9 DOE to Update Public Interest Analysis to Enhance National Security, Achieve Clean Energy Goals, and Continue Support for Global Allies, https://www.energy.gov/articles/doe-update-public-interest-analysis-enhance-national-security-achieve-clean-energy-goals.

this study, but would be important opportunities for further collaboration between industry and the DOE. This NPC report provides recommendations for addressing some of the key current trade-offs for U.S. LNG exports, including an evaluation of societal considerations and impacts (SCI) and community engagement best practices, simplified tools for estimating supply chain GHG emission intensity as part of measuring, monitoring, reporting, and verifying (MMRV) programs, pathways for significant methane reductions in the natural gas supply chain, including the suite of federal methane regulations across several agencies, and research, development, demonstration, and deployment opportunities for reducing supply chain carbon dioxide emissions, including from liquefaction. Chapter 4 uses a newly developed, streamlined life cycle assessment (LCA) model to evaluate all NGSC GHG emissions, including multiple LNG destinations.

The United States is the top global LNG exporter, providing supply diversity to importing countries. Thus, U.S. natural gas is a crucial part of global and domestic energy security and plays an important role in economic security. Since 2010, natural gas has been the top source of primary energy production in the United States. U.S. natural gas is reliable due to its diversity and scale. It has multiple producing basins, more than 300,000 miles of interstate and intrastate natural gas transmission pipelines, 2.3 million miles of distribution pipelines, and 388 underground storage facilities[10] that provide reliable energy security not only within the United States, but also globally, thus delivering reliability in the future energy mix. Chapter 1 covers the role of natural gas, the current policies and regulations, and the current state of GHG emissions.

U.S. natural gas is abundant and affordable. Resource estimates provide more than 100 years of production at current rates. The shale revolution has more than doubled U.S. production since 2005 and kept U.S. prices down. The low energy cost coupled with the legacy infrastructure provides universal access for energy equity.

Finally, U.S. natural gas can contribute to environmental sustainability by generating fewer GHG (methane and carbon dioxide) emissions, 40% less nitrogen oxide, and 44% less sulfur dioxide than coal—which was, until 2010, the top primary energy source in the United States—per megawatt-hour of electricity generated. Reduced emissions benefit both global climate and local air quality.[11, 12]

To reduce emissions, the study breaks down the composition and sources of those emissions. The NGSC GHG emissions are about evenly split between methane and carbon dioxide on a 100-year Global Warming Potential (GWP100) basis. Methane detection and quantification technologies are rapidly progressing and indicate that the primary source of methane is in the production stage. Carbon dioxide is easier to quantify through engineering calculations, but potentially harder to mitigate in the long run. Carbon dioxide's main source is known combustion

10 Dynamic Delivery - Downloads (npc.org), https://dynamicdelivery.npc.org/.

11 U.S. Energy Information Administration –(EIA),s https://www.eia.gov/todayinenergy/detail.php?id=48296.

12 Gouw, J. A. de, D. D. Parrish, G. J. Frost, and M. Trainer. 2014. "Reduced Emissions of CO2, NOx, and SO2from U.S. Power Plants Owing to Switch from Coal to Natural Gas with Combined Cycle Technology." *Earth's Future* 2 (2): 75–82. https://doi.org/10.1002/2013ef000196.

from flares, compressors, and other NGSC equipment. Chapter 5 addresses the actions needed to reduce both methane and carbon dioxide.

Charting the Course should be valuable for the DOE, other federal, state, and Tribal government agencies, policymakers, legislators, regulators, the oil and gas industry, technology innovators, commercial vendors, and standards-setting organizations. By working together, these organizations can reduce GHG emissions from the NGSC.

STUDY OVERVIEW

The Secretary asked the NPC to identify how the NGSC addresses three goals:

- **Goal: A 50 to 52% reduction in U.S. GHG emissions from 2005 by 2030.** This study estimates the U.S. NGSC will reduce its GHG emissions by an additional 131 million metric tons of GHGs, designated as the carbon dioxide equivalent, or CO_2e (~2% of 2005 baseline). This estimate is applicable for all defined pathways. In total, the NGSC will deliver at least 10% of the baseline or 20% of the U.S. GHG emissions reduction goal. This estimate excludes any future benefit of offsetting coal-fired power emissions. This estimate is applicable for all defined pathways.
- **Goal: Net zero emissions economy-wide by 2050.** The NGSC will contribute to this economy-wide goal, but additional policy, regulations, industry, and technology efforts, including examples in the TIP Pathway, are needed to reach net zero by 2050.
- **Goal: Global Methane Pledge, reduce global methane emissions by 30% from 2020 to 2030.** This study estimates that methane emissions from the NGSC will decrease by 63% by 2030 assuming existing policies, regulations, and announced voluntary efforts are implemented effectively, providing two-thirds of the reduction needed for the U.S. to achieve a 30% reduction by 2030. This estimate is applicable for all defined pathways.

In addition to addressing those three goals, the study identified key findings, which are listed below and can be summarized into six findings headlines.

INSET BOX

<u>FINDING HEADLINES</u>

Abundant, affordable natural gas is the largest source of primary energy production in the United States and will continue to play a crucial role in energy security and an important role in economic security beyond 2050 under all EIA scenarios.

Accurate, measurement-informed estimates of GHG emissions are critical to tracking and executing U.S. and global emissions reporting and reduction goals.

Both methane and carbon dioxide are GHG contributors along the NGSC. Mitigating methane emissions is a near-term priority, in tandem with accelerating policy and technology efforts regarding carbon dioxide.

Permitting reform is needed to enable construction and installation of GHG emissions mitigation projects.

GHG emissions reduction projects, activities, and policy should avoid or mitigate adverse impacts on communities, particularly the disadvantaged, while maximizing the effectiveness of community benefits that can flow from actions that reduce GHG emissions.

Remaining GHG emissions can be addressed with durable policy formation, including regulatory harmonization, acceleration of market mechanisms, and technology deployment and incentives for further technology research, development, demonstration, and deployment at speed and at scale.

END INSET

The following section lists simplified versions of the Executive Summary-level findings into key findings groups. Following the key findings is a list of the key recommendations.

KEY FINDING: Abundant, affordable natural gas is the largest source of primary energy production in the United States and will continue to play a crucial role in energy security and an important role in economic security beyond 2050 under all U.S. Energy Information Administration scenarios noting that EIA does not currently provide a net zero by 2050 scenario as it only recognizes existing policies and regulations.

- Abundant natural gas is the largest source of primary energy. Driven by the shale revolution, production, reserves, and resources are at all-time highs.
- The United States has large legacy infrastructure for energy security, reliability, affordability, connecting producing basins to industrial and consumer end users.
- The buildout of LNG capacity supports global energy security.

KEY FINDING: Accurate measurement-informed estimates of GHG emissions are critical to achieving U.S. and global emissions reporting and reduction goals.

- Detection technology has progressed rapidly.
- Quantification of detected emissions involves several steps post-detection: estimating emissions rate based on atmospheric concentration, estimating the emissions duration, and attribution of emissions source. These steps can benefit from further research, development, demonstration, and deployment.
- Continued progress in detection and quantification methods should be quickly integrated into regulation and policy.

KEY FINDING: Both methane and carbon dioxide are GHG emissions contributors in natural gas and LNG supply chains. Mitigating methane emissions is a near-term priority, in tandem with accelerating policy and technology efforts regarding carbon dioxide.

- Switching from coal to natural gas for power generation has driven U.S. GHG emissions lower and yet the NGSC produces 33% of methane and 5% of carbon dioxide, totaling 8% of U.S. GHG emissions.
- Significant policy, legislative, and regulatory actions along with market incentives will greatly reduce oil and natural gas methane emissions in the near term.
- As methane emissions decrease over time, EIA projections show carbon dioxide emissions growing in proportion to U.S. natural gas production, transmission distance, and LNG exports. Policies, regulations, and industry efforts will need to shift to emphasize carbon dioxide reductions.
- To achieve these reductions, NGSC companies need to undertake projects and actions that require permitting that will have societal considerations and impacts. And while operators do engage with stakeholders, communities want to see improvements and wider adoption of best practices.

KEY FINDING: Development and implementation of GHG emissions reduction projects, activities, and policy should avoid or mitigate adverse impacts on communities, particularly the disadvantaged, while maximizing the effectiveness of community benefits that can flow from such actions.

- The NPC *Harnessing Hydrogen* and *Charting the Course* studies collaborated to provide joint findings and recommendations as well as reference documents on the history of environmental justice and community engagement best practices.
- The NPC *Charting the Course* and *Harnessing Hydrogen* studies included, for the first time, dedicated, stand-alone societal considerations and impacts (SCI) task groups that evaluated and integrated community and social aspects into the study analysis, findings, and recommendations.
- Communities that may be impacted by GHG emissions reduction projects, activities, and policies may have concerns based on their unique and local historical experience with natural gas project development and operations. This experience may be informed by environmental justice concerns.
- Community concerns can be better understood and addressed through meaningful engagement. Industry should adopt the proposed community engagement best practices model when appropriate or adapt it as necessary for each situation.
- In general, GHG emissions reductions are sought to address climate change, but there may also be co-benefits of reducing some air pollutants. But as new infrastructure is needed in the reduction efforts, benefits should be shared more equitably with communities than was done historically.

KEY FINDING: Life cycle assessments (LCAs) are being used to quantify supply chain carbon intensities in the United States and globally.

- The NPC has developed a streamlined LCA model as a tool to help policymakers, industry, and others quantify and analyze the carbon intensity of natural gas quickly and easily along a supply chain. The integration of empirical datasets is a critical next step in improving LCA model estimates.
- The NPC LCA model uses only 22 key metrics (compared to well over 100 for most models) to attribute emissions along a supply chain. Thus, it is not a substitute for a consequential LCA when needing to compare the net GHG emissions impacts from introduction of natural gas or LNG, or policies related to energy use in the market.

KEY FINDING: Remaining GHG emissions will need to be addressed with durable policy formation, including regulatory harmonization, acceleration of market mechanisms, and technology deployment and incentives for further technology research, development, demonstration, and deployment at speed and at scale.

- LNG presents advantages for global energy security and emissions reductions, but without mitigation (like carbon capture and storage, or CCS) it may drive incremental U.S. carbon dioxide emissions in the supply chain.
- There is a need to engage all of industry in solving complex commercial, technical, and operational issues.

Given these summarized key findings and additional findings detailed in each chapter, the NPC team developed recommendations for industry, governments, and other groups. During the study, the NPC team learned that many of the NPC member companies, in all stages of the natural gas supply chain, are taking action to reduce the carbon intensity of U.S. natural gas. This informed our recommendation for operators and trade associations to provide a venue and resources for information sharing about operators' best practices, and for DOE to start a program similar to the Petroleum Technology Transfer Center with a focus on GHG emissions reduction. The recommendations for industry and government entities are summarized below into six key recommendations. The recommendations shown below are shortened for readability. Full text recommendations can be found later in the executive summary and in the chapters. Where the study recommends the DOE fund an effort it is understood that Congress appropriates the funds and DOE directs them.

KEY RECOMMENDATION: PROMOTE U.S. ENERGY AND ECONOMIC SECURITY

- Federal government should leverage consequential analysis and through climate and energy diplomatic efforts work to recognize GHG emissions reduction investments for lower emissions U.S.-exported products, including LNG
- Industry and government should engage to design durable policy

- The White House Methane Task Force should work with federal agencies to harmonize emissions reporting, control requirements, and technology approvals across the federal government
- Government should adopt market-based mechanisms focused on economy-wide or broad sector approaches

KEY RECOMMENDATION: PROMOTE SOCIETAL CONSIDERATIONS AND IMPACTS (SCI) AWARENESS

- Industry trade organizations should continue to develop specific community engagement training programs
- DOE should undertake a comprehensive SCI study on energy development
- DOE and other agencies should commit investments to address social, environmental, and public health impacts of natural gas supply chain projects and activities
- DOE should fund research on SCI best practices and community engagement
- DOE should commission a workforce study focused on the mismatch of current skills versus those skills needed for NGSC GHG emissions reduction projects
- Federal and state governments should assess which communities are positively and negatively impacted by natural gas supply chain emissions reduction projects and activities

KEY RECOMMENDATION: INCORPORATE MORE MEASUREMENT INTO MULTIPLE AREAS OF EMISSIONS MANAGEMENT

- DOE and EPA should lead a one-year, multistakeholder group to develop recommendations on incorporating company-specific, advanced technology measurements into GHGRP Subpart W
- DOE and EPA should improve the processes for incorporating advanced technology into regulatory requirements
- DOE should sponsor a multistakeholder expert advisory group to recommend how to integrate measurement data into life cycle assessments
- Standards-setting bodies should develop mechanisms to differentiate lower GHG emissions intensity natural gas, providing recognized frameworks, standards and metrics

KEY RECOMMENDATION: ADVANCE DETECTION AND OTHER TECHNOLOGIES TO ADDRESS EMISSION REDUCTION

- DOE should undertake new research, development, demonstration and deployment (RDD&D) focused on technologies to reduce the carbon intensity of energy use in the natural gas supply chain

- Federal government should coordinate policies for low-carbon technology RDD&D
- DOE should support emissions detection technology development by creating geographically diverse technology evaluation centers
- DOE should fund improvement of site/scale data resources and support technological innovations that lead to low-emitting facilities integrated with emissions detection and quantification systems
- DOE should sponsor multiscale measurement, public-private and global partnerships, and the development of dense networks of meteorological measurement stations, and should work with providers and operators to develop consistent data formats

KEY RECOMMENDATION: LEVERAGE LIFE CYCLE ASSESSMENTS THROUGHOUT THE NATURAL GAS SUPPLY CHAIN

- Industry and other parties should utilize life cycle assessment harmonization as presented in this study and in alignment with the National Academies of Sciences, Engineering, and Medicine's six pillars along with best practices
- Industry should leverage life cycle assessments to conduct contribution analyses along the natural gas supply chain
- DOE should sponsor research to develop measurement-informed geospatial life cycle assessment tools
- DOE should support the democratization and use of the NPC-developed life cycle assessment model, SLiNG-GHG, as a streamlined and simplified life cycle assessment tool

KEY RECOMMENDATION: EMPLOY ENABLERS TO SUSTAIN CHANGE

- Industry should dedicate additional resources to analyzing emissions reduction opportunities and to executing those projects
- Industry trade organizations and state oil and gas associations should fund policy and regulatory education, training, and sharing of best practices
- DOE should revitalize or start up an organization like the Petroleum Technology Transfer Council
- Governments should review options for marginal wells, including deduction of GHG emission reduction investments from state or federal tax or royalty obligations
- Federal government should advance permitting reform by incentivizing state and local governments, setting a two-year statute of limitations for filing lawsuits, expanding permit agency capacity, and expanding energy corridors along with categorical exclusions on federal lands

DISCUSSION OF THEMES

I. THEME 1: THE ROLE OF NATURAL GAS

Natural gas is the largest source of primary energy production in the United States and is expected to play a crucial role in energy security and an important role in economic security through 2050 under all EIA scenarios.

A. Energy Security

Natural gas underpins the U.S. economy as the largest source of U.S. primary energy production according to the EIA (see Figure ES-4). In 2022, natural gas provided significant percentages of primary energy use in the Electric Power (33%), Industrial (41%), Residential (42%), and Commercial sectors (24%). In the last two decades, natural gas consumption has increased by more than 55% to reach 32.3 trillion cubic feet (Tcf) in 2022. Through jobs and the energy supplied, the natural gas and oil industry supported $1.8 trillion of U.S. GDP, about $5,500 per person, and 7.6% of the national total.[13] The United States is now the world's leading exporter of LNG, and LNG is the third-largest U.S. export by value behind only petroleum products and crude oil, helping to balance the trade deficit. Internationally, U.S. LNG helped Europe weather a 54% drop in Russian gas deliveries during the winter of 2022.[14]

The crucial role of U.S. natural gas in supporting energy security is extensively discussed in this study. By providing additional supply into world markets, without destination-linked constraints, U.S. LNG provides market depth and allows rerouting of cargoes to alleviate localized supply shortages. U.S. LNG supply has supported European energy security by providing an alternative to curtailed Russian supply, while simultaneously providing supplies to Japan and other allies. China continues to purchase U.S. LNG, supporting U.S. balance of trade and providing a potentially constructive economic tie. Within North America, pipeline gas to Mexico is an important regional supply and is projected to supply Pacific Coast LNG plants under development.

B. GHG Emissions

While the NGSC delivers many benefits, it also contributes one-third of total U.S. anthropogenic methane emissions and one-twentieth of U.S. carbon dioxide emissions, excluding end use.[15]

This study focuses on the two most prevalent greenhouse gases: methane (CH_4) and carbon dioxide (CO_2). Methane is the primary molecule in natural gas. Compared to carbon dioxide,

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13 Impacts of the Oil and Natural Gas Industry on the U.S. Economy in 2021, PwC report prepared for American Petroleum Institute, https://www.api.org/-/media/files/policy/american-energy/pwc/2023/api-pwc-economic-impact-report-2023.

14 Maguire, Gavin. 2022. "Column: U.S. LNG Exports Both a Lifeline and a Drain for Europe in 2023." Reuters, December 21, 2022. https://www.reuters.com/business/energy/us-lng-exports-both-lifeline-drain-europe-2023-maguire-2022-12-20/.

15 Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021, https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Main-Text.pdf.)

methane traps approximately 28 times more heat based on the 100-year Global Warming Potential (GWP100) used in U.S. national and international reporting.[16] GWP is used to compare different GHGs and is done on multiple time horizons. On a 20-year GWP (GWP20) basis, methane's heat trapping effect is approximately 84 times more than carbon dioxide.[17] GWP places all GHGs on a carbon dioxide equivalent or CO_2e basis.

Figure ES-1 shows GHG emissions from the U.S. NGSC on the GWP100 basis. On this time horizon, NGSC GHG emissions are almost equally divided between methane and carbon dioxide.

Source: EPA, GHGI 2023

Figure ES-1. 2021 U.S. Natural Gas Supply Chain GHG Emissions, GWP100

16 U.S. EPA, Fact Sheet: Areas where differences between state greenhouse gas (GHG) inventories and the EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks by State: 1990-2021* estimates may occur. August 2023. https://www.epa.gov/system/files/documents/2022-03/fact-sheet-differences-epa-and-offical-state-ghgi.pdf.

17 Global Warming Potential Versions, SIMAP, https://www.epa.gov/system/files/documents/2022-03/fact-sheet-differences-epa-and-offical-state-ghgi.pdf.)

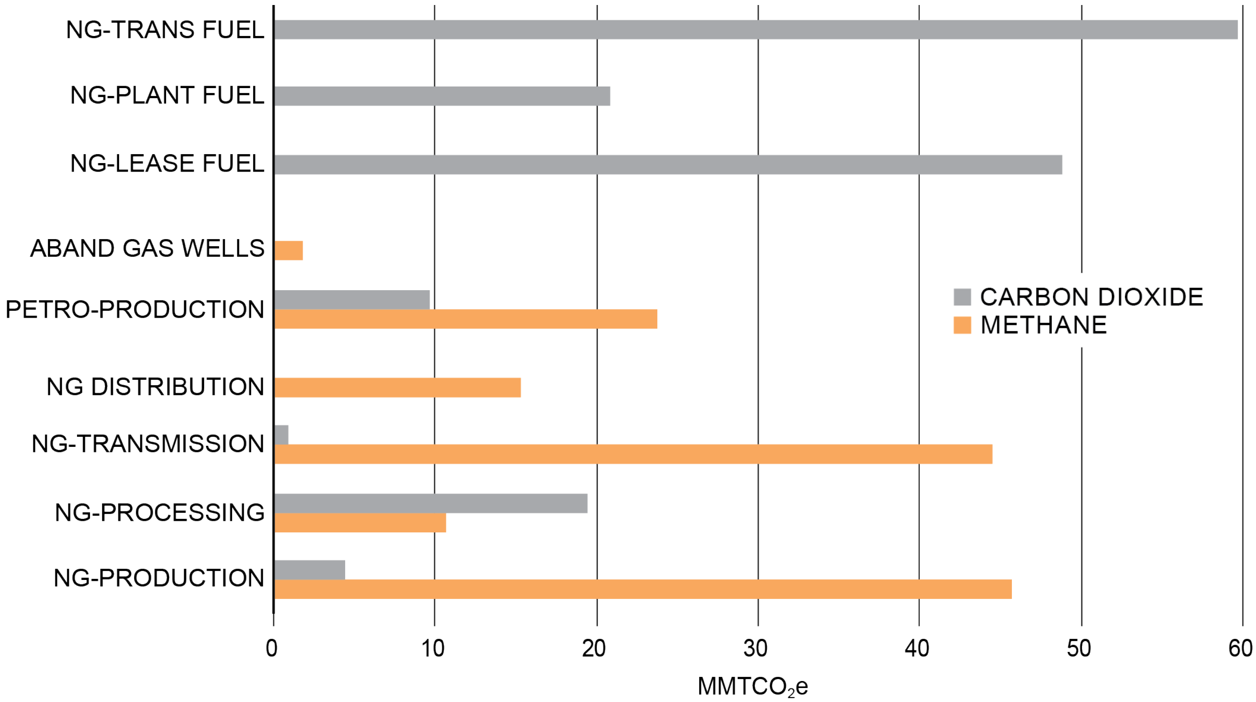
Source: EPA, GHGI 2023

Figure ES-2. 2021 U.S. Natural Gas Supply Chain GHG Emissions, GWP20

Figure ES-2 shows that methane emissions account for almost three-quarters of emissions based on GWP20. Thus, selecting a shorter time horizon for GWP more heavily weights methane emissions. Federal, state, and Tribal policies, regulations, and voluntary industry efforts are generally aligned in their focus on mitigating methane emissions. Throughout the study, key results will be shown primarily in GWP100 but also in GWP20 when the latter provides useful information regarding the emphasis on methane reductions.

GWP is a useful summarizing tool to combine methane and carbon dioxide (and other GHGs) into a unitary number, expressed as CO_2e; however, it does not provide granularity as to the specific combination of GHGs that makes up the CO_2e. Consequently, the study focuses on reducing methane emissions in the near term and effectively addressing carbon dioxide regardless of the GWP metric utilized.

The U.S. EPA Greenhouse Gas Inventory (GHGI) categorizes and tracks GHG emissions at the national level. Consistent with categorizations for reporting issued by the Intergovernmental Panel on Climate Change, the EPA tracks emissions from the NGSC across multiple categories in GHGI. This includes combustion emissions associated with fuel use for leases, plants, pipelines, and distribution and noncombustion emissions in natural gas systems, petroleum systems, and abandoned wells. Figure ES-3 shows the categories of emissions by supply chain segment and its relative contributions of methane and carbon dioxide. The emissions shown below are done on an allocated basis. Allocation is done on an energy equivalent basis for the main coproducts associated with natural gas: crude oil and natural gas liquids (NGL). Note that natural gas exploration and petroleum exploration were included in the study total but are excluded from the graph below as they total less than 1 MMT CO_2e, or 0.3%.



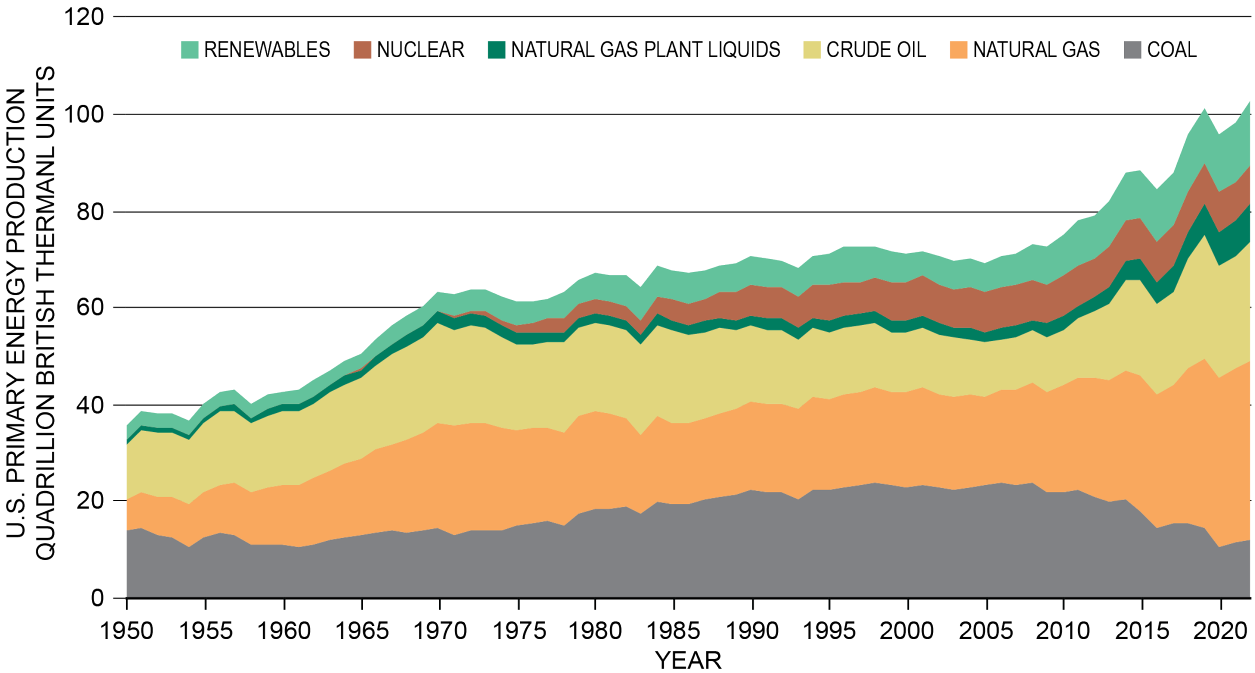
Note: NG-Trans is short for Natural Gas Transmission and represents Pipeline, Distribution, and LNG fuel use, per EIA.
Source: EIA, 2024, https://www.eia.gov/dnav/ng/TblDefs/ng_cons_sum_tbldef2.asp.

Figure ES-3. 2021 GHG Natural Gas Supply Chain Emissions Categories GWP100

Carbon dioxide is generated when fossil fuels like natural gas are combusted. The amount of carbon dioxide generated can be calculated reliably based on the amount of fuel burned and the combination of hydrocarbons in the fuel. Carbon dioxide is emitted along the NGSC from flares, gas-fired compressors, and other sources. Methane is emitted from sources that can include natural gas-powered pneumatic controllers, incomplete flare combustion, fugitive emissions, and other continuous or intermittent sources. Due to their dispersed nature along the supply chain, methane emissions are more difficult to detect and quantify than carbon dioxide.

C. The Rise of Natural Gas

During the 1970s and 1980s, coal, oil, and natural gas competed for the top spot in domestic energy production. Since 2010, natural gas has been the leader. Natural gas plant liquids, which include ethane, propane, and butane are also significant primary energy contributors. U.S. natural gas is also exported as LNG or via pipeline to Mexico and Canada. The United States is a net natural gas importer from Canada, but a net exporter overall. Figure ES-4 shows the U.S. energy production mix history.



Source: U.S. Energy Information Administration (EIA), *Monthly Energy Review,* Table 1.2, April 2023, preliminary data for 2022.

Figure ES-4. U.S. Primary Energy Production by Major Sources, 1950-2022

FINDING: Natural gas overtook coal as the largest source of U.S. primary energy production after 2010.

U.S. natural gas production nearly doubled from 2005 to 2021, driven by technological advancements such as combining horizontal well drilling with hydraulic fracturing for increased shale gas recovery. Shale gas accounted for more than 75% of all U.S. natural gas production in 2022. This new production arose from both nonassociated[18] shale gas basins—like the Marcellus/Utica in Pennsylvania, West Virginia, and Ohio, the Haynesville in Louisiana, the Barnett in Texas—and from associated gas from basins like the Permian in Texas and New Mexico, the Eagle Ford in Texas, the SCOOP-STACK and Anadarko in Oklahoma, the Denver-Julesberg in Colorado, and the Bakken in North Dakota. Roughly 40% of U.S. natural gas production is associated gas. Figure ES-5 shows the predominant gas-producing basins in the U.S.

[18] EPA definition: Associated gas means the natural gas from wells operated primarily for oil production that is released from the liquid hydrocarbon during the initial stage of separation after the wellhead. Nonassociated means natural gas from wells operated primarily for their gas production and the hydrocarbons are in gas form in the reservoir.

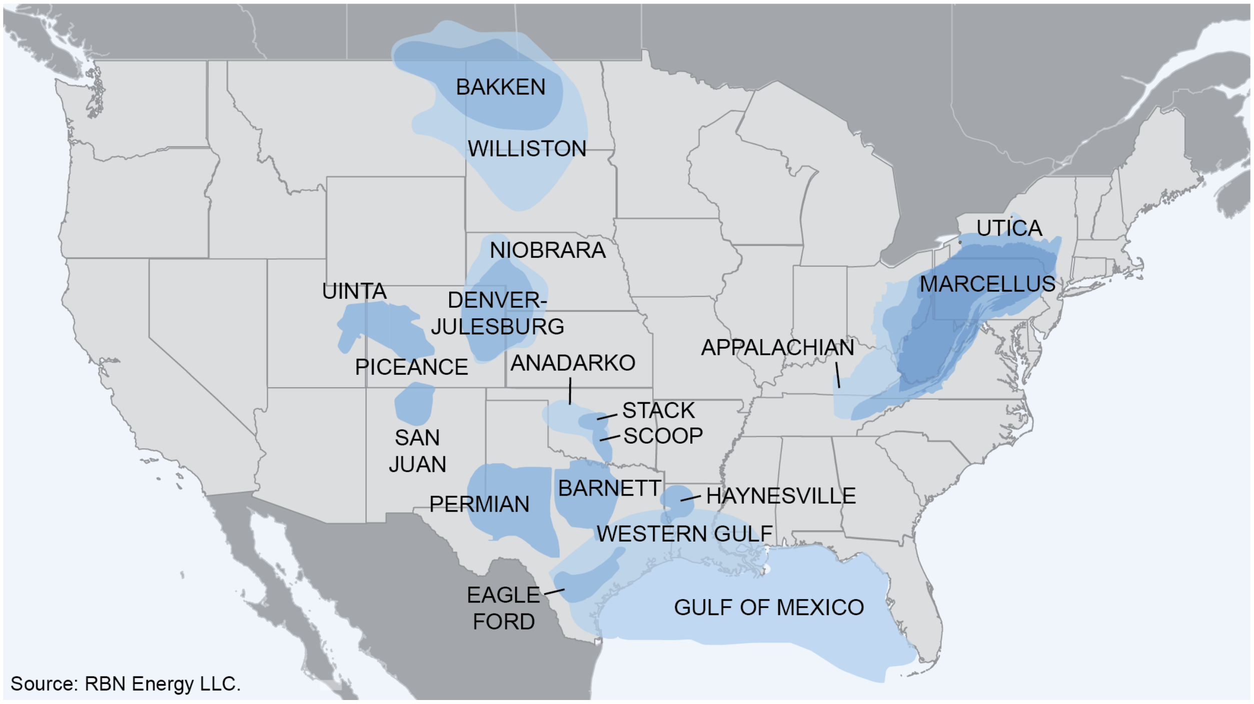
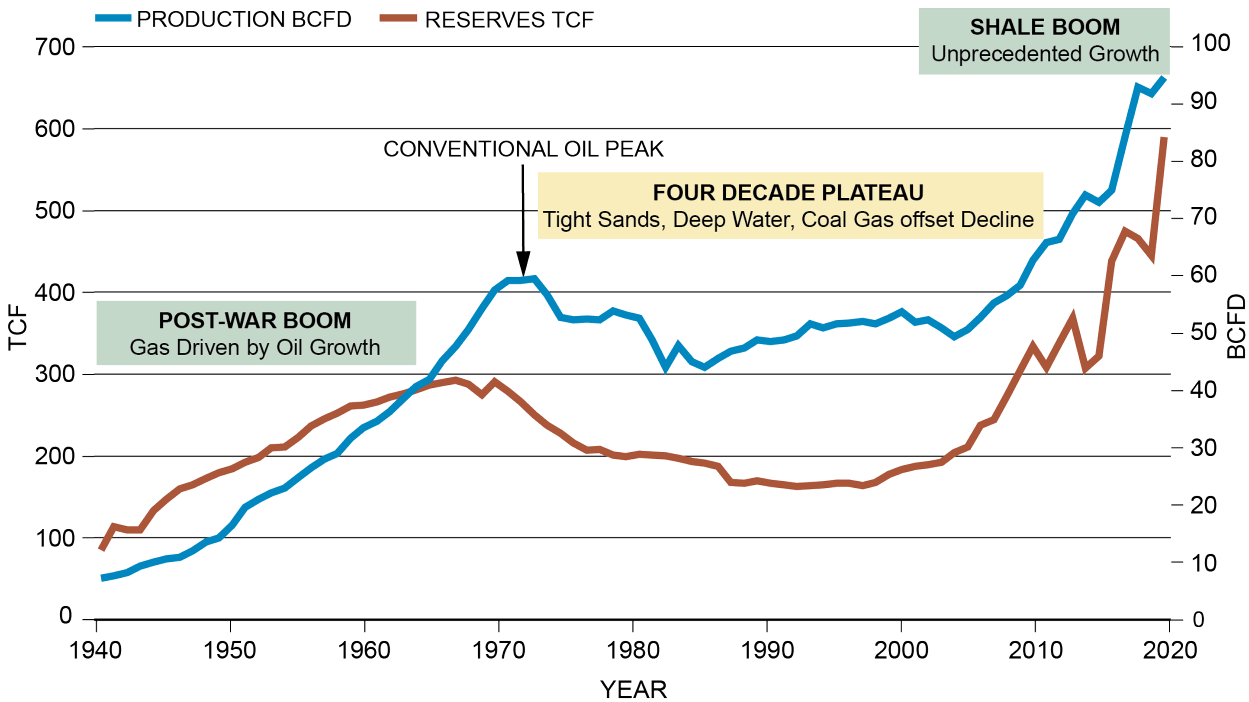


Figure ES-5. Basins that Account for the Majority of U.S. Natural Gas Production

Figure ES-6 shows the history of U.S. production and reserves[19] over 80 years. Dry gas production of 95 Bcf/d and reserves of 589 Tcf in 2021 both were at all-time highs. The Colorado School of Mines Potential Gas Committee estimates the remaining resource at 3,978 Tcf in 2022, also an all-time high.[20]

19 pg 4 sec.gov/Archives/edgar/data/711303/000104746909003560/a2192021zex-99_a.htm.

20 "Potential Gas Committee Reports Future Natural Gas Supplies in U.S. At Highest Reported Level on Record." https://www.minesnewsroom.com/news/potential-gas-committee-reports-future-natural-gas-supplies-us-highest-reported-level-record.



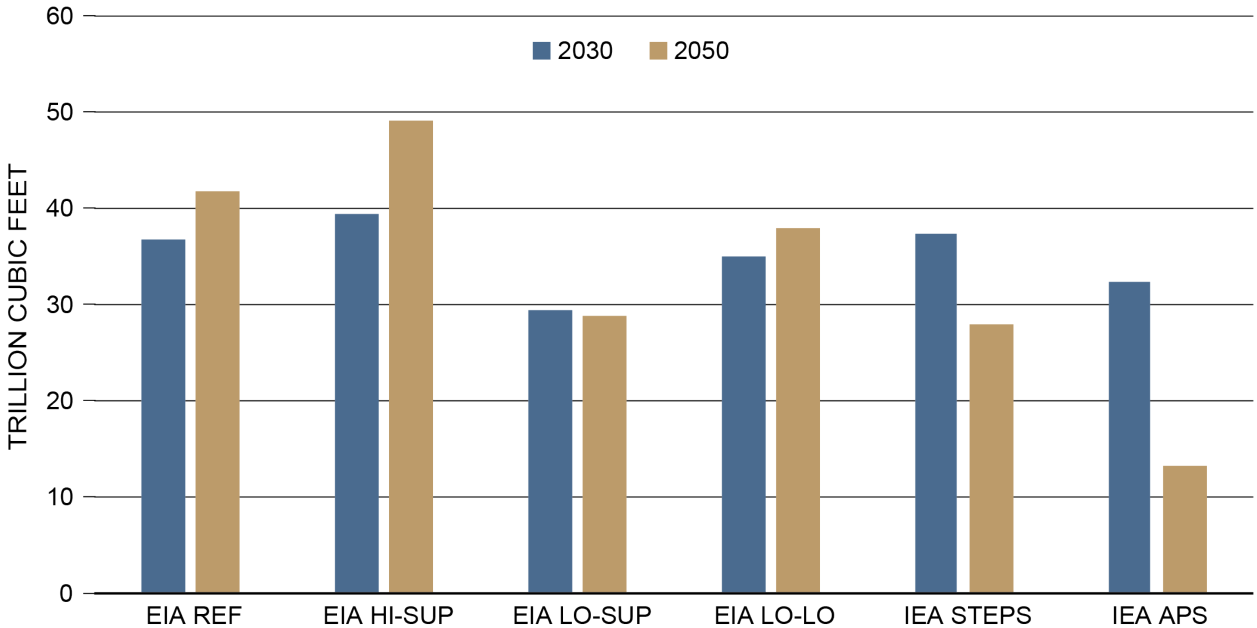
Source: U.S. Energy Information Administration

Figure ES-6. U.S. Natural Gas Production and Reserves History

FINDING: U.S. natural gas production, reserves, and resources are at all-time highs.

D. Projected Natural Gas Supply & Demand to 2050

Natural gas is the largest primary energy source for electricity generation and plays a crucial role in many sectors of the U.S. economy, including Residential, Commercial, and Industrial (both heat and feedstock). The U.S. EIA modeled four scenarios for natural gas's supply through 2050. In all four scenarios, U.S. natural gas is forecast to be a significant source of primary energy. The IEA also ran scenarios that forecast U.S.-specific dry gas supply. Figure ES-7 shows the four EIA scenarios ranging from the highest to the lowest production forecasts from the 2023 Annual Energy Outlook along with two IEA scenarios. The EIA Reference (REF) and High Oil and Gas Supply scenario (HI-SUP) show an increase in natural gas production through 2050. The lowest EIA production scenario is the Low Oil and Gas Supply Scenario (LO-SUP). The EIA Low Macro and Low Zero-Carbon Technology scenario (LO-LO) is a low economic growth case in which zero-carbon technologies like renewables further decrease in cost. In this scenario, natural gas production stays relatively stable near its all-time high. The IEA Stated Policies scenario (STEPS) and Announced Policies scenario (APS) show declines in 2050 U.S. natural gas supply.



Sources: U.S. Energy Information Administration, *Annual Energy Outlook* 2023 (https://www.eia.gov/outlooks/aeo/); International Energy Agency, *World Energy Outlook 2023* (https://www.iea.org/reports/world-energy-outlook-2023).

Figure ES-7. U.S. Natural Gas Production Scenarios

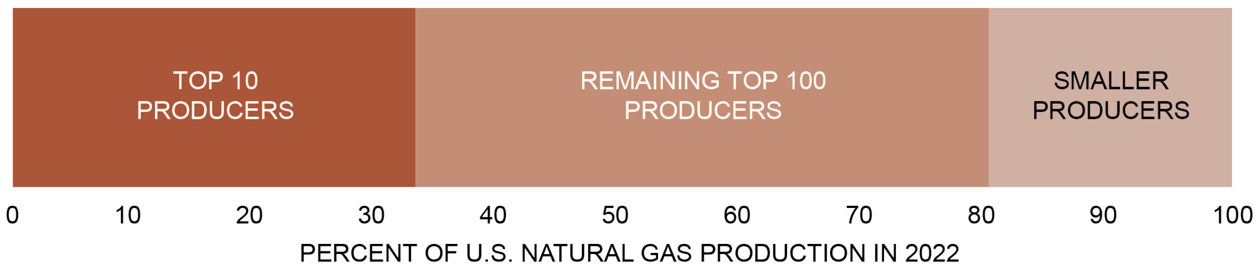
FINDING: U.S. natural gas scenarios exhibit a wide range of 2050 outcomes.

In addition to STEPS and APS, the IEA has a global net zero scenario (net zero emissions or NZE) in which global gas demand is assumed to decline by 78% from 2022 to 2050.[21] IEA does not project U.S. supply or demand within that scenario. The IEA NZE scenario is representative of several other scenarios that seek to limit warming to a threshold. While they are useful at a global level, they do not address supply or demand from a specific country like the United States. In these scenarios, the natural gas that meets the remaining demand will be the low GHG emission natural gas. This study provides recommendations provide lower GHG emission natural gas to the domestic and global market that are relevant in any production scenario.

E. A Diverse Natural Gas Supply Chain

As described in the NPC's 2019 report *Dynamic Delivery,*[22] the United States has a large, legacy infrastructure endowment with multiple producing basins, more than 300,000 miles of interstate and intrastate transmission pipelines, 2.3 million miles of distribution pipelines, and 388 underground storage sites. The production landscape is complex. The top 10 companies produce just over 30% of U.S. natural gas. It takes the top 100 producers to produce 80% of natural gas and thousands of smaller producers deliver the balance, demonstrating the depth and diversity of market participants across the supply chain.

[21] "Net Zero Roadmap: A Global Pathway to Keep the 1.5 °c Goal in Reach – Analysis." n.d. IEA. https://www.iea.org/reports/net-zero-roadmap-a-global-pathway-to-keep-the-15-0c-goal-in-reach.
[22] 2019 NPC Dynamic Delivery Study, https://dynamicdelivery.npc.org/downloads.php.



Source: Rystad.

Figure ES-8. Operated Gross Natural Gas Production in 2022

FINDING: The U.S. NGSC is large and complex and achieving U.S. GHG emissions reduction goals requires engagement by many types and sizes of companies.

More than 1,600 active gas producers exist in Texas alone.[23] The large number of producers, combined with different sets of companies responsible for gathering, processing, transporting, and storing natural gas, makes the overall system resilient. But it also provides a challenge. All operators of all segments need to be engaged to reduce GHG emissions effectively and rapidly.

F. Less Capitalized Operators

The study conducted four "Less Capitalized Operator" (LCO) workshops in Houston, Midland, Denver, and Pittsburgh. LCO was loosely defined. The invitations were directed to companies with generally less than $2B market capitalization value and with production ranging from less than 1,000 barrels of oil equivalent per day (Boe/d) to more than 50,000 Boe/d. More than 70 companies attended the workshops. Some companies had one employee while others employed a few hundred. These smaller operators shared operational practices and feedback. Workshop findings include:

FINDING: Some leak detection and repair programs can be executed at low cost to materially reduce methane emissions. LCOs shared successful cases of implementing audio, visual, olfactory, and practical advanced technology applications.

FINDING: Many LCOs are concerned about emissions and strive to comply with emerging federal regulations but do not have the organizational structure and expertise to interpret complex, sometimes conflicting requirements.

FINDING: In addition, LCOs may not have the staff to address GHG emissions reduction opportunities through emissions measurement tools, facility modifications, operating procedure changes, or evaluation and implementation of new technology.

23 Texas Oil and Gas Producers by Rank, https://www.rrc.texas.gov/oil-and-gas/research-and-statistics/operator-information/texas-oil-and-gas-producers-by-rank-2021/.

FINDING: Several participants highlighted the potential for upstream producers and midstream companies, along with regulators, to investigate ways to jointly address GHG emissions by looking more holistically at the entire natural gas supply chain.

RECOMMENDATION: INDUSTRY FUNDS EDUCATION AND TRAINING

The NPC recommends the development of education and best practice sharing programs and materials by local oil and gas associations and state regulators to increase smaller and marginal operator access and understanding of technical, information technology, and operational best practices to detect and reduce GHG emissions.

The NPC recommends revitalizing or starting up an organization in the model of the Petroleum Technology Transfer Council to transfer GHG emissions reduction technology and best practices to smaller and marginal well operators.

LCOs often deal with marginally economic wells. Marginal wells have production rates below 15 Boe/d or 90 Mcf/d of natural gas per day for combined oil and gas production. While nearly all companies have marginal wells, those companies whose well inventory is primarily made up of marginal wells are more challenged to make new capital or expense investments. LCOs expressed concerns that proposed methane regulations have no minimum production rate threshold for applicability and thus may be challenging to implement on marginal wells.

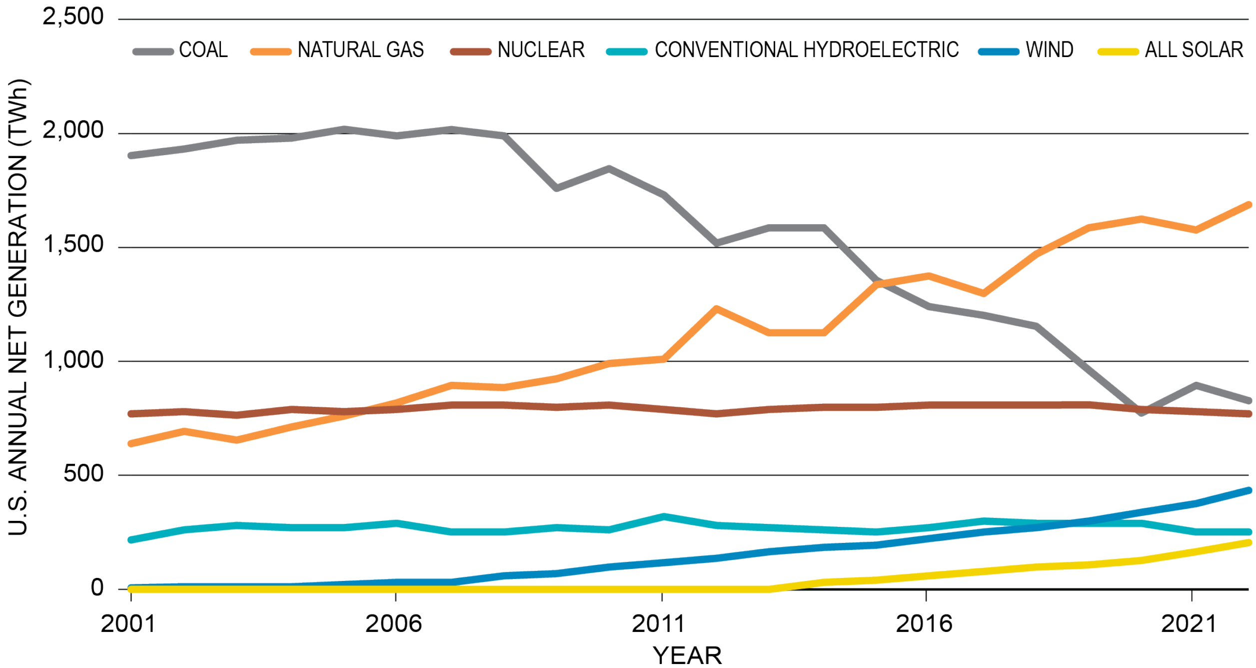
RECOMMENDATION: GOVERNMENTS PROVIDE EMISSIONS REDUCTION INCENTIVES

The NPC recommends state and federal governments review options for marginal wells, including deduction of GHG emissions reduction investments from state or federal taxes or royalty obligations.

II. THEME 2: GHG EMISSIONS SOLUTION AND CHALLENGE

Natural gas can be part of the solution by displacing coal, but its supply chain emissions present a challenge, by generating 33% of U.S. methane and 5% of carbon dioxide emissions.

From 2005 to 2019, coal-fired power generation was reduced by more than 1,000 Terawatt-hours. Natural gas displaced most of this generation with renewables accounting for the rest. According to the EIA, "Of the 819 million metric ton decline in CO_2 emissions from 2005 to 2019, approximately 248 million metric tons (30%) of that is attributable to the increase in renewable generation. In comparison, almost 532 million metric tons (65%) of the decline in CO_2 emissions from 2005 to 2019 is attributable to the shift from coal-fired to natural gas-fired electricity generation."

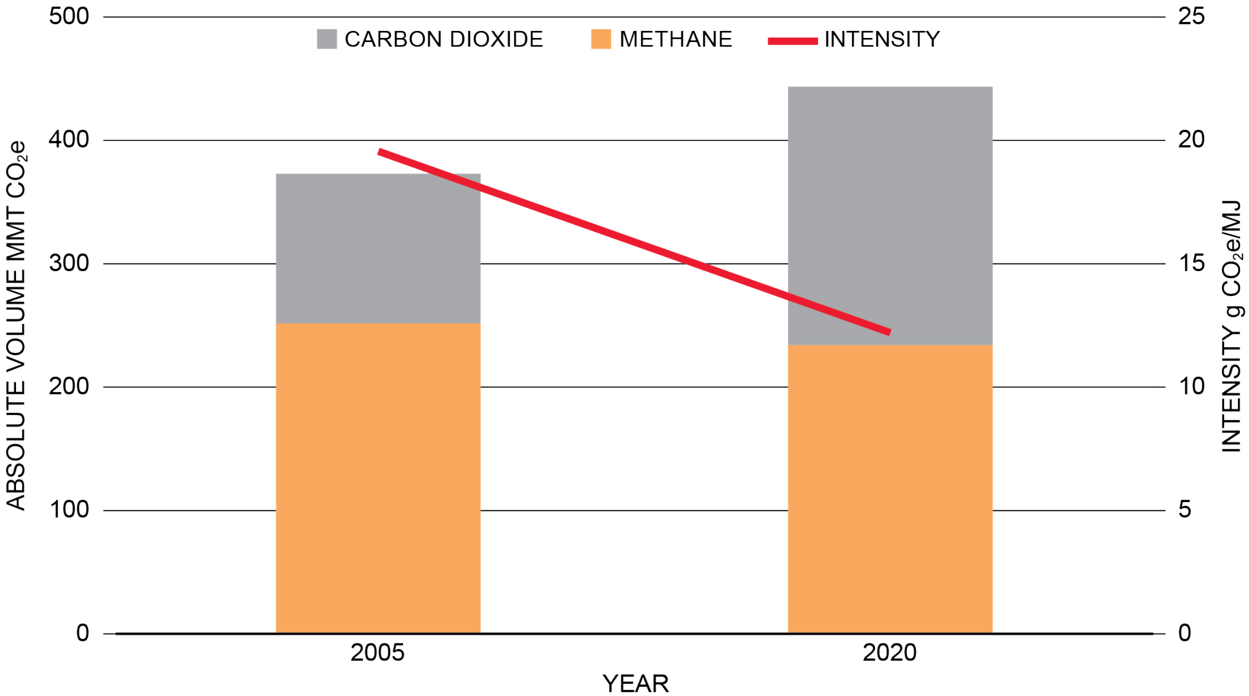


Source: U.S. Energy Information Administration (EIA).

Figure ES-9. U.S. Net Electricity Generation from Selected Resources

FINDING: Natural gas displacing coal reduced U.S. emissions by 532 million metric tons of carbon dioxide or 65% of the U.S.'s total carbon dioxide reduction from 2005 to 2019.

Three changes happened simultaneously: Natural gas displacing coal lowered total U.S. GHG emissions; the carbon intensity of the NGSC decreased, according to U.S. GHGI; and absolute emissions in the NGSC crept up. Since 2005, new sources of shale gas were discovered and brought online, enabled by existing infrastructure (as detailed in the *Dynamic Delivery* NPC study). These new sources, along with reduced venting and flaring, drove carbon intensity down over the same period as natural gas production rose (Figure ES-10).



Source: EPA GHGI and U.S. Energy Information Administration

Figure ES-10. Methane Emissions, Carbon Intensity, and Total Emissions from 2005 to 2020 (GWP100)

Total NGSC emissions increased from 2005 to 2020 while methane and overall emissions intensity decreased. The factors causing this were:

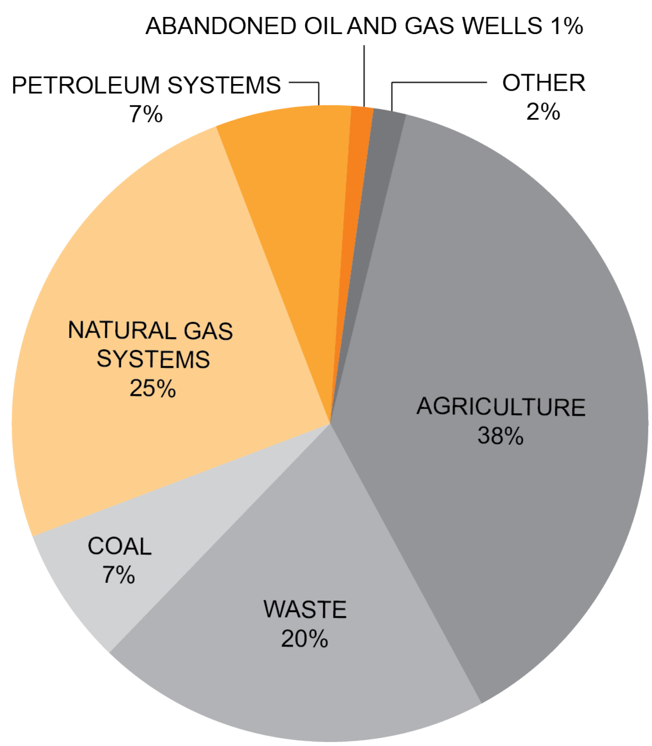
- Production increased from 45 Bcf/d to 96 Bcf/d, a 113% increase, from 2005 to 2021.
- Despite the production increase, absolute methane emissions were reduced by 7% as operators improved performance across the supply chain.
- Carbon dioxide emissions increased by 73% due to larger energy requirements to produce, process, and transport the larger natural gas volumes.
- Overall, carbon intensity decreased by more than 33% despite the rise in carbon dioxide emissions.

The GHGI includes four categories that contribute to NGSC GHG emissions that are examined within the scope of this study:

- **Natural gas systems**: Emissions associated with the NGSC, excluding behind-the-meter and end-use emissions due to study scope.
- **Petroleum systems**: Emissions associated with the crude oil and petroleum products supply chain, excluding end use. This study includes emissions from oil production, but not transport or refining, which are outside the scope of the natural gas supply chain.

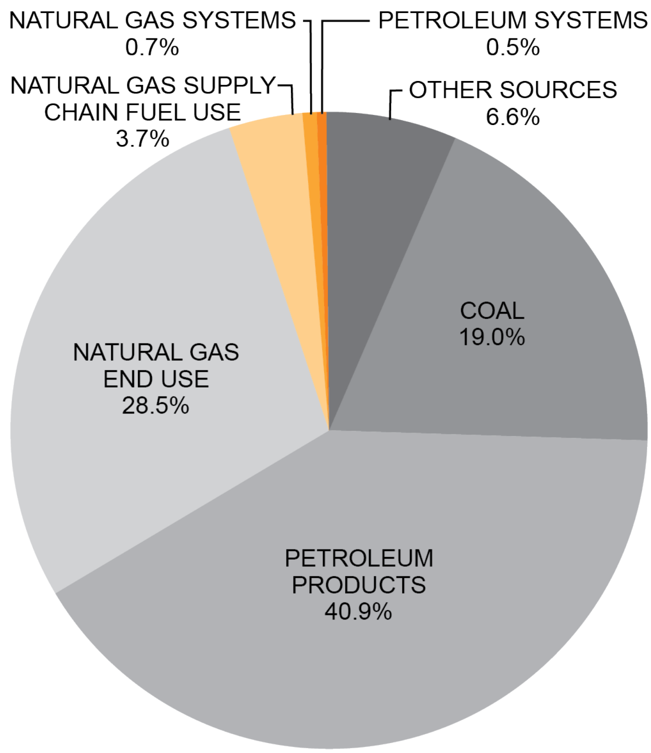
- **Abandoned oil and gas wells**: Emissions associated with plugged and unplugged wells at the end of their economic life are included in this study.
- **Natural gas supply chain fuel use**: Emissions associated with use of natural gas for energy along the supply chain. This study examines a subset of emissions related to lease fuel associated with the production and gathering of oil and gas; plant fuel used in natural gas processing; and pipeline and distribution fuel use that account for energy use in transmission, distribution, and liquefaction plants.

These four categories represent 8% of national net GHG emissions, 33% of methane emissions (Figure ES-11), and 5% of carbon dioxide emissions (Figure ES-12). "Natural gas systems" includes production of NGLs, and "petroleum systems" includes production of crude oil, yet all emissions are included in this total. The study recommends how to allocate emissions to these coproducts for life cycle assessments in Chapter 4. Study recommendations are applicable to oil and gas production, processing, and transmission (the full supply chain) and will help reduce emissions from all categories represented here. Additionally, the study discusses actions to find, measure emissions from, and permanently plug existing orphan wells as well as preventing more orphan wells.



Source: EPA GHGI 2023

Figure ES-11. U.S. Total Methane Emissions by Sector in 2021 from GHGI



Source: EPA GHGI 2023

Figure ES-12. U.S. Total Carbon Dioxide Emissions by Sector in 2021 from GHGI

FINDING: The natural gas supply chain, inclusive of crude oil and natural gas liquids (NGLs), accounts for 8% of overall national net GHG emissions, 33% of methane emissions, and 5% of carbon dioxide emissions.

Measuring, monitoring, reporting, and verifying (MMRV) emissions takes money and resources. The LCOs voiced significant concern over the impact of increasing MMRV costs. There were smaller companies among the LCOs that believe the effort was beneficial to both the environment and to their companies' bottom line.

RECOMMENDATION: INDUSTRY DEDICATES ADDITIONAL RESOURCES

- The NPC recommends that companies throughout the natural gas supply chain dedicate additional resources to analyze further GHG emissions reduction opportunities and execute projects that they consider to be cost effective.

III. THEME 3 ADDRESSING THE SECRETARY'S THREE GOALS

Natural gas supply chain emissions reductions contribute to achieving U.S. climate goals such as reducing total emissions, meeting the net zero emissions by 2050 goals, and fulfilling the Global Methane Pledge.

A. Goal 1: A 50 to 52% Reduction in GHG Emissions from 2005 Levels by 2030

Efforts to reduce GHG emissions in the NGSC are currently focused on methane reduction. These efforts include policy and regulations by all levels of government, voluntary commitments by companies either individually or as part of organizations, and technology advancements from academia and innovators. Going forward, GHG emissions reduction efforts should also address carbon dioxide. This study defines three future pathways for total GHG emissions reductions for the NGSC.

- *Existing Policies (EP):*
  - Includes reductions from federal methane and flaring regulations
  - Assumes supply chain stages average intensity performance reaches Methane Emissions Reduction Program benchmarks (0.2% of gas in the production stage)
  - Uses EIA projections for NGSC fuel use, which assumes no additional technology or innovation breakthrough, efficiency improvements, or market mechanisms
- *Continued Reductions (CR):*
  - Same as EP to 2030
  - Additional GHG emissions intensity reductions to 2050 that trend with current rates of improvement and levels of policy enablement

Technology gains for engine efficiency, compressor slip reductions, and deployment of CCS e.g., 50% CCS for acid gas[24] plants.

  - Does not assume additional market mechanisms
- *Technology, Innovation, and Policy (TIP):*
  - Same as EP to 2030
  - Includes all initiatives in CR above
  - Policy and voluntary efforts shift to CO_2 as CH_4 is reduced
  - Technology-enabled advancements in key areas, e.g., increased electrification, CCS for all acid gas and LNG plants, further deployment of technologies to reduce compressor slip
  - Market mechanisms support wider CCS deployment and electrification

The United States has launched several policy and regulatory initiatives to address methane in oil and gas operations. The Inflation Reduction Act (IRA) provides funds for emissions reduction efforts and institutes a methane waste emissions charge of $1,500/metric ton by 2026 for methane emissions above certain emissions intensity thresholds. Additionally, the EPA regulations—through the current OOOO/OOOOa and new OOOOb/c ones—address how facilities

24 Acid gas is natural gas that contains H_2S or CO_2 https://glossary.slb.com/en/terms/a/acid gas.

should be designed or retrofitted. The OOOOb/c regulations will likely reduce the major sources of known methane emissions. Further reductions will require ongoing efforts to identify and eliminate anomalous operating conditions.

The Pipeline Hazardous Materials Safety Administration (PHMSA) is also introducing regulations on leak detection, blowdown rules, and volume tracking for pipelines under its jurisdiction. The Infrastructure Investment and Jobs Act (IIJA) includes up to $4.7 billion in potential funding for states, Tribes, and federal land-management agencies to plug orphan wells. Under the EP Pathway, the study estimates emissions assuming the existing policy and regulatory initiatives such as the IRA, OOOO/a/b/c and IIJA are implemented as proposed at the time of publishing this report. Implementing these regulations will require facility and technology deployment investments along the supply chain.

In addition to these governmental efforts, larger and smaller companies have joined voluntary organizations and/or launched their own efforts to address methane emissions. OGMP 2.0, ONE Future, The Environmental Partnership, and Veritas are examples of these voluntary efforts. Many emissions reduction practices included in federal regulations were first adopted in voluntary programs by operators and included in prior state regulatory environments.

The combined effects of policy, regulation, technology, and operational efforts on reducing GHG emissions are shown in Figure ES-13 below.

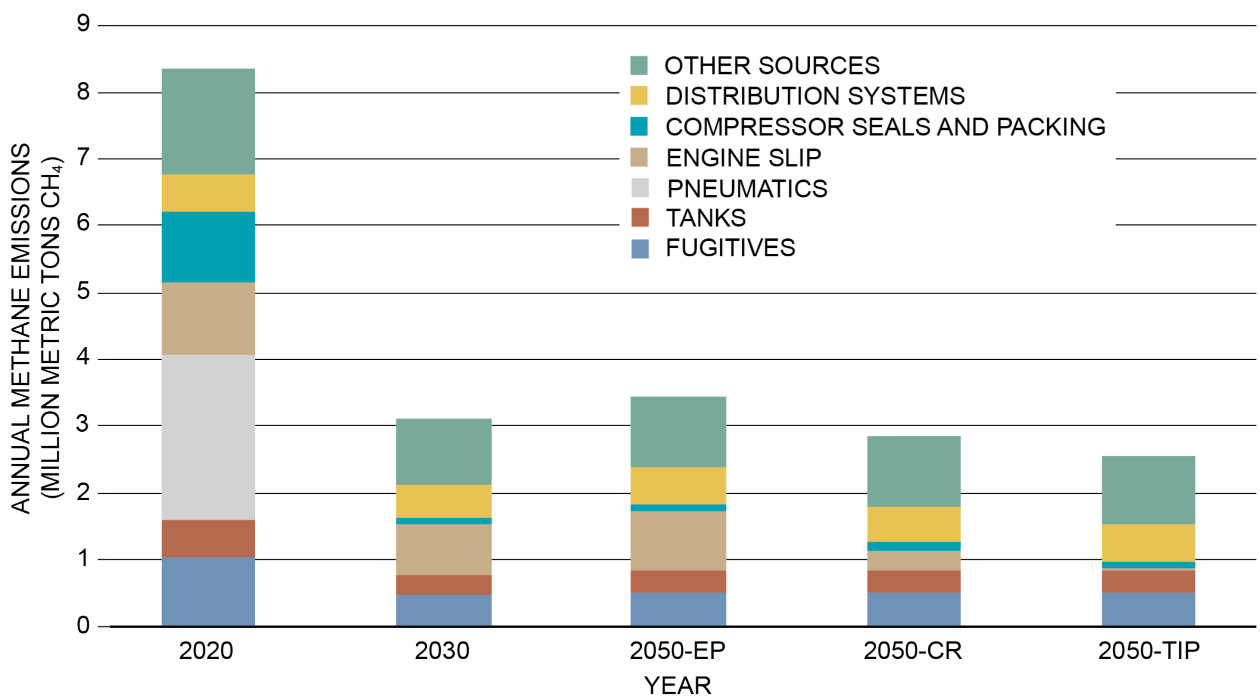


Figure ES-13. Reference Case Projections of Methane Emissions

Methane emissions are expected to drop by more than 60% in the EP Pathway by 2030. Decreases of 50-70% are expected through 2050 depending on the success of technology development and deployment. The drop from 2020 to 2030 is primarily due to reductions in venting, flaring, and fugitive emissions associated with emerging federal methane regulations. The combination of pathways and gates analyzed in this study represent delivered methane intensity reductions ranging from 66-81%, compared to the 2020 baseline.

The Global Methane Pledge is a voluntary international goal to reduce anthropogenic methane emissions by 30% in 2030, relative to a 2020 baseline. For the United States, the 2030 methane reductions modeled in this study represent ~20% reduction in U.S. total methane emissions, or two-thirds of the total reductions needed for the U.S. to achieve the 30% methane reduction as part of the Global Methane Pledge. Additional policy in other methane emitting sectors, such as coal mining and agriculture, will be needed to meet a 30% reduction.

FINDING: 2030 Global Methane Pledge: The EP Pathway for this study estimates that reductions associated with a suite of federal regulations will reduce methane emissions from sources in the U.S. GHGI 63% by 2030 and contribute approximately two-thirds of the reductions needed for the United States to contribute a 30% reduction to the Global Methane Pledge.

This suite of proposed and new federal methane regulations will make an important contribution to U.S. methane and global GHG emissions reduction efforts, including regulations at different stages of development with EPA, the Bureau of Land Management, and the Pipeline and Hazardous Materials Safety Administration. At the same time, these regulations have been developed in a relatively short time frame and with several agencies across the federal government. The NPC has noted several key examples for differing source control requirements and rules for advanced methane detection and measurement technologies across these rules that could be better harmonized to focus on emissions reduction and minimize duplicative or conflicting compliance requirements. Further, the durability and effectiveness of regulations is enhanced by ensuring they are reasonable and cost-effective.

A key remaining challenge for methane voluntary and regulatory frameworks is the development of measurement-informed inventories that better reflect actual methane emissions in the field, by incorporating more facility-specific observations into emissions inventories. Key to this interface is the role of advanced methane detection and measurement technologies that have emerged in the last five years that offer a pathway for scaled deployment across diverse types of operations.

Regulatory frameworks for leak detection and emissions measurement should evolve with technology and offer a pathway for innovative approaches to emissions management. Such information will be valuable for improving the accuracy of national inventories and as input into the next generation of life cycle models to better understand performance, though protocols will need to be developed to account for quantification uncertainty, which is discussed in Chapter 3.

Carbon dioxide emissions are shown in Figure ES-14.

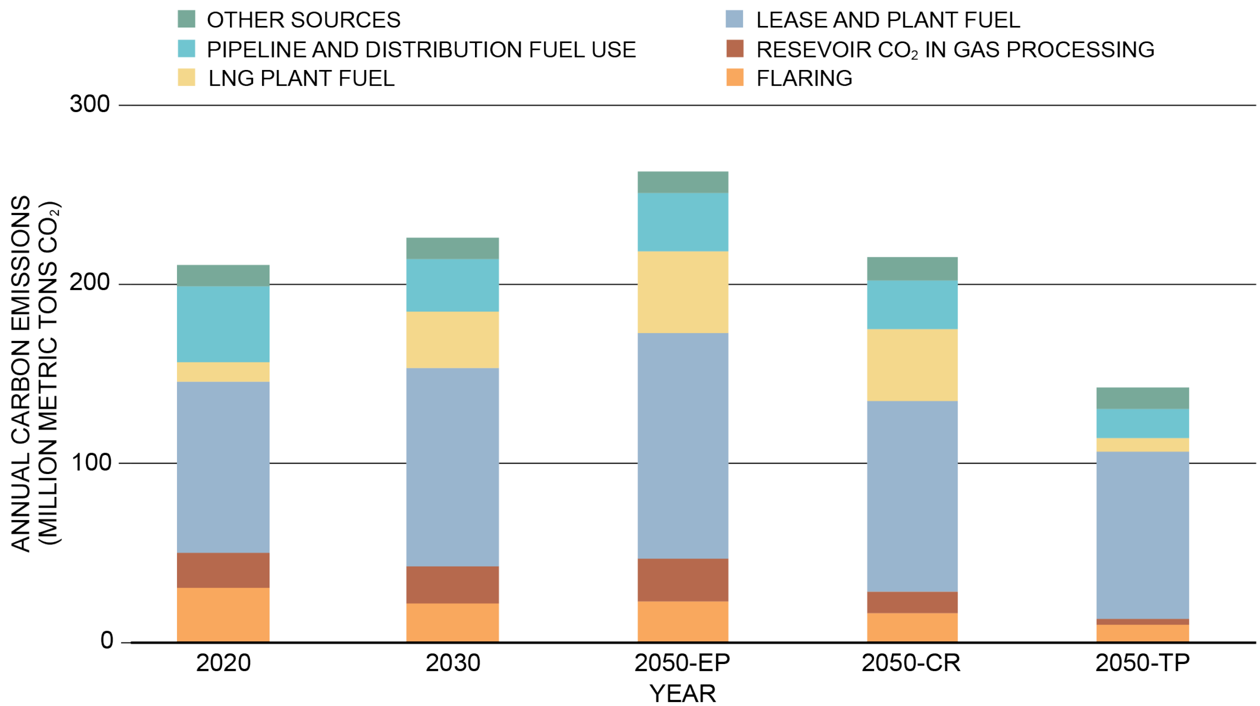


Figure ES-14. Reference Case Projections of Carbon Dioxide Emissions

Carbon dioxide emissions increase from 2020 through 2050 in the Reference scenario for the EP Pathway for two reasons: Overall, more natural gas is produced, moved along the supply chain, and a higher percentage converted to LNG. The additional energy required to liquefy natural gas is generated in the EP Pathway by combusting natural gas to generate electricity on site for the liquefaction process without sequestering the carbon dioxide. In the TIP Pathway, these emissions are assumed to be captured through CCS.

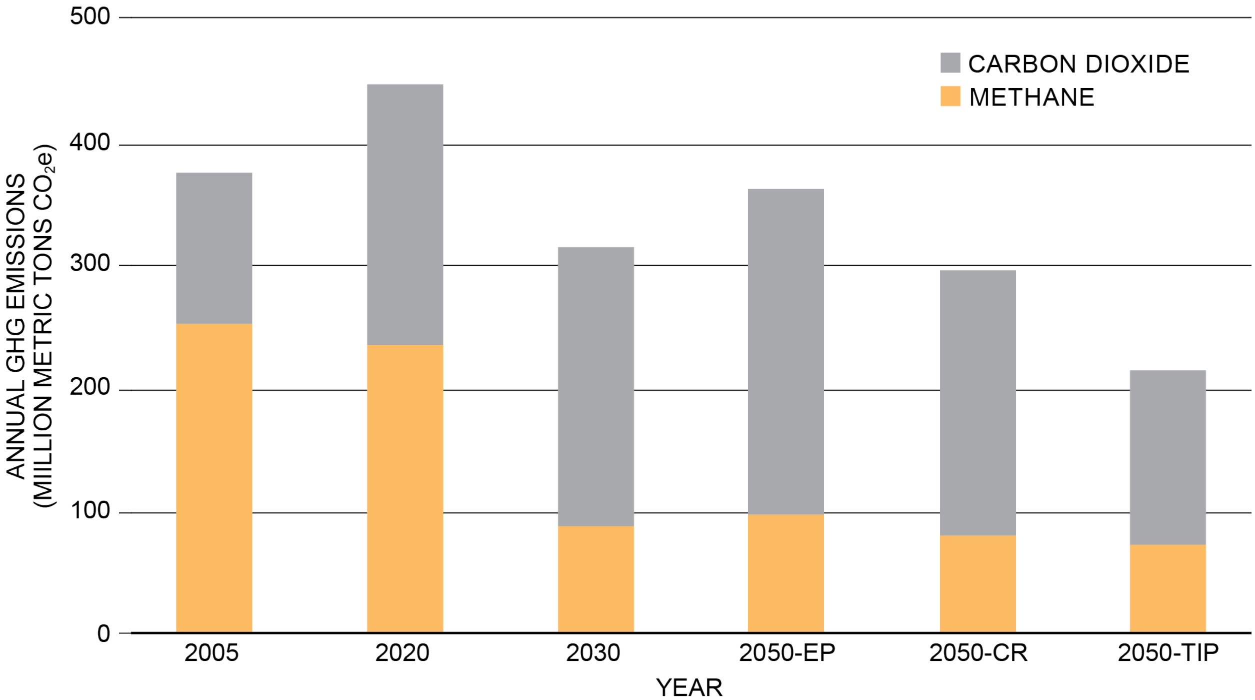


Figure ES-15. GHG Emissions Pathways in This Study, Based on EPA GWP100 Factors

B. Goal 2: Net Zero Emissions Economy-Wide by 2050

The Nationally Determined Contribution for the United States under the Paris Agreement[25] includes a 50 to 52% reduction in economy-wide net GHG emissions by 2030, relative to a 2005 baseline. For 2020, the EPA[26] estimates an economy-wide net emissions reduction of 22% relative to the 2005 baseline across all sectors of the economy. For the NGSC, reductions modeled in this study, particularly in methane emissions, would contribute ~2% out of the 50 to 52% reductions for the U.S. pledge in 2030 relative to 2005. On an economy-wide, net basis, the natural gas industry could enable additional reductions through the displacement of more carbon intensive fuel sources like coal-fired power generation. Estimating continued fuel switching in the U.S. or abroad is outside the study scope.

FINDING: 2030 Total GHG Emissions: The Existing Policies Pathway for this study estimates that emissions reductions within the scope of this study could contribute ~2% (4% relative) of the 50-52% reduction in economy-wide net GHG emissions by 2030, relative to a 2005 baseline, as part of the Paris Agreement's Nationally Determined Contribution for the United States.

25 United States NDC April 21 2021, https://unfccc.int/sites/default/files/NDC/2022-06/United%20States%20NDC%20April%2021%202021%20Final.pdf.

26 Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021, https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2021.

FINDING: For all levels of supply and demand, reducing the natural gas supply chain carbon intensity will play an important role in allowing this commodity to contribute to worldwide energy security.

The range of 2050 emissions pathways examined in this study represents reductions of 1-3% relative to 2005 U.S. net GHG emissions. From a policy perspective, residual or remaining emissions in any one sector, including the NGSC, can be compatible with an NZE societal pathway, as negative emissions technologies, from nature-based solutions to engineered solutions like direct air capture, could be used to offset residual emissions from other sectors. The U.S. oil and gas sector is uniquely positioned to develop technology and help enable deployment of these GHG emissions abatement tools. Modeling the scale and potential of negative emissions technologies warrants its own scientific analysis and is outside the scope of this study. As discussed in Chapter 4 (LCAs), GHG intensity is also an important metric when analyzing reductions along the NGSC. Pathways in this study would represent 25-54% reductions in intensity in 2050, relative to 2020.

Further technology and policy development beyond those contemplated in this study could additionally reduce residual GHG emissions from the NGSC over the coming decades. Technologies that can cost effectively scale to thousands of existing operations would have the most GHG emissions reduction potential. Research, development, and deployment funding from DOE has helped to catalyze technological advancement in methane detection and measurement approaches. Similar technology development efforts around reducing natural gas combustion for energy use in the supply chain would be an important lever for continued GHG emissions reduction in the sector, as this represents 50-60% of emissions in 2030 and 2050 in the pathways used in this study. Realizing these emissions reductions from mitigations such as compressor electrification with low-carbon power, CCS, and low carbon intensity hydrogen will involve the need to permit and build new and reliable support infrastructure.

FINDING: Contribution to net zero by 2050: While methane emissions are expected to reduce rapidly, carbon dioxide emissions will increase through 2050 on the Existing Policies Pathway. The Technology, Innovation, and Policy Pathway estimates methane emissions reduction of more than 70% and carbon dioxide reduction of more than 25% by 2050, which would represent ~3% of all 2005 national GHG emissions.

The TIP Pathway requires a large infrastructure build out for electrification, carbon capture and sequestration and hydrogen production. The *Dynamic Delivery* and *Harnessing Hydrogen* NPC studies address the need for infrastructure permit reform. Permit reform enables the building of more efficient infrastructure, which can lower the carbon intensity of energy use throughout the NGSC. Additionally, new technology could be brought to bear to lower carbon intensity. The following recommendations are shared from *Harnessing Hydrogen* as they are important to implementing the TIP Pathway.

RECOMMENDATION: GOVERNMENTS ADVANCE PERMIT REFORM

The NPC recommends the administration and/or Congress:

- Incentivize state and local permitting reform and coordination, clarify eminent domain use, direct federal land-management agencies to create national maps of environmental sensitivity and community vulnerability and use Programmatic Environmental Impact Statements to speed up project permitting
- Streamline permitting litigation timeline to two years by setting the statute of limitations for filing lawsuits and setting timelines for judicial remands
- Expand permitting agency capacity by adopting the Federal Permitting Improvement Steering Council recommendations and ensuring adequate staffing resources
- Expand energy corridors on federal lands and consider categorical exclusions to accelerate infrastructure

RECOMMENDATION: DOE UNDERTAKES ENERGY EFFICIENCY RDD&D

The NPC recommends the DOE undertake new research, development, demonstration, and deployment (RDD&D) programs that are focused on affordable and reliable technology options that could reduce the carbon intensity of energy use in the natural gas supply chain for compression, heat, and power activities.

C. Goal 3: Fulfilling the Global Methane Pledge

Methane emissions are expected to drop by more than 60% in the EP Pathway by 2030. Decreases of 50-70% are expected through 2050 depending on the success of technology development and deployment. The drop from 2020 to 2030 is primarily due to reductions in venting, flaring, and fugitive emissions associated with emerging federal methane regulations.

The Global Methane Pledge is a voluntary international goal to reduce anthropogenic methane emissions by 30% in 2030, relative to a 2020 baseline. For the United States, the 2030 methane reductions modeled in this study represent ~20% reduction in U.S. total methane emissions, or two-thirds of the total reductions needed for the U.S. to achieve the 30% methane reduction as part of the Global Methane Pledge. Additional policy in other methane emitting sectors, such as coal mining and agriculture, will be needed to meet a 30% reduction.

FINDING: 2030 Global Methane Pledge: The Existing Policies Pathway for this study estimates that reductions associated with a suite of federal regulations will reduce methane emissions from sources in the U.S. GHG Inventory 63% by 2030 and contribute approximately two-thirds of the reductions needed for the United States to contribute a 30% reduction to the Global Methane Pledge.

IV. THEME 4: SOCIETAL CONSIDERATIONS AND IMPACTS (SCI)

The NPC *Charting the Course* and *Harnessing Hydrogen* studies include, for the first time, dedicated, stand-alone societal considerations and impacts task groups to evaluate and integrate community and social aspects into the study analysis, findings, and recommendations.

The respective SCI tasks groups worked together to develop shared SCI analysis and recommendations (noted below as joint recommendations). Recommendations specific to the NGSC were also developed. The outcome of the joint effort is an overview of environmental justice-linked issues, some community perspectives related to the energy sector, and a discussion of community engagement best practices.

The study achieved limited, although critical, participation from community and environmental justice (EJ) groups. To help address this gap, the study conducted a series of focus groups and polls in communities[27] that interact with the NGSC across the United States. This primary research was an opportunity to assess what issues are important to respondents and hear directly from their experiences and perspectives on energy development and community engagement.

FINDING: SCI is included as a specific NPC focus area for the first time.

FINDING: The study achieved limited, although critical, participation from community and environmental justice groups.

RECOMMENDATION: DOE UNDERTAKES ADDITIONAL SOCIETAL CONSIDERATIONS AND IMPACTS STUDY

(JOINT) The NPC recommends that the Department of Energy (DOE) undertake a stand-alone, comprehensive Societal Considerations and Impacts study, related to energy development, including but not limited to, LCI hydrogen development and GHG emissions reduction value chains as well as other facets of energy development. It is recommended that this study be conducted with the National Academy of Sciences, Engineering, and Medicine's Division of Behavioral and Social Sciences and Education and the Board on Energy and Environmental Systems, with coordinated input and concerted effort from the NPC and other stakeholders.

27 These communities included Odessa, TX; Port Arthur, TX; Longmont, CO; Pittsburgh, PA; Shreveport, LA; and New York, NY. These areas represent communities along the entire natural gas supply chain from the point of production to distribution to consumption.

While not a new social concept, EJ has reached new prominence in U.S. public discourse in recent years. From the outset, EJ advocates have sought remedies for the disproportionate impact borne by marginalized communities due to social policies[28] or land-use planning.[29] In some cases, siting and the associated impacts of industrial facilities disproportionately affect disadvantaged individuals, groups, or communities.[30]

FINDING: Environmental justice was conceived decades ago by representatives of and advocates for disadvantaged communities to address inequity and potential disproportionate impacts from environmental hazards due to government policies and industrial activities in their communities.

The development and operation of energy infrastructure specifically has potential environmental and societal impacts.[31] EJ advocacy seeks to secure equal environmental protection under law as well as resources to help vulnerable frontline and overburdened communities engage in critical decisions affecting where they live and work, avoid and mitigate impacts, and secure benefits.

FINDING: Adverse impacts of emissions reduction infrastructure and policy on historically disadvantaged communities should be avoided or minimized when possible. Those communities' views of proposed emissions reductions projects will be based on their unique and local historical experience, which can best be understood and reconciled through meaningful engagement with the community.

RECOMMENDATION: GOVERNMENTS COMMIT TO SOCIETAL CONSIDERATIONS AND IMPACTS

(JOINT) The NPC recommends DOE, decision-makers, corporations, researchers, governments, and regulatory bodies actively commit to comprehensively consider and equitably address societal, environmental, and public health impacts during the development and implementation of GHG emissions reductions projects.

A common theme among differing SCI and EJ perspectives is that local, state, and federal government and industry are called upon to meaningfully engage with historically disadvantaged communities. Effective community engagement is a critical means to address concerns in general, and EJ particularly.

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28 Rothstein, Richard. 2015. “The Making of Ferguson.” Journal of Affordable Housing & Community Development Law 24 (2): 165–204. https://www.jstor.org/stable/26408162. https://www.jstor.org/stable/26408162. See also: Moyers, Bill. 2015. “How a Century of Racist Policies Made Ferguson Into a Pocket of Concentrated Despair, https://billmoyers.com/2014/10/27/century-racist-policies-created-ferguson/.

29 https://www.epa.gov/sites/default/files/2015-02/documents/napa-land-use-zoning-63003.pdf; See also: Equitable Development and Environmental Justice, https://www.epa.gov/environmentaljustice/equitable-development-and-environmental-justice.

30 “The Complicated History of Environmental Racism,” n.d. UNM Newsroom. https://news.unm.edu/news/the-complicated-history-of-environmental-racism.

31 Adgate, John L., Bernard D. Goldstein, and Lisa M. McKenzie. 2014. “Potential Public Health Hazards, Exposures and Health Effects from Unconventional Natural Gas Development.” Environmental Science & Technology 48 (15): 8307–20. https://doi.org/10.1021/es404621d.

FINDING: Identifying opportunities to proactively address community concerns requires meaningful engagement with impacted or potentially impacted communities. This approach helps ensure the opportunity to provide their perspectives on projects and weigh the benefits, impacts, and trade-offs of a given project, and support more equitable distribution of community value and benefits while mitigating disproportionate negative impacts.

This study's focus group and poll respondents confirmed the need and demand for engagement and shared their perspectives on how effective engagement should occur. Successful community engagement is characterized by an iterative framework conceptualized below. These activities are most effective when done at the local level.

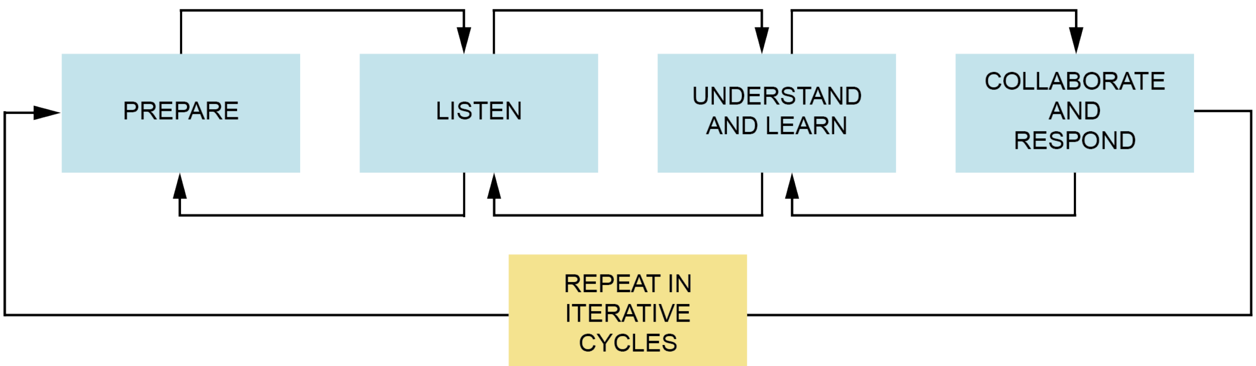

Figure ES-16. SCI Engagement Framework

Underlying these practices are several core principles that help define best practices for meaningful community engagement, including:

- Authenticity and building trust
- Transparency
- Early, open, responsive, and accessible engagement
- Identifying and responding to community input and concerns
- Articulation and delivery of community value (by a project developer) and recognition of value (by the community and government)

FINDING: For successful community engagement, robust best practices characterized by an iterative framework should be implemented.

RECOMMENDATION: DOE RESEARCHES SOCIETAL CONSIDERATIONS AND IMPACTS BEST PRACTICES

(JOINT) The NPC recommends that DOE consider funding research on the impact of best practices in community engagement, both through case studies and quantitative analysis. This research could be conducted by academia independently with industry providing support either through trade associations or partnerships formed with academia. This would provide valuable insights into the outcomes of best practices in community engagement and help improve future engagement efforts.

(JOINT) The NPC recommends that the U.S. government charter national and/or regional public/private council(s) of excellence in effective industry-community engagement practices to develop and encourage the adoption of best practices that include equal representations from industry, community organizations, and government.

Energy project developers may differentiate themselves by developing and implementing robust and long-term community engagement programs, including innovative social and environmental practices, increased trust-based relationships that in turn provide resources and information.[32]

FINDING: Applying best practices for community engagement can also bring benefits to an energy developer by fostering positive stakeholder relationships, aligning project goals with community interests, and providing valuable insights and feedback.

Community engagement is not a new activity for some segments of the natural gas industry, but not all engagement practices have been adequate or conducted consistently. The structure of the natural gas industry is complex as described in Chapter 1. Large operators may already possess the set of capabilities and experience needed to address community engagement. Medium-sized and less capitalized operators might not have the same type or level of experience with community engagement but may live in the communities they serve. Newer and domestic-focused firms might be addressing SCI issues in a robust way for the first time and may face unique challenges in adapting their current community engagement practices to today's expectations.

FINDING: The structure of the natural gas industry is complex and not all operators have the same level of exposure to the community and experience in effectively managing community relationships. Different segments of the industry may benefit from specialized, targeted training and capacity building for effective community engagement.

RECOMMENDATION: INDUSTRY ELEVATES COMMUNITY ENGAGEMENT

The NPC recommends, as community engagement best practices become formalized and consolidated, that trade associations or other industry groups develop specific community engagement training programs for their members that target specialized

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32 Hastings, Marilu, 1999. "A new operational paradigm for oil operations in sensitive environments: an analysis of social pressure, corporate capabilities and competitive advantage," Business Strategy and the Environment, Wiley Blackwell, vol. 8(5), pages 267-280, September. Handle: RePEc:bla:bstrat:v:8:y:1999:i:5:p:267-28.0 DOI: 10.1002/(SICI)1099-0836(199909/10)8:53.0.CO;2-E.

needs of upstream, midstream, and downstream operators; and whether they are large, medium, or less-capitalized firms.

Reduction of GHG emissions from the NGSC is viewed as a net benefit on a national and global scale, but there may be trade-offs, impacts, or benefits at a local and regional level of these activities and projects that should be understood and addressed.

These trade-offs may be made by individuals or communities, maybe for the short-term or long-term, between economic, environmental, health factors, between local and global considerations. These trade-offs are complex, often localized, and difficult to ascertain as they are often made at an implicit level.[33] The trade-offs between benefits and impacts must be examined to determine the roles government and industry should play in reducing burdens on impacted communities.

Workforce development and job creation are two key issues commonly voiced in surveys of energy impacted communities.[34] Concerns regarding the type of jobs and the ability of the local workforce to fill available jobs in the associated energy sector activity are paramount.

The NGSC has created a specialized workforce that has supported a rapid expansion of the natural gas industry in the United States,[35] with many of these highly skilled employees having spent their careers in the NGSC. NGSC operators should ensure that opportunities to implement GHG emissions reduction actions are made available to retain these highly skilled workers. A government-industry-academic study to understand the potential workforce implications of rapidly evolving GHG emissions mitigation approaches from the NGSC could help identify opportunities and risks for workforce retention. Such a study could also assess the real impact on the workforce and identify new opportunities for job creation where GHG emissions reduction projects would be too costly and could result in premature cessation of operations.

FINDING: Local workforce and job creation solutions depend on local circumstances and require meaningful community engagement.

FINDING: Workforce development and job creation is specific to each location, based on the type of natural gas activity at that location, and the work needed to mitigate GHG emissions there. GHG emissions reduction activities will precipitate impacts on segments of the natural gas supply chain differently. There is a need for more information and data related to the workforce for the natural gas sector and how it might be deployed to GHG emissions reduction activity skills within different segments of the industry.

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33 Richard H. Thaler, Cass R. Sunstein, Nudge: Improving decisions about health, wealth, and happiness Yale University Press, New Haven, CT, 2008. See also: “Unconscious Trade-offs” by Daniel Kahneman (2011).
34 The importance of focusing on jobs and fairness in clean energy transitions https://www.iea.org/commentaries/the-importance-of-focusing-on-jobs-and-fairness-in-clean-energy-transitions.
35 Bozick, Robert, Gabriella C Gonzalez, Cordaye Ogletree, and Diana Gehlhaus Carew. 2017. Developing a Skilled Workforce for the Oil and Natural Gas Industry: An Analysis of Employers and Colleges in Ohio, Pennsylvania, and West Virginia. RAND Corporation EBooks. RAND Corporation. https://doi.org/10.7249/rr2199.

RECOMMENDATION: DOE COMMISSIONS WORKFORCE STUDY

The NPC recommends that DOE, with guidance from its 21st Century Energy Workforce Advisory Board,[36] commission a comprehensive study to look at any mismatch between the skills of the current natural gas supply chain workforce and skill needs for implementing GHG emissions reduction projects. This study would serve as a blueprint for policy and investments to address human capital needs to deliver the country's GHG emissions reduction goals.

GHG-mitigating projects and technology interventions have the potential to address concerns about human exposure to emissions, especially when coupled with well-designed and thoughtfully implemented policies.[37] Changes in operations to reduce GHG emissions can affect the emissions of other chemicals emitted with methane and, along with them, levels of ambient air pollutants, and by extension, the potential exposures and health effects. It would be valuable to gain better understanding of the health effects and benefits of GHG emissions reduction activities along the NGSC specifically on disadvantaged communities.

RECOMMENDATION: GOVERNMENTS IDENTIFY AFFECTED COMMUNITIES

The NPC recommends federal and state public health and other regulatory agencies should continue to work together to assess which communities might benefit from, or be harmed by, specific GHG reduction infrastructure siting or operational decisions, policies, and technologies and whether those communities are environmental justice communities or other areas that experience high environmental exposures or other social disadvantages.

V. THEME 5: DETECTION AND MEASUREMENT

Measurement-informed estimates of emissions are critical to tracking progress toward U.S. and global GHG emissions reduction goals. Continued development and deployment of methane detection and quantification technology will play important roles in enabling progress.

Reliable, quantitative tracking of the GHG emissions from the natural gas supply chain is an important element in making progress toward climate goals. Tracking of carbon dioxide emissions is primarily based on fuel consumption, and emissions estimates are generally viewed as reliable. In contrast, methane emissions can be challenging to detect and quantify due to the diverse nature and sources of the emissions. The capabilities of methane emissions detection and

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37 21st Century Energy Workforce Advisory Board (EWAB), Department of Energy, https://www.energy.gov/policy/21st-century-energy-workforce-advisory-board-ewab.

37 Dougherty, William, Sivan Kartha, Chella Rajan, Michael Lazarus, Alison Bailie, Benjamin Runkle, and Amanda Fencl. 2009. "Greenhouse Gas Reduction Benefits and Costs of a Large-Scale Transition to Hydrogen in the USA." Energy Policy 37 (1): 56–67. https://doi.org/10.1016/j.enpol.2008.06.039.

quantification systems have expanded rapidly over the last decade and are continuing to expand rapidly, in part due to previous support from the DOE. Approximately a decade ago, measurements of methane emissions were sparse, difficult, and expensive. Today, a wide variety of measurements and observation platforms (fixed sites, ground vehicles, drones, aircraft, high-altitude platforms, and satellites) are available and are generating large data volumes globally.

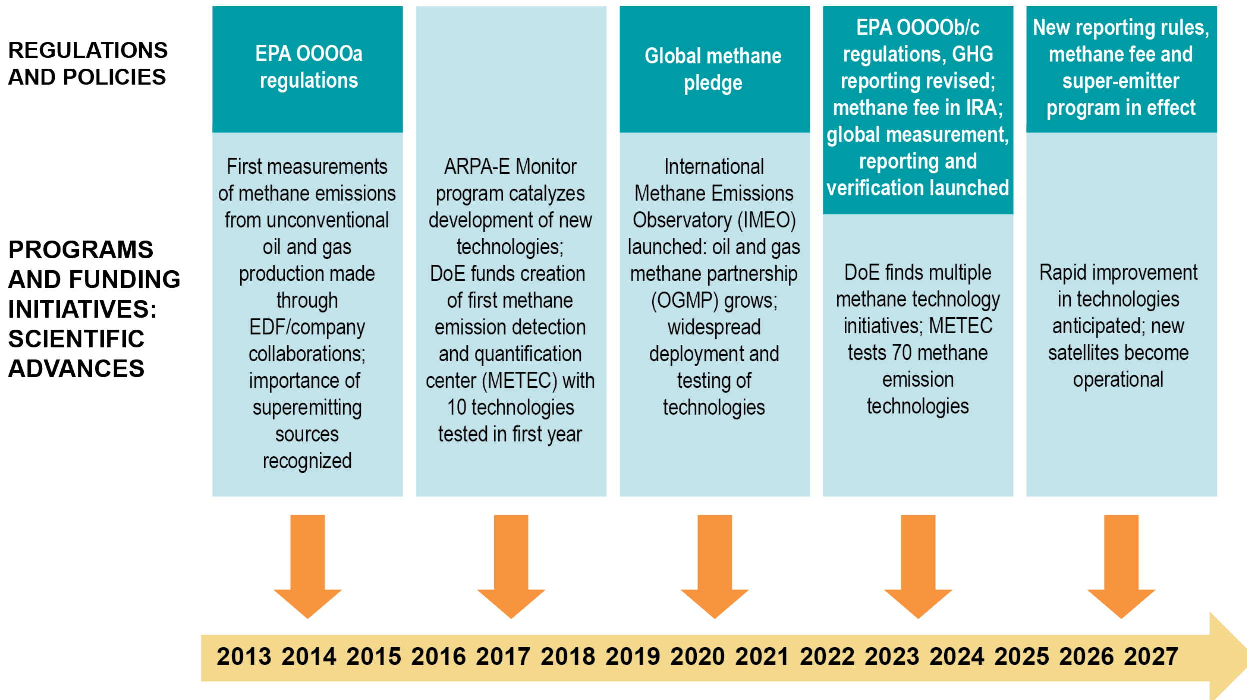

Figure ES-17. Methane Emissions Capabilities, Regulations, and Policies Evolution

Generally, current methane emissions detection and quantification systems provide estimates of emissions by: (1) making periodic measurements of methane concentration remote from a source; (2) using various types of atmospheric data and models to convert methane concentrations into an emissions rate; and (3) extrapolating these, frequently short duration, estimates of emissions rates into annual or other long-term estimates. Technical capabilities need to be expanded in all three of these areas, including support for consistent data analysis methods and systems approaches to enable intercomparison of data from different technologies. Technology evaluation centers, which have been highly successful in evaluating the performance of methane emissions detection and quantification systems, also need to be expanded. Finally, given the historical and expected evolution in methane emissions detection and quantification technologies, advances will need to be regularly and rapidly reviewed to facilitate the use of these technologies in regulatory applications. All three of these elements—improved measurement systems, robust testing capabilities, and evolving use of technologies in regulation and policy—are necessary for continued advancement of technologies.

FINDING: Continued investments in methane emissions detection and quantification systems are needed to improve the accuracy of emissions estimates.

RECOMMENDATION: DOE SUPPORTS DETECTION TECHNOLOGY IMPROVEMENT AND EVALUATION

The NPC recommends that DOE sponsor geographically diverse technology evaluation centers addressing sampling environment and emissions types representative of multiple segments of the supply chain. These centers would perform evaluations that would quantify the probability of detection, time to detection, probability of detection, and accuracy (uncertainty and bias) of emissions quantification.

A. Improved Measurement Systems

A key challenge for methane voluntary and regulatory frameworks is the development of measurement-informed inventories that better reflect actual methane emissions in the field, by incorporating more facility-specific observations into emissions inventories. Key to this interface is the role of advanced methane detection and measurement technologies that have emerged in the last five years that offer a pathway for scaled deployment across diverse types of operations.

Regulatory frameworks for leak detection and emissions measurement should evolve with technology and offer a pathway for innovative approaches to emissions management. Such information will be valuable for improving the accuracy of national inventories and as input into the next generation of life cycle models to better understand performance, though protocols will need to be developed to account for quantification uncertainty, which is discussed in Chapter 3.

RECOMMENDATION: DOE & EPA INCORPORATE MORE MEASUREMENT INTO SUBPART W

The NPC recommends a one-year multistakeholder group led by DOE and EPA develop recommendations on incorporating company-specific, advanced technology measurements into Greenhouse Gas Reporting Program Subpart W reporting.

B. Detection and Testing

To be actionable, information from emissions detection and quantification technologies needs to be correctly attributed to sites or facilities and needs to be communicated rapidly to operators. Rapid detection and prompt response to unexpected emissions events has been proven by many operators to be an effective way to reduce emissions. Combining emissions information with other operational data and systems increases the utility of the information. Operator data on underlying oil and gas processes is useful to quickly confirm emissions detections, to attribute emissions to specific sources such as maintenance events or known conditions, and to infer the frequency of the event or activity that caused the emission. However, integrating data from operational systems with emissions detection and quantification systems requires coordination between technology providers, operators, and other stakeholders monitoring emissions. The ability to effectively respond to the detected emissions is in large part based on accurate attribution of the emissions to sites/facilities (and potentially to locations on those facilities) from the variety of emissions detection and quantification solutions available.

Multiscale measurement-based data (i.e., regional and site level) is critical to improve accuracy of reporting and track changes in emissions over time. Additionally, for mitigation purposes, information from emissions detection and quantification at more granular scales can be combined with operational data and systems to maximize its utility.

FINDING: Information from emissions detection and quantification systems needs to be actionable; combining the emissions information with operational data and systems will maximize its utility.

FINDING: Continued investments in methane emissions detection and quantification systems are needed to improve the accuracy of emissions estimates.

RECOMMENDATION: DOE FUNDS FACILITY AND PROCESS DATA INTEGRATION

The NPC recommends DOE fund the improvement of site/facility-scale data resources used in the public attribution of emissions sources.

The NPC recommends that DOE continue to support technology innovations to reduce cost and improve the effectiveness of next-generation, low-emitting facilities across multiple supply chain sectors that integrate emissions detection, and quantification systems with other data collection systems. Innovations include, but are not limited to, development of predictive emissions monitoring systems and machine learning systems for data analysis, targeting metering, and process sensing/monitoring systems.

Methane emissions detection and quantification technologies each have unique strengths and limitations. No single technology is universally applicable for detecting and quantifying all emissions from all oil and natural gas sources. As a result, measurements are frequently performed with multiple, complementary technologies deployed in tandem. These technologies are increasingly deployed at multiple scales (e.g., equipment level, site level, basin level). Measurement data from different systems operating at different scales are currently difficult to reconcile, compare, and independently verify. The emissions measurement data can also be augmented with coordinated data from operator systems, but common data exchange formats make combining data systems difficult. Further, some ground-based detection systems rely on cell networks to communicate data and those networks are not uniformly available across the NGSC.

FINDING: Methane emissions detection and quantification systems need to be applied at scale, providing information at hundreds of thousands of sites.

RECOMMENDATION: DOE SUPPORTS MULTISCALE DATA AND DEMONSTRATIONS

The NPC recommends DOE improve the efficiency and transparency of multiscale methane monitoring of the energy sector, from handheld devices to satellites, by continuing to sponsor public-private and global partnerships and making measurements across multiple scales.

The NPC recommends DOE and other governmental organizations support the development of dense networks of meteorological measurement stations in regions likely to be targets for localized and wide area detection and measurement of methane emissions. Spatially dense, vertically, and horizontally resolved, and temporally high frequency measurement of wind velocity (i.e., speed and direction) is a priority.

The NPC recommends that federal agencies should work with technology providers, operators, and others to develop consistent data interchange formats and to promote infrastructures such as communication capabilities, that would promote deployments of advanced emissions detection and quantification systems.

C. Technology Policies

While emissions detection and quantification technologies are developing rapidly, multiple federal agencies (EPA, BOEM, BSEE, BLM, PHMSA, etc.) are grappling with rapidly evolving regulatory or programmatic requirements. Subtle changes within these programs could accelerate or slow the adoption of emissions detection and quantification technologies. Robust interagency coordination should focus on incorporating the development trajectory of solutions into federal and international policy initiatives. In addition to developments in the United States, international initiatives will drive the direction of both international and domestic emissions detection and quantification. Regularly updated information on emissions detection and quantification technologies, their commercial readiness level, technology gap analyses, and performance metrics of each technology is needed. Furthermore, the processes for incorporating advanced detection technology into regulatory requirements could be improved.

FINDING: Rapidly evolving emissions detection and quantification systems need to be integrated into public and private decision-making.

RECOMMENDATION: DOE & EPA INCORPORATE EVOLVING TECHNOLOGY INTO REGULATIONS

The NPC recommends the DOE work with the EPA and other agencies to improve the processes for incorporating advanced detection and quantification technology as part of regulatory requirements. The use of information from other available state and national programs to inform the revision of EPA and other agency requirements could improve the timeline and effectiveness of these processes.

VI. THEME 6: LIFE CYCLE ASSESSMENTS

There is a growing interest in understanding the life cycle GHG emissions associated with U.S. natural gas production and exports. Natural gas GHG LCAs can inform emissions reduction opportunities along the natural gas supply chain and support the understanding of GHG emissions intensities of supply chains.

Many methodologies and metrics are useful for comparing environmental impacts from the NGSC. For this study, the NPC collaborators developed the "Streamlined Life cycle assessment of Natural Gas – Greenhouse Gases model" (SLiNG-GHG model), which focuses on the metric of life cycle GHG emissions because of several important and distinct benefits of such analyses. LCA is a technique for estimating the potential environmental impacts (e.g., GHG emissions) of a product or service over all or part of its life. That includes procurement of raw materials, manufacturing activities, use of the product, and end-of-life disposal. LCAs, as practiced for more than five decades and codified in international standards,[38,39,40] enable fair and consistent comparison of different technologies, processes, or supply chains that produce the same product or has the same utility, considering emissions sources across the full supply chain.

Natural gas GHG LCAs provide a thorough comparison of the product across the supply chain and therefore a comprehensive understanding of GHG emissions from natural gas products. LCAs analyze the contributions of the various GHGs on the life cycle GHG emissions intensity. In LCAs, life cycle GHG emissions normalized per mega-joule (MJ) of natural gas enable customers to compare natural gas to other end-use fuel choices and to understand the attribution of GHG emissions to derivative products, such as chemicals, that use natural gas as an energy source and/or feedstock. Similarly, LCAs can support informed assessments in product-focused regulations such as carbon border adjustment mechanisms. Employing a normalized LCA-derived GHG emissions metric (on a MJ basis) enables a purchaser, investor, or regulator to differentiate products fairly and rigorously. LCAs also allow for allocation of GHG emissions to energy products commonly produced along with natural gas (e.g., NGLs, oil, etc.).[41] Such allocations are not typically performed when measuring methane emissions and are challenging because of lack of geospatial and operational data to support specific understanding of amounts, timing, and location of each of these products through the supply chain.

GHG LCAs can support decision-makers with answers to GHG emissions intensities from the product or process across the supply chain or the net GHG emissions impacts from introduction of the product or process to the market.[42] "Attributional" LCAs analyze environmental impacts across the supply chain of the product. This study seeks to understand the GHG emissions intensities of natural gas from different production basins to markets. The SLiNG-GHG model is an attributional model, which attributes GHG emissions normalized to functional unit (MJ of natural gas) at the boundary or gate being studied.

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38 ISO14040. International Standard. Environmental management- Life cycle assessment – Principles and framework; International Organization for Standardization: Geneva, Switzerland, 1997. https://www.iso.org/standard/23151.html.
39 ISO14044 International Standard. Environmental management-Life cycle assessment - Requirements and guidelines; International Organization for Standardization: Geneva, Switzerland, 2006. https://www.iso.org/obp/ui/#iso:std:iso:14044:ed-1:v1:en.
40 ISO14067 International Standard. Greenhouse gases – Carbon footprint of products – Requirements and guidelines for quantification; International Organization for Standardization: Geneva, Switzerland, 2018. https://www.iso.org/standard/71206.html.

41 Also known as coproduct allocation. See Chapter 4 for further details.
42 "Current Methods for Life Cycle Analyses of Low-Carbon Transportation Fuels in the United States." 2022, October. https://doi.org/10.17226/26402.

A. Model Types and Limitations

Attributional LCAs do not consider how individual supply chains may impact other supply chains or the larger market. "Consequential" LCAs, another type of analysis, not considered in this study, review the net environmental impacts of bringing the product to the market, accounting for how the marketplace would respond in terms of overall supply mix. In comparison, the SLiNG-GHG model is an "attributional" model, which attributes GHG emissions normalized to functional unit (MJ of natural gas) at the boundary or gate being studied.

Increased focus on the emissions intensity of traded energy products is creating new demands for life cycle GHG emissions intensity assessments. That demand includes certified natural gas schemes from private companies, supply chain specific LCAs,[43] and transparent frameworks for MMRV[44] for pipeline gas and LNG. The MMRV program includes representatives from the U.S., EU, East Mediterranean Gas Forum, and more than 15 countries. The U.S. and EU want to develop "a common tool for life cycle assessment of methane emissions for hydrocarbon suppliers and purchasers," with the hope of improving the accuracy and transparency of emissions data at "cargo, portfolio, operator, jurisdiction, and basin level."[45]

The IRA created new LCA requirements related to new tax credits for producing hydrogen, sustainable aviation fuel, and biofuels. Aside from North America and Europe, much of the early interest in LCAs for natural gas has been centered in Northeast Asia, particularly in Japan and South Korea, two of the world's top three LNG importers.[46] In addition, sustainable investment policies in the EU and Japan have seen growing interest or requirements in using LCA tools.[47]

While there is a growing interest in GHG emissions related LCAs for natural gas and LNG, there is limited usage of natural gas LCA models by stakeholders. The expertise needed to create LCAs for the NGSC is limited to certain companies, national laboratories, and scientific institutions. This is likely due to the complexities of modeling, a lack of historical regulatory or

43 Roman-White, Selina A., James A. Littlefield, Kaitlyn G. Fleury, David T. Allen, Paul Balcombe, Katherine E. Konschnik, Jackson Ewing, Gregory B. Ross, and Fiji George. 2021. "LNG Supply Chains: A Supplier-Specific Life-Cycle Assessment for Improved Emission Accounting." *ACS Sustainable Chemistry & Engineering* 9 (32): 10857–67. https://doi.org/10.1021/acssuschemeng.1c03307.

44 "Greenhouse Gas Supply Chain Emissions Measurement, Monitoring, Reporting, Verification Framework." n.d. Energy.gov. https://www.energy.gov/fecm/greenhouse-gas-supply-chain-emissions-measurement-monitoring-reporting-verification-framework.

45 https://www.state.gov/joint-statement-on-the-u-s-eu-energy-council/. https://ec.europa.eu/commission/presscorner/detail/en/statement_23_2121.

46 International Group of Liquefied Natural Gas Importers (GIIGNL), *Annual Report,* 2023. https://giignl.org/wp-content/uploads/2023/07/GIIGNL-2023-Annual-Report-July20.pdf. Notwithstanding the quote from the U.S.-EU Council, the major focus of EU comment and regulation is not LCA specific, it is GHG and specifically methane emissions. The same applies to Asia where there has so far been much less interest in general, but what exists refers to emissions in general rather than LCA.

47 The European Commission (2022), EU Taxonomy for sustainable activities. https://finance.ec.europa.eu/sustainable-finance/tools-and-standards/eu-taxonomy-sustainable-activities_en. Japan Climate Transition Bond Framework (2023). https://www.meti.go.jp/policy/energy_environment/global_warming/transition/climate_transition_bond_framework_eng.pdf. https://www.meti.go.jp/english/press/2023/pdf/0210_003c.pdf.

commercial drivers for supply-chain-focused analysis, a lack of expertise by policymakers and companies, and a dearth of publicly available natural gas-specific LCA models.

FINDING: Growing interest in GHG emissions natural gas LCAs is hindered by modeling complexity and other factors.

An open-source and accessible natural gas LCA model with transparent key model inputs (KMIs) that are updated at a regular interval with empirical data will allow for greater use of LCAs in public policies and corporate strategies while improving LCA estimates at the required boundary in the NGSC.

B. The NPC SLiNG-GHG Model

The NPC constructed the SLiNG-GHG model focused on selected key emissions sources for the NGSC. The model was developed after screening more than 2,000 published LCAs, and associated results from other relevant studies and the judgment of study experts. The SLiNG-GHG model provides a screening-level estimate of the GHG emissions footprint for the NGSC from production through three gates with the following endpoints: Gate 1 interstate transmission, Gate 2 local distribution company, and Gate 3 the point of LNG delivery to a regasification facility. The model can be used by nonexpert audiences to develop their own screening-level LCA estimates with a publicly available tool based on a transparent set of a limited number of KMIs.

By employing the SLiNG-GHG model, the NPC finds that using national average datasets to estimate life cycle GHG emissions for individual NGSCs may obscure their estimated GHG emissions profiles and therefore mitigation opportunities due to multiple factors, including heterogeneous operating practices, distances to customers, emissions sources, and infrastructure.

Further, the NPC proposes a generalized framework for incorporating measurement data into LCAs and demonstrates the flexibility of the SLiNG-GHG model. To the extent future measurement studies produce LCA-compatible estimates of methane emissions, these results can be used as inputs to the SLiNG-GHG model to enhance the empirical foundation of the life cycle GHG emissions estimates. Likewise, as the U.S. EPA continues to make progress incorporating empirical data from measurement studies into its bottom-up inventories and similarly advances its Greenhouse Gas Reporting Program (GHGRP), use of these datasets as sources of input data to SLiNG-GHG (as they are commonly used in LCAs already) could enhance the empirical foundation of SLiNG-GHG's life cycle GHG emissions estimates.

This analysis highlights the versatility of the SLiNG-GHG model in comparing GHG emissions impacts from natural gas supply chains and helping develop effective mitigation policies across the supply chain. In addition to aiding in the verification of GHG emissions intensity claims, the SLiNG-GHG model can help to screen differentiated natural gas in procurement and to inform natural gas investments and regulatory oversight of gas utilities and users such as electric utilities.

FINDING: To demonstrate an approach that would enable wider use of life cycle assessment tools in public policy and corporate strategies across the natural gas supply chain, the NPC has developed an open-source, user-defined, simplified, and streamlined natural gas well-to-gate life cycle assessment model (SLiNG-GHG) that can generate reasonably representative, screening-level GHG emissions estimates.

RECOMMENDATION: DOE SUPPORTS THE DEMOCRATIZATION OF LCAS

The NPC recommends that DOE support the adoption of open-source, user-defined, simplified and streamlined models such as the SLiNG-GHG model as part of its Measuring, Monitoring, Reporting, and Verifying (MMRV) efforts (and through the Federal Life Cycle Assessment Commons interagency process) as an easy-to-use screening tool, especially for stakeholders who do not have the capacity to conduct detailed life cycle assessment modeling. The integration of measurement-informed or empirical datasets is a critical next step in improving life cycle assessment estimates.

The representativeness of the SLiNG-GHG model was assessed by comparing estimates of natural gas carbon footprints from the streamlined model with estimates from four external modeling teams using their own detailed LCA models (Figure ES-18). Under GWP20,[48] the SLiNG-GHG results are generally higher than three out of the four external modeling team results, but as in the GWP100 case, the differences are smaller at Gate 3. These results from the SLiNG-GHG model calibrating against complex external LCA models illustrates its utility for screening-level estimation in public policies and corporate strategies.[49]

48 Results under GWP20 are available in Chapter 4.

49 The SLiNG-GHG model is not recommended to take the place of detailed LCAs where they are necessary to support more accurate estimation of life cycle GHG emissions intensities.

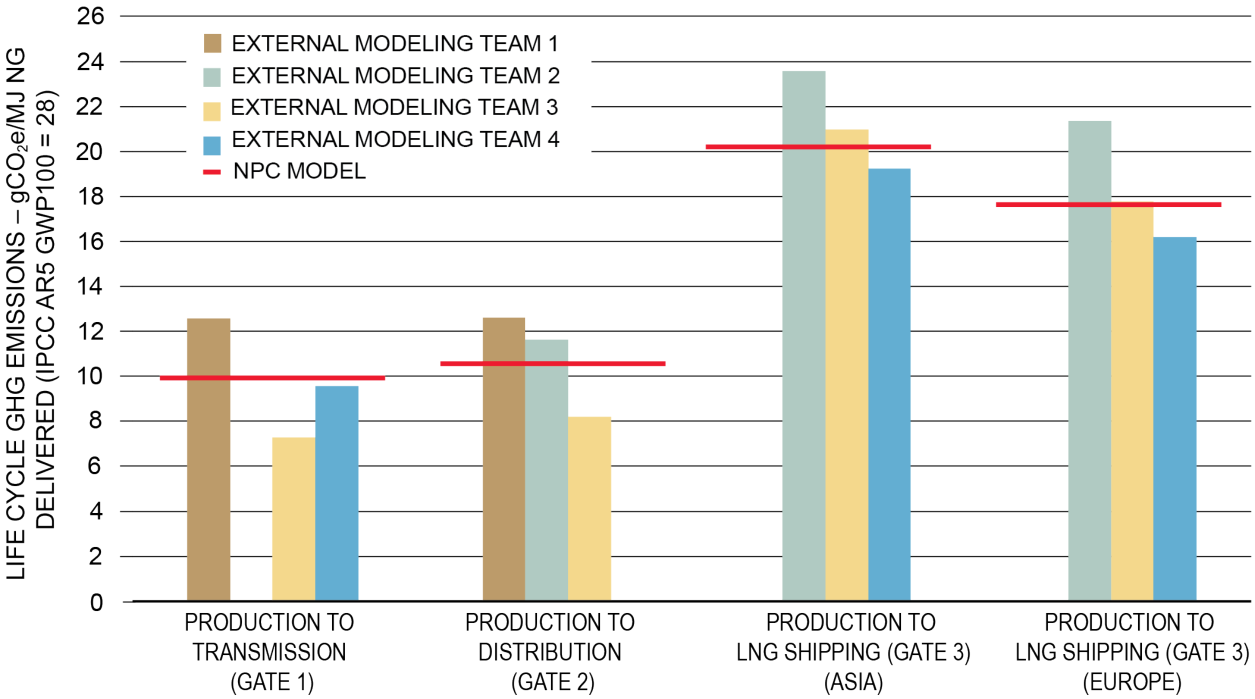


Figure ES-18. Comparison of SLiNG-GHG Model Results with External Modeling Teams

FINDING: The NPC's SLiNG-GHG model may be used to estimate the life cycle GHG emissions of natural gas across the natural gas supply chain using a reduced number of key modeling inputs related to emissions sources.

C. Supply Chain Analysis

Assessing the contribution of the two primary GHG (carbon dioxide and methane) in the SLiNG-GHG model's national Reference case, the study finds the contribution of methane emissions to total GHG emissions is a majority (more than 50%) under both GWP100 and GWP20 for Gates 1 and 2 and is a significant contributor when considering Gate 3. Similarly, use of the SLiNG-GHG model results can be explored to illuminate the contribution of individual emissions sources to the total carbon footprint at any boundary. Figure ES-19 illustrates the contribution of key emissions sources at each stage of the NGSC. This result underscores the need to monitor, measure, and mitigate methane emissions across the supply chain.

Carbon dioxide is the predominant life cycle GHG contributor when framed in the context of long-term mitigation, especially in the liquefaction, processing, shipping, and transmission segments. Therefore, targeted mitigation actions such as electrification of gas-driven combustion sources, CCS, reduced flaring, improvements in prime-mover efficiencies, etc., can support greater GHG reductions.

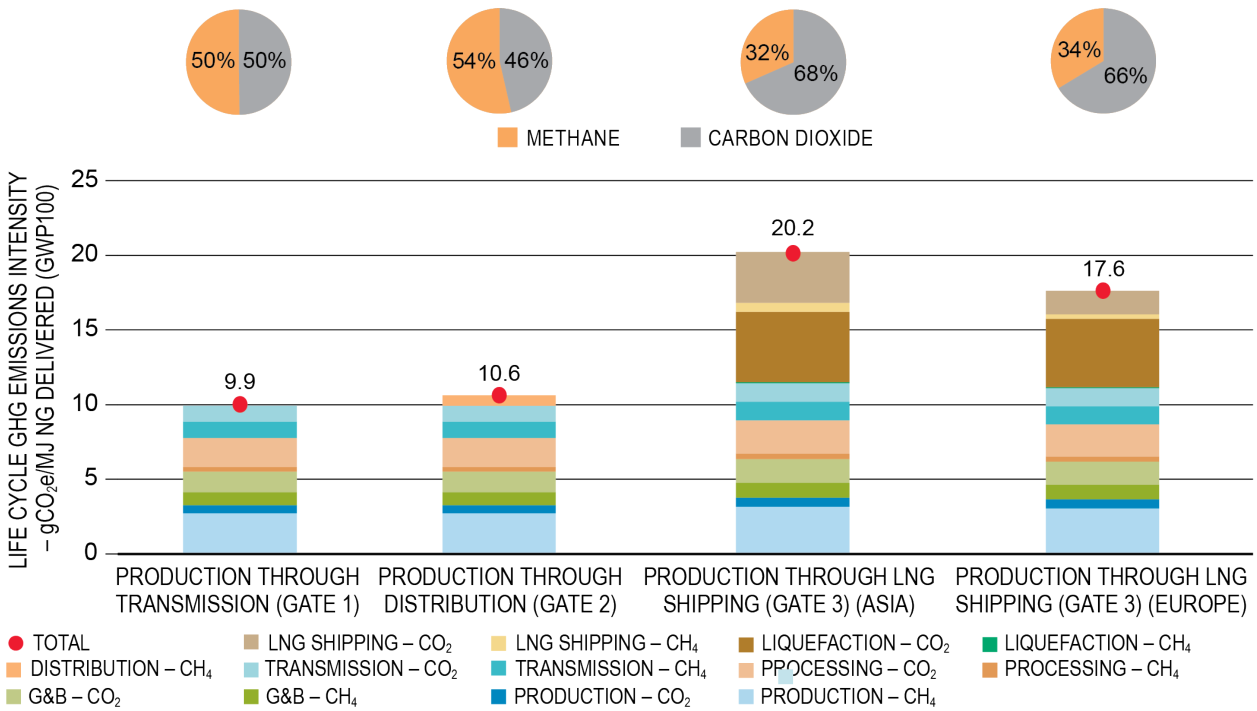


Figure ES-19. SLiNG-GHG Model Contribution Analysis by Stage and GHG

Pathway Analysis

The SLiNG-GHG model was used to assess the life cycle GHG emissions intensity of U.S. natural gas supply chains under four future emissions reduction pathways defined by the NPC in this study considering U.S. actions on its domestic supply chains.[50] The values for KMIs for these pathways were defined by the LCA researchers and industry subject matter experts to represent the combination of future policies, voluntary actions, and technology improvements assumed for each pathway.[51] Figure ES-20 summarizes the model results for the NPC-defined future pathways.[52] Relative to the Reference case, GHG emissions intensities would be expected to decrease by about 40% for Gates 1 and 2, and by about 25% for Gate 3 by 2030. In the most ambitious reduction pathways modeled, GHG emissions intensities would be expected to decrease by 70-80% by 2050.

Across all boundaries and pathways, the study future emissions reduction pathways were found to yield between 66-72% reduction in life cycle methane intensities with modest

50 The reductions anticipated in the shipping sector through IMO's 2023 GHG strategy, the EU regulations covering the shipping sector through the EU Emissions Trading System, and proposed FuelEU maritime standards are not considered here. IMO's 2023 GHG strategy aims to reduce the carbon intensity of international shipping by 40% by 2030 relative to 2008 and the uptake of zero or near-zero technologies to cover 5% of the energy used. FuelEU Maritime standards aims to reduce the GHG intensity on a well-to-wake basis starting with 2% reduction compared to a 2020 average baseline and reaching a reduction goal of 80% by 2050.

51 Assumptions and the default values of the KMIs used for the assessing the pathways is included in Appendix G, Chapter 4.

52 Results under GWP20 are available in Chapter 4.

reductions (2-5%) in carbon dioxide intensities by 2030. This is a function of the assumptions defining the 2030 pathway scenario, in which significant reductions in methane are anticipated to meet a suite of methane regulations, including the IRA methane fee, but little reductions in carbon dioxide outside of decreased flaring are anticipated.

Under the TIP future emissions reduction pathways by 2050, methane intensity reductions of about 74-81% are estimated to be achieved across all boundaries in addition to 28% reductions in CO_2 intensities for domestic NGSCs and 37-43% CO_2 intensity reductions in the LNG supply chains considered in this study. This is because in the 2050 TIP Pathway, methane emissions reductions continue to play a significant role along with electrification of some gathering and boosting facilities and transmission compressor stations, as well as carbon capture and storage at LNG liquefaction plants.

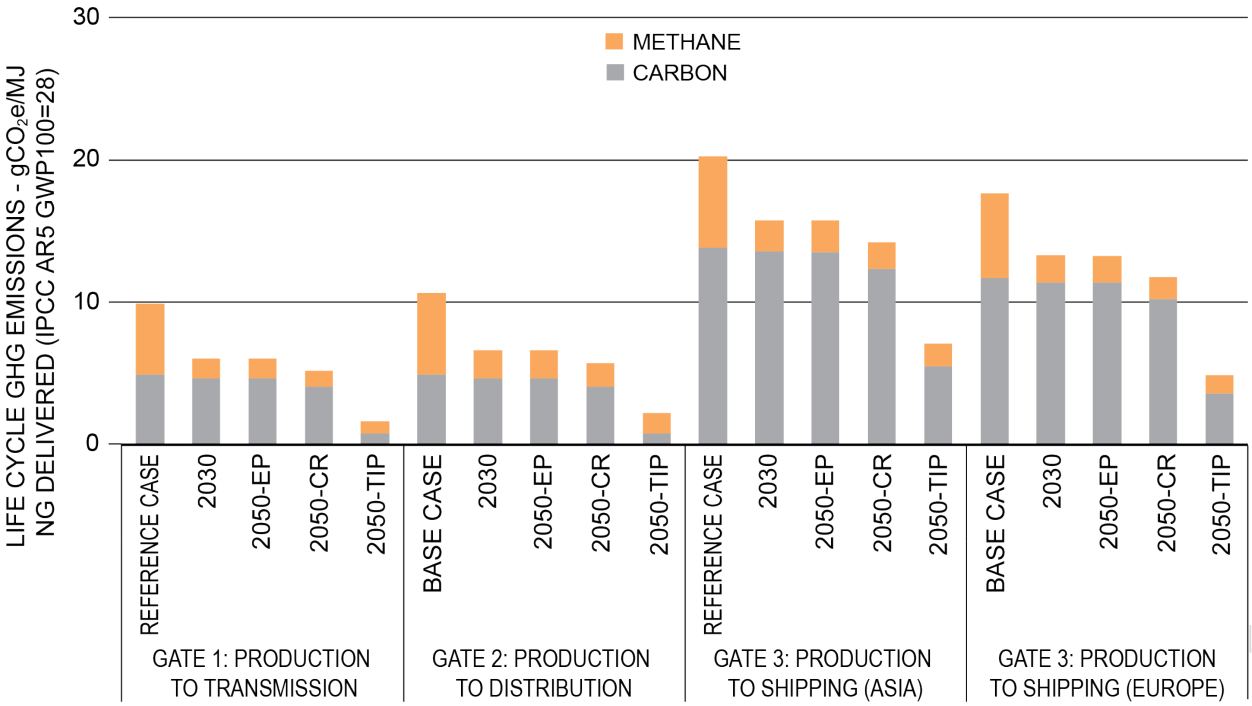
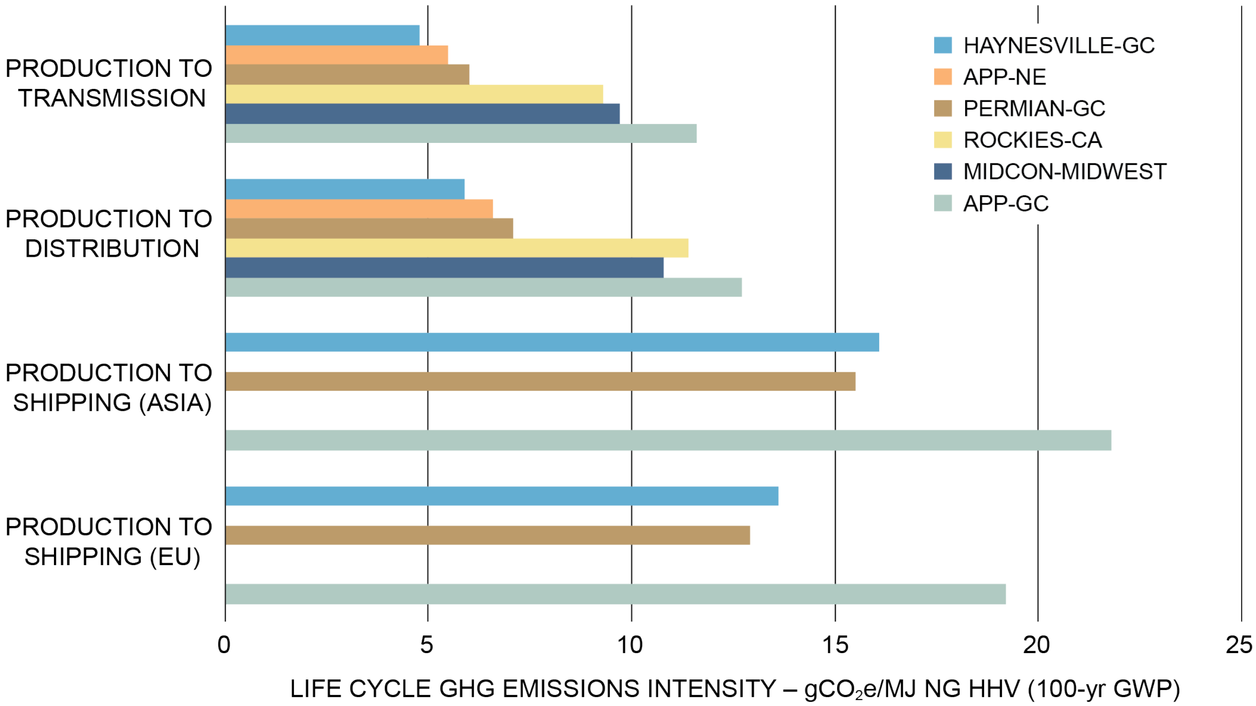


Figure ES-20. SLiNG-GHG Model Results for NPC-Defined Pathways

Most publicly available life cycle GHG emissions models have been parameterized at the national level, with model input values identified to be representative of overall U.S. oil and gas operations. The study used the SLiNG-GHG model to assess the variability in GHG emissions intensities of specific supply chains under the Reference case. The supply chain scenarios considered in this study included: Appalachia to Northeast, Appalachia to Gulf Coast, Haynesville to Gulf Coast, Midcontinent to Midwest, Permian to Gulf Coast, and Rockies to West Coast. Starting with the U.S. national Reference case set of inputs for each supply chain, adjustments to the KMIs of the SLiNG-GHG model were made to best represent these regional supply chains with publicly available data under specific pathways.[53] As illustrated in Figure ES-21, there is variation in the GHG emissions intensities between supply chains.



Note: Results under GWP20 are available in Chapter 4.

Figure ES-21. SLiNG-GHG Model Results for Various NPC-Defined Supply Chains

Relative to the national averages, supply chain results are estimated to range from 50% lower to 20% higher for Gates 1 and 2, and 40% lower to 15% higher for Gate 3.[54] Figure ES-22 illustrates the "drill-down" on key emissions sources contributing to the GHG emissions intensities in different supply chains. Methane emissions are a key contributor to the intensities for the Rockies to California supply chain, while CO_2 emissions from compressor stations in transporting gas from Appalachia to the Gulf Coast (due to larger transmission distances and therefore more compression needed for the gas to move from the production basin to end use) negates its relatively lower methane intensity of the Appalachian Basin. Our analysis also shows that CO_2 from flaring and midstream activities may be significant contributors to the GHG emissions intensities for the Permian to Gulf Coast supply chain. This illustrates the capabilities of LCA tools to provide a holistic review of various supply chain GHG emissions intensities and develop bespoke mitigation options.

53 The default KMIs used and assumptions on data sources for each supply chain are provided in Appendix L, Chapter 3. Default methane KMIs are from U.S. EPA's GHGRP.

54 Note only the Gulf Coast supply chains were estimated on the production through shipping boundary, as the majority of U.S. LNG is exported from the Gulf Coast.

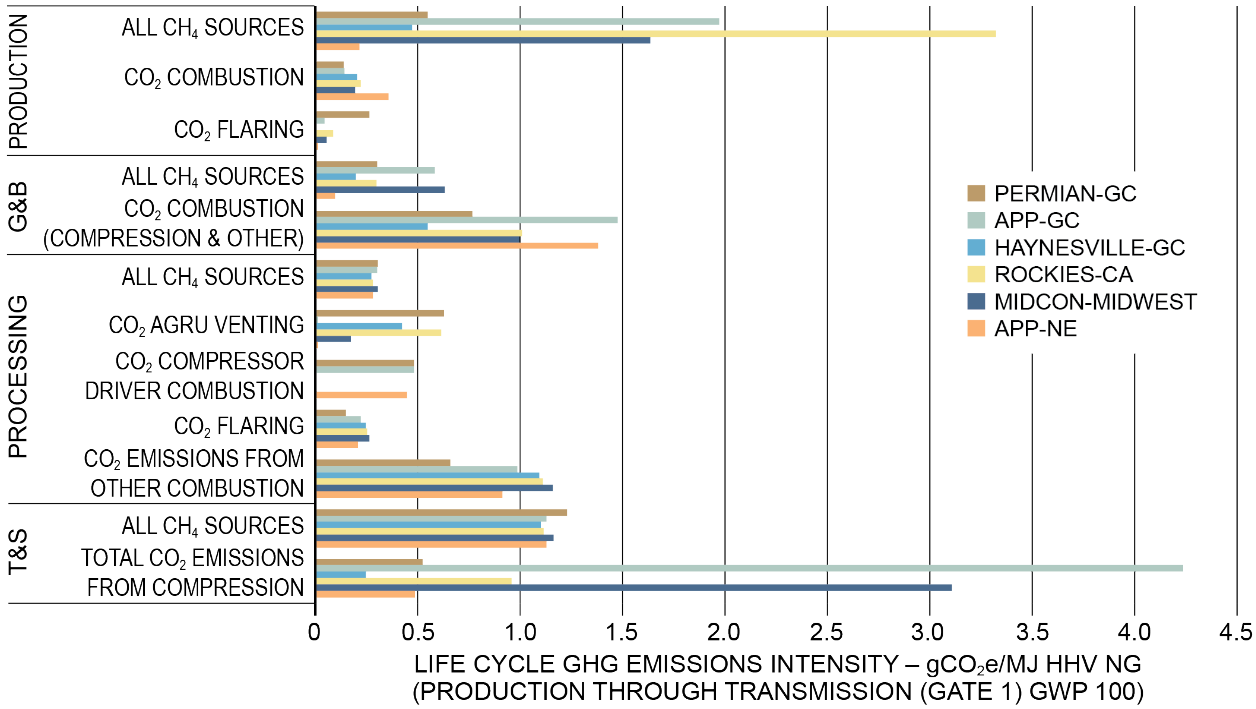


Figure ES-22. Drill-Down of SLiNG-GHG Model Results for Key Emissions Sources from NPC-defined Supply Chains

While the SLiNG-GHG model's flexibility allows the user to modify the KMI input values to represent different scenarios, such as the six supply chains analyzed in this study, the quality of data used as an input into an LCA study is a critical component to be considered when assessing the results of a study. The greater the use of supply chain-specific inputs into the LCA model, the better the representation of the supply chain GHG emissions intensity. On the other hand, models using "national average" data may be suitable for studies focusing on the performance of the U.S. natural gas system, without offering specific insights into potential reductions in emissions. Furthermore, past policies and voluntary initiatives did not require subnational or supply chain-specific differentiation. Geospatial emissions and operational datasets for use as KMIs for NGSCs are currently available in a limited context and maintained by state regulatory agencies or the private sector. However, these datasets are not harmonized and are not readily usable in the context of geospatial LCAs that are necessary to fully assess the differences in GHG emissions intensities for various supply chains. Regarding data inventory selection and sources, the individuals conducting the LCA will require a level of subject knowledge and expertise to assess the relevance of the data selected for use in the study.

FINDING: The NPC's SLiNG-GHG model can be used to conduct contribution analyses to assess the impacts of emissions sources and individual GHGs and potential mitigation opportunities in each stage of the natural gas supply chain.

RECOMMENDATION: INDUSTRY LEVERAGES LCAS TO CONDUCT CONTRIBUTION ANALYSES

The NPC recommends use of life-cycle assessments, including the SLiNG-GHG model, by relevant stakeholders to conduct contribution analysis of each GHG to screen the impact of potential mitigation opportunities in each stage of the natural gas supply chain.

The NPC recommends the use of life-cycle assessments to assess the GHG intensities of different supply chains and pathways. The NPC recommends that DOE sponsor research to develop measurement-informed, geospatial life cycle assessment tools that make use of ongoing and future availability of highly resolved geospatial GHG emissions datasets across the U.S. oil and gas supply chain.

Recent LCA studies[55,56] that incorporated methane emissions measurements in a limited manner indicate life cycle GHG emissions intensities from well to gate can have material differences in emissions intensities relative to using national default factors from conventional inventory programs such as the GHGRP. Furthermore, resource characteristics, operational practices, and the regulatory environment vary across the U.S., resulting in significant differences in methane emissions by operator, state, and basin.

Interpreting measurements, including uncertainties associated with measurements conducted at different spatial and temporal scales, to each unit process or KMI within the context of process-based LCA frameworks is challenging. In addition to the spatial and temporal boundary matching challenges, allocating observed emissions to different product streams requires knowledge of production or throughput volumes and resource composition at the time of measurement. This creates emissions estimates in different studies that are not directly comparable. Thus, reporting standards must be established to enable use of measurement data to develop life cycle inventories.

Further, top-down measurement studies often do not report uncertainty ranges for KMIs for use in LCAs. Public policy and regulations such as the GHGRP typically use a single datapoint (e.g., emissions factors for methane and CO_2 sources) to represent national or regional averages without uncertainty ranges. In Chapter 3, this study found wide ranges of uncertainty in measurements of methane emissions across technology platforms. Uncertainty should be reported with any results of an LCA model.

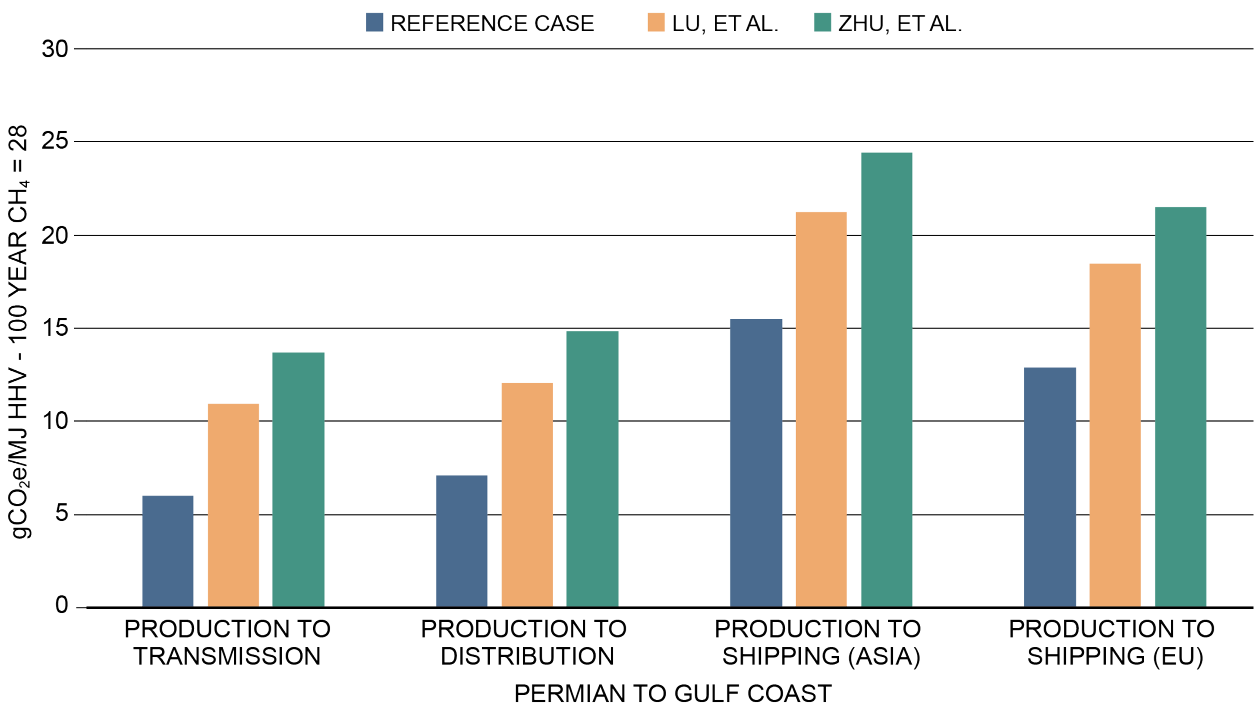
55 Rai, Srijana, James Littlefield, Selina Roman-White, George Zaimes, Gregory Cooney, and Timothy Skone. 2021. "Industry Partnerships & Their Role in Reducing Natural Gas Supply Chain Greenhouse Gas Emissions – Phase 2." *OSTI OAI (U.S. Department of Energy Office of Scientific and Technical Information)*, February. https://doi.org/10.2172/1647225.

56 Roman-White, Selina A., James A. Littlefield, Kaitlyn G. Fleury, David T. Allen, Paul Balcombe, Katherine E. Konschnik, Jackson Ewing, Gregory B. Ross, and Fiji George. 2021. "LNG Supply Chains: A Supplier-Specific Life-Cycle Assessment for Improved Emission Accounting." *ACS Sustainable Chemistry & Engineering* 9 (32): 10857–67. https://doi.org/10.1021/acssuschemeng.1c03307.

D. Sensitivity Analysis

The SLiNG-GHG model developed in this study employs central estimates for methane from harmonization of relevant studies and uses GHGRP data as default methane KMIs for various supply chains evaluated in this study. Similarly, the sensitivity analysis used in this work employs basinwide-allocated methane intensity estimates without uncertainty ranges due to limitations related to primary data sources.

The default methane KMIs employed in the Permian to Gulf Coast supply chain Reference case in the SLiNG-GHG model were compared to two cases[57,58] developed using empirically derived methane KMIs representative of the Permian to Gulf Coast supply chains (Figure ES-23) for the three boundaries considered in this study. Results suggest that a replacement of nationally representative default model input data with selected national or regional measurement data could affect understanding of estimated life cycle GHG emissions.[59]



Source: Lu, ET AL., Zhu ET AL.

Figure ES-23. Permian to Gulf Coast Sensitivity Analysis

57 Lu, Xiao, Daniel J Jacob, Yuzhong Zhang, Lu Shen, Melissa P Sulprizio, Joannes D Maasakkers, D J Varon, et al. 2023. “Observation-Derived 2010-2019 Trends in Methane Emissions and Intensities from US Oil and Gas Fields Tied to Activity Metrics” 120 (17). https://doi.org/10.1073/pnas.2217900120.

58 Zhu Y, Allen D, Ravikumar A. Geospatial Life Cycle Analysis of Greenhouse Gas Emissions from US Liquefied Natural Gas Supply Chains. ChemRxiv. 2024; doi:10.26434/chemrxiv-2024-9v8dw Chains Geospatial Life Cycle Analysis of Greenhouse Gas Emissions from US Liquefied Natural Gas Supply Chains | Energy | ChemRxiv | Cambridge Open Engage

59 Full results comparing the results from the SLiNG GHG model using default methane KMIs, and using the measurement-informed methane KMIs from both Lu et al., and Zhu et al., are presented in Chapter 4.

While exact impact varies, both sensitivity case studies suggest that the use of empirical data for methane has a greater impact on life cycle GHG emissions intensity for some geographies relative to others, a finding that would need more evidence from other regions to corroborate. With upcoming state and federal policies to address methane emissions from the oil and gas sector, the NPC study finds that methane emissions are expected to decline significantly over the next several years. Tracking progress on mitigation on a supply chain basis requires timely, measurement-informed, and accurate emissions inventories at high spatial resolution. This is consistent with the DOE's goals in its proposed MMRV framework[60] and expectations surrounding collecting and reporting GHG emissions data, including the value of measurement data. Methane intensities from peer-reviewed or high-quality measurement studies may be incorporated into the SLiNG-GHG model. They should havesufficient spatial and temporal resolution to allow for appropriate integration (e.g., coproduct allocation between oil and gas products, measurement boundaries, etc.) and geospatial and operational datasets are generated in a manner that allows for development of inputs as replacements of the default values in the SLiNG-GHG model. While there is less uncertainty of CO_2 emissions relative to methane emissions across the supply chain, there is a need for improved measurement-informed or empirical datasets.

FINDING: There is limited integration of measurement-informed datasets in life cycle assessments (LCAs). Integrating measurements into LCAs is challenging. Sensitivity analyses employing methane emissions data from two top-down measurement studies reinforce the versatility of the SLiNG-GHG model and the need for empirical datasets for use in LCA models. Establishing a global differentiated natural gas framework through a common measurement, monitoring, reporting, and verification (MMRV) program requires the ability to verifiably distinguish emissions across different global natural gas supply chains, a goal that the SLiNG-GHG model could support.

RECOMMENDATION: DOE INTEGRATES MEASUREMENT DATA INTO LCAS

The NPC recommends that DOE sponsor the creation of a multistakeholder expert advisory group to meet periodically and create recommendations on integrating GHG emissions measurement data from multiple technologies across the natural gas supply chain into conventional life cycle assessment frameworks. Additional recommendations on the leadership, organization and content of the guidelines are summarized in Appendix O.

E. Harmonization of LCAs

Harmonization (systematic review and meta-analysis) of recently published LCAs of natural gas allows for a higher degree of transparency and comparability of their estimates of the carbon footprint of natural gas. Moreover, it reduces uncertainty associated with estimates in the literature, and better informs policymaking and research decisions. This process ensures

60 https://www.energy.gov/fecm/greenhouse-gas-supply-chain-emissions-measurement-monitoring-reporting-verification-framework.

consistency across studies and forms an initial set of minimum requirements for future natural gas LCAs. The SLiNG-GHG model's KMIs reflect the most influential parameters identified through the harmonization process. As supply chains evolve to reduce emissions, the importance of these parameters may change. Future LCAs should conduct a materiality assessment of key emissions sources in each stage of its supply chain and assess against the default 24 emissions sources recommended by the NPC in the SLiNG-GHG model. When evaluating LCA results, users are encouraged to review the harmonization process adopted in this study and assess results from such studies against the National Academies of Sciences, Engineering, and Medicine (NASEM) six pillars. The NASEM pillars are listed below and alignment of the SLiNG-GHG model to the NASEM pillars is comprehensively covered in Chapter 4.

- Six NASEM Pillars: Usability and timeliness, Information transparency, Evaluation and validation, Completeness, Inclusivity, Communication.

The SLiNG-GHG model aligns with five out of the six NASEM pillars—all but "completeness" by nature of alignment to the scope of the NPC study excluding emissions associated with end use of natural gas. Users should recognize this limitation and ensure that a streamlined model is appropriate for their use case. The SLiNG-GHG model's capability to allow for input of user-defined KMI values allows stakeholders to incorporate measurement-informed datasets relevant for their specific facilities in their specific region or country, thereby further improving the accuracy and usability of the model.

FINDING: Evaluation of GHG emissions data presented in natural gas life cycle assessment (LCA) studies can be enhanced by the harmonization process presented in this study and the use of six pillars recommended by the National Academies of Sciences, Engineering, and Medicine (NASEM).[61] Harmonization can illuminate the challenges with current LCA practices and provide useful guidance to improve LCA methodologies and ensure consistency.

RECOMMENDATION: STAKEHOLDERS USE LCA HARMONIZATION AND DOE PUBLISH BEST PRACTICE GUIDELINES

The NPC recommends that when evaluating LCA results from other studies or work, users are encouraged to review the harmonization process adopted in this study and assess results from such studies the six pillars recommend by the National Academies of Sciences, Engineering, and Medicine.

The NPC recommends that DOE initiate and publish best practice guidelines for conducting natural gas life cycle assessments, incorporating these recommendations.

61 https://www.nationalacademies.org/our-work/development-of-a-framework-for-evaluating-global-greenhouse-gas-emissions-information-for-decision-making.

VII. THEME 7: INTEGRATED ANALYTICS AND TRADE-OFFS

Evaluating the complex trade-offs involved in reducing GHG emissions in the natural gas supply chain through 2050.

Chapter 5 evaluates the feasibility and effectiveness of different approaches— individually and in combination—to reduce and/or offset GHG emissions across the existing and evolving NGSC. The NPC study identified two paradigms for the delivery of GHG emissions reductions: command-and-control regulations, and market-based mechanisms. Command-and-control regulations specify or prohibit certain activities and technologies, and the ability to reduce cost is constrained by the specificity of the regulation. Market-based mechanisms seek to encourage flexibility in emissions reduction methods by providing various incentives for operators to reduce GHG emissions at the least cost or greatest value. Both will be needed in different circumstances. Beyond the expected methane and carbon dioxide reductions of the EP Pathway, remaining emissions will need to be addressed with durable policy formation, including through regulatory harmonization, introduction of market mechanisms, and further technology deployment. This can be enhanced and supported through industry coordination and international diplomatic efforts.

A. Durable Policy

One of the key pieces that will enable change is the creation of durable policy, including the harmonization of natural gas GHG emissions policy, legislation, and regulation across multiple agencies with authority for different parts of supply chains.

Despite this record of significant energy systems change, the U.S. has not previously undertaken an intentional policy effort to drive transition to new fuels or technologies.[62] Yet, society has decided to reduce impacts of its energy choices, including GHG emissions, and, most recently, reduce disproportionate impacts on disadvantaged communities. To effectively deliver this outcome, policy addressing GHG emissions in natural gas supply chains will need to be durable, meaning it will endure beyond changing political climates, economic fluctuations, and societal shifts. Durable policies are marked by their adaptability and capacity to address evolving challenges without the need for constant reform.[63]

Durable policy refers to a set of guidelines, regulations, or principles developed and implemented by governments, institutions, or organizations that exhibit resilience and effectiveness over time. These characteristics include:

- **Relevance and flexibility**: Durable policies include mechanisms for periodic review and adjustment to ensure ongoing suitability.
- **Stakeholder engagement**: To remain durable, policies must engage stakeholders from diverse backgrounds, interests, and expertise.

62 S&P Global Commodity Insights, May 2023. "Future Energy Outlooks Special Report"; Carlson and Fri, *Daedalus*, p. 121.
63 "Policy Durability and Adaptability." In *Limiting the Magnitude of Future Climate Change*. Washington, DC: National Academies Press, 2011.

- **Evidence-based**: Durable policies are rooted in evidence and thorough analysis and will also evolve in a continuous cycle of adaptive management.
- **Political consensus**: When policies have bipartisan or multipartisan support, they are less likely to face reversals when leadership changes, promoting long-term stability.
- **Transparency and accountability**: Durable policies build in mechanisms for accountability, allowing for scrutiny and assessment of societal impact.
- **Balanced objectives**: While addressing immediate concerns, durable policies also consider the potential consequences and benefits in the future, making them sustainable as challenges evolve.
- **Continual evaluation**: A durable policy is subject to regular evaluation and assessment and incorporates feedback mechanisms.
- **Economic considerations**: To ensure policies remain durable, considerations should be made for economic impacts and trade-offs. Policies that anticipate the relevant costs and benefits from their implementation are more likely to gain lasting support.

There are multiple benefits from the use of durable policy best practices, including:

- **Stability and predictability**: Durable policies provide stability in governance and the business environment, which allows individuals and businesses to plan and invest in GHG emissions mitigations with confidence.
- **Economic growth**: Durable policies provide clarity and confidence for businesses to make investments, promote economic growth, and create job opportunities.
- **Public trust**: Policies that stand the test of time foster public trust in the government or organization responsible for their implementation.
- **Effective governance**: Governments that prioritize durable policies can focus on implementing and enforcing those policies, rather than engaging in policy reversals or rewrites.

FINDING: As the federal government and states further advance policies to address GHG emissions in natural gas supply chains, the durability of such policies will directly impact the success of these policies. The implementation of durable policies will provide for a stable and predictable environment to enable long-term investments, strengthen public trust and acceptance, and to incentivize further innovation in emissions reduction practices and the deployment of new technologies.

RECOMMENDATION: GOVERNMENTS DESIGN DURABLE POLICY

As the federal government and states advance policymaking on GHG emissions in natural gas supply chains, they seek to design policy in a durable way.

B. Harmonization of Policy/Regulatory Efforts

The administration has mobilized a "whole of government" approach to GHG emissions reduction,[64] including for the natural gas sector; this has resulted in related but different regulatory efforts, some of which remain in draft or proposal form as of completion of this study. There are several opportunities for this interagency cooperation. An advanced technology approach approved by EPA in the final NSPS (New Source Reporting Standard) rulemaking should be an allowed compliance approach in other federal rules. For example, BLM's proposed rule incorporates "relevant advances in technology" as a factor for "reasonable measures to prevent waste." With performance standards appropriate for quantification of methane emissions, the NSPS approval process could also be relied on for Subpart W reporting and the methane emissions waste charge. The proposed PHMSA rulemaking also addresses an advanced technology approval approach. This could be done jointly with EPA's NSPS approval process to minimize duplication of technologies used in the midstream that could already be approved approaches under EPA's NSPS rule. To date, there is limited evidence to suggest that such interagency coordination is occurring as each agency is working to finalize their individual rules. The White House Methane Task Force[65] that was established by the Biden administration could work to promote coordination and innovation for emerging technology and to incorporate the experience of the natural gas industry in effective and useful deployment.

FINDING: There is opportunity for the federal departments and agencies regulating methane emissions to harmonize measurement, methane controls, and policies by coordinating requirements across these rules, while complying with individual agency limitations by statutory authority. This could accelerate the deployment of methane detection and measurement, reduce compliance costs, minimize duplicative compliance and reporting requirements, and improve the comparability and accuracy of data across programs.

RECOMMENDATION: GOVERNMENTS HARMONIZE REPORTING, CONTROL, AND TECHNOLOGY REQUIREMENTS

The NPC recommends the White House Methane Task Force work with federal departments regulating methane emissions to harmonize emissions reporting, control requirements, and technology approvals for methane detection and measurement.

This harmonization approach applies across the suite of proposed federal rules, methane controls, and policies by coordinating requirements across these rules to accelerate the deployment of methane measurement, reduce compliance costs, and minimize duplicative compliance and reporting requirements. If new methane regulations are included in other sectors of the economy, many technologies developed and used for methane detection and mitigation in the oil and gas sector would be applicable to other major methane generating sectors like agriculture and coal mining.

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[64] National Climate Task Force, The White House, https://www.whitehouse.gov/climate/.

[65] White House Methane Summit | The White House

C. Market Mechanisms

Beyond rules, controls, and policies, market mechanisms are another important way to influence commodity businesses. Market mechanisms include GHG emissions intensity standards, carbon pricing mechanisms, valuation of emissions reductions, supply incentives, and demand incentives. These types of mechanisms have been applied across a wide range of jurisdictions and have been demonstrated to succeed at their intended goals under a range of conditions, though trade-offs exist between the selection of specific market mechanisms.

The primary characteristics of market mechanisms are that they provide a financial input to decision-making—either an incentive-lowering cost or a benefit to value creation. The vast majority of the NGSC elements are operated by for-profit entities (publicly traded, privately owned, and Tribal corporations and funds), and their primary metrics are financial in nature.

FINDING: Multiple examples of market-based mechanisms exist that have been demonstrated to effectively incentivize GHG emissions reductions.

RECOMMENDATION: GOVERNMENTS EVALUATE MARKET MECHANISM OPTIONS

The NPC recommends federal and state governments adopt market-based mechanisms that recognize the contributions of and generate incentives for investments in GHG emissions reduction across natural gas supply chains. Market-based mechanisms should focus on implementing economy-wide or sector-based approaches that can be more efficient and effective at addressing GHG emissions than narrow, industry-specific mechanisms.

D. Differentiated, Assured, Certified Gas

Some natural gas buyers and end users have expressed an interest in purchasing certified gas products for a variety of reasons, including improved assurance around Scope 3 emissions within their supply chain for tracking progress on corporate net zero goals or potentially for access to tax credits or import markers that may require such information in the future. Many of the transactions among sellers, marketers, and buyers are currently individual, bilateral agreements and are considered private competitive information; therefore, tracking the actual value in the marketplace is largely unavailable currently. Trading platforms and marketplaces are attempting to provide pricing benchmarks and the range of value for the Methane Performance Certificate, one option on the market, was between one and five cents per MMBtu in 2022 based on data from Platts.[66] The North American Energy Standards Board developed a Certified Gas Addendum for its base contract for increased transactability in the certified gas market.

[66] Carlson and Fri, 2021.

FINDING: Today there are few regulatory or other policy structures in place that enable the passthrough of incremental value associated with lower GHG emissions intensity natural gas. While certified markets have grown, they are limited in scale.

RECOMMENDATION: GOVERNMENTS PROVIDE DIFFERENTIATED STANDARDS

The NPC recommends standards-setting bodies develop mechanisms to enable utilities, gas marketers, and consumers of natural gas to differentiate lower GHG intensity natural gas, specifically providing recognized standards, frameworks, and metrics for buyers and sellers to incorporate into gas transaction contracts. These standards should be measurement-based where feasible.

While methane emissions across natural gas supply chains are projected to decline over time, the share of NGSC CO_2 emissions is expected to rise from 34% in 2020 to 60% in 2050 because of increased fuel use across the natural gas supply chain. Reducing these emissions will require a range of technologies, including low GHG emissions intensity electrification, energy efficiency, CCS, and use of low carbon intensity hydrogen within gas supply chains. Many technologies are nascent today or have not been demonstrated in specific applications relevant to NGSCs.

Based on EPA estimates in the U.S. GHG Inventory, the use of natural gas as fuel for compression, heat, and power, including drilling/completion activities, represented ~34% of U.S. NGSC GHG emissions (~150 $MMTCO_2e$) in 2020. Due to future reductions in methane and flaring emissions across the natural gas supply chain, emissions pathways in this NPC study suggest that supply chain natural gas combustion could represent 50-60% of emissions in 2030 and 2050. Like current DOE programs supporting research, development, and deployment activities for methane measurement and control technologies, there is an opportunity for DOE to develop a new program to support lower carbon intensity technologies to provide these needed functions in the U.S. natural gas industry.

Technologies to further reduce GHG emissions from natural gas supply chains include electrification with low GHG emissions intensity power, energy efficiency, CCS, and low carbon intensity hydrogen consumption within natural gas supply chains. Many of these technologies are still relatively nascent and lack large-scale demonstration, such as carbon capture and low concentrations or small-scale hydrogen. Others, like electrification and energy efficiency technologies, have been demonstrated, but not in applications relevant to those required in natural gas supply chains. Therefore, more investment in research, development, and demonstration can drive up the maturity of these technologies while reducing their costs.

FINDING: Carbon dioxide is expected to become the more dominant GHG in future natural gas supply chain emissions.

RECOMMENDATION: GOVERNMENTS COORDINATE LOW CARBON RDD&D

The NPC recommends the federal government coordinate policies and initiatives for low-carbon technology RDD&D and to maximize GHG emissions reductions impacts along the U.S. natural gas supply chain.

Like current DOE programs supporting RDD&D activities for methane measurement and control technologies, there is an opportunity for DOE to develop a new program to support lower carbon intensity technologies to provide these needed functions in the U.S. natural gas industry. For CO_2 abatement, this includes but not is not limited to deployment of carbon capture and storage in LNG liquefaction, scaling electrified solutions across gas supply chains, and enabling the availability of low carbon power for relevant natural gas supply chain stages.

U.S. LNG exports have been growing rapidly and that growth is projected to continue. In 2020 the United States exported an average of 5.4 Bcf/d of natural gas via LNG, which is projected by the EIA to increase to 32.9 Bcf/d by 2050. Given that production growth, CO_2 emissions from LNG production in the United States are projected to increase from 38MT CO_2e in 2020 to 174MT CO_2e in 2050 under the EP Pathway. Under the TIP Pathway, emissions from LNG are projected to be considerably less at 77.4MT CO_2e in 2050, but still more than present.

Globally, the growth of U.S. LNG exports can serve to drive down GHG emissions in importing countries when that natural gas consumption displaces or avoids consumption of other more emissions-intensive energy sources. Those climate benefits from LNG exports can be recognized internationally in multiple ways, including directly for operators through LNG contracts or more broadly though credit mechanisms such as carbon offset credits for companies or Internationally Transferable Mitigation Outcomes between governments. Such mechanisms can help compensate for investments to reduce the GHG emissions intensity of LNG production, including for CCS or adoption of electric drive liquefaction with low-carbon power.

FINDING: The growth in U.S. LNG exports will reduce GHG emissions globally but may result in an increase in U.S. GHG emissions, primarily CO_2.

RECOMMENDATION: GOVERNMENT SUPPORTS CONSEQUENTIAL ANALYSIS

The NPC recommends the U.S. federal government climate and energy diplomatic efforts work toward standardizing exported products GHG emissions intensity and recognize investments that reduce GHG emissions intensity of natural gas supply and associated impacts for lower emissions intensity of U.S. exported products, including LNG. As noted earlier, a consequential analysis on net GHG emissions and social impacts in destination countries is recommended.

Reducing emissions from the U.S. natural gas supply chain is a priority that requires collaborative solutions. This study makes recommendations for actions by industry, government, and researchers to reduce GHG emissions in natural gas production, transportation, distribution, and LNG exports.