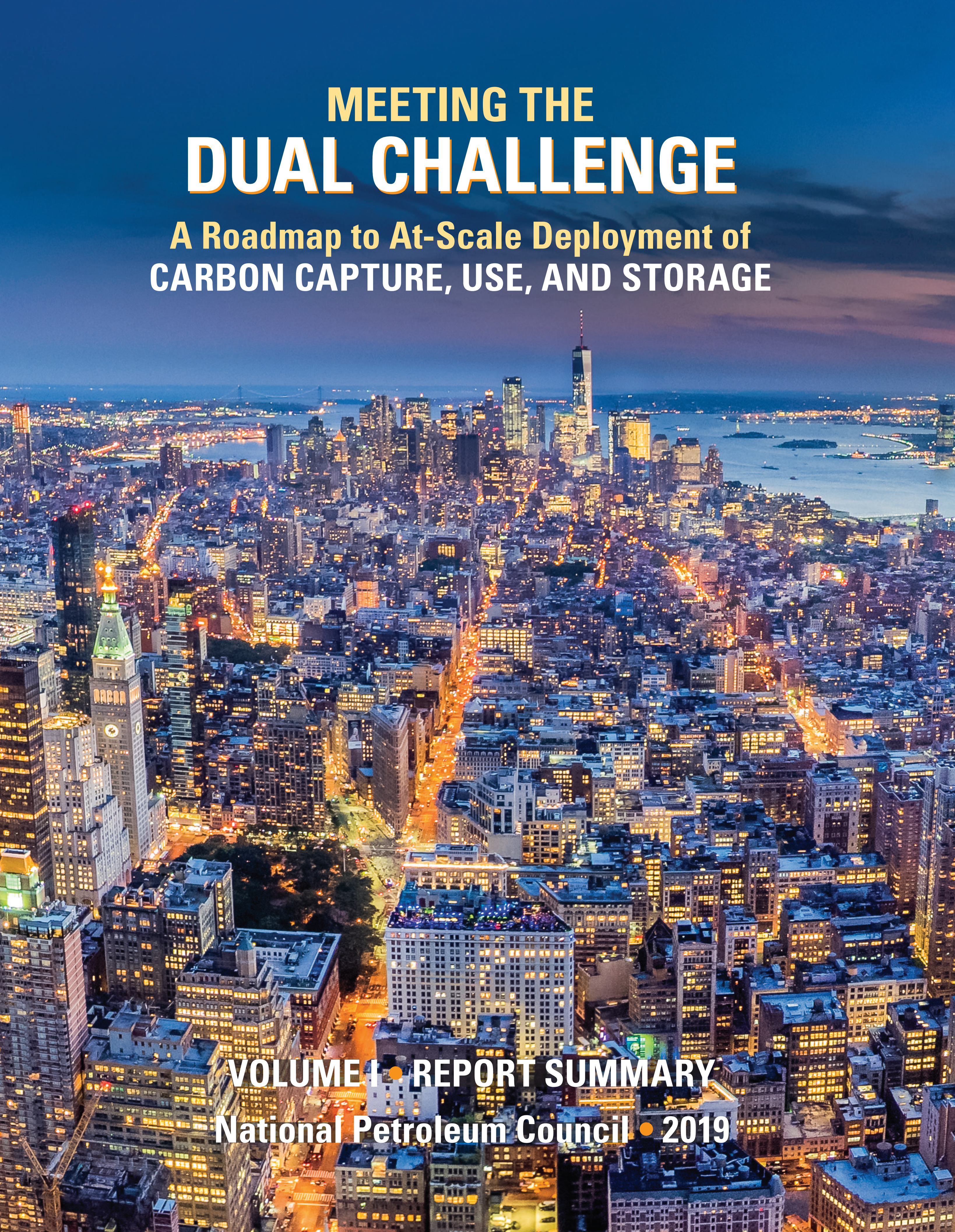
MEETING THE DUAL CHALLENGE

A Roadmap to At-Scale Deployment of CARBON CAPTURE, USE, AND STORAGE



VOLUME I • REPORT SUMMARY

National Petroleum Council • 2019

National Petroleum Council

An Oil and Natural Gas Advisory Committee to the Secretary of Energy

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December 12, 2019

The Honorable Dan R. Brouillette
Secretary of Energy
Washington, D.C. 20585

Dear Mr. Secretary,

By letter dated September 21, 2017, Secretary of Energy Rick Perry requested the National Petroleum Council's (NPC) advice on actions needed to deploy commercial carbon capture, use, and storage (CCUS) technologies at scale into the U.S. energy and industrial marketplace. Achieving this objective will promote economic growth, create domestic jobs, protect the environment, and enhance energy security for the United States.

The response to the request required a study that considered technology options and readiness, market dynamics, cross-industry integration and infrastructure, legal and regulatory issues, policy mandates, economics and financing, environmental impact, and public acceptance. The effort involved over 300 participants from diverse backgrounds and organizations, 67% of whom are employed by organizations outside of the oil and natural gas industry.

Over the next two decades, global population and gross domestic product (GDP) are expected to grow significantly. Many outlooks anticipate a 25% to 30% increase in global energy demand by 2040 as well as a need to address rising greenhouse gas (GHG) emissions. The Council found in this "Roadmap to At-Scale Deployment of CCUS" that as global economies and populations continue to grow and prosper, the world faces the dual challenge of providing affordable, reliable energy while addressing the risks of climate change. Widespread CCUS deployment is essential to meeting this dual challenge at the lowest cost.

The United States is uniquely positioned as the world leader in CCUS and has substantial capability to drive widespread deployment. The United States currently deploys approximately 80% of the world's carbon dioxide (CO_2) capture capacity. However, the 25 million tonnes per annum (Mtpa) of CCUS capacity represents less than 1% of the U.S. CO_2 emissions from stationary sources. The study lays out a pathway through three phases of deployment – activation, expansion, and at-scale – that supports the growth of CCUS over the next 25 years, and details recommendations that enable each phase. In the first phase, clarifying existing tax policy and regulations could double existing U.S. capacity within the next 5 to 7 years. Extending and expanding current policies and developing a durable legal and regulatory framework could enable a second phase of CCUS projects (i.e., 75 to 85 Mtpa) within the next 15 years. Achieving CCUS deployment at scale (i.e., additional 350 to 400 Mtpa) within the next 25 years will require substantially increased support driven by national policies.

In addition, substantially increased government and private research, development, and demonstration (RD&D) is needed to improve CCUS performance, reduce costs, and advance alternatives beyond currently deployed technology. Increasing understanding and confidence in CCUS as a safe and reliable technology is essential for public and policy stakeholder support. The oil and natural gas industry is uniquely positioned to lead CCUS deployment due to its relevant expertise, capability, and resources.

The Council's policy, regulatory, and legal recommendations have been grouped into three phases:

Considering the activation phase, the NPC recommends the following:

- The IRS should clarify the Section 45Q requirements for credit transferability, options for demonstrating secure geologic storage, construction start definition, and credit recapture provisions.
- The Department of the Interior (DOI) and individual states should adopt regulations to authorize access to use pore space for geologic storage of CO_2 on federal and state lands.

Considering the expansion phase, the NPC recommends the following:

- Congress should amend Section 45Q to extend the construction start date, extend the duration of credits, lower the CO_2 volume threshold, and increase the value of the credit for storage and use applications.
- Congress should expand access to Section 48 tax credits and other existing financial incentives to all CCUS projects, effectively expanding current policies to a level of ~$90 per tonne to provide incentive for further economic investment.
- Congress should amend existing statutes to allow CO_2 storage in federal waters from all anthropogenic sources, and the Department of Energy (DOE) and DOI should establish processes to enable access to pore space and regulate CO_2 storage in federal waters.
- Concurrently with the activation phase, DOE should create a CO_2 pipeline working group to study the best way to harmonize the federal, state, and local permitting processes, establish tariffs, grant access, administer eminent domain authority, and facilitate corridor planning. DOE should also convene an industry and stakeholder forum to develop a risk-based standard to address long-term liability.

Considering the at-scale phase, the NPC recommends the following:

- To achieve at-scale deployment of CCUS, concurrently with the expansion phase, congressional action should be taken to bring cumulative value of economic policies to about $110 per tonne.
- The oil and natural gas industry should continue to fund research and development at or above current levels in support of new and emerging CCUS technologies.

Concurrently with all three phases, and to achieve at-scale deployment of CCUS, Congress should increase the level of RD&D funding for CCUS technologies to $15 billion over the next 10 years, with a significant amount directed to less mature and emerging technologies that offer the greatest potential for a step change in performance and cost reduction.

Integral to success is adherence to the Council's following recommendations for engaging stakeholders:

- Government, industry, and associated coalitions should design policy and public engagement opportunities to facilitate open discussion, simplify terminology, and build confidence that CCUS is a safe and secure means of managing emissions.
- The oil and natural gas industry should remain committed to improving its environmental performance and the continued development of environmental safeguards.
- Commensurate with the level of policy enactment being recommended, the oil and natural gas industry should continue its investment in CCUS.

The attached report provides additional details and recommendations. The Council looks forward to sharing this study with you, your colleagues, and broader government and public audiences.

Respectfully submitted,

Greg L. Armstrong
Chair

Attachment

MEETING THE
DUAL CHALLENGE

A Roadmap to At-Scale Deployment of CARBON CAPTURE, USE, AND STORAGE

VOLUME I • REPORT SUMMARY

A Report of the National Petroleum Council
December 2019

Committee on Carbon Capture, Use, and Storage
John C. Mingé, Chair

NATIONAL PETROLEUM COUNCIL

Greg L. Armstrong, Chair
J. Larry Nichols, Vice Chair
Marshall W. Nichols, Executive Director

U.S. DEPARTMENT OF ENERGY

Dan R. Brouillette, Secretary

The National Petroleum Council is a federal advisory committee to the Secretary of Energy.

The sole purpose of the National Petroleum Council is to advise, inform, and make recommendations to the Secretary of Energy on any matter requested by the Secretary relating to oil and natural gas or to the oil and gas industries.

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REPORT OUTLINE

Volume I — Report Summary

Volume II — Analysis of CCUS Deployment At-Scale

Volume III — Analysis of CCUS Technologies

Web-Only Materials

The Report Volumes and Topic Papers may be downloaded
at no charge from the NPC report website, dualchallenge.npc.org.
Printed copies of the Report Volumes may also be purchased from the NPC.

PREFACE

NATIONAL PETROLEUM COUNCIL

The National Petroleum Council (NPC) is an organization whose sole purpose is to provide advice to the federal government. At President Harry Truman's request, this federally chartered and privately funded advisory group was established by the Secretary of the Interior in 1946 to represent the oil and natural gas industry's views to the federal government: advising, informing, and recommending policy options. During World War II, under President Franklin Roosevelt, the federal government and the Petroleum Industry War Council worked closely together to mobilize the oil supplies that fueled the Allied victory. President Truman's goal was to continue that successful cooperation in the uncertain postwar years. Today, the NPC is chartered by the Secretary of Energy under the Federal Advisory Committee Act of 1972, and the views represented are considerably 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 provides a forum for informed dialogue on issues involving energy, security, the economy, and the environment of an ever-changing world.

STUDY REQUEST AND OBJECTIVES

By letter dated September 21, 2017, Secretary of Energy Rick Perry formally requested the National Petroleum Council to undertake a study to define potential pathways, including research and development, regulatory, and policy options for integrating carbon capture, use, and storage (CCUS) at scale into the energy and industrial marketplace, with specific emphasis on the petroleum industry. The Secretary requested the Council's advice on five key questions:

- What are the United States' and global future energy demand outlooks and, based on these outlooks, the environmental benefits resulting from the application of CCUS technologies in various end-use sectors?
- What research and development, technology, and infrastructure barriers must be overcome to ensure the economic deployment of CCUS at scale in various end-use sectors?
- How should the success of CCUS at scale be defined?
- What actions can be taken to establish a framework that guides public policy and stimulates private-sector investment to advance the development and deployment of CCUS technologies capable of achieving substantive gains in efficiency, economics, and environmental performance?
- What regulatory, legal, liability, or other issues should be addressed to progress commercial CCUS investment and enable U.S. industry to be the global technology leaders?

In addition to those questions, Secretary Perry's letter suggested other areas of inquiry, advice, and comment, including the following:

- Development of a roadmap of remaining technology and project development challenges that can enable successful economic deployment of CCUS at scale across the spectrum of industries and fuel types.
- Recognition that integrating technology and deploying CCUS at scale will require significant capital investment, major new infrastructure, and cooperation of multiple industries and government institutions.
- The study should address the entire CCUS value chain and consider technologies applicable to power generation, industrial processes, and enhanced oil recovery (EOR), as well as different fuel types or energy sources (coal, oil, natural gas).
- Factors to be considered should include technology options and readiness, market dynamics, cross-industry integration and infrastructure, legal and regulatory issues, policy mandates, economics and financing, environmental footprint, and public acceptance.

Appendix A contains a copy of the Secretary's request letter and a description of the NPC.

STUDY CONTEXT

As the United States explores options to promote economic growth and ensure energy security while protecting the environment by reducing carbon dioxide emissions over time, Secretary Perry requested the NPC to undertake and deliver a comprehensive study that would define potential pathways for deploying and integrating CCUS technologies at scale into the energy and industrial marketplace in the United States, with an emphasis on the petroleum industry.

Large-scale CCUS technologies require significant investments and infrastructure, as well as the cooperation of multiple industries. The oil and natural gas industry has unique capabilities to contribute to CCUS at the scale required, including the handling of large volumes of gas and liquids, deploying world-scale equipment, evaluating the subsurface for safe storage resource, monitoring the integrity of storage, constructing pipeline infrastructure, and managing the construction and operation of large capital-intensive projects.

Accordingly, this report addresses the entire CCUS supply chain from capture through use and/or storage. It makes clear that the success of CCUS at scale requires economic and operational integration across industries, harmonized local/state/federal regulations, and broad public acceptance. The report addresses the technology advances and choices needed, infrastructure requirements, economics, cross-sector integration, regulation, policy options, and public acceptance.

STUDY SCOPE AND PROCESS

At the outset of the study in early 2018, the study leadership focused on developing a proposed work plan for the study that would define the study scope, organization, and timetable. This step was to ensure that there was alignment on the study plan so that a final report could be submitted to the Secretary by the end of 2019.

It was agreed that the overarching goal of the CCUS study was to define potential pathways leading to CCUS deployment at scale. To do so, the work plan delineated that the study would:

- Evaluate the CCUS value chain from capture through use and/or storage across diverse industrial sectors and fuel types
- Establish the business case for CCUS in the United States
- Address a broad range of factors consistent with the Secretary's request (e.g., technology, legal, regulatory, economics, etc.)
- Focus primarily on accelerating CCUS deployment within the United States while learning from, and considering implications for, the rest of the world
- Deliver an actionable set of recommendations for short-, medium-, and long-term scale-up of CCUS deployment, including specific recommendations for the U.S. government.

While this report's emphasis is on accelerating deployment in the United States, the study learned from, and shared insights with, other countries as the effort was conducted. While many of the report's findings are global in nature, its recommendations are the Council's response to the Secretary's request for advice and, therefore, are U.S. focused.

Based on lessons learned from recent Council studies and other CCUS activities, the following principles were used to guide the study process:

- Redefine CCUS value in terms of energy security, economic growth, and jobs, in addition to environmental benefits
- Maximize use of prior studies and previous research
- Engage broad participation from industries, government, nongovernmental organizations (NGOs), and academia
- Use the work of the National Coal Council
- Leverage organizational strengths, drawing upon collective resources and expertise
- Involve global perspectives to ensure a comprehensive study that leverages learnings from abroad
- Coordinate closely with the concurrent NPC study on U.S. Oil and Natural Gas Transportation Infrastructure
- Ensure comprehensive communication of the report's assumptions and conclusions via tailored presentations delivered to multiple interested parties.

The study drew on available analysis from a variety of sources such as the International Energy Agency (IEA), the U.S. Energy Information Administration (EIA), the U.S. National Academy of Sciences (NAS), U.S. Department of Energy/National Energy Technology Laboratory studies and reports, other peer-reviewed research and development (R&D) reports, and data from demonstration and commercial-scale projects.

This NPC study was conducted in full compliance with all regulations and laws, including antitrust laws and provisions and the Federal Advisory Committee Act. It did not include evaluations of commodity prices despite the important role these play in encouraging research and technology investments required for the widespread deployment of CCUS at scale.

STUDY GROUP ORGANIZATION

In response to the Secretary's request, the National Petroleum Council established a Committee on Carbon Capture, Use, and Storage composed of more than 60 members of the Council. The Committee's purpose was to conduct a study on this topic and to supervise 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 Cochair, and nine members representing a cross section of the Committee. The Steering Committee provided timely guidance and resolution of issues during the course of the study.

A Coordinating Subcommittee and three analytical Task Groups were also established to assist the Committee in conducting the study. These study groups were aided by multiple Study Teams and Subgroups focused on specific subject areas supplemented by workshops and other outreach. Figure P-1 provides an organization chart for the groups that conducted the study's analyses, and Table P-1 lists those who served as leaders of these groups.

The members of the various study groups were drawn from NPC members' organizations as well as from many other industries, state and federal agencies, NGOs, other public interest groups, financial institutions, consultancies, academia, and research groups. Approximately 300 people served on the study's Committee, Subcommittee, Task Groups, Teams, and Subgroups. While all had relevant expertise for the study, fewer than 33% were from the oil and natural gas industry. Figure P-2 depicts the diversity of participation in the study process, and Appendix B contains rosters of the participants in each of the study groups. 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 on a specific topic, or to reviewing proposed materials. Involvement in these activities should not be construed as a participant's or their organization's endorsement of or agreement with all the statements, findings,

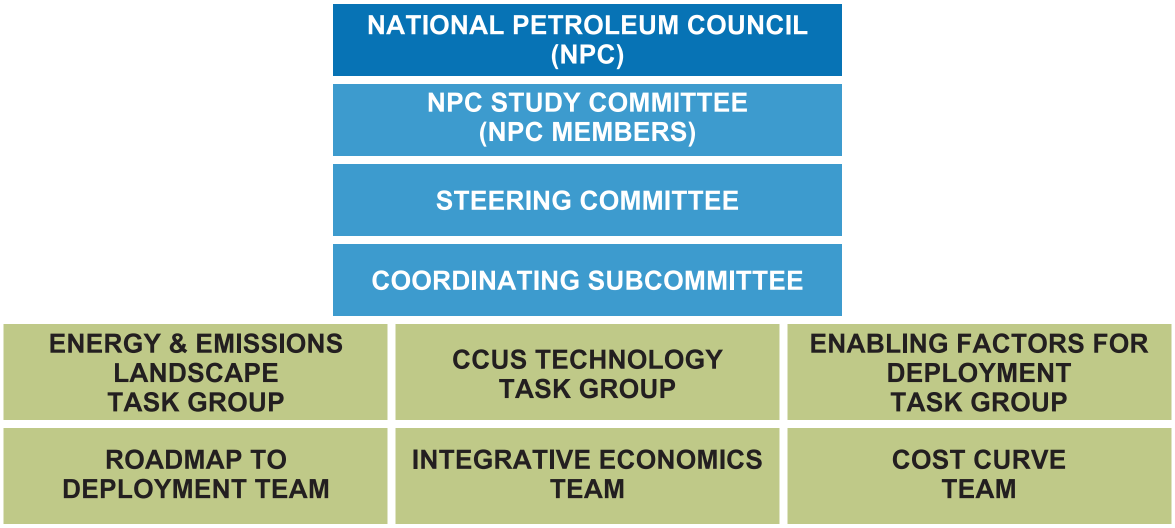

Figure P-1. *CCUS Study Organization*

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. Likewise, some other participants from certain non-advocacy, nonprofit organizations, such as the Electric Power Research Institute, did not take positions on the study's recommendations.

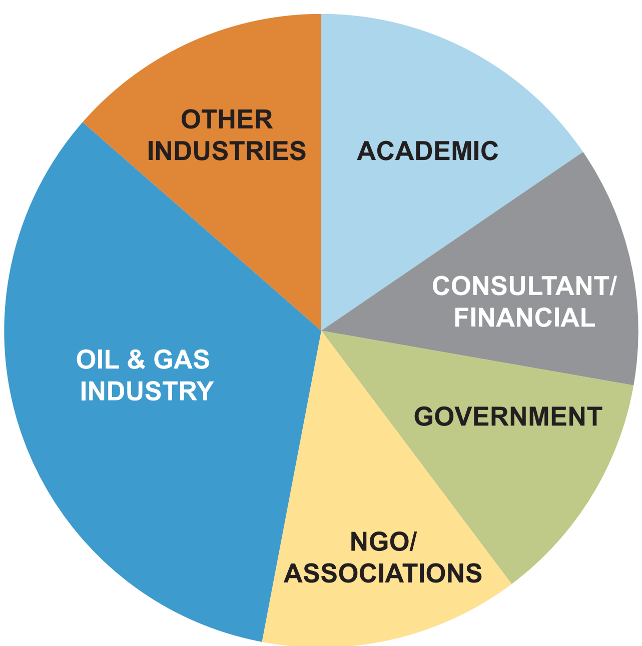

Figure P-2. *CCUS Study Participation Diversity*

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

REPORT STRUCTURE

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

Volume I, Report Summary, includes the report transmittal letter, outline of the entire report, preface, executive summary, roadmap for enabling the widespread implementation of CCUS at scale, a complete list of the detailed recommendations of the study, and appendices providing the study request letter, NPC roster, study group rosters, and description of web-only materials. This volume provides two levels of summarization:

- *Report Transmittal Letter* is the first layer; it submits the report to the Secretary of Energy

NPC Committee on Carbon Capture, Use, and Storage

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John C. Mingé
Former Chairman and President
BP America, Inc.

Government Cochair
Dan R. Brouillette
Deputy Secretary of Energy
U.S. Department of Energy

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Lead – Integrative Economics Team
Jeffrey D. Brown
University of Wyoming Enhanced Oil Recovery Institute
Brown Brothers Energy & Environment, LLC

Lead – Cost Curve Team
Rick Callahan
Senior Vice President, Low Carbon Ventures
Occidental Petroleum Corporation

Table P-1. *CCUS Study Leaders*

as the Council's response to his request for advice on carbon capture, use, and storage. It provides a very brief, high-level overview of the report's key messages.

- *Executive Summary* is the second layer and provides a broad overview of the study's principal findings and resulting recommendations for enabling the widespread implementation of CCUS at scale.

Volume II, Analysis of CCUS Deployment At-Scale, provides more detailed discussion and additional information on the study's deployment at-scale analyses:

- *Chapters 1 to 4* provide discussions and background on the study assessments of CCUS deployment. The four chapters in this volume address: the role of CCUS in the future energy mix; CCUS supply chains and economics; policy, regulatory, and legal enablers; and building stakeholder confidence. These chapters provide supporting data and analyses for the findings and recommendations presented in the Report Summary Volume.
- *Appendices* in this volume provide background material, including CCUS project case studies and an assessment of the economic impacts of CCUS deployment.

Volume III, Analysis of CCUS Technologies, provides an overview and detailed discussions of the technologies used in the CCUS supply chain.

- *Chapters 5 to 9* provide more detailed discussion and additional information on CCUS technologies. The five chapters in this volume address the capture, transport, geologic storage, enhanced oil recovery, and use of CO_2. These chapters provide supporting data and analyses for the findings and recommendations presented in the Report Summary Volume.
- *Appendices* in this volume provide additional background material on CO_2 capture and enhanced oil recovery.

Topic Papers provide a final level of detail for the reader. These papers, developed or used by the study's Task Groups, Subgroups, and Teams, are included on the NPC website. They were used in the development of the full report. A list of the topic papers is provided in Description of Web-Related Materials at the end of this volume.

The Council believes that these materials will be of interest to the readers of the report and will help them better understand the results. The members of the NPC were not asked to endorse or approve all of the statements and conclusions contained in the topic papers but, rather, to approve the publication of these materials as part of the study process. The topic papers were reviewed by the applicable Subgroup but are essentially stand-alone analyses. As such, statements and suggested findings that appear in the topic papers are not endorsed by the NPC unless they were incorporated into the report.

Cost Curve Model. A differential feature of this study was to assess the costs to capture, transport, and store CO_2 from all sectors and fuel types, covering the largest facilities and a total of approximately 80% of all U.S. stationary sources. Using "reference cases" and standard economic assumptions was essential to developing the cost curve, formulating recommendations, and assessing the potential impact of those recommendations on CCUS deployment at a national level. Costs for individual projects will vary based on location factors and the economic assumptions specific to each project.

In order to provide a useful public resource and ensure transparency of the work of the NPC CCUS study, this cost assessment tool is being hosted online by Gaffney, Cline & Associates, allowing stakeholders to change the cost and financial assumptions to generate their own view of costs at the following link: http://gaffney-cline-focus.com/npc-ccus-cost-assessment-tool.

The Report Volumes and Topic Papers described above may be downloaded for free from the NPC report website at: dualchallenge.npc.org. Also, printed copies of the report volumes may be purchased from the NPC.

EXECUTIVE SUMMARY

INTRODUCTION

Over the next two decades, global population is expected to grow by about 1.5 billion people and reach about 9.2 billion people by 2040. At the same time, gross domestic product (GDP) is expected to more than double. This growth in global prosperity will lift billions of people out of poverty and into the middle class. To enable this dramatic increase in prosperity, many outlooks anticipate a 25% to 30% increase in global energy demand by 2040. In addition to providing affordable, reliable energy to support growing economies and populations, the world will also need to address rising greenhouse gas (GHG) emissions and the risks of climate change. Carbon capture, use, and storage (CCUS), including transport, will be an essential element in the portfolio of solutions needed to take on this dual challenge of supplying energy while addressing the risks of climate change.

The United States leads the world in CCUS deployment today with approximately 80% of the world's carbon dioxide (CO_2) capture capacity, with many of the early projects driven by market economics, including the availability of low-cost supply of CO_2 and demand for CO_2 for enhanced oil recovery (EOR). And, although the United States is currently the world leader, its 25 million tonnes of CCUS capacity represents less than 1% of the CO_2 emissions from stationary sources. The United States has more than 6,500 large stationary sources emitting approximately 2.6 billion tonnes of CO_2 per year across multiple industries. Many of these sources are located near geologic formations suitable for CO_2 storage, providing opportunities to expand deployment of CCUS and extend the U.S. leadership position.

The United States has a demonstrated track record of successful CCUS projects and an established regulatory framework that is underpinned by world-leading policy support. In addition to geology that favors CO_2 storage, the United States possesses an innovative business climate and cutting-edge research capabilities. Continued U.S. leadership in CCUS can create domestic jobs, benefit the economy, and augment energy security priorities. The U.S. oil and natural gas industry has the expertise, capability, and resources to partner with governments and stakeholders in expanding the United States' leadership position in CCUS. This report describes the opportunity and actions needed to expand the application of CCUS in the United States. The second volume of the report begins with an overview of the U.S. and global energy and CO_2 emissions landscape, describing why CCUS is essential to meeting the dual challenge of providing affordable and reliable energy while addressing the risks of climate change. It then describes the opportunities to deploy CCUS in the United States and lays out a pathway through three phases of deployment—activation, expansion, and at scale—that would enable the growth of CCUS in the United States over the next 25 years, and details the recommendations that enable each phase. The third volume of the report comprises five chapters that describe the technology elements of the CCUS supply chain and the opportunities that exist for continued development of each.

The Executive Summary discusses the following findings:

1. As global economies and populations continue to grow and prosper, the world faces the dual challenge of providing affordable, reliable energy while addressing the risks of climate change.
2. Widespread CCUS deployment is essential to meeting the dual challenge at the lowest cost.
3. Increasing deployment of CCUS can deliver benefits and favorably position the United States to participate in new market opportunities as the world transitions to a lower CO_2 intensive energy system.
4. The United States is uniquely positioned as the world leader in CCUS and has substantial capability to drive widespread deployment.
5. Clarifying existing tax policy and regulations could activate an additional 25 to 40 million tonnes per annum (Mtpa) of CCUS, doubling existing U.S. capacity within the next 5 to 7 years.
6. Extending and expanding current policies, and developing a durable legal and regulatory framework, could enable the next phase of CCUS projects (an additional 75 to 85 Mtpa) within the next 15 years.
7. Achieving CCUS deployment at scale, an additional 350 to 400 Mtpa, in the next 25 years will require substantially increased support driven by national policies.
8. Increased government and private research, development, and demonstration is needed to improve performance, reduce costs, and advance alternatives beyond currently deployed technology.
9. Increasing understanding and confidence in CCUS as a safe and reliable technology is essential for public and policy stakeholder support.
10. The oil and natural gas industry is uniquely positioned to lead CCUS deployment due to its relevant expertise, capability, and resources.

Following the Executive Summary is a CCUS roadmap for the United States that uses an infograph to detail the final recommendations and expected impact on deployment at each phase. Following the roadmap, a detailed list of all recommendations developed as part of this study is provided. Volumes II and III contain the nine chapters that provide the details that underpin the Executive Summary, roadmap, and recommendations.

KEY FINDINGS AND RECOMMENDATIONS

Finding 1

As global economies and populations continue to grow and prosper, the world faces the dual challenge of providing affordable, reliable energy while addressing the risks of climate change.

Over the next two decades, the global population is expected to grow by about 1.5 billion people, reaching approximately 9.2 billion by 2040.[1] This increase is more than four times the population of the United States in 2019. At the same time, GDP is expected to more than double. This growth in global prosperity will lift billions of people out of poverty and into the middle class. To enable this dramatic increase in prosperity, many outlooks anticipate a 25% to 30% increase in global energy demand by 2040.[2]

This anticipated demand growth is reflected in the International Energy Agency's (IEA) Stated Policies Scenario (STEPS), which aims "to provide a detailed sense of the direction in which existing policy frameworks and today's policy ambitions would take the energy sector out to 2040."[3] Figure ES-1 shows that the STEPS estimates global energy demand will increase more than 25% through 2040. Most of this growth will come from India and China, as well as other emerging economies, as prosperity rises and populations increase. Conversely, demand in developed economies, like the United States, is expected to remain flat or decline, as energy efficiency improves.

1 United Nations, Department of Economic and Social Affairs, Population Division (2019). World Population Prospects 2019, Online Edition. Rev. 1.

2 BP Energy Outlook 2019, ExxonMobil Outlook for Energy 2019, IEA World Energy Outlook 2019 Stated Policies Scenario.

3 International Energy Agency (2019) World Energy Outlook, https://www.iea.org/weo/weomodel/steps/.

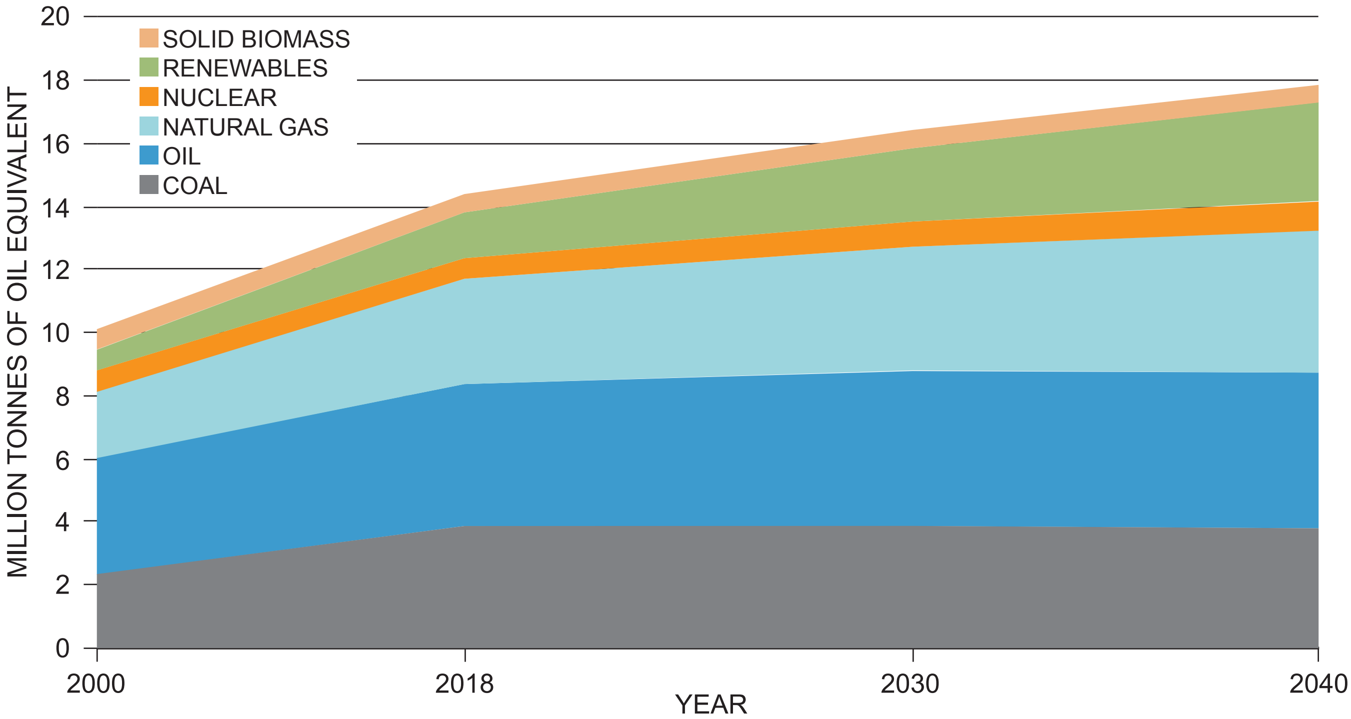


Figure ES-1. *IEA Stated Policies Scenario Shows More Than a 25% Increase in Global Primary Energy Demand by 2040*

In the Energy Poverty Action Initiative, the World Economic Forum recognizes that "access to energy is fundamental to improving quality of life and is a key imperative for economic development." Figure ES-2 illustrates this well-established relationship, comparing the United Nations Human Development Index—an assessment of life expectancy, education levels, and gross national income per capita—to annual energy use per capita. The data suggest that as energy use per capita rises, quality of life increases significantly, and the relationship flattens out at about 100 gigajoules (GJ) per capita per year.

Eighty percent of the world's population lives in countries where per capita energy consumption is less than 100 GJ per year, and the global average is about 82 GJ. In comparison, the average annual energy consumption for members of the Organization for Economic Co-operation (OECD) is about 169 GJ.[4] This pronounced difference in consumption—more than double the global average—highlights the gap between most OECD countries and those in developing economies.

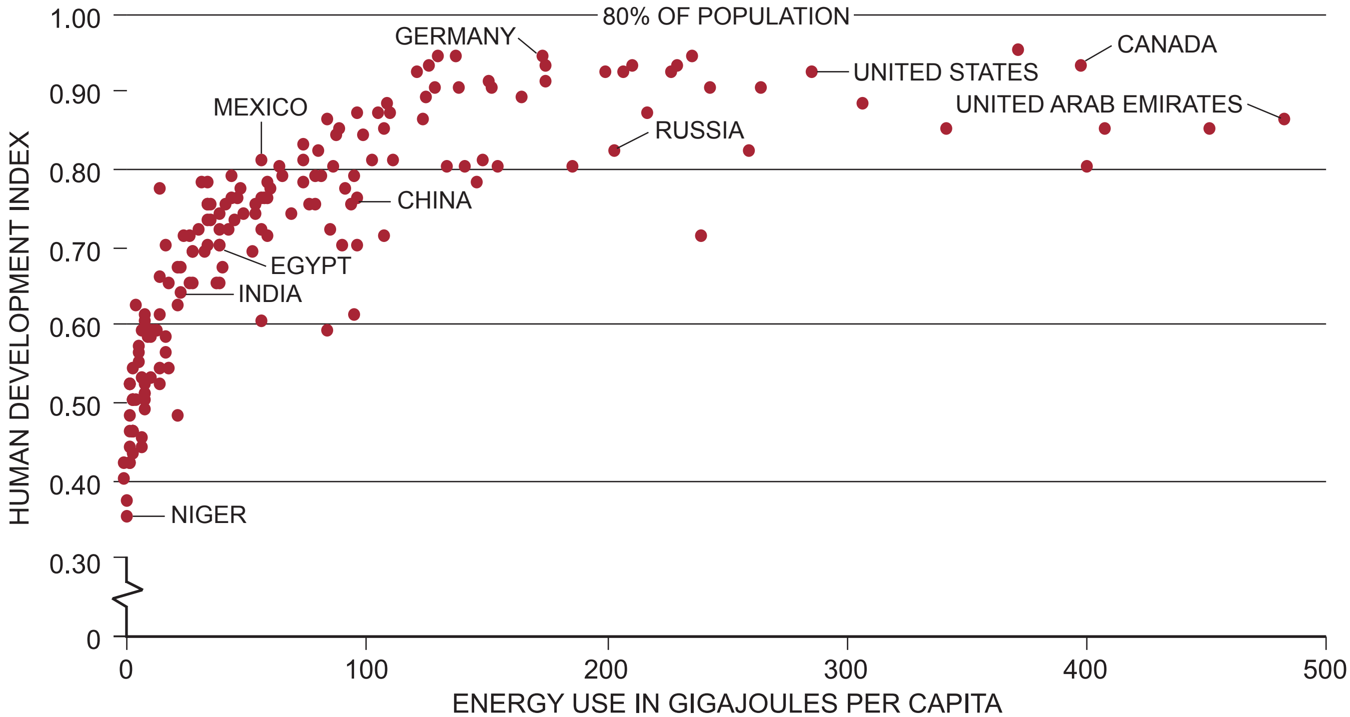
In addition to providing more affordable, reliable energy to support growing economies and populations, the world will need to address rising GHG emissions and the risks of climate change. In 2019, atmospheric concentrations of CO_2 climbed to more than 400 parts per million (ppm) from a pre-Industrial Revolution level of 280 ppm.[5]

According to the Intergovernmental Panel on Climate Change (IPCC), "it is extremely likely that more than half of the observed increase in global average surface temperature from 1951 to 2010 was caused by the anthropogenic[6] increase

4 OECD average excludes Iceland because they were not included in the data set.

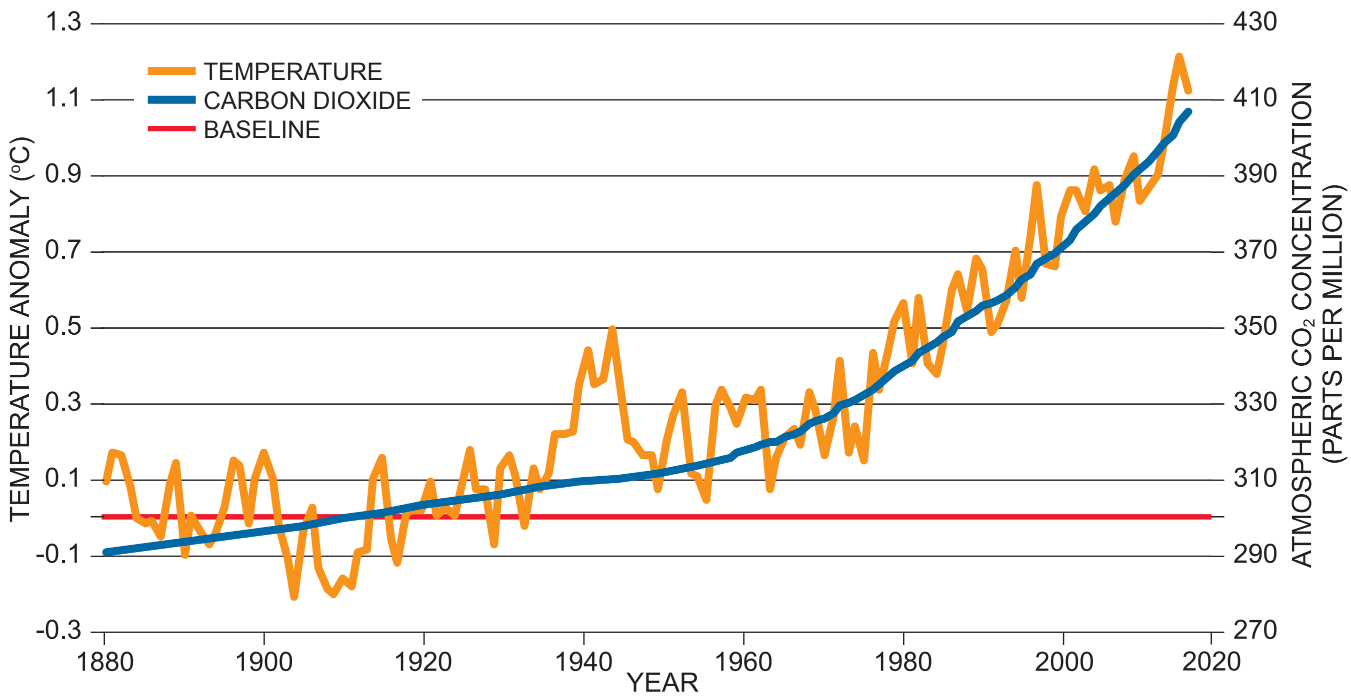
5 Lindsey, R. (2019). "Climate Change: Atmospheric Carbon Dioxide," climate.gov website. Accessed September 2019. https://www.climate.gov/maps-data.

6 anthropogenic (adjective): of, relating to, or resulting from the influence of human beings on nature. In Merriam-Webster's online dictionary. Accessed September 2019. https://www.merriam-webster.com/dictionary/anthropogenic.



Source: 2017 United Nations Human Development Index and BP Energy Outlook 2019.

Figure ES-2. *2017 Human Development Index and Energy Consumption per Capita*



Note: Global temperature anomalies averaged and adjusted to early industrial baseline (1881-1910).
Source: Climate Central, "Rising Global Temperatures and CO_2," November 20, 2018.

Figure ES-3. *The Relationship between CO_2 Concentration and Global Temperature, 1880-2017* in greenhouse gas concentrations,"[7] and "continued emission of greenhouse gases will contribute to further warming and long-lasting changes in all components of the climate system."[8] The historical relationship between CO_2 concentration and global temperature is shown in Figure ES-3.

Finding 2

Widespread CCUS deployment is essential to meeting the dual challenge at the lowest cost.

7 IPCC, 2013: *Climate Change 2013: The Physical Science Basis. Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, p. 17.

8 IPCC, 2014: *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, p. 8.

CCUS combines several technologies to reduce the level of CO_2 emitted to the atmosphere or remove CO_2 from the air. The CCUS supply chain, as shown in Figure ES-4, involves the capture (separation and purification) of CO_2 from stationary sources so it can be compressed and transported to a suitable location where it is converted into useable product or injected deep underground for safe, secure, and permanent storage.

Although CCUS supply chains can have many forms, the building blocks are generally described as follows:

Capture. CO_2 is produced in combination with other gases during industrial processes, including hydrocarbon-based power generation. CO_2 capture involves the separation of the CO_2 from these other gases. This separation can be accomplished using many different technologies, the most common of which is amine absorption. Once the CO_2

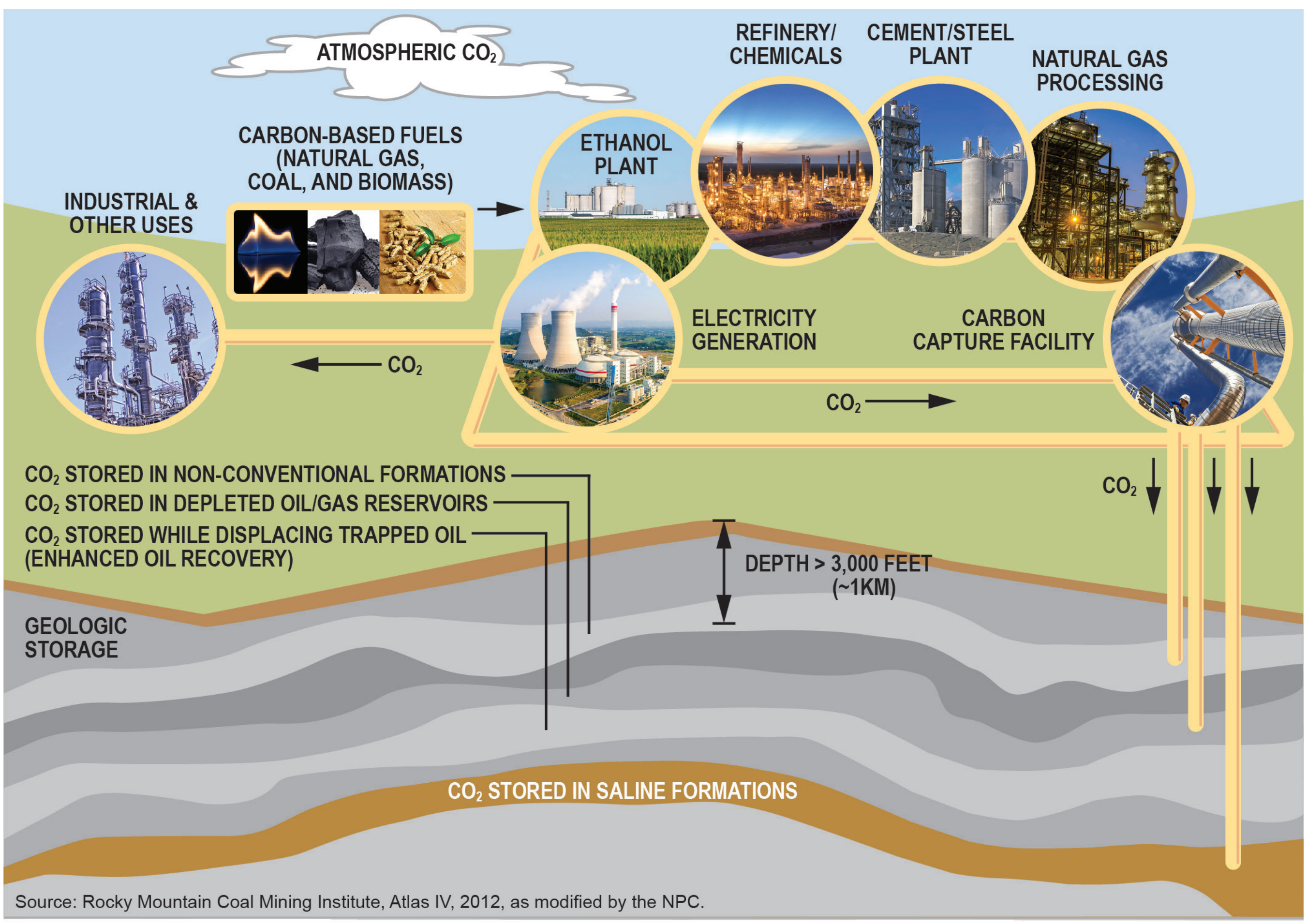


Figure ES-4. *Supply Chain for Carbon Capture, Use, and Storage* is separated, it is typically dehydrated to avoid corrosion and then compressed or refrigerated so that it behaves like a liquid, making it ready for transport.

Transport. In most cases, captured CO_2 will need to be transported from the capture location to a different location where it can be stored or used. This transport is typically accomplished using pipelines operating at a pressure that enables the CO_2 to remain in a dense phase. Sometimes CO_2 is transported using rail, trucks, or marine vessels.

Use. While most CO_2 captured over the next few decades will likely be stored, it can also be used to produce valuable products and services. Examples of CO_2 use include building materials and carbon nanotubes. CO_2 use is currently an outlet for only a small fraction of the captured CO_2 but may provide a meaningful option with further market and technology development.

Storage. There are multiple pathways for CO_2 storage. Compressed CO_2 is injected into carefully selected subsurface geological formations for safe, secure, and permanent storage. Examples of subsurface formations include saline formations, depleted oil and natural gas reservoirs, and un-mineable coal seams. CO_2 can also be used to produce oil in a process known as enhanced oil recovery. Operational experience indicates that approximately 99% of the CO_2 used in EOR is ultimately trapped in hydrocarbon-producing geologic formations.

The Unique Role of CCUS

CCUS is an essential element in the portfolio of solutions needed to change the emissions trajectory of the global energy system. In its Fifth Assessment Report, the IPCC concluded that the costs for achieving atmospheric CO_2 levels consistent with holding average global temperatures to 2°C—referred to as a "2°C world"—will be more than twice as expensive without CCUS.[9]

In support of that report, the Energy Modeling Forum 27 at Stanford University evaluated various scenarios with specific stabilization targets consistent with a 2°C world that would, for example, limit atmospheric CO_2 to 450 ppm.[10] As part of that work, Figure ES-5 presents potential outlooks for global CO_2 emissions under stabilization scenarios (assessed 2°C scenarios) relative to baseline scenarios that represent pathways with limited change in policy.

The set of baseline scenarios shows CO_2 emissions growing steadily out to 2100. The assessed 2°C scenarios show that global CO_2 emissions must decline to zero, and in most cases become negative, in the second half of the century. To achieve these reductions, the assessed 2°C scenarios require technologies that remove CO_2 from the atmosphere. These CO_2 removal technologies enables "negative emissions."

Bioenergy with CCUS (BECCS) and direct air capture (DAC) with CCUS are two negative emissions approaches that could be applied to achieve a 2°C outcome. BECCS involves the conversion of biomass, which extracts CO_2 from the atmosphere as it grows, to energy with the resulting CO_2 captured and geologically stored. DAC takes CO_2 from the air that can be geologically stored or used.

The IEA considers the role of CCUS in its Sustainable Development Scenario (SDS). Figure ES-6 depicts the difference between global emissions projections in the IEA STEPS and SDS. CCUS contributes 9% of cumulative emissions reductions globally to 2050, making it a vital part of the mix of solutions needed to reach SDS targets.[11] As the IEA explained in 2017, "Our analysis consistently shows that CCUS is a critical part of a complete clean energy technology portfolio that provides a sustainable path for mitigating

9 IPCC, 2014: *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

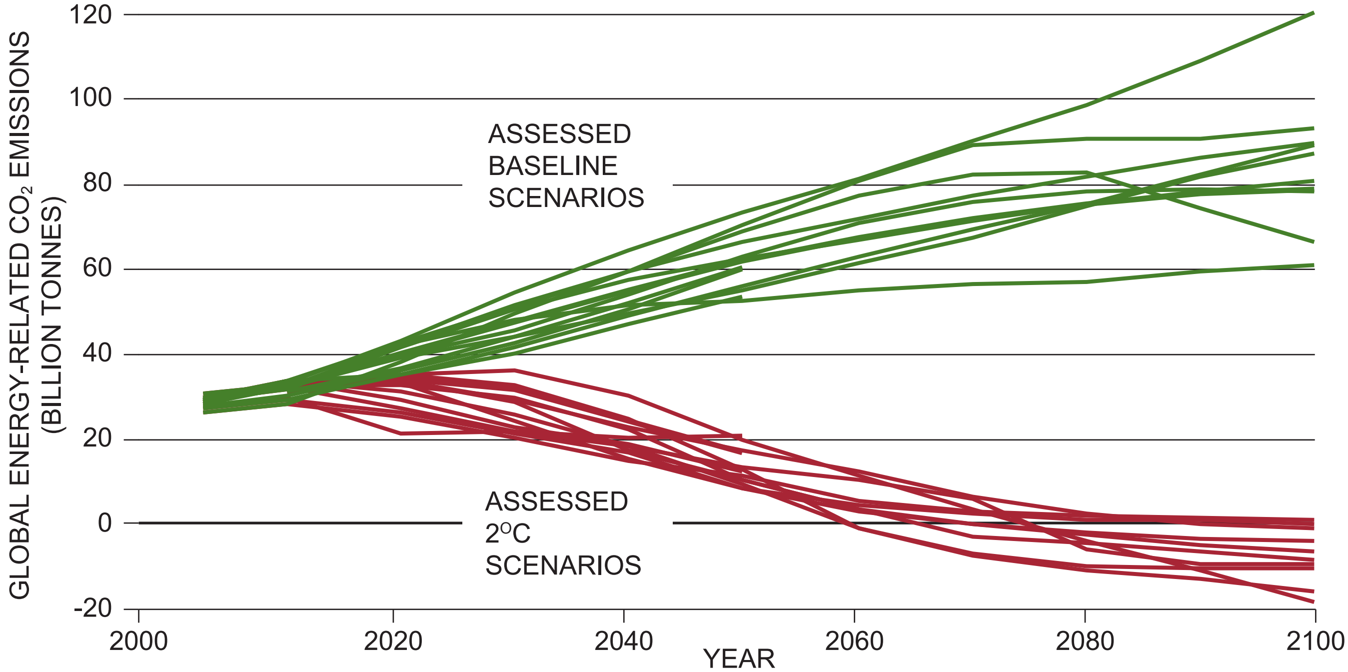
10 ExxonMobil Outlook for Energy, 2019, p. 41.

11 The SDS "sets out the major changes that would be required to reach the key energy-related goals of the United Nations Sustainable Development Agenda." These are:

An early peak and rapid subsequent reductions in emissions, in line with the Paris Agreement (Sustainable Development Goal [SDG] 13)

Universal access to modern energy by 2030, including electricity and clean cooking (SDG 7)

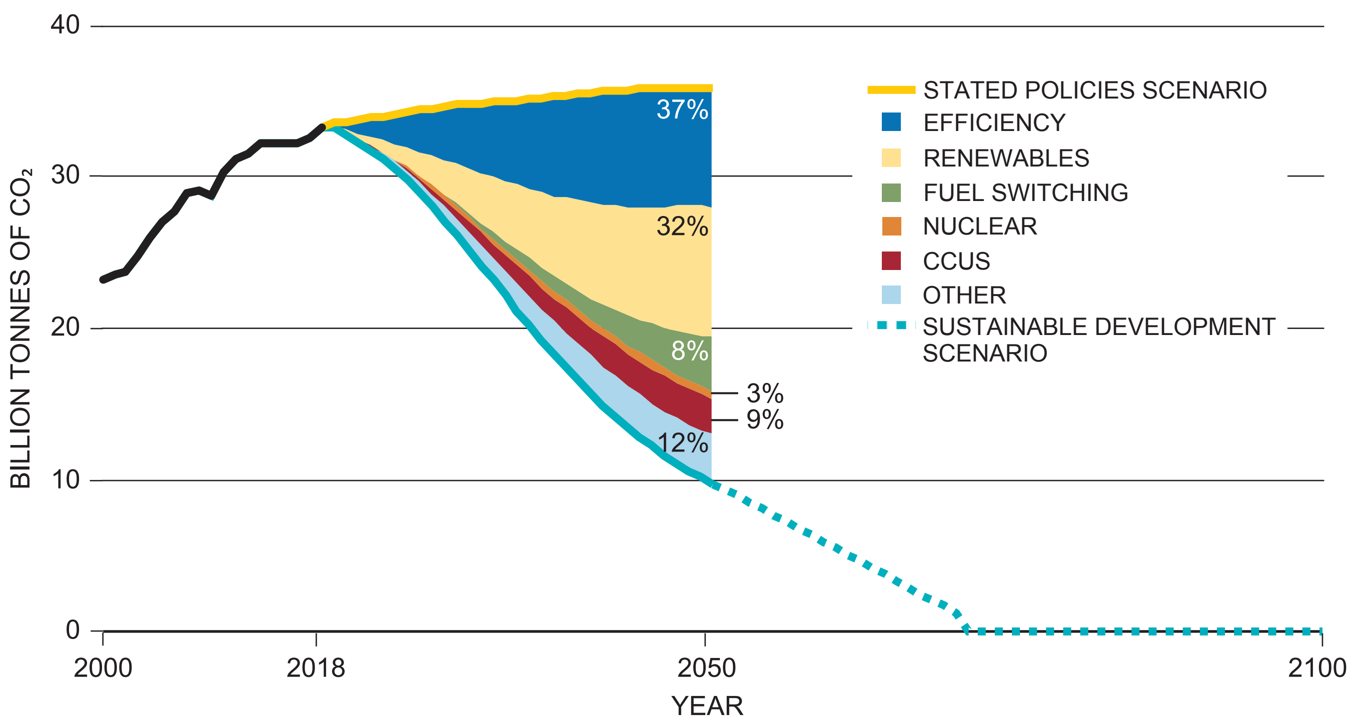
A dramatic reduction in energy-related air pollution and the associated impacts on public health (SDG 3, 9).



Notes: Assessed scenarios included CO_2 emissions from energy and industrial processes.
Assessed scenarios refer to EMF27 baseline and 450 ppm full technology scenarios.

Source: ExxonMobil Outlook for Energy, 2019.

Figures ES-5. *Comparison of Assessed Baseline and 2°C Scenarios to Achieve Global Net-Zero Emissions by 2100*



Source: Based on data from International Energy Agency, World Energy Outlook 2019.

Figure ES-6. *Global Emissions Projections for the IEA's Stated Policies Scenario and Sustainable Development Scenario* greenhouse gas emissions while ensuring energy security."[12]

Finding 3

Increasing deployment of CCUS can deliver benefits and favorably position the United States to participate in new market opportunities as the world transitions to a lower CO_2 intensive energy system.

Since the beginning of the Industrial Revolution, global energy demand has soared, and the mix of energy sources has continued to evolve. This evolution has been enabled by advancements in technology that have brought greater utility in the delivery and use of energy. Figure ES-7 illustrates global primary energy sources by share. Throughout history it has taken decades for new energy sources to achieve a substantial market share.

12 International Energy Agency. (June 7, 2017). "IEA and China Host High-Level Gathering of Energy Ministers and Industry Leaders to Affirm the Importance of Carbon Capture." *https://www.iea.org/newsroom/news/2017/june/iea-and-china-host-high-level-gathering-of-energy-ministers-and-industry-leaders.html.*

For much of history, the primary drivers behind energy choices were availability and cost. However, as societies developed, the environmental impacts of energy sources became more noticeable. Air and water pollution became key concerns when adverse health impacts on populations resulted from smog and acid rain. Concerted efforts from governments and industry working together have led to successful reductions in these environmental impacts over a comparatively short time frame.

Over the past few decades, the public has placed greater emphasis on the risks of climate change. In response, many governments have enacted policies to reduce emissions, leading to widespread deployment of lower CO_2 intensive technologies. In the United States, policy helped create a market for energy sources with lower emissions. In 2018, wind, biofuels, and solar accounted for 8.5% of U.S. primary energy consumption.[13]

13 *Annual Energy Outlook 2019 with Projections to 2050*. Washington, D.C.: U.S. Energy Information Administration, 2019.

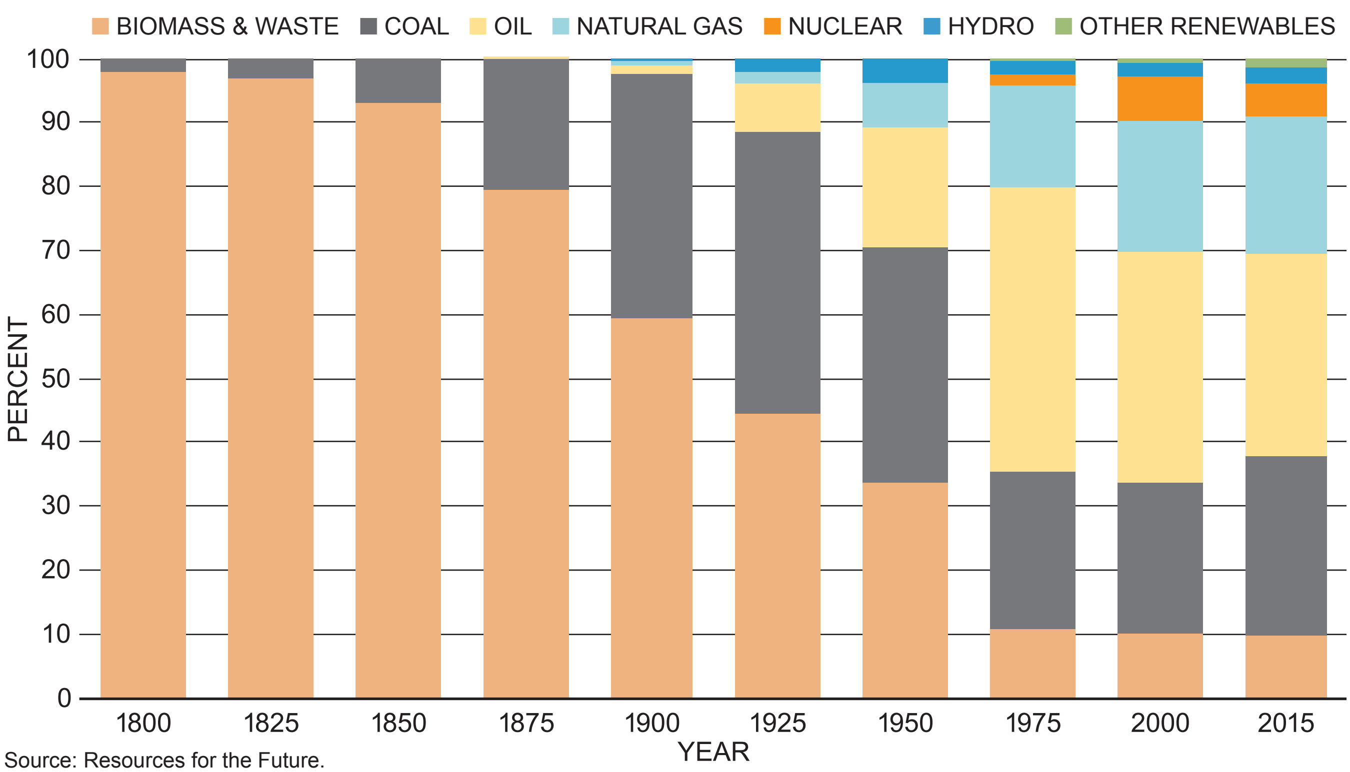
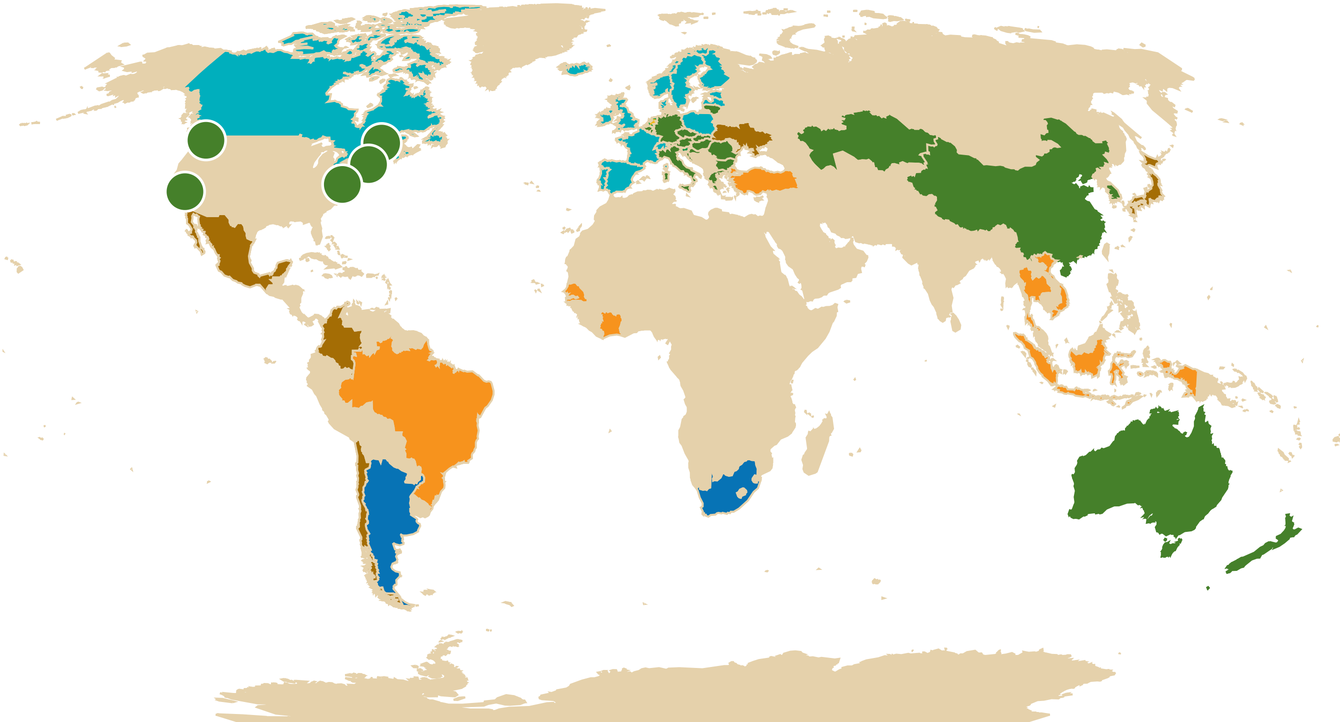


Figure ES-7. *Global Primary Energy Sources by Share*



ETS IMPLEMENTED OR SCHEDULED FOR IMPLEMENTATION
ETS OR CARBON TAX UNDER CONSIDERATION
CARBON TAX IMPLEMENTED OR SCHEDULED, ETS UNDER CONSIDERATION
CARBON TAX IMPLEMENTED OR SCHEDULED FOR IMPLEMENTATION
ETS AND CARBON TAX IMPLEMENTED OR SCHEDULED

Note: The circles on the map represent cooperation initiatives on carbon pricing between subnational jurisdictions.
Source: The World Bank, Carbon Pricing Dashboard, August 1, 2019.

Figure ES-8. *Countries That Have Implemented or Scheduled Implementation of Carbon Pricing*

Some governments have embraced carbon pricing to reduce emissions. As of September 2019, there were 57 carbon pricing initiatives—comprising both emissions trading systems (ETS) and carbon taxes—implemented or scheduled for implementation worldwide (Figure ES-8) that address 11 billion tonnes of CO_2 equivalent, or about 20% of global GHG emissions. Furthermore, in their Nationally Determined Contributions (NDC) under the Paris Agreement, 100 countries consider carbon pricing to meet their emissions reduction ambitions.[14] Beyond carbon pricing, 13 entities, including China, Japan, and the European Union, have included CCUS in their NDCs/low-carbon roadmaps. In addition to carbon pricing, some governments have also implemented standards, mandates, and financial incentives to reduce GHG emissions.

The United States has implemented multiple policies to address the risks of climate change. Today, there are more than 3,500 policies at the local, state, and federal level that are intended to address a range of issues from energy efficiency to renewable energy and biofuels deployment.[15] One of the most recent and impactful policies implemented at the federal level in support of CCUS deployment is the Section 45Q tax credit.

Societal expectations and government action to lower GHG emissions will continue to create future opportunities for technology development and new markets, particularly for CCUS. The

14 United Nations Climate Change website, About Carbon Pricing, "What does the Paris Agreement say on Carbon Pricing?" https://unfccc.int/about-us/regional-collaboration-centres/the-ci-aca-initiative/about-carbon-pricing#eq-7.

15 DSIRE Database. North Carolina State University. (2019). U.S. climate related policies, Accessed September 2019.

United States is uniquely positioned to compete in this global market by exporting the world-leading technologies and expertise it has already gained through the existing CCUS projects. The United States will increase its competitiveness in the global market by continued development of its domestic capabilities and resources through at-scale deployment of CCUS.

In 2014, through the process of carefully injecting compressed CO_2 into existing oil fields to recover oil and natural gas, known as EOR, produced approximately 300,000 barrels of oil per day—more than 2% of U.S. oil production.[16] By expanding the use of CO_2 for EOR through further development of domestic resources, the United States can sustain its energy security. Increased production also creates economic benefits for businesses, local communities, and states, and it helps maintain and expand jobs associated with oil and natural gas production. Additionally, EOR has a relatively small environmental footprint because existing infrastructure is often used to produce incremental oil. A 2015 study by the IEA estimated that oil produced through EOR is 63% less carbon intensive than oil produced through traditional methods.[17]

There may also be an opportunity for the United States to market its CO_2 storage resources to countries that do not have favorable geology. Because the volume of subsurface storage potential in the United States greatly exceeds the capacity likely to be used by U.S. sources, there could be value in importing and storing CO_2 from countries with insufficient storage resources. For example, CO_2 import and storage along the Gulf Coast could become a parallel market to gas exports via liquefied natural gas (LNG). This concept is similar to the Northern Lights project being developed in Norway whose goal is to develop the world's first storage facility capable of receiving CO_2 from diverse sources.

16 Kuuskraa, V., and Wallace, M. (2014). CO_2-EOR Set for Growth as New CO_2 Supplies Emerge, *Oil & Gas Journal,* April 7, 2017. Accessed September 2019. https://www.adv-res.com/pdf/CO2-EOR-set-for-growth-as-new-CO2-supplies-emerge.pdf.

17 IEA, Insights Series 2015 – Storing CO_2 through Enhanced Oil Recovery. IEA, November 3, 2015, 48 pp.

According to the IEA, there is a growing perspective that clean hydrogen will play a key role in the world's transition to a lower CO_2 intensive energy system.[18] As of 2019, over 90% of the hydrogen produced in the United States is made through the steam methane reforming (SMR) process, which results in a pure stream of CO_2 when separated. Continued innovation and cost reduction in CCUS technology could help to underpin a low-carbon source of hydrogen that could compete in emerging low-carbon markets globally.

Other potential opportunities may exist in the development and export of low-carbon and decarbonized products as well as the use of CO_2 as a feedstock. This market for CO_2 based products is expected to grow due to an anticipated increase in consumer demand for low-carbon products. Although many of these new products are still in early development, there is an opportunity for the United States to be a leader in commercializing new uses of CO_2.

Finding 4

The United States is uniquely positioned as the world leader in CCUS and has substantial capability to drive widespread deployment.

The United States has become the world leader in CCUS by:

- Executing successful CCUS projects
- Investing in CO_2 pipeline infrastructure
- Establishing a supportive regulatory framework
- Enacting world-leading policy support
- Investing in research and development

and is uniquely positioned to extend this leadership position by:

- Extending cutting-edge research capability
- Developing its vast geologic resource
- Expanding CCUS deployment.

18 van Hulst, N., "Commentary: The Clean Hydrogen Future has Already Begun," IEA, April 23, 2019. Accessed September 2019, https://www.iea.org/newsroom/news/2019/april/the-clean-hydrogen-future-has-already-begun.html.

Successful CCUS Projects

Today, 19 industrial-scale[19] CCUS projects are operating worldwide, with a total capacity of ~32 million tons CO_2/year. Ten of these projects, totaling ~25 million tonnes of CO_2 per year, are in the United States, representing ~80% of global capacity. These projects span multiple industries, including natural gas processing (~17 Mtpa), synthetic natural gas production (3 Mtpa), fertilizer production (2 Mtpa), coal-fired power generation (1 Mtpa), hydrogen production (1 Mtpa), and ethanol production (1 Mtpa). It is noteworthy that six of the 10 U.S. projects were exclusively driven by market factors, including the availability of a low-cost CO_2 supply and demand for CO_2 from the EOR industry. Four of the 10 projects required significant policy support to be economically viable.

19 Industrial-scale as defined by Global CCS Institute.

Investment in CO_2 Pipeline Infrastructure

In addition to having approximately 80% of the world's CCUS capacity, the United States has approximately 85% of the total CO_2 pipeline mileage in the world with more than 5,000 miles (Figure ES-9). The CO_2 transported through this pipeline network is a mix of anthropogenic and natural CO_2 and is primarily used for EOR. The U.S. oil industry leads the globe in CO_2 EOR deployment and has been safely injecting CO_2 underground for nearly 50 years, extending the life of older fields and maximizing the value of U.S. hydrocarbon resources.

Established Regulatory Framework

The United States has actively pursued the establishment of a strong regulatory framework to assure safe and secure transportation and storage of CO_2. The Environmental Protection Agency (EPA) has developed specific regulatory and permitting frameworks under the Safe Drinking Water Act to protect underground sources of

Figure ES-9. *Schematic Map of CO_2 Pipelines in the United States* drinking water during injection operations. These include the Class II (oilfield injection) and Class VI (saline formation storage of CO_2) permitting processes for CO_2 injection wells.[20] The EPA also maintains the Greenhouse Gas Reporting Program and has developed accounting protocols under the Clean Air Act for the injection of CO_2 for geological storage. The CO_2 pipelines are regulated by the Pipeline and Hazardous Materials Safety Administration within the Department of Transportation, which sets the standards for permitting and operation.[21]

World-Leading Policy Support

In 2009, the American Recovery and Reinvestment Act (Recovery Act; P.L. 111-5) provided the U.S. Department of Energy (DOE) $3.4 billion for CCUS[22] demonstration projects and related activities. Recovery Act funding was intended, in part, to help the DOE achieve its research, development, and demonstration (RD&D) goals as outlined in the department's 2010 Carbon Dioxide Capture and Storage RD&D Roadmap. The large and rapid influx of funding for industrial-scale CCUS projects was intended to accelerate development and demonstration of CCUS in the United States. Three projects that are currently in operation, the Air Products Steam Methane Reformer CO_2 capture project, ADM Illinois Industrial CCS project, and the NRG/JX Petra Nova CO_2 capture project all benefited greatly from this funding. Additionally, many other projects were successfully completed as a result of this funding, including the Air Liquide project using a cold membrane process to remove CO_2 from the flue gas of coal-fired power plants and the Novomer CO_2 use project to convert CO_2 into a number of polymers for a range of manufacturing applications.

CCUS has also benefited from federal tax policy as well as state and regional incentives. The 2018 Bipartisan Budget Act amended Section 45Q of the U.S. tax code for operators of carbon capture equipment, increasing the tax credit from $20 to $50 per tonne of CO_2 stored in dedicated geological storage and from $10 to $35 per tonne for CO_2 stored through EOR or for CO_2 used. The legislation also removed some limits on the size of projects that can qualify and the total amount of credits that can be claimed.

Cutting-Edge RD&D and Capability

The United States has benefited from a more than 20-year history of DOE leadership, funding support, and public-private partnerships between government, academia, and industry. Since 1997, DOE has supported CCUS research and development, and since 2012 Congress has provided over $4 billion in RD&D funding to DOE for CCUS activities.[23] As a result, the United States is currently the leader in CCUS technology and deployment capability.

Much of this development was accomplished through DOE's Regional Carbon Sequestration Partnership program, which includes 40 states and 4 Canadian provinces. The regional partnerships joined together academic, research, and industrial experience to deliver 19 small-scale CO_2 injection pilot programs and 6 large-scale CO_2 injection test projects.[24] Together, these projects have cemented U.S. leadership in the safe operation, monitoring, verification, and secure closure of CO_2 storage facilities.

Vast Geologic Storage Resource

The United States has one of the largest assessed CO_2 geologic storage capacities in the world. Most of the U.S. Lower 48 states possess some subsurface CO_2 storage potential, as shown in Figure ES-10. While estimates of U.S. storage resource vary, experts generally agree that it is adequate to store hundreds of years of CO_2 emissions from U.S. stationary sources.

20 United States Environmental Protection Agency, Underground Injection Control (UIC), Last Updated September 6, 2016. Accessed September 2019. https://www.epa.gov/uic/underground-injection-control-well-classes.

21 United States Department of Transportation, Pipeline and Hazardous Materials Safety Administration, PHMSA Regulations, Last Updated September 8, 2017. Accessed September 2019. https://www.phmsa.dot.gov/phmsa-regulations.

22 The act refers to carbon capture and sequestration.

23 Folger, P. (2018). FY2019 Funding for CCS and Other DOE Fossil Energy R&D, Congressional Research Service, July 2, 2018, 2 pp. Accessed October 20, 2019. https://fas.org/sgp/crs/misc/IF10589.pdf.

24 National Energy Technology Laboratory, Regional Carbon Sequestration Partnerships Validation Phase list of small-scale projects. Accessed November 15, 2019. https://netl.doe.gov/node/5900.

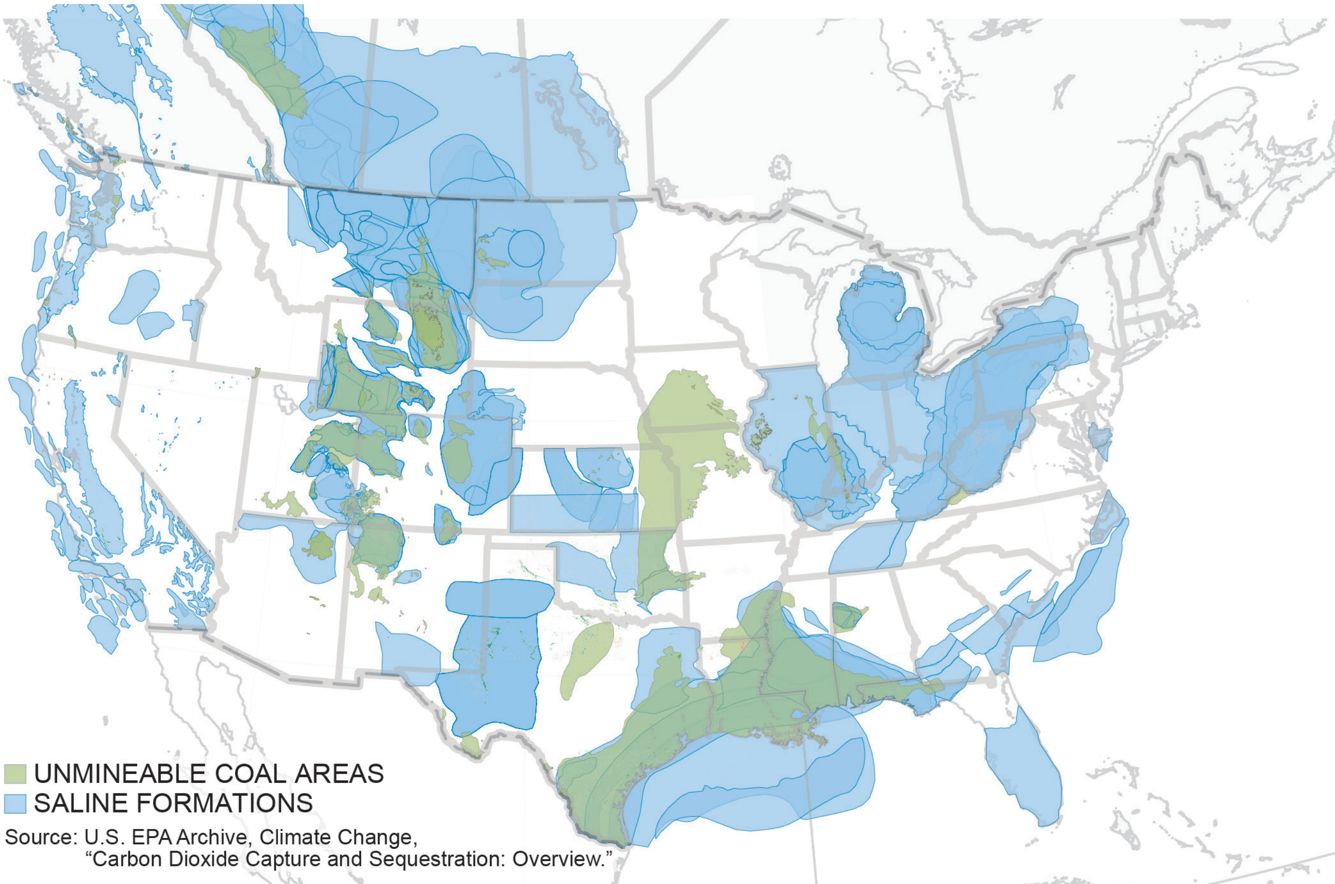


Figure ES-10. *U.S. Assessment of Geologic CO_2 Storage Potential*

Additionally, with more than 40 years of safe and effective operations, EOR offers an important CO_2 storage solution in the near term. The volume of anthropogenic CO_2 that is safely stored through EOR today, approximately 24 Mtpa, has the potential to materially increase in the next 5 to 7 years. EOR offers an important near-term CO_2 storage solution, though its potential to store CO_2 is relatively small when compared with the total U.S. onshore CO_2 storage resource. Studies also suggest that U.S. offshore storage resource may be as large as the onshore resource.

Expanding CCUS Deployment

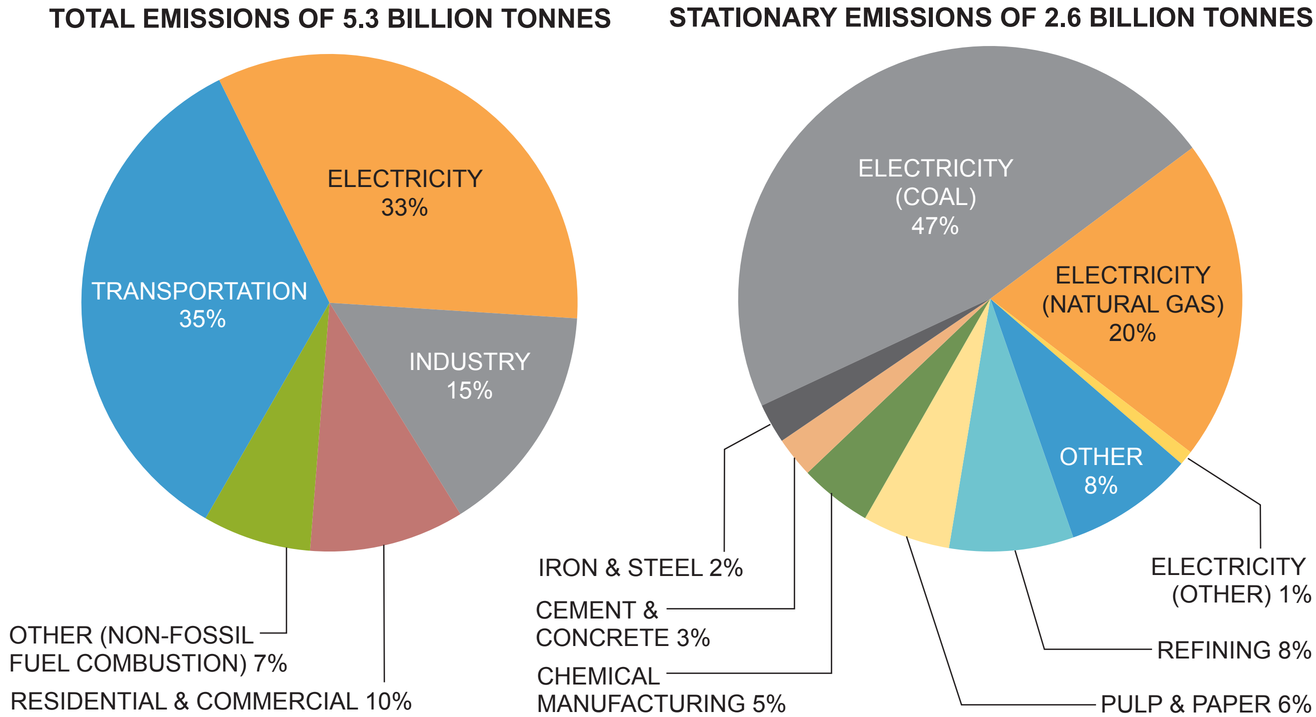
In 2017, U.S energy-related CO_2 emissions totaled approximately 5.3 billion tonnes. The left side of Figure ES-11 depicts the distribution of total U.S. CO_2 emissions by sector.

Stationary emission sources from industrial and power generation facilities represent nearly 50% of total U.S. CO_2 emissions. The United States has more than 6,500 large stationary sources emitting approximately 2.6 billion tonnes of CO_2 per year across a range of industries. The right side of Figure ES-11 breaks down U.S. stationary emissions by industry type.

Electricity generation accounts for more than two-thirds of stationary source CO_2 emissions. Process emissions associated with various industries contribute to most of the balance, led by refining and followed by pulp and paper, chemical manufacturing, cement, and iron and steel manufacturing. These stationary sources are prime candidates for CCUS deployment. As shown in Figure ES-12, while these sources are distributed across the country, many are located near geologic formations suitable for CO_2 storage.

Assessing the Cost of CCUS

As part of this study, the costs associated with the capture, transport, and storage of CO_2



Source: U.S. EPA, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2017.*

Figure ES-11. *2017 U.S. Energy-Related CO_2 Emissions by Sector (left) and Stationary CO_2 Emissions by Industry Type (right)*

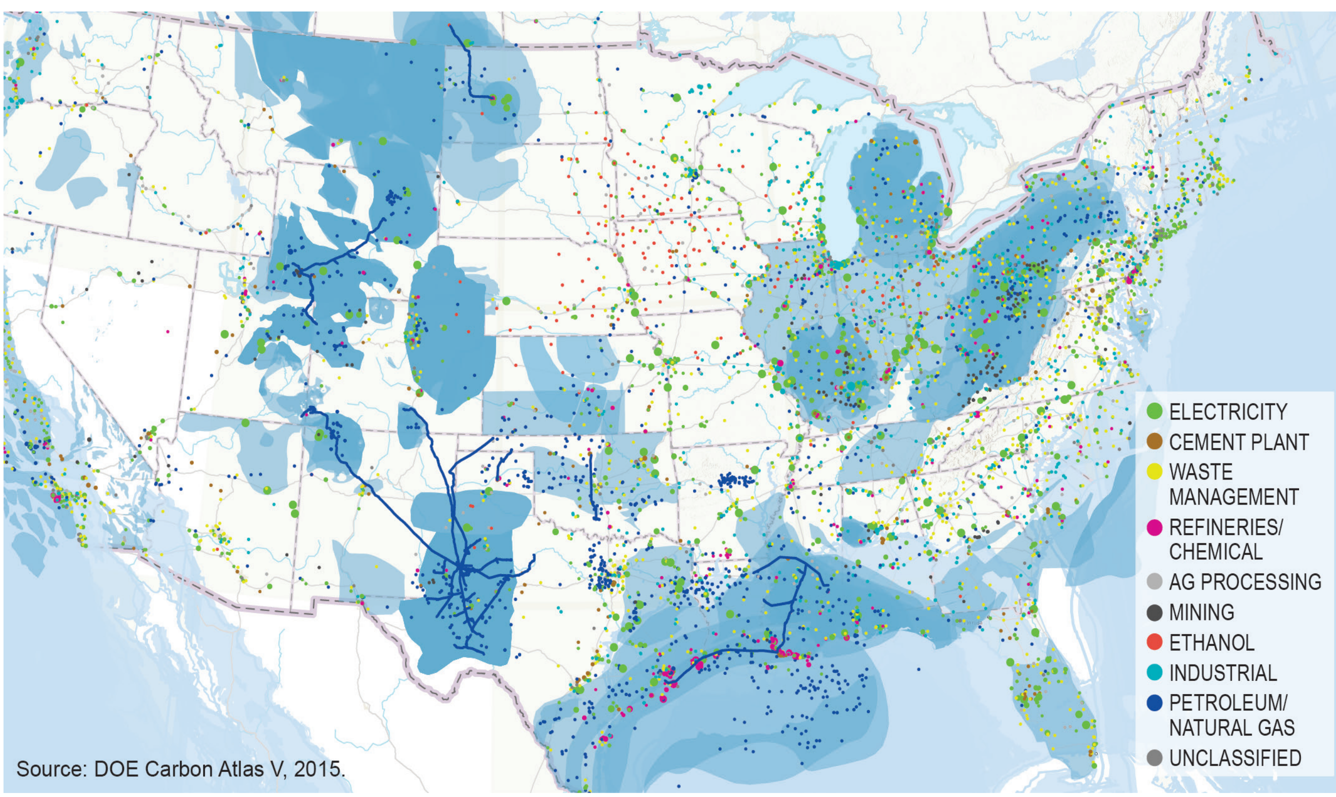


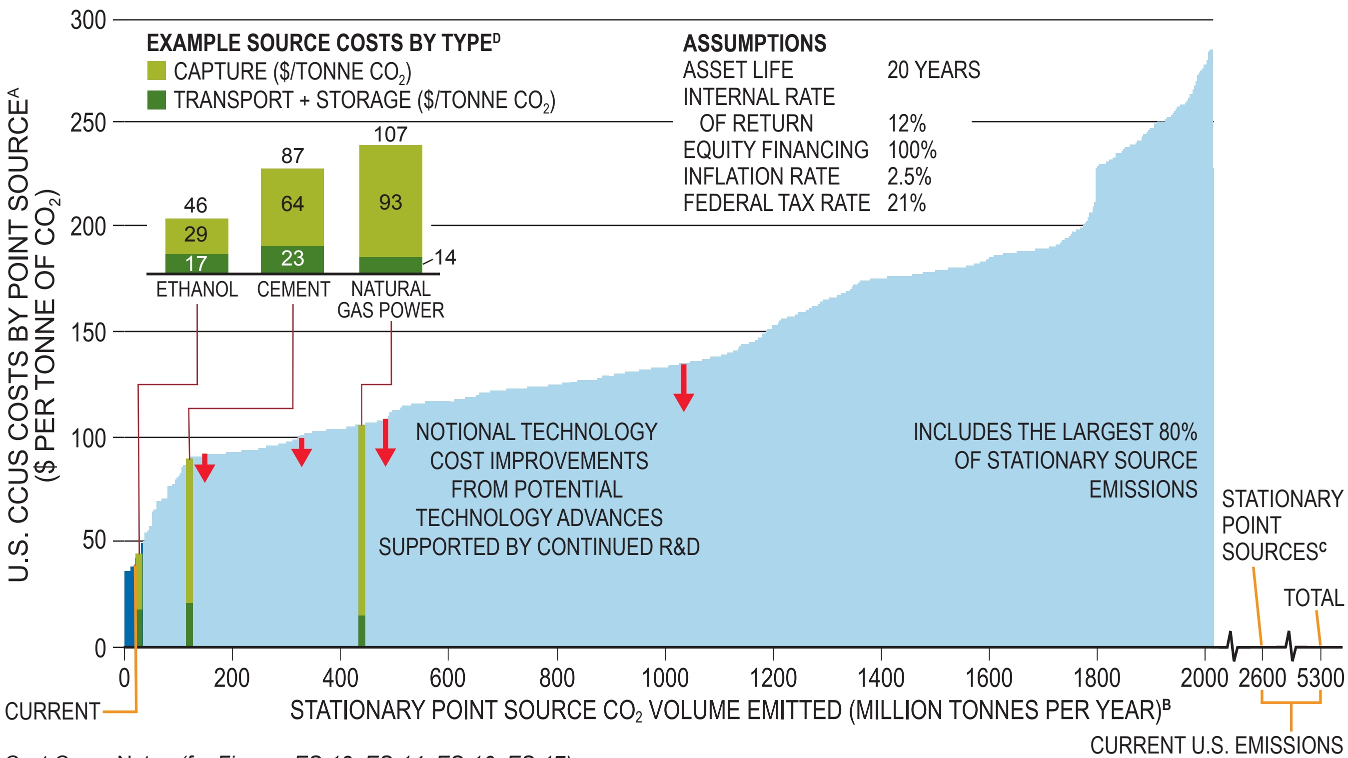
Figure ES-12. *U.S. Stationary Sources of CO_2 Emissions (by Type and Sized by Volume), Saline Formations, and Existing CO_2 Pipelines* emissions from the largest 80% of U.S. stationary sources have been assessed. These results are presented as a CCUS cost curve in Figure ES-13, where the cost to capture, transport, and store one tonne of CO_2 is plotted against the volume of CO_2 abatement it could provide.[25] This curve generally reflects the highest CO_2 concentration sources with the lowest capture costs to the left of the graph, and the sources with the lowest concentration and highest cost of capture sources to the right. Three example sources are shown on the graph to represent an illustrative view of the combined capture, transport, and storage costs for those point sources.

In the cost curve, the red down arrows illustrate the notional cost improvements of 10% to 30% resulting from potential technology advances supported by continued research and development.[26] The CCUS Supply Chains and Economics chapter provides a more detailed explanation of the cost curve, and the basis of the costs, methodology, and assumptions used (Volume II, Chapter 2).

To achieve CCUS deployment at scale, the U.S. government will need to reduce the uncertainty on existing incentives, establish adequate additional incentives, and design a durable regulatory and legal environment that drives industry

25 The costs presented in this study are based upon a variety of project types across a broad spectrum of industries in the United States. Using "reference cases" and standard economic assumptions was essential to developing the cost curve, formulating study recommendations, and assessing the potential impact of those recommendations on CCUS deployment at a national level. Costs at an individual project level will vary based on the economic assumptions specific to each project. Chapter 2, Volume II, explains the basis of the costs, methodology, and assumptions used to generate the study's cost curve for at-scale deployment of CCUS across a wide range of stationary source CO_2 emissions in the United States. It also briefly addresses why the approach taken in this study differs from other studies.

26 IEAGHG (2019). Further Assessment of Emerging CO_2 Capture Technologies for the Power Sector and their Potential to Reduce Costs, pp. 278.



Cost Curve Notes *(for Figures ES-13, ES-14, ES-16, ES-17)*:

A. Includes project capture costs, transportation costs to defined use or storage location, and use/storage costs; does not include direct air capture.

B. This curve is built from bars each of which represents an individual point source with a width corresponding to the total CO_2 emitted from that individual source.

C. Total point sources include ~600 Mtpa of point sources emissions without characterized CCUS costs.

D. Bar width is illustrative and not indicative of the volumes associated with each source.

Figure ES-13. *U.S. CCUS Cost Curve Showing Capture, Transport, and Storage Costs for the Largest 80% of U.S. 2018 CO_2 Stationary Source Emissions* investment in CCUS. The next four findings describe the opportunity and actions needed to deploy CCUS in the United States.

Findings 5, 6, and 7 lay out a pathway through three phases of deployment—activation, expansion, and at scale—that can enable the growth of CCUS in the United States over the next 25 years and detail the actions needed in each phase. The phases have been prioritized based on deployment economics and ease of implementation but recognizing that all three phases need to begin immediately. In addition, the potential economic impacts of the investment associated with the three phases of development were evaluated. That economic impact analysis shows that these investments will have a direct impact on jobs, GDP, income, and tax revenues in addition to "multiplier effects" (see Appendix D in Volume II for additional details).

Finding 8 describes the continued commitment to RD&D needed by both government and industry to drive down the cost of capture technology and identify suitable large-scale storage locations. RD&D plays a critical role in improving performance, reducing costs, and driving innovation.

Finding 5

Clarifying existing tax policy and regulations could activate an additional 25 to 40 Mtpa of CCUS, doubling existing U.S. capacity within the next 5 to 7 years.

The United States currently has approximately 25 Mtpa of CCUS capacity. Clarification of existing tax policy and regulations could double existing CCUS capacity deployment within the next 5 to 7 years. This activation phase of deployment could be achieved without congressional action. Figure ES-14 shows the notional CCUS projects that could be deployed as a result.

This additional capacity is likely to be deployed where large, high-concentration CO_2 sources

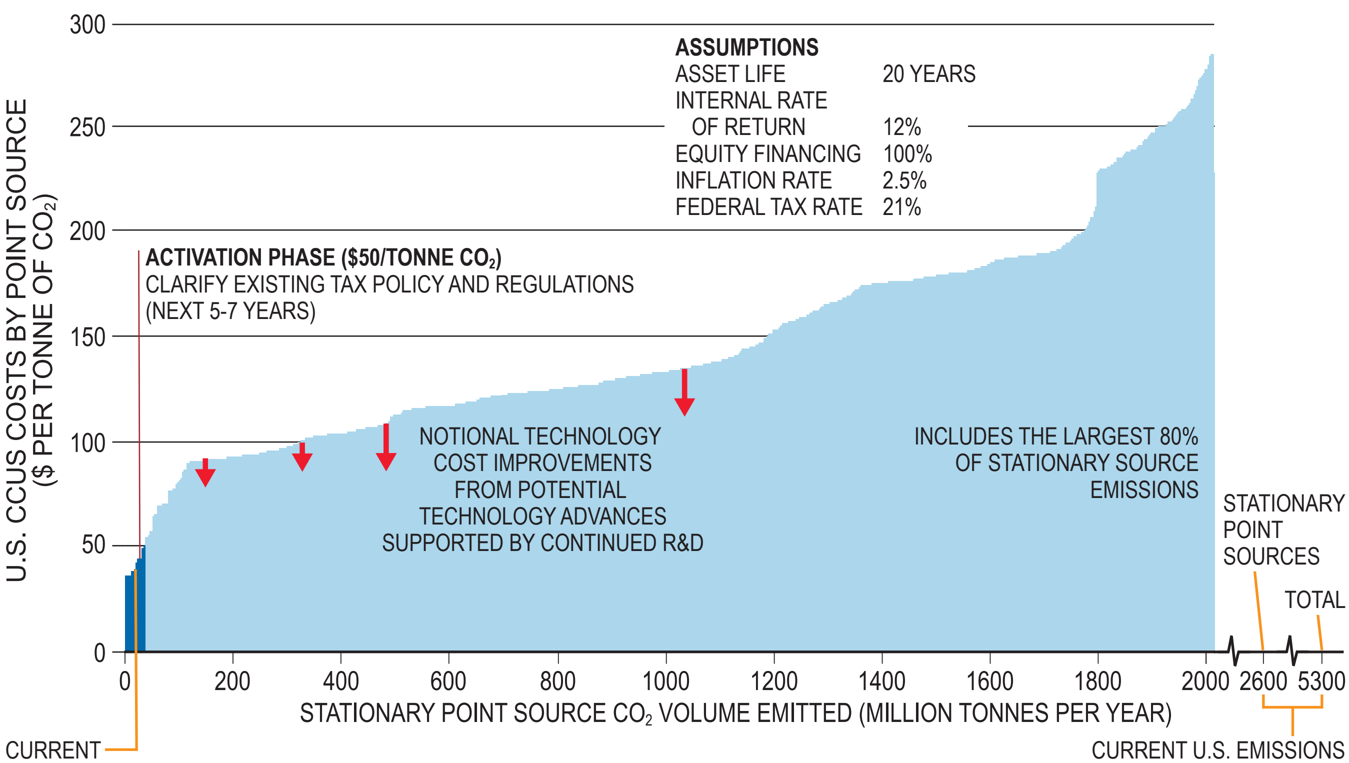


__Figure ES-14.__ CCUS Cost Curve Highlighting Activation Phase Deployment Volume

	MINIMUM SIZE OF ELIGIBLE CARBON CAPTURE PLANT BY TYPE (KILOTONNES OF CO_2/YR)			RELEVANT LEVEL OF TAX CREDIT IN A GIVEN OPERATIONAL YEAR ($/$TCO_2$)									
TYPE OF CO_2 STORAGE/ USE	POWER PLANT	OTHER INDUSTRIAL FACILITY	DIRECT AIR CAPTURE	2018	2019	2020	2021	2022	2023	2024	2025	2026	BEYOND 2026
DEDICATED GEOLOGICAL STORAGE	500	100	100	28	31	34	36	39	42	45	47	50	INDEXED TO INFLATION
STORAGE VIA EOR	500	100	100	17	19	22	24	26	28	31	33	35	
OTHER UTILIZATION PROCESSES[1]	25	25	25	17[2]	19	22	24	26	28	31	33	35	

[1] Each CO_2 source cannot be greater than 500 kilotonnes of CO_2 ($KTCO_2$) per year.

[2] Any credit will only apply to the portion of the converted CO_2 that can be shown to reduce overall emissions.

Source: Energy Futures Initiative, 2018.

Figure ES-15. *Section 45Q Tax Credit Value for Different Sources and Uses of CO_2*

are in reasonable proximity to suitable storage locations or existing CO_2 pipelines. Large, high-concentration CO_2 emissions—representing approximately 4% of U.S. CO_2 emissions—such as those from ethanol, natural gas processing, and hydrogen production typically have the lowest CO_2 capture cost and generally only require dehydration and compression to produce CO_2 that is ready for transport.

Accessing Section 45Q Tax Credits

In 2008, the 110th U.S. Congress passed the Energy Improvement and Extension Act authorizing a tax credit for the capture and storage of 75 million tonnes of CO_2 (i.e., Section 45Q). To date, approximately 85% of those tax credits have been claimed. The Bipartisan Budget Act of 2018 amended the existing Section 45Q tax credits for CCUS projects.[27] These amendments significantly expanded the value, duration, and eligibility of these tax credits. Figure ES-15 shows the level of tax credits available under the amended 45Q. However, Internal Revenue Service (IRS) clarifications, through guidance or regulations, are needed to provide investors certainty in the near term.

Since its original enactment in 2008, and again in 2018, Section 45Q has included a requirement that the Department of the Treasury (Treasury), in consultation with the EPA, DOE, and Department of the Interior, issue regulations related to claiming these tax credits. The Treasury issued guidance in 2009 but has not yet issued regulations. The requirements necessary to access the 45Q tax credits have been unclear. For example, clarity is needed regarding options for demonstrating secure geologic storage for the CO_2 used in EOR and, as a result of the 2018 amendments, how credits can be transferred between parties, credit recapture provisions, and what constitutes "beginning construction." Resolving these requirements through new rules provided by the IRS will reduce uncertainty for investors, helping to enable the development of CCUS projects needed to begin moving toward at-scale deployment.

27 PL-115-123, February 9, 2018.

The NPC recommends that the IRS clarify the Section 45Q requirements for credit transferability, options for demonstrating secure geologic storage, the construction start date definition, and credit recapture provisions.

Access to Pore Space on Federal and State Lands

As noted previously, the United States has one of the largest known CO_2 geologic storage endowments in the world. However, access to this storage can be challenging due to the complexity of securing the rights to use the pore space from multiple property owners. In most of the United States, the land (surface) owner also owns the subsurface pore space in which CO_2 can be stored. For saline formation CO_2 storage projects, securing access rights to a large subsurface storage area might require agreement from hundreds if not thousands of landowners.

Federal and state lands can have a significant advantage over privately owned lands because large areas of land are owned by one party. Federal lands have long been used for commercial activities such as oil and natural gas production, mining, farming, logging, livestock grazing, and public recreation. Accordingly, government statutes and regulations have been developed to manage these activities. There are, however, no current government mechanisms to grant access and use to pore-space rights on federal or state lands. Formulating these regulations is critical to unlocking the CO_2 storage resource in the United States.

The NPC recommends that the U.S. Department of the Interior and individual states adopt regulations to authorize access to and use of pore space for geologic storage of CO_2 on federal and state lands.

Class VI Well Permitting

As proven by various CCUS demonstration projects, CO_2 storage in deep saline formations can result in safe, secure, and permanent storage of large volumes of CO_2. To protect underground sources of drinking water, the EPA has developed a Class VI well design and permitting processes related to the injection of CO_2 into saline formations. However, as of mid-2019, only two Class VI well permits had been issued by the EPA, with a typical permit application processing time of 6 years.

Permit application processing time has proved to be a significant obstacle for the development of CCUS projects, increasing both the time and financial resources needed to deploy them. Resolving these permitting challenges will be a key enabler to the development and construction of new CCUS projects within the time period required to take advantage of the current 45Q tax credits.

The Class VI rules, which were modeled after the Class I Hazardous Waste regulations, take a very precautionary and prescriptive approach and are more onerous than is warranted based on anticipated risk profiles from CO_2 storage. These rules should be revised based on the lessons learned to date and adopt a more risk- and performance-based approach.

The NPC recommends that the EPA issue a Class VI Permit to Drill within six months. The NPC also recommends that upon receipt of a Well Completion Report, the EPA review, make any necessary modifications, and issue a Permit to Inject within six months.

The NPC recommends that the EPA—in consultation with DOE and other state and industry stakeholders—undertake the planned periodic review of the Class VI well rules, guidance, and implementation so that they are aligned with a site-specific risk and performance-based approach.

Pipeline Development

Although the United States has more than 5,000 miles of CO_2 pipelines, activating this phase of CCUS deployment will require additional point-to-point CO_2 pipelines to connect first phase CO_2 sources, primarily from ethanol production, to nearby geologic formations or EOR. To enable this initial infrastructure development, government backed loans will be needed to help stimulate investment. Access to existing loan programs, such as the Rural Energy for America Program (REAP), through the Department of Agriculture will be required in the near term. REAP provides financial assistance, through government loan guarantees to agricultural producers and small businesses in rural America in support of renewable energy and energy efficiency projects.

Clarifying existing policies and regulations to resolve these tax policy and regulatory issues, and facilitating near-term point-to-point CO_2 pipeline development through existing programs, will likely enable the United States to double its current CCUS capacity and begin moving toward at-scale deployment.

Finding 6

Extending and expanding current policies, and developing a durable legal and regulatory framework, could enable the next phase of CCUS projects (an additional 75 to 85 Mtpa) within the next 15 years.

Accounting for existing U.S. CCUS capacity and the capacity enabled through the activation phase, the total U.S. capacity could reach approximately 60 Mtpa during the next 5 to 7 years. Extending and expanding current policies to achieve a combined level of ~$90/tonne and further development of a durable legal and regulatory framework could incentivize an additional 75 to 85 Mtpa of capacity, bringing the total U.S. capacity to approximately 150 Mtpa. This expansion phase of deployment could be achieved within the next 15 years.

The additional capacity is likely to be deployed where large high-concentration CO_2 sources can be connected to suitable storage locations or where lower-concentration CO_2 sources can take advantage of existing pipeline infrastructure that has been developed because of high-concentration source CCUS deployments to EOR areas.

To achieve this additional deployment, 45Q tax credits will need to be extended and expanded and they will need to be combined with increased access to other financial incentive mechanisms such as investment tax credits and the ability to access tax exempt debt. These financial incentives must be also underpinned by a durable legal and regulatory framework. These policy changes would likely require congressional action as well as rulemaking by U.S. federal agencies. The cost curve in Figure ES-16 highlights the amount of CCUS capacity that could be enabled in this phase.

Under the current 45Q tax credit, the deadline to begin construction by January 1, 2024, will limit near-term deployment of CCUS projects. In general, the time needed to identify, prove, plan, acquire access to, and permit a CCUS project is more than 3 years. The project development timeline might be longer if there are complex commercial arrangements between multiple parties, a need for tax equity, pore-space negotiations, and the structuring of insurance and liabilities. Unless a project was already in some stage of development when the Bipartisan Budget Act of 2018 passed, it will be challenging for CCUS project developers to accomplish the necessary tasks in time to qualify for the deadline.

Qualified projects are eligible to receive the credit for a 12-year period from the date the capture equipment is originally placed in service. In most cases, the total value of the tax credit during this period will be insufficient to incentivize investment. In addition, more than half of electricity-generation units and a quarter of industrial sources do not generate enough CO_2 each year to meet their respective minimum size requirements to be eligible for the 45Q tax credits. Furthermore, CCUS project opportunities, particularly storage and use projects, will remain limited because the value of the tax credit is often less than the costs for such projects.

The NPC recommends that Congress amend Section 45Q to extend the construction start date to 2030, extend the duration of credits to 20 years, lower the CO_2 volume threshold, and increase the value of the credit for storage and use

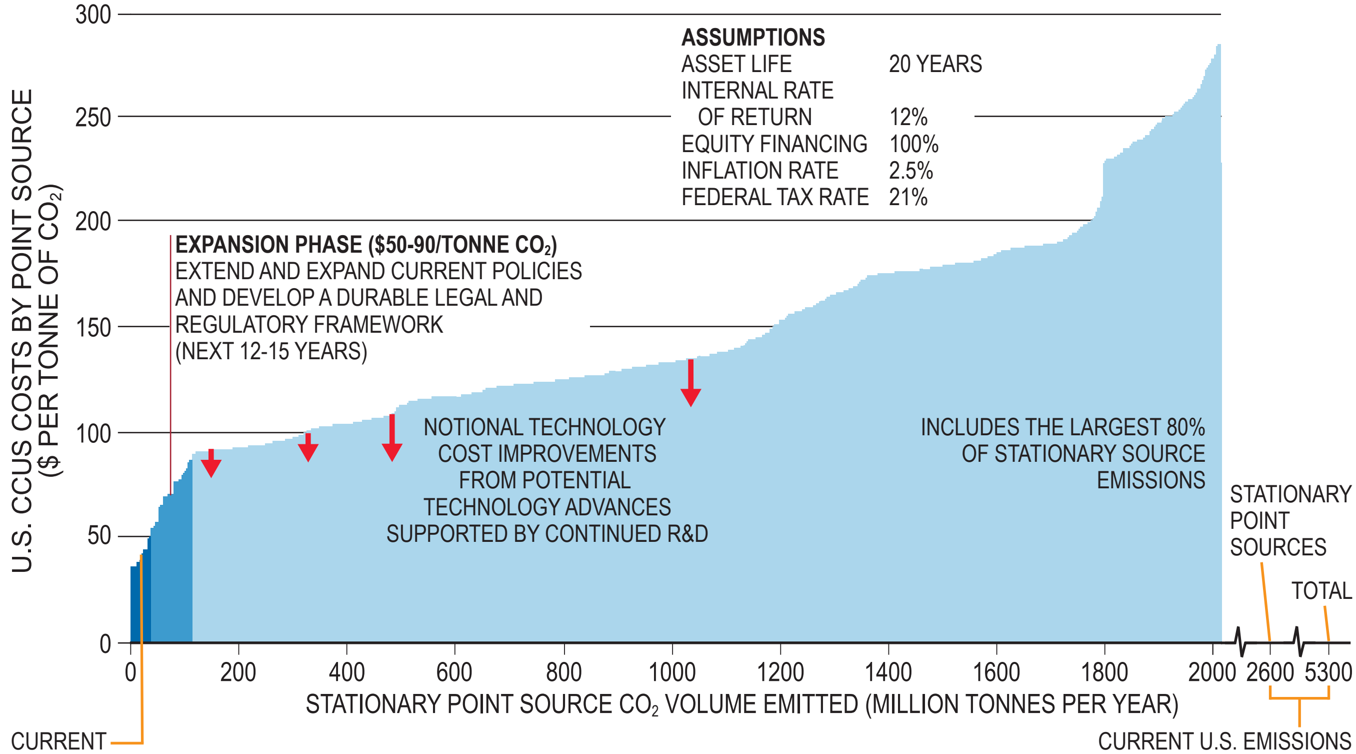


Figure ES-16. *CCUS Cost Curve Highlighting Expansion Phase Deployment Volume*

applications as appropriate based on economic conditions at the time of implementation.

Expand Existing Federal Incentives to CCUS

Section 48 of the tax code provides a 30% investment tax credit targeted at incentivizing CCUS on coal-fired power generation. Currently, these tax credits can only be accessed by CCUS projects on coal-fired power generation plants. Expanding access to Section 48 to all CCUS projects will likely incentivize multiple projects that remain uneconomic with the expanded policies described in Finding 5.

In addition to tax credits, other tax-related instruments and structures can provide incentives for CCUS deployment. For example, master limited partnerships (MLPs) and private activity bonds (PABs) can provide incremental incentives to CCUS projects. Historically, MLPs have been crucial to building infrastructure and pipeline networks by allowing a lower effective tax rate for investors. PABs can lower the cost of debt and provide incremental incentives for potential CCUS projects. Currently, CCUS projects do not have the ability to use MLP structures or issue PABs.

While the United States has the world's most extensive CO_2 pipeline network today, at-scale deployment of CCUS across the United States will require at least a ten-fold expansion of the existing CO_2 pipeline infrastructure safely operating today. Programs like the Transportation Infrastructure Finance and Innovation Act (TIFIA) provides credit assistance to major transportation investments of regional and national significance in the form of direct loans, loan guarantees, and standby lines of credit (rather than grants) to projects of national or regional significance.[28] Expanding access to programs like TIFIA will enable expansion of a CO_2 pipeline network.

28 United States Department of Transportation, "TIFIA Credit Program Overview." Accessed September 2019. https://www.transportation.gov/tifia/tifia-credit-program-overview.

The NPC recommends that Congress expand access to Section 48 tax credits, the use of master limited partnership structures, and the authority to issue private activity bonds for all CCUS projects. The NPC also recommends that Congress expand access to, and funding for, the TIFIA program to enable CO_2 pipelines to qualify.

The EPA's Underground Injection Control Program

Under the Safe Drinking Water Act, the EPA has regulatory jurisdiction over the injection of materials into the subsurface. For CO_2 injection, two well classes are most relevant: Class II wells pertain to oilfield operations, including the injection of CO_2 for EOR, and Class VI wells pertain to projects where the primary purpose is CO_2 storage. Class VI is a relatively new class of wells established in 2010 and to date, only two of these wells have received complete permitting and one has commenced injection.

Increased activity as a result of increased deployment of CCUS with respect to both Class II and Class VI wells will require additional funding. EPA funding for the Underground Injection Control (UIC) program has remained at the same level for 16 years while the level of compliance, reporting, and implementation expenses has continued to increase. By default, the EPA is the permitting authority under the UIC program, but states can apply for primacy to obtain state permitting authority. To date, Wyoming and North Dakota have applied for primacy for Class VI wells, and only North Dakota has been granted primacy, but it is expected that other states may soon pursue primacy.

The NPC recommends that Congress increase funding to the EPA and states by $20 million for UIC Class II and $50 million for Class VI to support the EPA and states with or seeking primacy to implement the anticipated increases in injection well permitting and timely reviews.

Access to CO_2 Geologic Storage in Federal Waters

One of the largest opportunities for saline formation storage in the United States can be found in federal waters, particularly in the Gulf of Mexico. The Outer Continental Shelf Lands Act (OCSLA) has been interpreted to prohibit storage in deep saline formations on the federal continental shelf for CO_2 emitted from refineries, natural gas power plants, or nonenergy industries (e.g., steel or cement). Only CO_2 captured from coal-fired power plants is permissible. Similarly, the Marine Protection, Research, and Sanctuaries Act (MPRSA) of 1972 is intended to prevent pollution of the seas by "waste generated by a manufacturing or processing plant." Under the existing statute, CO_2 would be considered a waste and is therefore prohibited from offshore storage. Federal waters represent a significant CO_2 storage resource. Accordingly, barriers to their use should be removed.

The NPC recommends that Congress amend the OCSLA and MPRSA to explicitly allow CO_2 storage in federal waters without respect to the origin of the CO_2. Further, the DOE, Bureau of Ocean Energy Management, and Bureau of Safety and Environmental Enforcement should establish processes to enable access to pore space in federal waters and regulate CO_2 storage in those waters.

Addressing Pipeline Regulatory Issues

Expanding deployment of CCUS will require significant expansion of CO_2 pipeline infrastructure to connect emissions sources to EOR or storage locations.

The interstate and intrastate pipeline permitting processes are complex, often involving multiple federal, state, and local agencies, as well as the public. In addition, several factors can affect the time frame for the permitting process of a given project, including different types of federal permits or authorizations, delays in the reviews needed by governmental stakeholders, and incomplete applications. Federal efforts are needed to streamline this process.

Further, an entity transporting CO_2 by pipeline is not currently considered to be a common carrier under the Interstate Commerce Act. Thus, there are no consistent regulations for CO_2 transportation rates and services, and there is no federal eminent domain authority for acquiring land for CO_2 pipelines.

The NPC recommends that DOE create a CO_2 pipeline working group made up of relevant federal and state regulatory agencies and interested stakeholders to study the best way to harmonize the federal, state, and local permitting processes; establish tariffs; grant access; administer eminent domain authority; and facilitate corridor planning. The working group should be established concurrently with the activation phase.

Addressing Long-Term Liability

During CO_2 injection operations—which may last from 10 years to more than 60 years—the operator generally holds and provides financial assurance for liabilities. These financial assurance mechanisms may cover responsibility for monitoring, mitigation, and remediation of any leaks; paying back incentives associated with CO_2 that ceases to be stored; risks of subsurface trespass, which entails migration to a storage area for which storage rights were not acquired; and potential litigation for personal or property damage.

When operations cease, the operator generally remains liable for legal violations until the statutes of limitations expire and regulatory requirements cease to apply. The operator maintains responsibility for overseeing a site for a specified amount of time. For example, under Class VI permitting for storage in saline formations, the default requirement for monitoring is 50 years, or at the discretion of the EPA administrator, but under California's Low-Carbon Fuel Standard CCS Protocol, the default requirement is 100 years. These potential long-term liabilities and responsibilities have a detrimental effect on project development. Some have advocated that long-term liabilities should be handed over to state or other governmental agencies. Others have advocated for only partial transfer of liability. Today, only a few states have defined a process to manage liability for CO_2 injection, including long-term liability. However, because no commercial storage operations in the United States have entered the post-injection site care phase, long-term liability transfers have yet to be tested, so questions remain regarding the evolution of the current legal standards for post-injection site closure and liability management.

The NPC recommends that DOE convene an industry and stakeholder forum to develop a risk-based standard to address long-term liability. The forum should be established concurrently with the activation phase.

Defining Pore-Space Ownership

Prior to injection, the operators seeking to undertake storage operations must either own the pore space, have permission from the owner, or have statutory or common law right to use the pore space that avoids potential liability or exposure to trespass and nuisance claims. In the United States, the law concerning private property rights is a basic responsibility of the state rather than the federal government. In most states, the surface estate owns the pore space unless the pore-space rights have been conveyed away.

This ownership is subject to a right of the mineral estate to make reasonable use of the surface estate as necessary to produce minerals from the tract. The right of use would include the right to inject substances, such as CO_2, for EOR. The fact that CO_2 injection might also result in the long-term storage of CO_2 should not alter the right of the mineral estate owner to engage in CO_2 injection for EOR.

However, with respect to CO_2 storage in formations that do not include the mineral estate, the right to inject CO_2 solely for storage would most likely be held by the surface owner. Three states—North Dakota, Wyoming, and Montana—have enacted legislation clarifying ownership of pore space for CO_2 storage. These three states clarified that the subsurface pore space belongs, at least presumptively, to the surface owner.

Although state law generally supports surface owner title, the question of whether the surface estate or mineral estate owns the private property interest in the pore space for geologic storage of CO_2 is not clearly settled. In this phase of deployment, commercial viability of CCUS may depend upon whether and how property rights issues are resolved.

The NPC recommends that state policymakers enact legislation enabling access to storage resources on private lands, including pore-space ownership, setting a threshold and process for forced unitization, and fair compensation.

Finding 7

Achieving CCUS deployment at scale, an additional 350 to 400 Mtpa, in the next 25 years will require substantially increased support driven by national policies.

Incentivizing at-scale CCUS deployment will require even greater extension and expansion of U.S. government policies than what has been described in Findings 5 and 6. As shown in the cost curve in Figure ES-17, if these new policies provide a financial CO_2 incentive of $110/tonne,[29] an additional 350 to 400 Mtpa of capacity could be deployed within the next 25 years, bringing U.S. capacity to approximately 500 Mtpa. With this level of support, CCUS could be deployed on nearly 20% of U.S. stationary emissions, a level this study defines as at-scale deployment.

The additional CO_2 capture capacity would be deployed in industries, such as power generation, refining and chemicals manufacturing, and cement and steel. These industries typically have low concentrations of CO_2 emissions (less than 20%), but these represent more than half of all U.S. emissions sources.

Substantial congressional policy action, backed by industry investment and public support, will be required to achieve this level of CCUS deployment. Considering the significant allocation of

29 $110/tonne is based on this study's assessment of Nth of a kind capture technology cost.

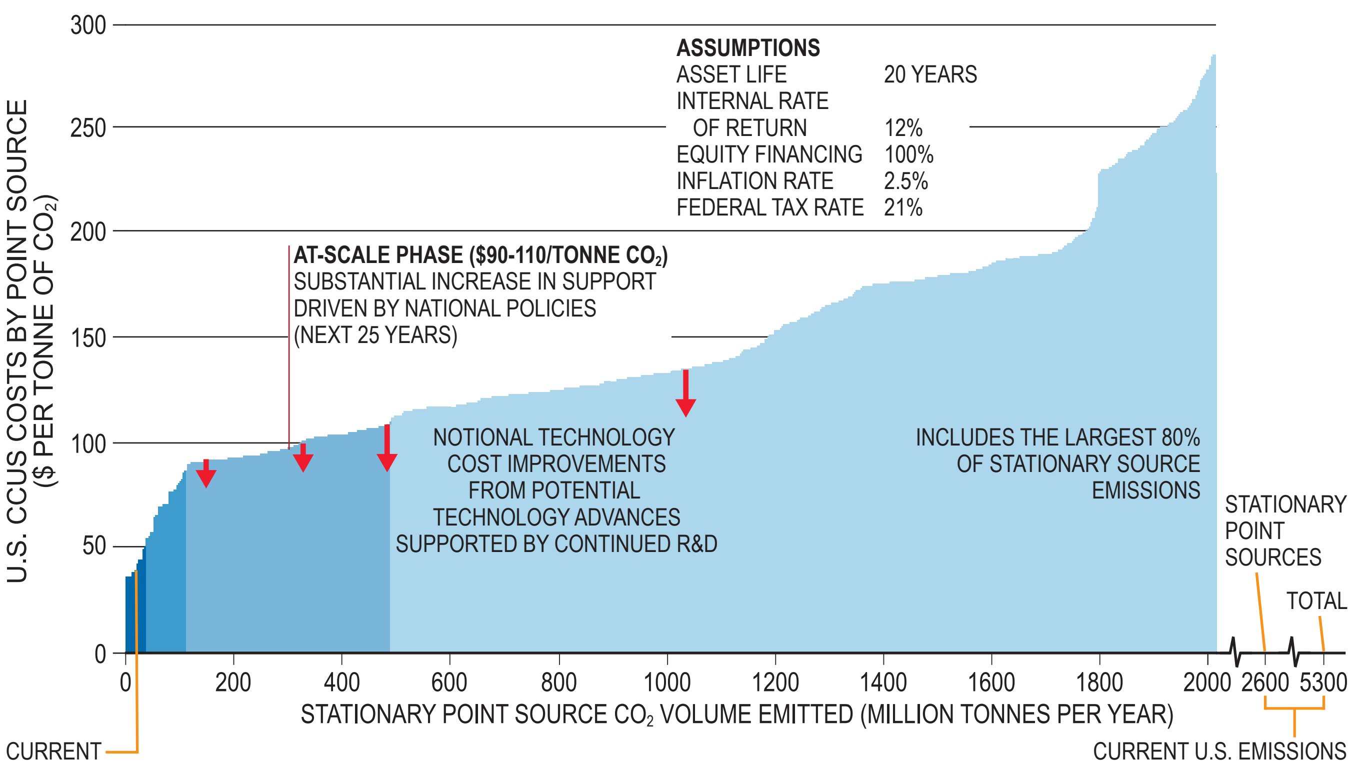


***Figure ES-17.** CCUS Cost Curve Highlighting At-Scale Phase Deployment Volume* resources that will be needed to deploy CCUS at scale, the policy to incentivize these projects should be as economically efficient as possible. Accordingly, policy options that include standards and mandates, financial incentives, and market-based policies should be thoroughly evaluated.

Standards and Mandates

The U.S. government and many states have mandated the use of certain products and technologies to reduce emissions. They have also established a performance standard that certain technologies must achieve. For example, the federal Renewable Fuel Standard requires that specified volumes of biofuels be blended into U.S. transportation fuels.

At the state level, a range of policies have been put in place to drive emissions reductions. One of the most common state policies is a renewable portfolio standard (RPS) that requires certain amounts of electric capacity to come from renewable sources or alternative energy sources. Twenty-nine U.S. states, Washington, D.C., and three territories have adopted an RPS, while eight states and one territory have set renewable energy goals. RPS mandates have created strong demand for renewable power. It is estimated that 58% of all renewable capacity in the United States installed from 1998 to 2014 is being used to meet RPS targets (excluding hydropower). Currently, electric power associated with CCUS technology is not eligible under RPS policies.

Fundamentally, a standards and mandates approach will likely be the most difficult to implement in a manner that yields the most emissions reduction for the least cost. This is because in a complex system, it is difficult for the standard-setter to be able to identify and specify the precise economic optimum and to continually update the standards as technology develops, market conditions change, or to adjust for other factors in the economy.

Financial Incentives

There are three types of policy driven financial incentives available to CCUS projects—investment incentives, production or operations incentives, and financing support. By increasing the value of the existing incentives, a broader range of CCUS projects becomes economic, making them more attractive to investment. For many projects, it will be necessary to combine available incentives to make a project viable. The amount of incentive and level of support needed will vary based on each company's ability to finance and take advantage of certain tax credits, gain access to pipelines, generate revenue from the sale of CO_2, and other factors. Ultimately, that combined level of incentives needs to reach approximately \$110/tonne to achieve at-scale deployment of CCUS.

The renewable energy industry provides an example of how policy can incentivize at-scale deployment of technology. Between 2005 and 2015, the federal government provided \$51.2 billion in financial incentives in support of solar and wind power development, 90% of which came from tax incentives. Those financial incentives, combined with a range of renewable energy standards and other supportive policy at the federal and state level, helped establish the renewable energy industry. Today, more than 5% of U.S. electricity is supplied by wind and solar energy.

However, financial incentives have limitations similar to those described in the standards and mandates framework, in that they put the government in the position of choosing which technologies to incentivize (i.e., picking winners and losers). One risk to investors relying solely on financial incentives to drive CCUS deployment is the uncertainty regarding the life of the incentive. As governments and societal expectations change, policy priorities and programs will change. Uncertainty is a key issue for project developers and investors.

Market-Based Policies

For more than a decade, there has been considerable discussion in the United States regarding a national price on CO_2 emissions to incentivize deployment of lower emissions technologies. Putting a price on CO_2 emissions is generally referred to as a price on carbon. There are two main types of carbon pricing: carbon taxes and emissions trading systems (e.g., cap and trade).

A carbon tax assigns a fixed price per tonne of CO_2 emissions while an emissions trading system assigns a fixed volume of CO_2 emissions. In the United States, several states and regions have cap-and-trade programs in place, including California, Massachusetts, and 10 Northeast and Mid-Atlantic states participating in the Regional Greenhouse Gas Initiative.

Both cap-and-trade and tax programs attempt to overcome the difficulty of identifying and specifying the economic optimum by employing market mechanisms, which in theory combine the knowledge of many participants and evolve over time. Both systems function by establishing a cost for emitting. A tax program has a theoretical advantage over cap and trade for reducing GHG emissions because a tax should produce a more predictable price, has broader application, and provides a stable planning basis for the large capital investments necessary to make a significant reduction in GHG emissions over many decades. Conversely, a cap-and-trade system subjects the participants to more price volatility and is less transparent to the public. Under either approach, studies suggest that the most effective system would impose a gradually increasing real carbon cost over time.

Recognizing that, in the near term, incentives will likely be a more effective way to drive deployment. In the long term, a market-based approach is likely a much more economically efficient way of reducing CO_2 emissions than standards and mandates or financial incentives. Various articles have been written detailing the benefits and drawbacks of incentive-driven programs versus market-based approaches. Most economists agree that a market-based approach is a more effective approach for reducing emissions and more efficient for the overall economy.

The NPC recommends that to achieve at-scale deployment of CCUS, congressional action be taken to implement economic policies amounting to about $110 per tonne. The evaluation of these policies should occur concurrently with the expansion phase.

Finding 8

Increased government and private research, development, and demonstration is needed to improve performance, reduce costs, and advance alternatives beyond currently deployed technology.

The United States has made significant strides in the development of CCUS technologies over the last two decades, aided by government investment in R&D along with public-private partnerships. Between 2012 and 2018, Congress provided more than $4 billion in appropriations for CCUS R&D through DOE. The American Recovery and Reinvestment Act of 2009 provided an additional $3.4 billion in funding, primarily for large-scale demonstration projects.[30] Over the last several years, a number of energy and technology companies have made substantial investments into CCUS technologies with a goal of reducing technology costs and operational complexity.

To achieve more substantive cost reductions and improve performance for CCUS deployment, continued investment in the R&D of emerging technologies and demonstration of developed technologies—collectively referred to as RD&D—is necessary and should increase.

Figure ES-18 describes the range of technology readiness levels (TRL) for many of the component technologies described in this study, using the U.S. Department of Energy's TRL definitions.[31] Each technology is assigned a technology readiness level range that represents its stage of technical development and maturity (vertical axis). The TRL scale ranges from 1 (basic principle observed) through 9 (operational at scale). The higher the TRL level (i.e., >7), the closer a technology is to commercial readiness and deployment.

For more mature technologies, only incremental cost and performance gains are anticipated.

30 Folger, P. (2018). FY2019 Funding for CCS and Other DOE Fossil Energy R&D, Congressional Research Service, July 2, 2018, 2 pp. Accessed October 20, 2019. https://fas.org/sgp/crs/misc/IF10589.pdf.

31 U.S. Department of Energy, DOE G 413.3-4A Chg 1 (Admin Chg), Technology Readiness Assessment Guide, last update 22 Oct 2015 (reference: https://www.directives.doe.gov/directives-documents/400-series/0413.3-EGuide-04-admchg1).

Less mature and emerging technologies (TRL 6 and below) offer the greatest potential for a step change in performance and cost reductions. A significant level of R&D funding should be directed to these and other new technologies that may emerge. RD&D funding for more mature technologies should be limited primarily to large-scale demonstration pilot programs that enable learning by doing.

Supporting CO_2 Capture RD&D Beyond Coal-Based Power Generation Sources

Much of the capture RD&D to date has focused on CO_2 capture from coal power plants. However, the dynamics of the power generation sector are changing, driven by the availability of low-cost natural gas and the increased use of renewables that require backup power that is easy to deploy, making natural gas an ideal choice. As such, CCUS on natural gas combined-cycle power plants and industrial sources will be a growing application of CCUS going forward.

Funding CO_2 Storage Resource RD&D

Further support for CO_2 storage characterization and monitoring, especially for saline formations, will also expedite deployment and reduce costs. In 2003, DOE established the Regional Carbon Sequestration Partnerships to promote better insight into storage resources across the United States. These public-private coalitions of researchers performed early screening of regional opportunities, which led to significant CCUS capability development, local opportunity refinement, community engagement, and the injection of more than 11 million tonnes of CO_2. This was followed by the CarbonSAFE program in 2016, which provides financial assistance to teams to perform

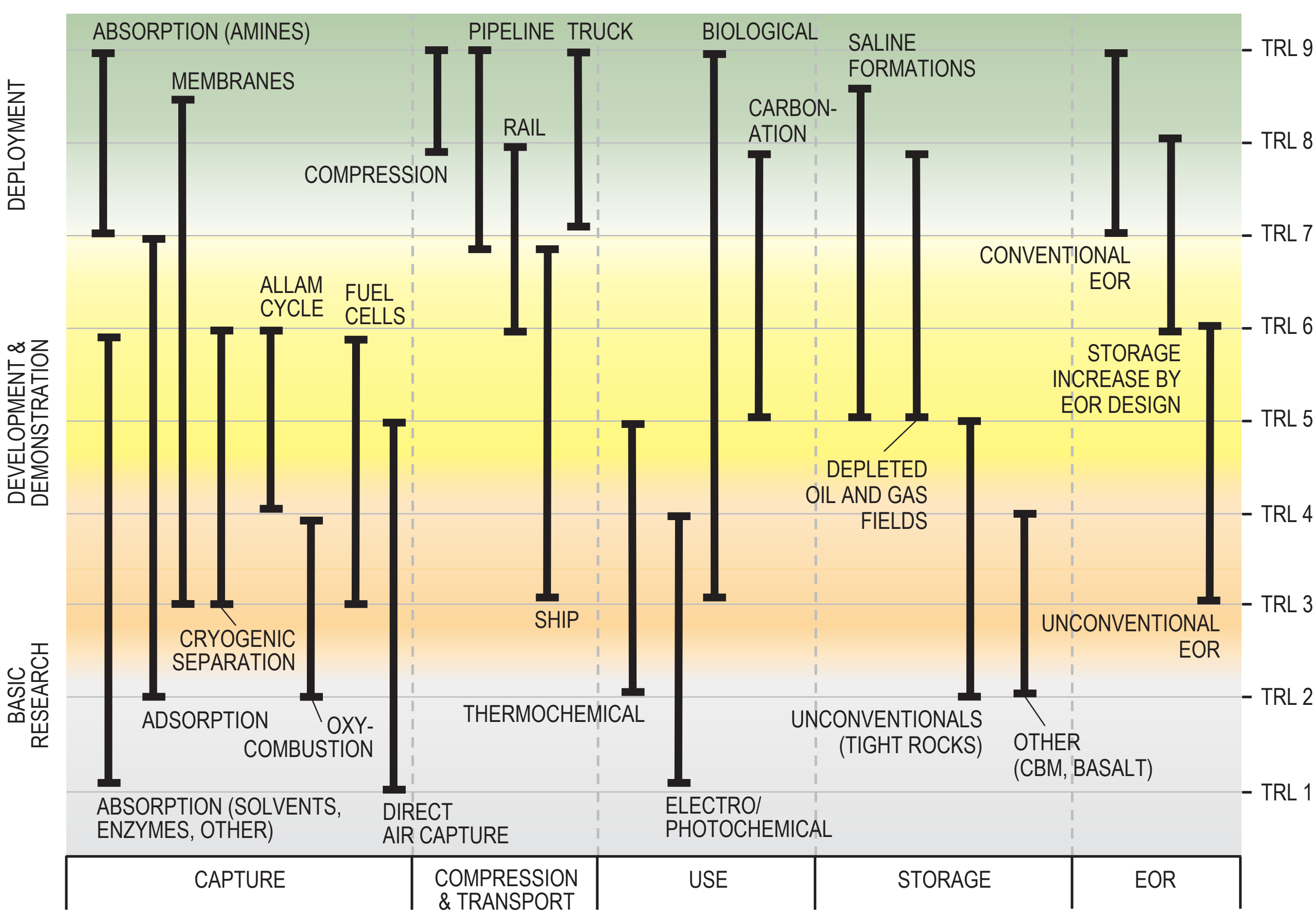


Figure ES-18. *Technology Readiness Level (TRL) Ranges for CCUS Technologies* the geological, geophysical, and geochemical assessments that are necessary to reduce the cost and risk of project implementation.[32]

Kick-starting CCUS projects through early engagement and characterization is intended to help lower or eliminate project risks and demonstrate the technical and commercial feasibility of CCUS, thus accelerating at-scale deployment. Sustaining and increasing support of CarbonSAFE, Regional Partnership Initiatives, and other storage-oriented efforts is vital to facilitating rapid deployment. Increasing support for development and refinement of monitoring techniques will also further reduce implementation costs.

Advancing CO_2 Use Technology RD&D

CO_2 use technologies represent an important future opportunity to permanently store CO_2 emissions in the form of value-added products and potentially provide more sustainable alternatives for carbon-intensive products. Although the use of CO_2 does not presently account for a significant level of GHG reduction, CO_2 use pathways may offer viable future options in geographies where access to transportation or storage is limited. Also, CO_2 use technologies may help with hard-to-decarbonize applications where conventional post-combustion capture and storage is not feasible. A wide range of potential CO_2 use technology pathways have been identified and are being actively researched, but most are at a low TRL level and will need committed RD&D to progress. Advancing the development of these technologies via RD&D funding support will help to better quantify those areas with the greatest potential.

Supporting Negative Emission Technology RD&D

Advancing the development of negative emissions technologies, which remove existing CO_2 from the atmosphere, will be needed to achieve more aggressive CO_2 emissions goals. This can be accomplished by coupling the absorption of CO_2 by plant matter with CCUS to use the plant matter for energy, which would result in a net negative CO_2 footprint. An example of this process is applying carbon capture to a power plant that has been converted to run on agricultural products or wood pellets, for which there are already successful demonstrations. CCUS on biofuel power sources, termed bioenergy with CCS, could offer an area of major impact by mid-century. Direct air capture is another negative emissions technology that removes CO_2 from the air. The lower concentration of atmospheric CO_2, compared to process streams, presently results in higher capture costs. Due to the unique potential of these technologies to remove atmospheric levels of CO_2, RD&D in these areas should be actively supported.

Sharing RD&D Information

When researchers and technology providers work together to share information on their research designs, processes, and outcomes, while maintaining intellectual property protections, all parties benefit, and RD&D is more effective. Two means of accomplishing this are furthering public-private partnerships that integrate government, academia, and industry, and embracing the concept of open-source technology development. These options to maximize RD&D investment efficiency should be explored.

The NPC recommends that Congress appropriate the level of RD&D funding detailed in Table ES-1 over the next 10 years to enable the continued development of new and emerging CCUS technologies and demonstration of existing CCUS technologies.

The NPC further recommends that Congress amend existing appropriations language to allow for all CO_2 sources and fuel types in the allocation of RD&D funding for CCUS.

The NPC further recommends that the oil and natural gas industry continue to fund private research and development at or above current levels in support of new and emerging CCUS technologies.

32 National Energy Technology Lab. (2016). CarbonSAFE Program, Accessed September 2019. https://www.netl.doe.gov/coal/carbon-storage/storage-infrastructure/carbonsafe.

The NPC recommends that DOE promote public-private partnerships and consider open-source approaches to the development of CCUS technologies as appropriate.

Finding 9

Increasing understanding and confidence in CCUS as a safe and reliable technology is essential for public and policy stakeholder support.

Without public commitment and support of CCUS as a critical component of the United States' energy future, deployment will remain limited. CCUS stakeholder engagement alone cannot ensure successful delivery of projects, but when done well, it can be a significant enabler. Poor engagement can, and has, prevented CCUS projects from moving forward.

Key attributes of a robust stakeholder engagement plan require consideration of the context, including the sociopolitical landscape and alignment with objectives and policy, the full range of stakeholders, likely common ground, and points of opposition. The engagement strategy should be tailored to the audience and delivered by people with leadership or ownership of the project, policy, or initiative. The engagement team must be prepared to respond to opposition. Engagement must be respectful, authentic, adaptive, and must allow for stakeholder input to shape the project parameters to reconcile objectives and stakeholders' needs and concerns. These elements are key to building trust and lasting stakeholder relationships.

Public engagement on CCUS projects has a long-established precedent in the United States, in part because of the development of DOE's Regional Carbon Sequestration Partnerships, which demonstrated and refined successful public outreach and consultation programs. Drawing from the experiences of engagement practices throughout the CCUS value chain, comparative studies of projects in the United States, Australia, and Europe have shown that public engagement can significantly help successful implementation of projects.[33] It is also important to engage stakeholders as early as possible in the process.

Implementing the policy enablers discussed earlier will require support from a broad range of stakeholders, including policymakers, nongovernmental organizations (NGOs) and environmental NGOs (e-NGOs), and various industry

33 Ashworth P., Bradbury J., Wade S., Ynke Feenstra C.F.J., Greenberg S., Hund G., and Mikunda T. (2012). What's in store: Lessons from implementing CCS. *International Journal of Greenhouse Gas Control.* 9, 402-409.

Technology	R&D (including pilot programs)	Demonstrations	Total	10-Year Total
Capture (including negative emissions technologies)	$500 million/year	$500 million/year	$1.0 billion/year (over 10 years)	$10 billion
Geologic Storage	$400 million/year		$400 million/year (over 10 years)	$4 billion
Nonconventional Storage (including EOR)	$50 million/year		$50 million/year (over 10 years)	$500 million
Use	$50million/year		$50 million/year (over 10 years)	$500 million
Total	$1.0 billion/year	$500 million/year	$1.5 billion/year	$15 billion

Table ES-1. *10-Year RD&D Funding Levels Recommended by NPC Study on CCUS* groups. Federal, state, and local policymakers need to understand the role that CCUS can play as a cost-effective solution to CO_2 emissions reduction in both the near and longer term. Coalitions, such as the Carbon Capture Coalition, Energy Advance Center, and the Carbon Utilization Research Council, and independent organizations such as the Electric Power Research Institute, work closely with industry, policymakers, NGOs, and e-NGOs to educate, inform, and support policies that can drive CCUS deployment.

At present, general awareness of CCUS among the public is low, primarily because a limited cross-section of stakeholders has direct interaction with CCUS. As a result, the role CCUS can play in effectively addressing key issues, such as climate change, energy security, and economic growth, is not well understood. Similarly, knowledge and opinions about CCUS vary widely. Among those who have some knowledge of CCUS, it is often associated with coal and, to a lesser degree, oil and natural gas. Gaining public support for CCUS will require significant education about its essential role and demonstration of safe, environmentally sound operations.

It is also critical to simplify the CCUS concept and more closely relate the objective through, for example, simplifying the term to "carbon capture" or "carbon management." By creating an easily identifiable concept, technical detail can be included or excluded as needed for specific stakeholders while enabling the simple overall objective to be understood, explained, and embraced.

The NPC recommends that government, industry, and associated coalitions design policy and public engagement opportunities to facilitate open discussion, simplify terminology, and build confidence that CCUS is a safe and secure means of managing emissions.

The application of these skills and the financial support needed for at-scale CCUS deployment is vital for the United States to compete in the evolving global energy market. At-scale deployment of CCUS will help the U.S. energy industry shape the energy transition by continuing to supply the growing world population with more energy in the decades to come, while reducing emissions to limit the risks of climate change.

Industry has engaged in several collaborative actions to address the public concern related to climate change and GHG emissions. Some companies have taken steps to minimize GHG emissions, including reducing emissions within operations, funding and leading research to reduce emissions, and improving transparency of their actions and reporting. The oil and natural gas industry can continue to build confidence by working directly and through trade organizations to educate legislators and regulators, project developers, and the general public about its continuing commitment to improved safety and environmental performance.

The NPC recommends that the oil and natural gas industry remain committed to improving its environmental performance and the continued development of environmental safeguards.

The NPC further recommends that, commensurate with the level of policy enactment being recommended, the oil and natural gas industry continue its investment in CCUS.

Finding 10

The oil and natural gas industry is uniquely positioned to lead CCUS deployment due to its relevant expertise, capability, and resources.

The capability required for at-scale deployment of CCUS technologies resembles the skills needed for hydrocarbon production and processing. The U.S. oil and natural gas industry, working alongside the industrial gas industry, has more than a century of experience in the exploration and appraisal of subsurface geology, transport and injection of pressurized fluids, and development of technological solutions to resolve critical business challenges. The application of this technical capability to the abundant domestic resource base, supported by strong policies and a well-defined regulatory environment, has enabled the United States to become the world's largest producer of oil and natural gas.

In 2018, the United States produced an average of 10.6 million barrels of oil per day and 83.4 billion cubic feet of natural gas per day through nearly a million active wells.[34] These fluids are transported through more than 2.4 million miles of pipelines to customers across the United States and beyond as LNG and refined product export markets expand to the world. This combination of technical skill and project management experience can be applied to lead at-scale deployment of CCUS in the United States—capturing CO_2 from sources, compressing and transporting CO_2 to storage locations, injecting CO_2 into underground formations, and deploying monitoring technology to ensure containment.

The U.S. oil and natural gas industry has developed many of the largest, most complex, and most expensive projects in the world. For example, large LNG projects can cost as much as $50 billion. These projects require the discovery and appraisal of large amounts of natural gas with high confidence in the reservoir flow rate; upfront gas sales contracts with multiple parties for 15 to 25 years; a decade of engineering, design, construction, and commissioning; and continuous operations for up to 60 years. Typical projects involve securing financing from large international companies; negotiation of complex commercial agreements; stakeholder engagement; interaction with governments and regulatory bodies; coordination of multiple consultants and contractors performing engineering, design, and construction services; and the installation, commission, and operation of facilities deploying cutting-edge technologies at scale.

These projects have been delivered safely, on time, and on budget while complying with all regulations and achieving an attractive return on investment for the shareholders. CCUS projects will require the deployment of similar skills across the entire supply chain, integration and mitigation of cross-chain risk, management of competing drivers and stakeholder objectives, and ensuring safe and reliable operation.

34 EIA. (2019). Today in Energy. April 9, 2019.

A ROADMAP TO AT-SCALE DEPLOYMENT OF CARBON CAPTURE, USE, AND STORAGE IN THE UNITED STATES

The Secretary's letter requesting the NPC's advice on CCUS included the development of a roadmap of actions needed to drive widescale deployment of CCUS in the United States. In response, a diverse team of participants developed a roadmap of actions needed to enable deployment across a range of industries and fuel types.

The resulting "Roadmap to At-Scale Deployment of CCUS in the United States" shown on the following two pages details the study's recommendations in four pathways – financial incentives, supportive regulatory frameworks, technology and capability, and stakeholder engagement. These recommendations were allocated across three phases — **activation, expansion,** and **at-scale** — to achieve widespread deployment of CCUS over the next 25 years. Recommendations within each phase build upon the previous phase, but all recommendations require immediate action to ensure timely delivery.

The upper panel of the roadmap illustrates the potential economic impacts — cumulative investment, jobs, and infrastructure — associated with the actions taken to deploy each phase and includes maps showing the notional location and scale of CO_2 capture and storage in each phase of deployment. Further detail regarding the economic impacts of deployment across each phase can be found in Appendix D (Volume II).

The middle panel of the roadmap describes what is needed across each of the four pathways within each phase to achieve widescale deployment of CCUS. Prior to the activation phase, the current state of CCUS deployment highlights the ways in which the United States has become the world leader in CCUS.

The **activation phase** requires agency clarification of existing tax policy and regulations that could activate an additional 25 to 40 million tonnes per annum (Mtpa) of CCUS, within the next 5 to 7 years. This would require $50 billion in investment, including $2 billion for infrastructure investment, and support 10,000 annual jobs. The volume of CO_2 being captured, transported, and stored would be equivalent to ~10% of the U.S. crude oil infrastructure system.

The **expansion phase** requires extending and expanding current policies and developing a durable legal and regulatory framework that could enable the next phase of CCUS projects, achieving an additional 75-85 Mtpa of CCUS within the next 15 years. This would require $175 billion investment, including $9 billion for infrastructure investment, and support 40,000 annual jobs. The volume of CO_2 being captured, transported, and stored would be equivalent to ~25% of the volume moved in the U.S. crude oil infrastructure system.

The study defined **at-scale deployment** of CCUS as approximately 500 Mtpa that could be achieved within the next 25 years, which is roughly 20 times the current level of U.S. CCUS deployment and equivalent to about 10% of total U.S. CO_2 emissions as of the time of this report. This level of deployment will require substantially increased support driven by national policies. This would require a cumulative investment of $680 billion, including $28 billion for infrastructure investment, and support 230,000 annual jobs. The volume of CO_2 being captured, transported, and stored would be equivalent to ~75% of the volume moved in the current U.S. crude oil infrastructure system.

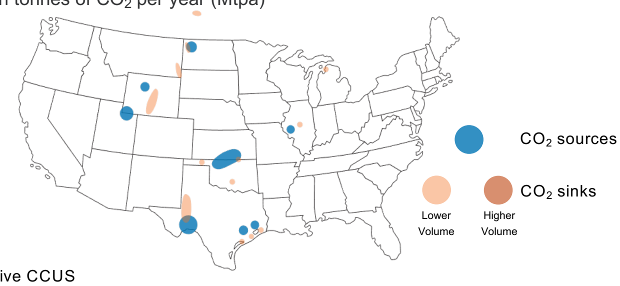
Based upon the CCUS cost curve described in detail in Chapter 2 (Volume II), each phase of deployment has a corresponding volume of CO_2 emissions that could be addressed through CCUS over the next 25 years. The bottom left panel in the roadmap provides an expanded view of the CCUS cost curve, with specific focus on the volume of CO_2 emissions that could be addressed within each of the three phases of deployment.

A commitment to CCUS must include a commitment to critical research and development. Alongside the policy and regulatory actions needed to incentivize deployment, substantially increased research, development, and demonstration (RD&D) will be needed to improve performance, reduce costs, and advance alternatives beyond currently deployed technologies. The down arrows shown on the CCUS cost curve along with the bottom right panel of the roadmap represents the technology evolution, providing a notional view of the expected 10% to 30% technology cost improvements and technological advances that could be achieved over the next 20 years as a result of the recommended level of continued RD&D investment.

Roadmap to At-Scale Deployment of Carbon Capture, Use, and Storage in the United States

Carbon capture, use, and storage (CCUS) today

Operating industrial CCUS project capacity in the United States totals ~25 million tonnes of CO_2 per year (Mtpa)

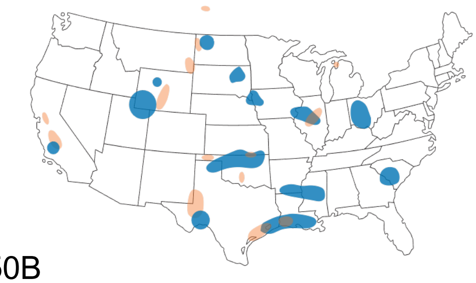


Key:

- Cumulative CCUS investment (20 years)
- Cumulative CO_2 pipeline investment
- Cumulative annual jobs
- Comparison to U.S. oil industry, % volume
- CCUS Cumulative Volume, Mtpa: ~25

Activation phase: ~ next 5 to 7 years from today

Promoting adoption of CCUS will require clarifying existing tax policy and regulations

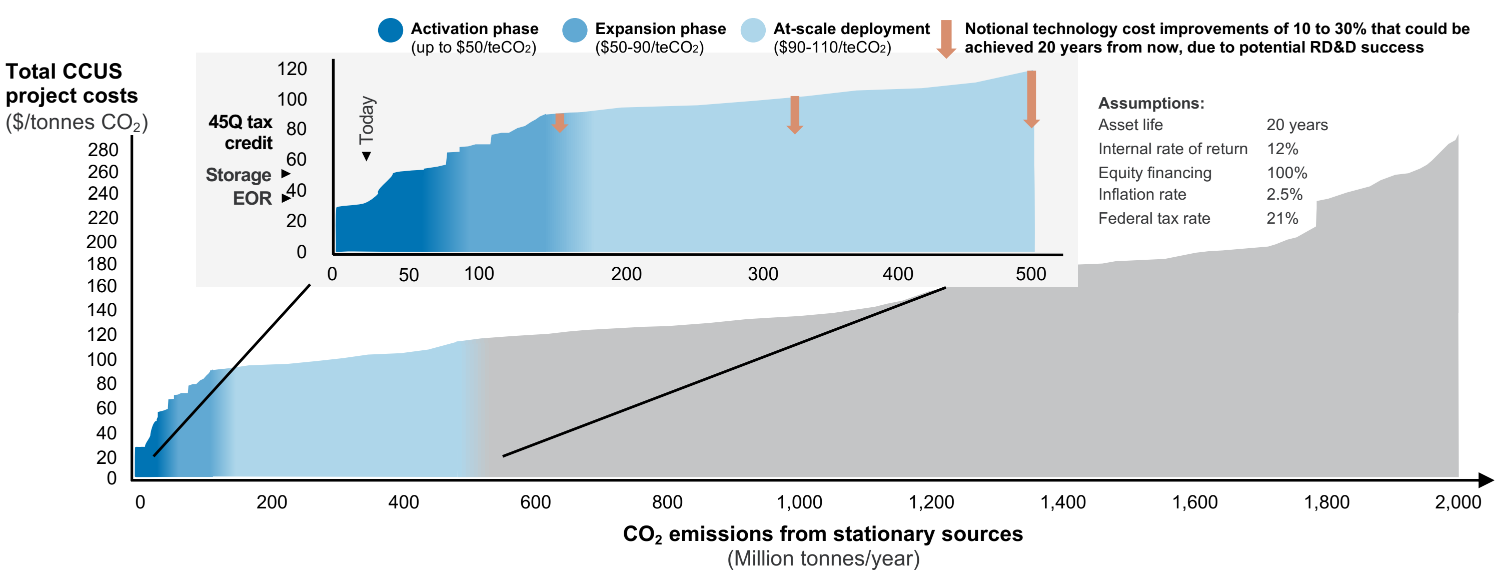


- ~$50B
- ~$2B
- ~10K/yr
- 10%
- CCUS Cumulative Volume, Mtpa: ~60

	Where we are today and how we got here	Recommendations to achieve CCUS at scale
Financial Incentives	• IRS implemented the original Section 45Q tax credit in 2008 to provide limited financial incentive • The 2018 Bipartisan Budget Act amended 45Q, increasing the tax credit for capturing and disposing of CO_2 in secure geological storage, for EOR or use	• IRS to clarify the Section 45Q requirements for credit transferability, demonstrating secure geologic storage, defining construction start date, and credit recapture provisions
Supportive Regulatory Frameworks	• EPA implemented regulatory and permitting frameworks in 2010 for safe and secure CO_2 geologic storage • EPA implemented a reporting program in 2010 for CO_2 injection and geologic storage • DOT regulated permitting and operation of CO_2 transportation pipelines	• DOI and states to adopt regulations to authorize access to and use of pore space for geologic storage on federal and state lands • EPA should issue a Class VI permit to drill within 6 months • EPA upon receipt of a Well Completion Report should review, make any necessary modifications, and issue a Class VI permit to inject within 6 months • EPA to undertake planned periodic review of Class VI wells to align with site-specific risk and performance-based approach
Technology and Capability	• DOE has led public-private partnership funding for CCUS technologies with investment of $4.5 billion over 20 years • DOE has implemented 19 small-scale CO_2 injection pilots and 7 large-scale CO_2 injection test projects across the United States and Canada	• DOE to continue characterization of scalable onshore and offshore geologic storage formations • The oil and gas industry to continue funding of R&D at or above current levels for new and emerging technologies • DOE to continue to promote public-private partnerships and consider open-source approaches for technology development as appropriate
Stakeholder Engagement	• The U.S. onshore CO_2 geologic capacity is adequate for hundreds of years of stationary source CO_2 emissions, and studies suggest the offshore storage resource may be just as large • EOR offers an important CO_2 storage solution in the near-term with more than 40 years of experience and ~24 Mtpa of geologic storage from man-made sources	• Government, industry, and associated coalitions should design policy and public engagement opportunities to facilitate open discussion, simplify terminology, and build confidence that CCUS is a safe and secure means of managing emissions • The oil and gas industry remains committed to improve its environmental performance and the continued development of environmental safeguards • The oil and gas industry to continue its investment in CCUS R&D, capture facilities, and pipeline infrastructure

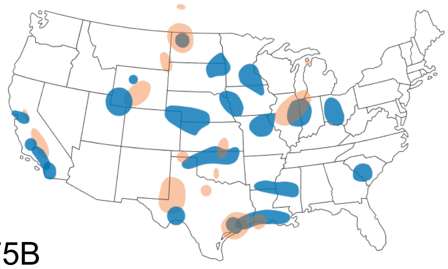
U.S. CCUS cost curve

The Supply Chain and Economics chapter provides more detailed explanation of the cost curve and how it was developed



Expansion phase: ~ next 15 years from today

Accelerating CCUS deployment will require extending and expanding current policies and developing a durable legal and regulatory framework

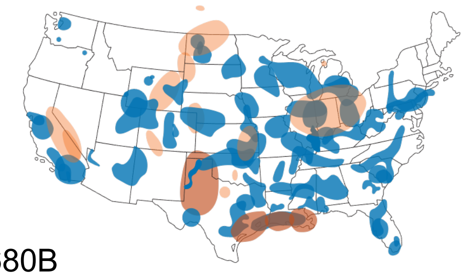


~$175B

~$9B ~40K/yr 25% CCUS Cumulative Volume, Mtpa ~150

At-scale deployment: ~ next 25 years from today

Achieving at-scale deployment of CCUS will require substantially increased support driven by national policies



~$680B

~$28B ~230K/yr 75% CCUS Cumulative Volume, Mtpa ~500

All recommendations are included in the next section of this Volume, and further background information can be found in report chapters.

- Congress to amend Section 45Q to extend construction start date to 2030, increase duration to 20 yrs, lower volume threshold, and increase credit for saline storage and use
- Congress to expand access to Section 48 tax credits for all projects, use of master limited partnership structures, issue private activity bonds, and TIFIA eligibility and funding

- Congress to increase EPA and state funding to support well permitting and timely reviews
- Congress to amend the Outer Continental Shelf Lands Act and Marine Protection, Research, and Sanctuaries Act to allow CO_2 geologic storage in federal waters from all CO_2 sources, and DOE, BOEM and BSEE to implement processes for access and regulation
- DOE to create a CO_2 pipeline working group made up of relevant federal and state regulatory agencies and interested stakeholders to harmonize permitting processes, establish tariffs, grant access, administer eminent domain authority, and facilitate corridor planning. The working group should be established concurrently with the activation phase
- DOE to convene a stakeholder forum to develop a risk-based standard to address CO_2 geologic storage long-term liabilities, and be established concurrent with the activation phase
- State policymakers to enact legislation for access, ownership, unitization, and fair compensation for CO_2 geologic storage on private lands

- Congress to appropriate $15B of RD&D funding over the next 10 years to enable continued development of new and emerging CCUS technologies and demonstration of existing technologies
- Congress to amend RD&D appropriations language to allow for all CO_2 sources and fuel types in the allocation of funding

- Congress to implement economic policies amounting to about $110/tonne. Evaluation of these should occur concurrently with the Expansion phase

CCUS Applications

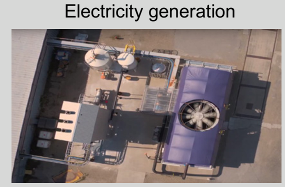
Natural gas processing

Refineries/Chemicals production

Ethanol fermentation

Electricity generation

Steel/Cement production



Direct air capture (pilot)

Technology evolution

The Technology chapters provide more detailed overview. Notional technology cost improvements of 10 to 30% could be achieved 20 years from now, resulting from potential technology advances supported by continued RD&D

Existing commercial options | **Future additional options**

Capture
- Existing: Gas processing; Chemical absorption
- Future: Membrane; Adsorption; Oxy-fuel combustion; Chemical looping; Process technology; Process intensification

Transport
- Existing: Local/regional CO_2 pipeline; Rail
- Future: At scale CO_2 pipeline network; Shipping

Use and storage
- Existing: Conventional CO_2 EOR; Saline formations
- Future: Unconventional CO_2 EOR; Nonconventional formations; Low carbon fuels and chemicals; Low carbon materials; Catalyst; Systems integration

10-fold return on RD&D investment in the long term

Infrastructure development

ALL STUDY RECOMMENDATIONS

POLICY, REGULATORY, AND LEGAL RECOMMENDATIONS

The NPC study lays out a roadmap that supports the growth of CCUS over the next 25 years through three phases of deployment—activation, expansion, and at-scale.

Specifically, the NPC recommends the following to enable each phase:

Phase I – Activation

The NPC recommends that the IRS clarify the Section 45Q requirements, specifically:

1. Establish that "beginning construction" is satisfied when the taxpayer has spent or incurred 3% of the expected total expenditure and construction continues without interruption for 6 years.

2. Clarify options for demonstrating secure geological storage as it relates to CO_2 via EOR. One potential option that has attracted significant stakeholder interest is ISO 27916. Utility of the standard for 45Q purposes has more to do with implementation than with the substance of the standard. The IRS should assess implementation issues and potential utility of this standard.

3. Make credit transferable to encourage tax equity investment. The tax credit should be transferable, in full or in part, to any party that has a vested interest in the capture project including project developer, the party capturing the CO_2, or the entity that stores the CO_2.

4. Provide that the tax credit will not be subject to recapture for longer than 3 years[1] after the time of injection, to encourage financing and investment, provided that the taxpayer continues to comply, either directly or by contract, with a Treasury recognized method for demonstrating secure geologic storage and has a plan to remediate leaks of CO_2 should they occur.

5. Clarify that additional CO_2 capture capacity placed in service after the Bipartisan Budget Act (BBA) should be based on the delta between the new capacity and the average of the amount of CO_2 captured in the 3 years prior to the enactment of the BBA or the facility's nameplate annual capacity.

6. The IRS should also specifically provide that the economic substance doctrine and provisions of Section 7701(o) will not be deemed relevant to a transaction involving the 45Q credit that is consistent with the congressionally mandated purpose of the credit: capture and geological storage or utilization of CO_2.

The NPC recommends that the U.S. Department of Energy, with EPA and Treasury, begin to develop a robust life-cycle analysis framework with common parameters to support technology development and direct RD&D funding.

The NPC recommends that the U.S. Department of the Interior and individual states adopt regulations to enable access to, and use of, pore space for geologic storage of CO_2 on federal and state lands similar to the approach under the Mineral

1 Where: Current year (time of injection) + 2 = 3 years.

Leasing Act where parties can join together and collectively operate under a cooperative or unit plan of development where it is determined by the Secretary of the Interior to be necessary or advisable in the public interest.

The NPC recommends that EPA undertake the planned periodic review of the Class VI rules, guidance, and implementation so that they are aligned with a site-specific and performance-based approach. Specifically, EPA should use the experiences and learnings since the program was promulgated to:

- Consider how the program could be modified to better incorporate a site-specific, performance-based approach
- Review guidance documents to be sure they reflect the latest technical and financial information, and they are consistent with the regulations. Include clarity regarding which aspects of the guidance documents are requirements versus recommendations.

This program review should be done in consultation with DOE, a national association of state groundwater agencies like the Ground Water Protection Council, the Interstate Oil and Gas Compact Commission (IOGCC), and relevant industry partners, including former and prospective Class VI permit applicants.

The NPC recommends that EPA issue a Permit to Drill within six months. The NPC further recommends that upon receipt of a Well Completion Report, the EPA should review, make any necessary modifications, and issue a Permit to Inject within six months.

The NPC further recommends that Congress, through its agency oversight process, emphasize to EPA the importance of accelerating the review of states' applications seeking primacy to implement the Class VI program.

The NPC recommends that the EPA adjust its computational modeling requirements for post-injection site care requirements with respect to small demonstration projects to make them fit for purpose.

The NPC recommends that the EPA amend the regulation to allow pilot and demonstration projects to be permitted under the underground injection control (UIC) Class V program as experimental technology wells, which give the agency much greater flexibility to tailor permit requirements to the individual project. DOE should consult with EPA to determine what additional research is needed to allow EPA to better define the scale of research projects that can be permitted as Class V experimental.

Phase II – Expansion

The NPC recommends that Congress amend Section 45Q such that it will:

1. Extend the deadline (January 1, 2024) for beginning construction to 2030.
2. Lengthen the duration the credit pays out to a project from 12 to 20 years.
3. Lower the project size CO_2 volume thresholds to 25,000 tonnes for industrial facilities, 100,000 tonnes for power plants, and 1,000 tonnes for use per year per site to accommodate smaller installations that may not qualify for the credit.
4. Increase the value of the credit for storage and use applications by notionally \$5 per tonne as the current value of the credit is often less than the costs for such projects. The actual adjustment should be based on economic conditions at the time of reassessment.

The NPC recommends that Congress amend the IRS Section 43 tax credit by raising the reference price to a value greater than \$50 per barrel of oil for CO_2 EOR projects that securely store anthropogenic CO_2.

The NPC recommends that Congress enact legislation to expand Section 48 of the tax code to create 48C for industrial sources and natural gas fired electricity generating technologies.

The NPC recommends that legislation be enacted to allow CCUS projects access to private activity bonds.

The NPC recommends that Congress enact legislation providing CCUS projects access to the use of master limited partnership structures and that the master limited partnership (MLP) be structured in a way that allows the Section 45Q tax credit to be passed through and applied toward an individual's income.

The NPC recommends that Congress enact legislation to allow CO_2 pipelines to qualify under Transportation Infrastructure Finance and Innovation Act (TIFIA) and provide the budget authority for the expanded program.

The NPC recommends that the EPA, in consultation with DOE, academics, Class II state directors, the IOGCC, NGOs, and industry develop a process for determining maximum pressure threshold or ratio, and/or maximum injection rates or volumes, above which the risk is such that the injection should transition from Class II to Class VI. At a minimum, EPA should codify the statements in its memo to Regional Directors "Key Principles in EPA Underground Injection Control Program Class VI Rule Related to Transition of Class II Enhanced Oil or Gas Recovery Wells to Class VI" from April 2015.

The NPC recommends that the EPA apply a risk-based approach when implementing the standard for endangerment and in the implementation of all aspects of the Class VI program.

The NPC recommends that the Class VI regulations be amended to allow indirect monitoring through perimeter and above zone monitoring of storage reservoirs to ensure containment.

The NPC recommends that the EPA, in consultation with experts in the field and stakeholders, clarify what information, including financial estimates for emergency and remedial response, should be provided to support a risk-based approach when evaluating financial responsibility.

The NPC recommends that the EPA amend the UIC Class VI regulations to allow the post-injection site care (PISC) time frames to be set based on actual site conditions by using a risk-based approach for the duration of the PISC period.

The NPC recommends that the Class VI regulations be amended to allow the Area of Review to be separated into different subareas that are focused on whether the primary concern is free-phase CO_2 or pressure-driven upward brine leakage.

The NPC recommends that, to facilitate state primacy for the Class VI program, Congress enact statutory changes for approval of state primacy of the Class VI program under the Section 1425 standard of equal effectiveness, similar to the Class II UIC program.

The NPC recommends that Congress increase the funding to EPA and the states by $20 million for UIC Class II and $50 million for Class VI to support EPA and the state's anticipated increase in workload in Phase II to review permit applications, to provide any additional training, and support state Class VI primacy applications and EPA's review of those primacy applications.

The NPC recommends that the EPA amend the UIC Class VI regulations to allow the use of the UIC two-part process for exempting aquifers.

The NPC recommends that Congress amend the Outer Continental Shelf Lands Act (OCSLA) or enact a separate statute explicitly authorizing the issuance of leases, easements, and rights-of-way for facilities used to transport and inject CO_2 in the OCS without respect to the origin of the CO_2. Further, the DOE, Bureau of Ocean Energy Management, and Bureau of Safety and Environmental Enforcement should establish processes to enable access to pore space in federal waters and regulate CO_2 storage in those waters.

The NPC recommends that Congress amend the Ocean Dumping Act to explicitly exempt CO_2 from the list of prohibited materials for disposal in the OCS.

The NPC recommends that DOE create a CO_2 pipeline working group to study how to: harmonize federal/state/local permitting processes; establish tariffs, grant access, and administer eminent domain; establish the authority to issue certificates of public convenience and necessity; and to facilitate corridor planning. The working group should be made up of relevant federal and state regulatory agencies such as the Federal Energy Regulatory Commission (FERC), the IOGCC, or the Environmental Council of the States, representatives of local governments and communities, industry, and interested NGOs. The working group should be established concurrently with the activation phase.

The NPC recommends that DOE convene an industry and stakeholder forum to develop a risk-based standard to address long-term liability. The forum should be established concurrently with the activation phase. Options to be considered for resolving long-term liability should include:

- Applicability and limitations of private insurance
- Government assumption of liability for early mover projects to incentivize and de-risk market creation[2]
- Transfer of liability risk and oversight to the government when secure geologic storage is demonstrated, likely with operators paying a fee into a stewardship or trust fund
- Layered responsibility approach for risk pooling among operators and government
- When evaluating damage claims consider the societal benefit of CO_2 storage.

The NPC recommends that state policymakers enact legislation enabling access to storage resources on private lands, including pore space ownership, setting a threshold and process for forced unitization, and fair compensation.

The NPC recommends that DOE conduct a study exploring the range of options to determine how to address CCUS dispatch and available capacity in the most cost-effective manner with input from Electric Power Research Institute, Edison Electric Institute, independent system operators, NGOs, FERC, National Association of Regulatory Utility Commissioners, the utilities, and independent power investors and industry. The study should begin concurrently with the activation phase.

2 Under the Anti-Deficiency Act, the United States may not agree to open-ended indemnification arrangements absent specific congressional authorization. See 31 U.S.C. 1341(a)(1)(B). Such authorizations have rarely been granted due to their inherent open-ended risk to the federal government and taxpayers. See Pub. L. No. 85-804 (codified as 50 U.S.C. § 1431 et seq.); the Price-Anderson Act, 42 U.S.C. § 2210; and Hercules Inc. v. United States, 516 U.S. 417, 426-29 & n.11 (1996).

Phase III – At-Scale Deployment

The NPC recommends that to achieve at-scale deployment of CCUS, congressional action be taken to implement economic policies amounting to about \$110 per tonne. The evaluation of these policies should occur concurrently with the expansion phase.

RESEARCH, DEVELOPMENT, AND DEMONSTRATION FUNDING

The NPC recommends that DOE promote public-private partnerships and consider open source approaches to the development of CCUS technologies as appropriate.

The NPC recommends that the oil and natural gas industry continue to fund private research and development at or above current levels in support of new and emerging CCUS technologies.

The NPC recommends that Congress amend appropriations language to allow for all CO_2 sources and fuel types in the allocation of RD&D funding for CCUS.

The NPC recommends that Congress appropriate \$1.5 billion of RD&D funding per year over the next 10 years to enable the continued development of new and emerging CCUS technologies and demonstration of existing CCUS technologies.

Specifically, the NPC recommends that RD&D funding be prioritized as follows:

CO_2 Capture Technology

The NPC recommends that public-private investment into CO_2 capture over the next 10+ years be funded annually as follows:

- For R&D (includes basic science and applied research, bench-scale, and small pilots): \$300 million per year at an 80% federal cost share (i.e., \$250 million) for a minimum of 10 years on CO_2 capture and advanced power cycles system development. Typically, the cost share is 80% federal.
- For pilot programs: \$300 million per year at 80% federal cost share (i.e., \$250 million) over a minimum of 10 years is needed for a large-scale pilot program.

- For demonstrations: $1.0 billion annually at a total 50% federal cost share (i.e., $500 million) over 10 years to support the needed CCUS technology demonstrations.

The NPC recommends that DOE undertake a study for industrial CCUS RD&D to determine a uniform approach for addressing CO_2 removal from industrial systems and prioritizing RD&D pathways. As part of the effort, DOE should identify how federal investments in CO_2 capture technologies currently in the DOE RD&D portfolio can be leveraged with industrial applications of those technologies.

The NPC recommends that the Clean Coal Power Initiative (CCPI) program be expanded to include all fuel sources or that Congress authorize a new commercial-scale demonstration program with a new set of criteria to be established and robust federal funding provided.

CO_2 Storage Technology

The NPC recommends that Congress increase RD&D funding for geologic storage to $400 million per year for the next 10 years. The funding should be allocated as follows: $100 million to the Regional Initiative to Accelerate CCUS Deployment; $100 million for characterization of geologic storage formations, including offshore, that have scale potential through the CarbonSAFE program or similar initiatives; and $200 million per year to enable field-scale projects that collect data and geologic samples used to advance the basic and applied science of long-term storage security.

Nonconventional CO_2 Storage (including EOR) Technology

The NPC recommends that Congress fund $100 million over the next 10 years for research into methods that can be used to improve effective application of CO_2 EOR for purposes of enhancing storage of CO_2 in conventional residual oil zone reservoirs, for application to unconventional CO_2 EOR reservoirs, and to storage in un-mineable coal deposits and basalts. This is needed so that widespread CO_2 EOR in these reservoirs can begin within 5 to 10 years.

CO_2 Use Technology

The NPC recommends that Congress provide $500 million in RD&D funding over 10 years for support to basic science. This is particularly important for CO_2 use technologies since many of them are still in low technology readiness levels (TRL). The design of RD&D funding structure should also be unique to the program.

The NPC further recommends that Congress provide an additional $500 million in years 10 to 15 for pilots, demonstration projects, and early deployment support. In order to do so, it is recommended that projects need to be field-deployed to at least the level of National Carbon Capture Center, Wyoming Integrated Test Center, or similar practical demonstration environment that uses real flue gas from coal and natural gas combined cycle (NGCC) sources, in an industrial environment.

RECOMMENDATIONS FOR BUILDING STAKEHOLDER CONFIDENCE

The NPC recommends that government, industry, and associated coalitions design policy and public engagement opportunities to facilitate open discussion, simplify terminology, and build confidence that CCUS is a safe and secure means of managing emissions.

The NPC recommends that the oil and natural gas industry remain committed to improving its environmental performance and the continued development of environmental safeguards.

The NPC further recommends that, commensurate with the level of policy enactment being recommended, the oil and natural gas industry continue its investment in CCUS.

Specifically, the NPC recommends the following:

Conduct Meaningful Engagement

The NPC recommends that all members in the spheres of engagement be engaged early in a series of national discussions on CCUS that includes federal and state government, industry, policy and environmental stakeholders, and the public to meet the dual challenge of providing energy while reducing environmental impacts. Discussion formats could include town hall meetings, policy briefings, focus groups, online interaction, and workshops.

The NPC recommends that all stakeholder levels better utilize and expand the stakeholder engagement process. CCUS policy and projects require systems thinking across CO_2 emitters, transporters, and users, each often having different risk profiles, return expectations, and contracting strategies and structures. Specifically, to:

- Address legal and regulatory issues, such as IRS clarification of the Section 45Q tax credit, use of federal land, and long-term liability
- Create and facilitate mechanisms, such as policy discussion events around this report, that encourage frank conversations about energy and emissions
- Create an ongoing series of listening sessions and conduct research to understand changing perceptions among policymakers and other stakeholders
- Continue demonstrating to the public that CCUS projects have environmental integrity and will sequester material amounts of CO_2 from the atmosphere
- Engage with financial institutions on the technical details and risks associated with CCUS, to better understand shareholder concerns, and to advance a broader conversation to address social issues
- Educate consumers on the merits of CCUS to enable consumer demand for low-carbon products.

The NPC recommends that industry and NGOs create coalitions and utilize trade organizations to work together to educate and engage internal and external stakeholders.

The NPC recommends that DOE increase and sustain federal and state crossover engagement opportunities and linkages through the Regional Partnership Initiative, state working groups, and other similar organizations.

The NPC recommends that industry, RD&D, coalitions, and DOE continue to demonstrate leadership in international carbon capture and storage, government, industry, and nongovernmental agency international forums, such as the IEA CCS Unit, IEA Greenhouse Gas R&D Programme (IEAGHG), Carbon Sequestration Leadership Forum, Oil and Gas Climate Initiative, and Clean Energy Ministerial.

The NPC recommends that DOE work with other agencies to formalize the interagency CCS work group to meet regularly, generate interagency reports, and provide materials suitable for stakeholder engagement that can facilitate integration of technical, economic, and societal aspects of CCUS.

The NPC recommends that all stakeholder spheres continue to require funded CCUS programs and projects to prioritize stakeholder engagement at the project level using best practices.

Clarify Messaging

The NPC recommends that multiple stakeholder groups work together to simplify the language used to discuss CCUS and agree upon an easy-to-understand and recognizable moniker.

The NPC recommends that government and industry develop a program for training communication champions and empowering stakeholders, including assessments to measure impact toward advanced deployment.

The NPC recommends that the National Petroleum Council evaluate engagement opportunities using the NPC CCUS study as a platform and create talking points and summary materials.

The NPC recommends that government, industry, and associated coalitions develop a clear set of recommendations of how to apply CCUS study findings to policy in their outreach activities.

The NPC recommends that DOE create events that share lessons learned and result in the continuation of deploying best practices for influencer and project-level stakeholder engagement efforts.

Demonstrate Societal Benefits

The NPC recommends that industry, academia, and DOE support mechanisms for evaluating and demonstrating the social benefits and impacts of CCUS, including a set of common metrics for tabulating the benefits of CCUS projects.

The NPC recommends that Congress expand DOE's authorization and appropriations to fund research on social and economic drivers of CCUS through organizations such as the IEAGHG Social Research Network.

The NPC recommends that DOE commission a national economic development and jobs research study to better understand the potential for CCUS-specific economic impact jobs.

Fund Engagement Research and Education Opportunities

The NPC recommends that DOE provide dedicated funding for CCUS education and research on stakeholder engagement processes and impacts, and require integrated analyses, results sharing, and joint work products as part of new CCUS projects and programs.

The NPC recommends that DOE collaborate with other agencies, such as the National Science Foundation and the Department of Education, to consider new funding models for education and engagement that align with emerging CCUS technologies and support continued research, development, and demonstration.

APPENDICES

Appendix A:
Request Letter and Description of the NPC

Appendix B:
Study Group Rosters

Description of Web-Only Materials

The Secretary of Energy
Washington, DC 20585

September 21, 2017

Mr. Greg L. Armstrong
Chair
National Petroleum Council
1625 K Street, NW
Washington, DC 20006

Dear Mr. Armstrong:

As the United States and other nations explore options to promote economic growth and ensure energy security while protecting the environment, one key opportunity is the deployment of carbon capture, utilization, and storage (CCUS) technologies. Integrating technology and deploying CCUS at scale remains a commercial investment challenge. Such would require significant capital investment and major new infrastructure, as well as the cooperation of multiple industries and government institutions. Substantial progress has been made in demonstrating the technical and environmental performance of CCUS technologies in specific settings in the United States and internationally. For example, earlier this year, the United States' first and the world's largest commercial post-combustion carbon capture system at a coal-fired power plant became operational. Nonetheless, a roadmap of remaining technology and project development challenges that can enable the successful economic deployment of large-scale CCUS across a spectrum of industries and fuel types remains elusive.

Oil and natural gas companies, including related support service companies, have extensive core competencies in designing, constructing, and operating large-scale capital-intensive energy and industrial projects, and a proven track record in delivering reliable and affordable fuels and feedstocks to energy consumers. This experience includes some of the world's largest facilities for carbon dioxide capture, processing, and use. The National Petroleum Council (NPC) is well-positioned to provide advice to the Department of Energy on the development and deployment of commercial CCUS technologies.

I request that the National Petroleum Council undertake a study to define potential pathways, including research and development, regulatory, and policy options, for integrating CCUS at scale into the energy and industrial marketplace, with specific emphasis on the petroleum industry. This study should address the entire CCUS value chain from capture through use and/or storage and consider technologies applicable to power generation, industrial processes, and enhanced oil recovery, as well as different fuel types or energy sources such as coal, oil, and natural gas. Factors to consider include—technology options and readiness, market dynamics, cross-industry integration and infrastructure, legal and regulatory issues, policy mandates, economics and financing, environmental footprint, and public acceptance.

Key questions to be addressed include:

- What are the United States' and global future energy demand outlooks and, based on these outlooks, the environmental benefits resulting from the application of CCUS technologies in various end-use sectors?
- What research and development, technology, and infrastructure barriers must be overcome to ensure the economic deployment of CCUS at scale in various end-use sectors?
- How should the success of CCUS at scale be defined?
- What actions can be taken to establish an economic framework that guides public policy and stimulates private-sector investment to advance the development and deployment of CCUS technologies capable of achieving substantive gains in efficiency, economics, and environmental performance?
- What regulatory, legal, liability, or other issues should be addressed to progress commercial CCUS investment and enable the U.S. industry to be the global technology leaders?

The study, while focused on the petroleum industry, should draw on available analyses from a breadth of sources. The National Coal Council (NCC) has issued several important reports that could inform this effort, and potentially be a valuable resource to identify possible study participants. The Department encourages collaboration and information sharing between the NPC and NCC. In addition, international organizations such as the International Energy Agency, the Global Carbon Capture and Storage Institute, and others may also add valuable contributions.

For the purposes of the study, I am designating Deputy Secretary Dan Brouillette to represent me. He will provide the necessary coordination between the Department and the NPC, and other government agencies as required. Mark Maddox, Acting Assistant Secretary for Fossil Energy, will work with the Deputy Secretary to identify leads from the Office of Clean Coal and Carbon Management and the Office of Oil and Natural Gas to serve on the study team.

Sincerely,

Rick Perry

Rick Perry

DESCRIPTION OF THE NATIONAL PETROLEUM COUNCIL

In May 1946, the President stated in a letter to the Secretary of the Interior that he had been impressed by the contribution made through government/industry cooperation to the success of the World War II petroleum program. He felt that it would be beneficial if this close relationship were to be continued and suggested that the Secretary of the Interior establish an industry organization to advise the Secretary and the Executive Branch on oil and natural gas matters. Pursuant to this request, Interior Secretary J. A. Krug established the National Petroleum Council (NPC) on June 18, 1946. In October 1977, the Department of Energy was established and the Council was transferred to the new department.

The purpose of the NPC is solely to advise, inform, and make recommendations to the Secretary of Energy on any matter requested by the Secretary, relating to oil and natural gas or the oil and gas industries. Matters that the Secretary would like to have considered by the Council are submitted in the form of a letter outlining the nature and scope of the study. The Council reserves the right to decide whether it will consider any matter referred to it.

Studies undertaken by the NPC at the request of the Secretary include:

- *Dynamic Delivery – America's Evolving Oil and Natural Gas Transportation Infrastructure* (2019)
- *Supplemental Assessment to the 2015 Report – Arctic Potential: Realizing the Promise of U.S. Arctic Oil and Gas Resources* (2019)
- *Emergency Preparedness Implementation Addendum* (2016)
- *Arctic Potential: Realizing the Promise of U.S. Arctic Oil and Gas Resources* (2015)
- *Enhancing Emergency Preparedness for Natural Disasters* (2014)
- *Advancing Technology for America's Transportation Future* (2012)
- *Prudent Development: Realizing the Potential of North America's Abundant Natural Gas and Oil Resources* (2011)
- *One Year Later: An Update On Facing the Hard Truths About Energy* (2008)
- *Facing the Hard Truths about Energy: A Comprehensive View to 2030 of Global Oil and Natural Gas* (2007)
- *Observations on Petroleum Product Supply* (2004)
- *Balancing Natural Gas Policy – Fueling the Demands of a Growing Economy* (2003)
- *Securing Oil and Natural Gas Infrastructures in the New Economy* (2001)
- *U.S. Petroleum Refining – Assuring the Adequacy and Affordability of Cleaner Fuels* (2000)
- *Meeting the Challenges of the Nation's Growing Natural Gas Demand* (1999)
- *U.S. Petroleum Product Supply – Inventory Dynamics* (1998)
- *Future Issues – A View of U.S. Oil & Natural Gas to 2020* (1995)
- *Research, Development, and Demonstration Needs of the Oil and Gas Industry* (1995)
- *Marginal Wells* (1994).

The NPC does not concern itself with trade practices, nor does it engage in any of the usual trade association activities. The Council is subject to the provisions of the Federal Advisory Committee Act of 1972.

Members of the National Petroleum Council are appointed by the Secretary of Energy and represent all segments of the oil and natural gas industries and related interests. The NPC is headed by a Chair and a Vice Chair, who are elected by the Council. The Council is supported entirely by voluntary contributions from its members.

Additional information on the Council's origins, operations, and reports can be found at www.npc.org.

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Appendix B

STUDY GROUP ROSTERS

STUDY PARTICIPATION

Participants in this study contributed in a variety of ways, ranging from work in all study areas, to involvement on a specific topic, or to reviewing proposed materials. 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. Likewise, some other participants from certain non-advocacy, nonprofit organizations such as the Electric Power Research Institute, 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. However, the Council believes that the broad and diverse participation has informed and enhanced its study and advice. The Council is very appreciative of the commitment and contributions from all who participated in the process.

This appendix lists the individuals who served on this study's Committee, Coordinating Subcommittee, Task Groups, Subgroups, and Teams, as a recognition of their contributions. In addition, the National Petroleum Council wishes to acknowledge the numerous other individuals and organizations who participated in some aspects of the work effort through outreach meetings or other contacts. Their time, energy, and commitment significantly enhanced the study and their contributions are greatly appreciated.

LIST OF STUDY GROUPS:

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DESCRIPTION OF WEB-ONLY MATERIALS

In addition to approving this CCUS report, the members of the National Petroleum Council approved making certain materials used in the study process available through the NPC website: dualchallenge.npc.org.

TOPIC PAPERS

Detailed, specific subject matter papers prepared or used by the study's teams

The Topic Papers were working documents that were part of the analyses that led to development of the summary results presented in the report's Executive Summary and Chapters.

These Topic Papers represent the views and conclusions of the authors. The National Petroleum Council was not asked to endorse or approve the statements and conclusions contained in these documents, but to approve the provision of these materials on the NPC website as part of the study process.

The NPC believes that these papers will be of interest to the readers of the report and will help them better understand the study results. These materials are being made available in the interest of transparency.

The titles and authors of the Topic Papers are as follows:

1. *Supply and Demand Analysis for Capture and Storage of Anthropogenic Carbon Dioxide in the Central U.S.* (Jeffrey D. Brown, Stanford University & University of Wyoming Enhanced Oil Recovery Institute, Brown Brothers Energy & Environment, LLC; Poh Boon Ung, BP Group Technology)
2. *An open-technology and open-access post-combustion capture initiative for power plants in the USA* (Jon Gibbins, Professor, UK CCS Research Centre, University of Sheffield; William R. Elliott, Operations Manager, Infrastructure and Power, Bechtel Global Corporation)
3. *Driving Sustainable Future via an Electro-Molecular Economy* (Bill Brown, Chief Executive Officer, NET Power/8 Rivers Capital; Damian Beauchamp, Chief of Staff and Head of Business Development, 8 Rivers Capital)
4. *The Layered Approach to Liability for Geologic Sequestration of CO_2*, a paper on pore space and liability (A. Scott Anderson, Senior Policy Director, Energy Program, Environmental Defense Fund; Frederick R. Eames, Partner, Hunton Andrews Kurth)

COST CURVE MODEL

Gaffney, Cline & Associates' model used to generate the cost curves in this NPC report

A differential feature of this study was to assess the costs to capture, transport, and store CO_2 from all sectors and fuel types, covering the largest facilities and a total of approximately 80% of all U.S. stationary sources. Using "reference cases" and standard economic assumptions was essential to developing the cost curve, formulating recommendations, and assessing the potential impact of those recommendations on CCUS deployment at a national level. Costs for individual projects will vary based on location factors and the economic assumptions specific to each project.

In order to provide a useful public resource and ensure transparency of the work of the NPC CCUS study, this cost assessment tool is being hosted online by Gaffney, Cline & Associates, allowing stakeholders to change the cost and financial assumptions to generate their own view of costs. Visit the following Gaffney-Cline link to sign up to use the model:

http://gaffney-cline-focus.com/npc-ccus-cost-assessment-tool