NATIONAL PETROLEUM COUNCIL

PRINCIPLES, AND OIL & GAS INDUSTRY INITIATIVES AND TECHNOLOGIES FOR PROGRESSING TO NET ZERO

December 2022

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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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1. INTRODUCTION

In mid-June 2022, President Biden wrote to seven major refiners in the United States concerning his views on the energy situation and its impacts. In those letters, he stated that he was directing the Secretary of Energy to convene an emergency meeting and engage the National Petroleum Council (NPC). As a result, Secretary Granholm requested a meeting with the NPC's Cochairs' Coordinating Committee (CCC), given that a purpose of the CCC is to discuss emerging issues with the Secretary and to discuss whether an NPC study would be useful. The CCC had a productive meeting with the Secretary on July 1st and provided the Committee members' individual views on the then-current situation and potential actions that could be taken in response. Subsequently, by letter dated July 29, 2022, the Secretary requested the Council to provide certain information and formal advice on these topics. The Secretary's letter, in part, requested:

1. Details, within 30 days, of (a) how industry is working to supply oil and refined products to meet U.S. demand; and (b) near-term steps the administration can consider to increase U.S. supply.
2. An analysis, within 120 days, of (a) the evolving global oil market and its implications on U.S. supply; and (b) industry efforts to support a net-zero economy by 2050.

As required by the Council's Articles of Organization, the NPC Agenda Committee reviewed the Secretary's request, and recommended that the request be accepted. In a follow-up discussion, Deputy Secretary of Energy David Turk explained that implicit in both the 30-day and 120-day requests is the desire to have the NPC's views on ways to improve government and industry coordination in responding to incidents of significant supply disruptions.

Consistent with the Agenda Committee's favorable recommendation, Deputy Secretary Turk's clarification, and in accordance with the Council's Articles of Organization's provision for addressing urgent requests from the Secretary, the Council:

- Utilized the membership of the Cochairs' Coordinating Committee, expanded as necessary, to respond, and constitute an NPC Committee on Short-Term Actions and Transition Strategies.
- Appointed Vice Chairs to lead three work streams:
  - Short-term industry and government actions
  - Emergency preparedness planning
  - Evolving global markets and the transition to net zero.

Figure 1 shows the organizational structure and workgroup leaders for the NPC Committee on Short-Term Actions and Transition Strategies.

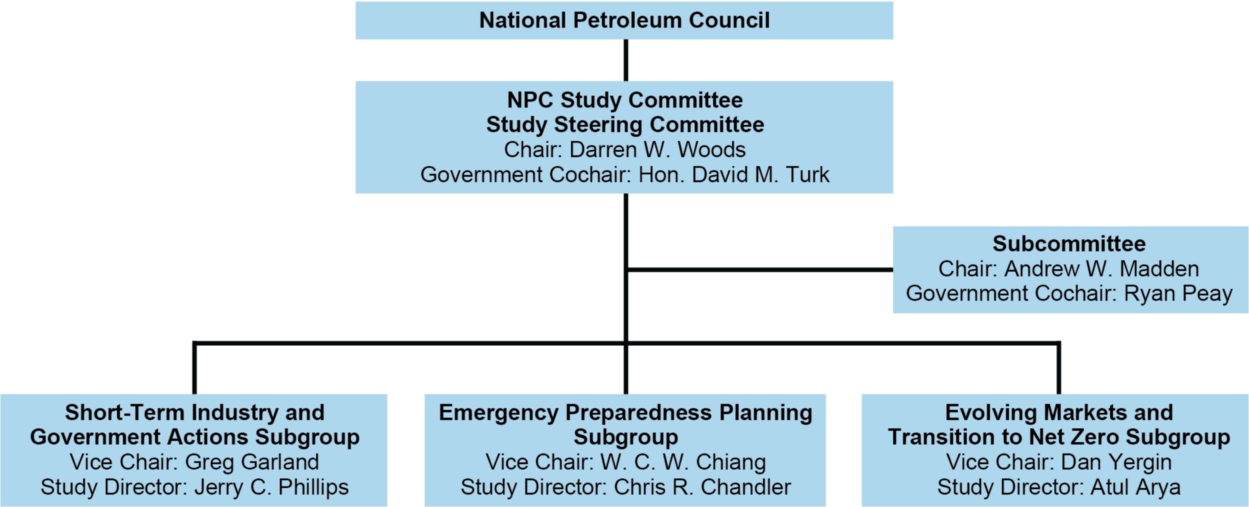


Figure 1. Organizational Structure of the NPC Committee on Short-Term Actions and Transition Strategies

Appendix A provides a copy of the Secretary's July 29, 2022, letter and a description of the National Petroleum Council. Appendix B provides rosters of the Committee on Short-Term Actions and Transition Strategies and its subgroups. Participants in this study contributed in a variety of ways, ranging from work in all study areas, to involvement on a specific topic. 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. The Council is very appreciative of the commitment and contributions from all who participated in the process.

However, as a federally appointed and chartered advisory committee, the NPC is solely responsible for the final advice provided to the Secretary of Energy.

1.1 Report Objectives

Secretary Granholm requested the NPC to provide a list of (1) the ways industry is preparing to secure consistent, physical supply for the American people, and (2) near-term actionable steps the Administration can consider to help increase physical supply of oil and refined products while continuing safe, efficient operations and maintenance of production facilities. "Supply" was clarified to refer to crude oil, refined petroleum products, natural gas, and natural gas liquids.

Other questions were raised in the Secretary's letter:

- How can we increase supply? Where is there efficiency and/or opportunity to increase current supplies of crude oil and refined products?
- What are current constraints and market hurdles to getting affordable products to U.S. consumers?
- How are companies reevaluating traditional emergency preparedness? Given the current tight market, how is industry making sure inventories are well supplied should there be a critical disruption from major and/or multiple storms, a cyber-attack, or other unforeseen events that would cause refineries or pipelines to shut down? What additional actions can the government be taking in coordination with industry to help enhance preparedness?

Finally, the Secretary requested that the Council provide an analysis of the changing global crude oil supply and the impacts on U.S.-based producers, suppliers, and refiners, as well as steps being taken by the industry to be an active player in a net-zero economy by 2050.

1.2 Approach Taken

The NPC Committee on Short-Term Actions and Transition Strategies organized three work groups to help develop a proposed final report for the Council's consideration. The three groups were organized to pull together expertise to address the questions as follows:

1. Short-term industry and government actions – Compile a list of actions being taken and suggested government actions that may assist in increasing supply of crude oil, refined products, natural gas, and natural gas liquids.
2. Emergency preparedness planning – Review the NPC study from 2014 and the supplement from 2016 to assess whether the findings are still relevant and the status of implementation as well as incorporating learning from more recent supply disruptions.
3. Evolving global markets and transition to a net-zero economy by 2050 – Outline the principles to be adhered to and the steps being taken by industry to help ensure a manageable transition to a net-zero economy.

Unless otherwise noted, the sources of the data in this document are the Department of Energy's Energy Information Administration (EIA) annual and monthly production data, inputs, and utilization data, as well as import/export data and weekly product supplied data.

On November 14, 2022, a Workplan and some initial considerations were sent to Deputy Secretary of Energy David Turk and all Council members. This report addresses the question on the longer-term analysis of the principles to be adhered to and the steps being taken to help ensure a manageable energy transition. A second companion report provides an analysis of the current petroleum markets and an assessment of the emergency response preparedness with recommendations on steps that could be taken to improve both supply of crude oil and petroleum products as well as improving emergency preparedness. While there was a single request from the Secretary, and the two topics do have some linkage, they were separated to enable different audiences and readers to read the reports(s) most relevant to them.

1.3 Study Report Structure

In the interest of transparency and to help readers better understand this study, the NPC is making the study results and the supporting 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 as follows:

- Executive Summary and Recommendations are the first layer and provide a broad overview of the study's principal findings and resulting recommendations.
- The body of the report provides detailed discussion and background on the study analyses. The individual sections are Background and Context, Energy Transitions, and Technologies Necessary to Achieve Net Zero. These sections provide the basis for the findings and recommendations presented in the Executive Summary and Recommendations.
- Topic Papers provide an additional level of detail for the reader. These papers were developed by the study committee and were used in the Technologies Necessary to Achieve Net Zero section. The Council believes that these materials will be of interest to the readers of the report and will help them better understand the findings. 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 Transition Strategies Subgroup but are essentially stand-alone analyses. As such, statements and suggested findings that appear in these topic papers are not endorsed by the NPC unless they were incorporated into this report.

  Topic Papers are available from the NPC website (npc.org) on the following technologies:

  1. Energy Efficiency
  2. Methane Abatement, and
  3. Geothermal

2. EXECUTIVE SUMMARY

For more than a century, U.S. consumers have relied on the U.S. oil and gas industry to provide safe, reliable, and secure energy wherever and whenever it is needed. In recent years, the country's energy position has changed. The United States went from being the world's largest importer of oil to be the world's largest producer of oil and natural gas, and the world's leading exporter of liquefied natural gas (LNG). The United States has attained a level of energy security that would not have been imagined a decade and a half ago. Moreover, this year, U.S. energy has become a foundation for European energy security in light of the Ukraine war, and America's energy strength has given a new dimension to the NATO alliance. This has all been accomplished with a partnership between the U.S. industry and the U.S. government.

Today, the energy industry in the United States and worldwide is in the midst of a major transition – to continue to provide energy needed for economic growth, poverty reduction, and well-being while reducing greenhouse gas (GHG) emissions. This "energy and emissions transition" has taken on increasing urgency, and it will be more challenging and consequential than previous transitions and will require continued and even closer partnership between industry and government. The U.S. oil the gas industry will be critical and essential to meeting the net-zero emission targets for the United States. And the capabilities it develops and deploys will also be applied around the world, providing a major contribution for meeting global targets for emission reduction.

There are a wide spectrum of technologies and pathways that will be necessary to reduce emissions across various end-use sectors. This report focuses on initiatives that the U.S. oil and gas industry is taking to advance decarbonization and the actions the U.S. government can take to help ensure a more manageable transition to a net-zero economy by working in partnership with the industry.

Broadly, there are several critical considerations to be taken into account to enable a successful transition over the future decades:

> ***Transition should be source agnostic.*** Climate ambitions should be targeted on the net reduction of GHG emissions, i.e., "emissions transition," not the elimination of specific energy sources. Rigid views on hydrocarbon vs. non-hydrocarbon energy sources may lead to an unmanageable transition, political turbulence, and potential pain for consumers. Over 750 million people around the world lack access to electricity and some 2.6 billion people do not have access to clean cooking. Satisfying this growth in energy demand responsibly, reliably, and affordably will take an all-of-the-above approach, at least in the near and the medium term.
>
> ***Increased technology collaboration is required to accelerate transition*.** According to the IEA (*Net Zero by 2050: A Roadmap for the Global Energy Sector*, 2020), globally almost half of the emissions savings needed by 2050 to reach net zero rely on technologies that are not

yet commercially available. The United States has the technology ecosystem necessary to reduce its emissions — from fundamental research to deployment. Universities, national labs, small companies, and large companies need to work together and in parallel to advance technologies. Government policy and DOE funding can be used for early deployment. DOE has announced focus areas including carbon capture and sequestration (CCS), direct air capture (DAC), biofuels, hydrogen, and geothermal. Industry R&D can be done in collaboration with DOE National Labs and universities to accelerate technology development and deployment.

Policy support is necessary to accelerate deployment and cost reductions. Technologies including CCS, DAC, biofuels, and hydrogen need to be deployed at scale to achieve emission reductions. Technologies to reduce carbon intensity of traditional energy, some already in use, should continue to be deployed. The oil and gas industry is developing new projects for CCS and low emission hydrogen: these include a recently announced hydrogen/ CCS project in Texas and a CCS project to decarbonize the industrial sector in Louisiana. The Inflation Reduction Act (IRA) provides timely support to progress new projects. While the industry deploys available technology, roadmaps detailing the pathway to lowering cost through deployments should be developed for each technology area (e.g., hydrogen). The focus for the next decade should on accelerating the deployment of current technologies while developing improved technology options. Following the success of solar and wind, technologies such as improved CCS (including direct air capture), lower carbon hydrogen, and geothermal can advance up the learning curve and down the cost curve over the next decade. IRA and DOE Earthshots can enable some of the funding. National labs can serve as test beds.

The oil and gas industry has an essential role to play to reduce emissions. Oil and gas and adjacent industries (power, petrochemicals, transportation) will play a foundational role in reducing emissions and deploying clean energy solutions of tomorrow. Tax credits and R&D support over the years enabled solar photovoltaics (PV) and wind to become commercially viable. Biofuels and hydrogen will be necessary to decarbonize high carbon intensity transportation and manufacturing. Capturing emissions already in atmosphere and getting to net zero will require deployment of CCS and DAC technologies at scale. The oil and gas industry is applying its capabilities and investing in research to develop and start deploying these technologies. It brings to bear the market scale, technical capabilities, access to capital, and talent to help deliver the infrastructure, technology, and commercial innovations required for an effective transition. There are natural synergies between the traditional energy industry and modern renewables in satisfying the full spectrum of consumer and market needs. A level playing field and equal access to energy transition opportunities for traditional and emerging energy players will lead to better – and quicker – outcomes.

Federal, state, and local governments also have essential roles to play. Government policies can affect industry actions and investments in fundamental and profound ways, both positively and negatively. Getting to net zero will be a marathon spanning decades – requiring strategic vision, consistency, and steadfast approach. Stable and predictable policies that support investments over a long time as well as supporting permitting for new energy infrastructure that will be necessary to bring clean energy to markets and reduce emissions will be necessary for manageable transition. Government policies will significantly influence where and when companies deploy capital and know-how in the global race to get to net zero.

Policies that inadvertently cause shortages and consumer pain should be avoided. Context and unintended consequences of policies should be assessed to avoid contributing to crises and shortfalls that impose burdens on the public that can be avoided. Policies should be based on the overall supply-demand picture and realistic views of scale and pace of deployment of new technologies. To assure supplies and facilitate transition, permitting needs to be made more rational and predictable. In addition, attention needs to be given to the availability of the much greater and reliable supply of minerals that will be required for the energy transition.

Energy transition will require significant new investments. Energy providers, governments, and consumers will face competing choices to balance the "three-legged stool" of energy security, energy affordability, and environmental stewardship. Alignment between industry actions and government policies will be necessary to balance the tradeoffs. Although estimates vary, reaching net zero by 2050 (or 2060/2070 in terms of China and India, respectively) will require significant additional investments. These investments will have to be made up front, while benefits will accrue gradually and over a long time. Industry and government need to work in close partnership not only to deliver on lower emissions but also to communicate the benefits as well as the challenges of transitioning to net zero.

3. RECOMMENDATIONS

Smart policy will enable a well-managed energy transition in the United States:

- Energy transition policy should focus on the reduction of carbon emissions and providing stable incentives to energy innovation. It should avoid selecting favorite technologies, industries, or business models.
- Given the uniqueness of the U.S. energy endowment, it would not be constructive to seek to replicate wholesale energy transition-focused policy from outside of the United States. U.S. transition policy needs to take into account the exceptional range of domestic sources available. Failure to do so could constrain the achievement of timely and optimal solutions to balance energy security, affordability, and transition to lower emissions.
- Permitting needs to be made more coherent and more predictable – and timely to achieve a successful transition and to avoid driving up costs that consumers will bear. Infrastructure permitting – critical for the execution of transition projects – should be accelerated.
- Premature intervention to phase out traditional sources of energy will jeopardize just transition and energy equity and will increase the likelihood of recurrent energy crises as demand pushes against the limits of supply. Delays in permitting have a direct impact on energy security and affordability, and impose higher costs, with disproportionate impact on those least able to pay. Decarbonization policy should recognize the fundamental differences in requirements among sectors such as agriculture, domestic power generation, ocean faring shipping, steel manufacturing, personal vehicles, etc. Consumers in each sector have unique characteristics in areas such as market scale, reliability, resources, and affordability.
- Seeking to accelerate transition through punitive interventions in traditional energy will create threats to energy security and affordability for the American consumers — therefore, the policy intervention path to energy transition would do best to focus on adding renewable energy capacity via incentives, not subtracting traditional energy capacity via penalties. Continuing priority should be put on policies that support innovation towards lower emissions across the energy spectrum.
- Policy formulation should be informed by considerations and context in addition to emissions. Non-GHG environmental considerations, energy security, diversity of supply, robustness of the economy to unforeseen (geo-political) shocks, mineral supply chains — all these should be part of the equation in developing energy transition policy.
- Increased technology collaboration will be required to accelerate transition. The United States has the technology ecosystem necessary to reduce its emissions — from

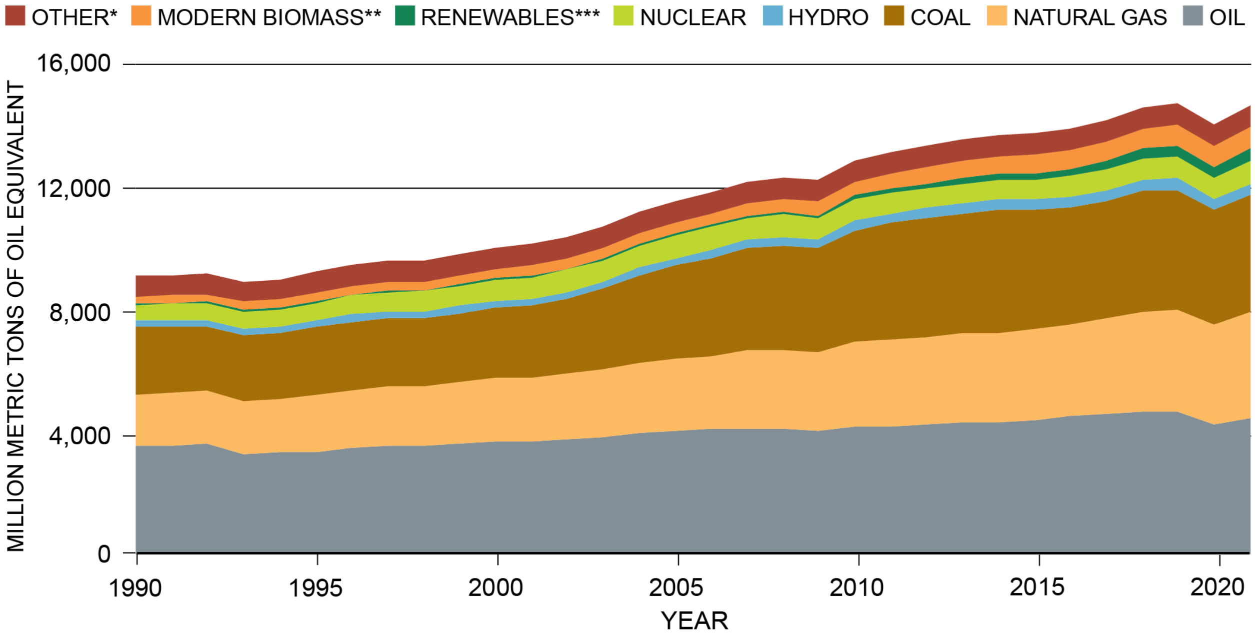
fundamental research to deployment. Universities, national labs, small companies, and large companies need to work together and in parallel to advance technologies.

- Government policy and DOE funding should continue to accelerate innovation and deployment of the following technologies discussed in this report as well other relevant technologies needed to reduce emissions:
    - Energy efficiency
    - Methane abatement
    - Carbon capture and sequestration
    - Direct air capture
    - Hydrogen
    - Renewable fuels
    - Geothermal.
- Managing the impact on consumers is vital for a well-managed and fair transition. Accelerating the energy transition will inevitably translate to more cost to the consumer in the short to medium term – either directly via product pricing, or indirectly via taxes required to fund incentives and subsidies. Without the support of consumers, who are also voters, a constructive energy transition is not feasible. Industry and government need to work together to find solutions that the customer can afford, be clear about the challenges of transition, and be an active supporter and partner in the development and deployment of technologies across the energy spectrum that bring down emissions.

4. BACKGROUND AND CONTEXT

4.1 Global Context – Energy and Emissions

Energy powers the modern economy and fuels economic growth worldwide. Global GDP has grown more than four-fold from about $24 trillion in 1990 to about $100 trillion in 2022. During the same period, the total primary energy consumption globally has increased by only about 65% due to significant improvement in energy productivity. Most of this growth in demand has been supplied by hydrocarbons (Figure 2).



* Includes solid waste, traditional biomass (used in the domestic sectors; inlcudes charcoal, wood, bagasse), ambient heat, and net trade of electricity and heat.

** Includes biofuels in transport and biomass used in industry, power generation, district heating and refineries.

*** Includes solar, wind, geothermal and tide/wave/ocean energy.

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Figure 2. Global Primary Energy Demand by Fuel

The share of hydrocarbons in the primary energy mix globally has remain unchanged at about 80% over the last 20 years (Table 1). During the same period, in power generation, the share of oil, gas, and coal has also remained almost constant at around 65%. Share of renewables in power generation globally has grown from negligible to about 8% and share of nuclear energy has declined by about 7%, i.e., one "clean" source of power has been replaced by another. In essence, the last two decades have primarily been all about "energy addition."

Globally, GHG emissions from human activity have increased from about 31 gigatons of CO_2 equivalent (CO_2e) in 1990 to 48 gigatons of CO_2e in 2019. Extraction, transportation, and use of hydrocarbons is the major source of GHG emissions.[1] Emissions declined by about 6% in

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[1] Agriculture contributes some 25% of global GHG emissions but is excluded from this report.

2020 when the global economy shrank significantly due to Covid — in essence demonstrating the magnitude of the challenge to reduce emissions.

Table 1. Global Primary Energy Mix, 2000 vs. 2019

Fuel Mix Primary Energy				Fuel Mix Electricity		
coal/oil/gas ~80%				coal/oil/gas ~63-65%		
	2000	**2019**			**2000**	**2019**
Coal	23%	26%		Coal	39%	38%
Oil	36%	31%		Oil	8%	2%
Gas	21%	23%		Gas	18%	23%
Nuclear	7%	5%		Nuclear	17%	10%
Hydro	2%	3%		Hydro	17%	16%
Biomass	10%	10%		Biomass	1%	3%
Renewables	1%	2%		Renewables	0%	8% (including solar and wind)

Source: Copyright 2022 S&P Global Inc: All rights reserved.

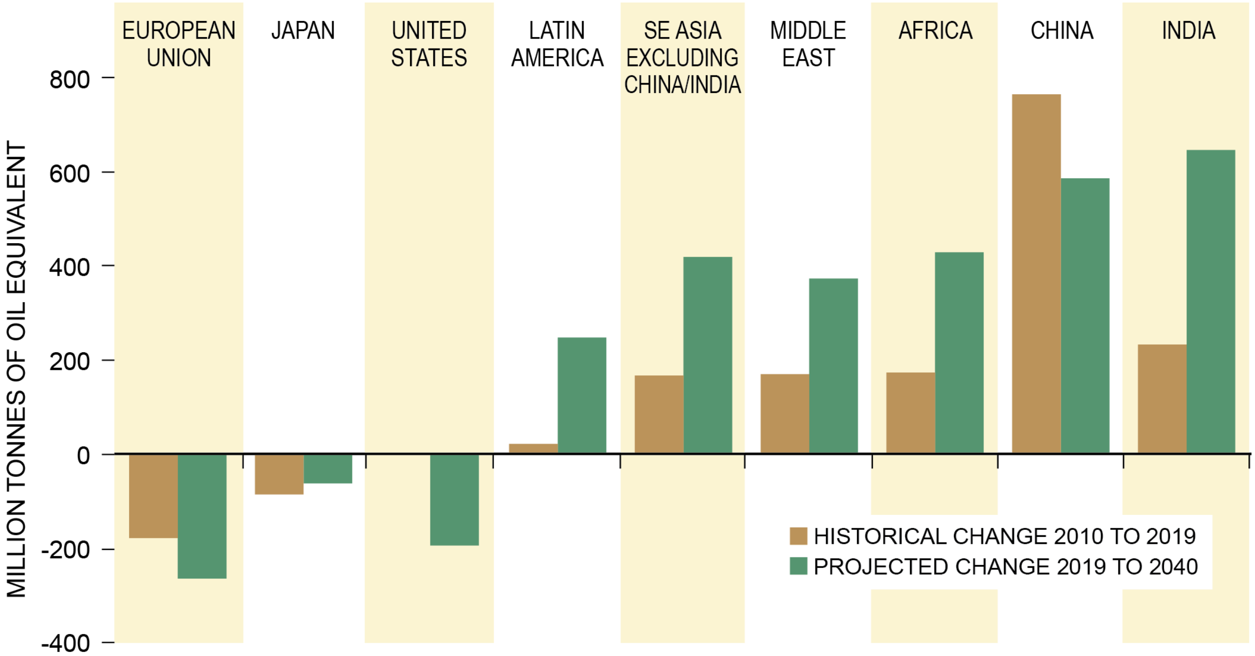
Today, the world is facing the unparalleled challenge to decrease global emissions while continuing to provide affordable and reliable energy to growing population with increasing incomes and resulting energy use. This is now coupled with the need for energy security within a challenging new geopolitical landscape. Balancing the demands of energy affordability, energy security, and sustainability is the major challenge for governments, industry, and consumers. Russia's February 2022 invasion of Ukraine and the impact on global markets is a stark reminder that there cannot be significant and timely progress on net-zero goals and energy transition without energy security.

4.2 Energy Demand and Energy Access

The United Nations estimates that the global population will be almost ten billion people by 2050. Most of this population growth will come from emerging economies. With more population, and with rising incomes, comes more demand for energy. It was only in 2013 that the developing world overtook the developed world as the leading consumer of oil. Energy demand is expected to increase by about 50% over the next 30 years and with most of the growth anticipated to come from developing world (Figure 3). To meet the world's energy needs and support development of these emerging economies, investment in all forms of energy will be required — an all-of-the-above approach.

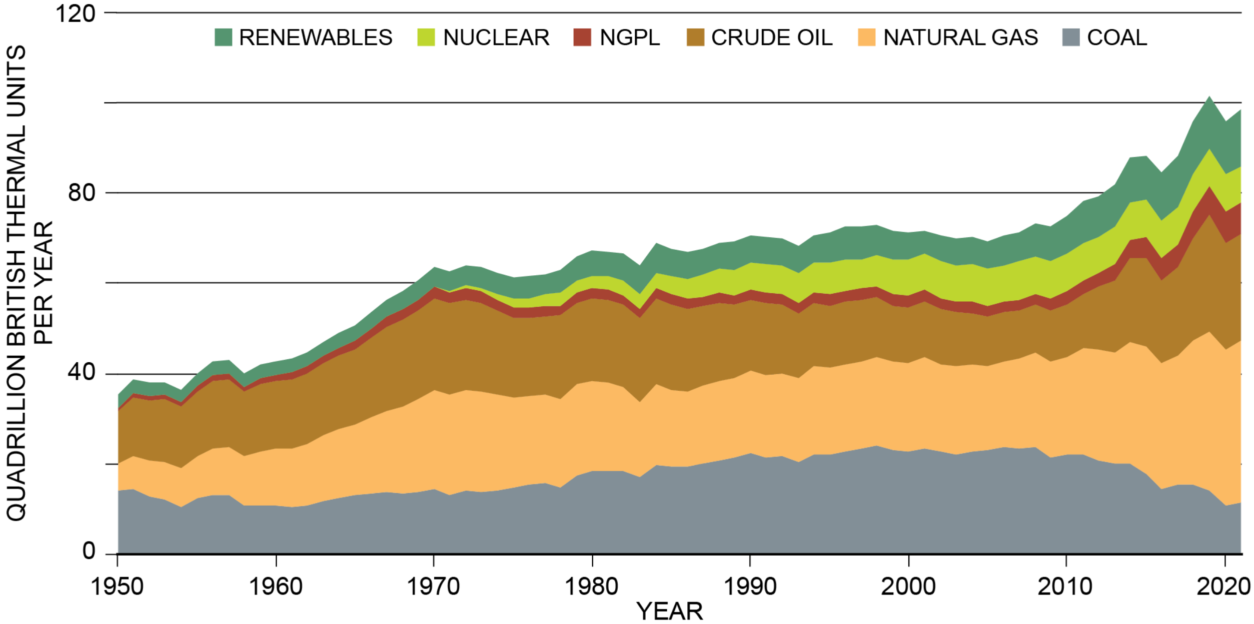
4.3 U.S. Context

The United States enjoys a comparative advantage due to its energy resource endowments. Hydrocarbons have been the predominant source of primary energy in the United States for more than a century, although the mix has changed over the years (Figure 4). U.S. domestic oil and gas resources have played a fundamental role in supporting the nation's energy security.



Source: International Energy Agency Stated Policies Scenario. 2020.

Figure 3. Change in Primary Energy Use, Past and Future

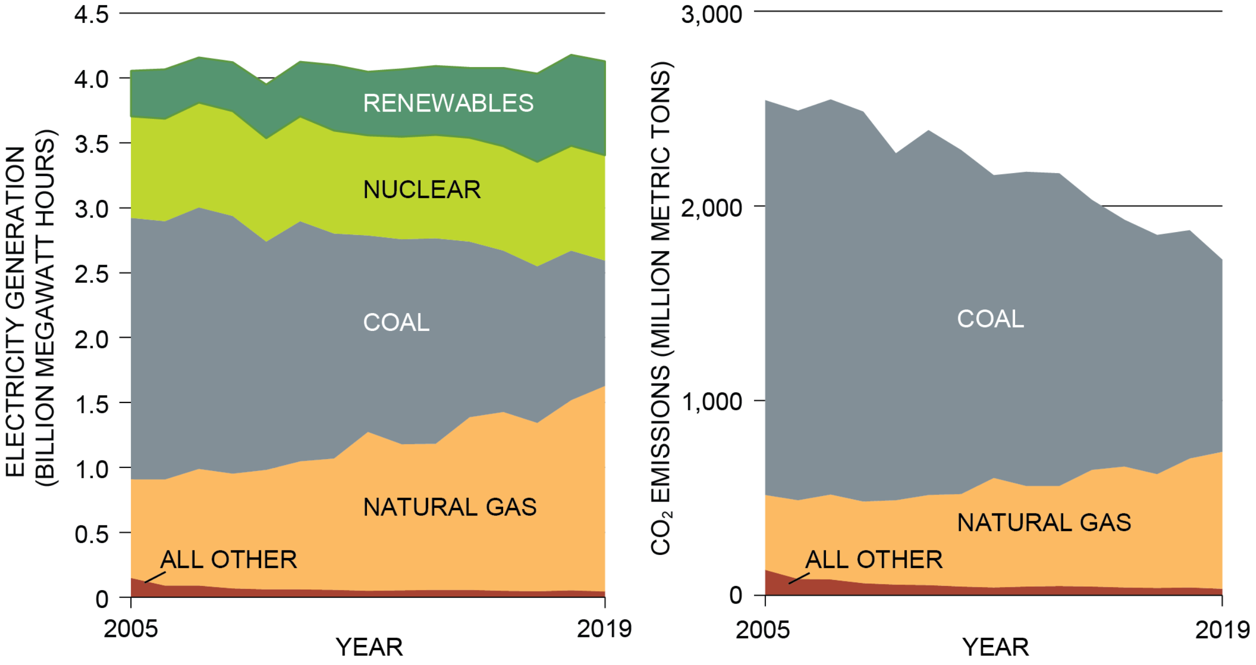


Data source: U.S. Energy Information Administration, *Monthly Energy Review,* Table 1.2, April 2022, preliminary data for 2021.
Note: NGPL is natural gas plant liquids.

Figure 4. U.S. Primary Energy Production by Major Source, 1950-2021

Over the past 15 years, the U.S. electricity generation mix has shifted away from coal and toward natural gas and renewables, resulting in lower CO_2 emissions. In 2019, the U.S. electric power sector produced about 32% less CO_2 than in 2005. Three factors contributed to lower CO_2 emissions in the power sector: gas replacing coal, increased efficiency, and growth in deployment of renewables. All were underpinned by technological developments and improved operating performance. Renewables and efficiency improvements benefited from policy support including incentives.

In 2005, 50% of electricity generation in the United States came from coal and 19% from natural gas. By 2019, share of coal in power generation had declined to 23% and share of natural gas had increased to 38% (Figure 5).



Source: U.S. Energy Information Administration, Power Plant Operations Report.

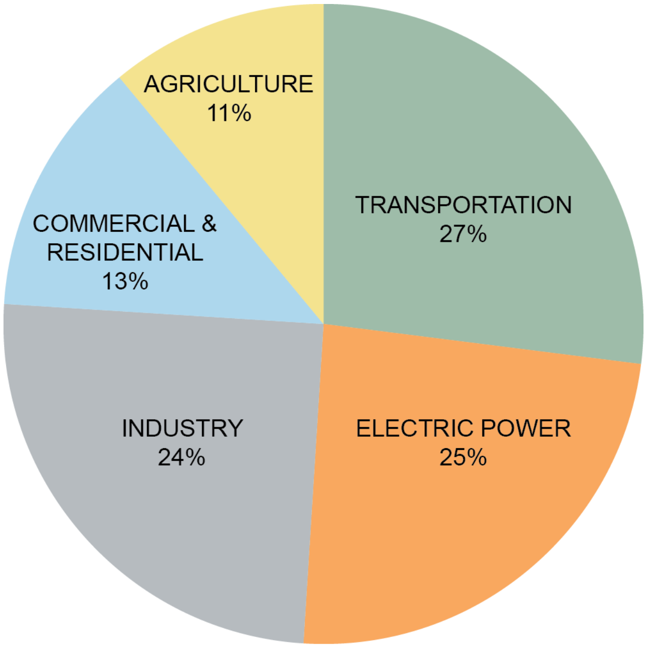
Figure 5. U.S. Electricity Generation and CO_2 Emissions by Source (2005-2019)

Oil makes up about 36% of U.S. primary energy consumption. It has many roles in the U.S. economy — oil provides 90% of the energy for transportation, but also has many other uses — from garments to pharmaceuticals. Gas provides 32% of primary energy supply in the United States and is the primary fuel for industrial, residential, and commercial sectors. Nearly 187 million Americans and 5.5 million businesses use natural gas. More than 50% of American households currently use natural gas as a heating fuel and it is used for industrial heat and in the manufacture of plastics, fertilizer, and many other products.

Renewables, coal, and nuclear make up 12%, 11%, and 8%, respectively, of the primary energy supply in the United States, with almost all going towards power generation.

4.4 GHG Emissions in the United States

In 2020, total GHG emissions in the United States amounted to 5,981 million metric tons of CO_2 equivalent. Transportation, electric power generation, and industry each contributed to about a quarter of the emissions, with commercial and residential sectors and agriculture accounting for the last quarter (Figure 6).



Source: U.S. Environmental Protection Agency (2022). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2020.

Figure 6. Total U.S. GHG Emissions by Economic Sector in 2020

A wide spectrum of technologies will be necessary to reduce emissions from each of these sectors:

- In the electric power sector, fuel switching from coal to gas, increased use of nuclear, and increased end-use energy efficiency have all contributed to reduction in GHG emissions. Reducing venting, flaring, and methane leakage in production and transportation of natural gas will enable reduction in GHG emissions. Emission reducing technologies such as carbon capture and sequestration (CCS) and hydrogen co-firing will allow the sector to produce low-carbon power.
- In the transportation sector, fuel switching including biofuels, hydrogen, and electricity from renewable sources will enable reduction in emissions. In addition, increased fuel efficiency using advanced design and materials is making vehicles more fuel efficient.
- The industrial sector includes manufacturing of materials and products that are used in daily life — steel, cement, fertilizers, glass, paper, refining, and petrochemicals. Many of these processes require heat, which is generated using natural gas and coal. In the

future, hydrogen from various sources could provide the fuel necessary for these processes. CCS will be necessary to produce low carbon “blue” hydrogen for industrial decarbonization. Negative emission technologies such as direct air capture (DAC) and nature-based solutions (NBS) will also be necessary to achieve “net-zero” emissions.

- In the commercial and industrial sectors, reducing energy use through energy efficiency such as better insulation, efficient lighting, and waste heat capture and reuse are some of the technologies to reduce emissions. In addition, renewables and geothermal could offer pathways for decarbonizing space heating and cooling.

Section 6 of this report, Technologies Necessary to Achieve Net Zero, describes the status and future roadmap for these technologies. Opportunities where the oil and gas industry and the Department of Energy can collaborate to accelerate deployment of these technologies are also outlined.

4.5 Role of the U.S. Oil and Gas Industry

The U.S. oil and gas industry will play a key part in reducing emissions and in developing new supplies of energy over the next decades. Many companies in the industry have the scale and technical capabilities to implement complex projects, access capital, and the talent and technical skills necessary to deliver the infrastructure, technology, and commercial innovations required for this transition. As an example, upgrading our nation’s pipeline network since 1990 has resulted in 69% reduction in emissions from the natural gas distribution system.[2]

The United States has the unique capability of being able to continue to reduce energy-related emissions through lower-emission oil and natural gas, while building the supply chain and infrastructure for the transition to a low-carbon energy system. This can be best achieved if industry and government work together to find solutions that consumers can afford, and to be transparent about the pace and costs of transition. Several industry-wide initiatives[3] have been launched to push for lower emissions.

Many energy companies operating in the United States are also global companies, and at any given time they have more opportunities to invest globally in new projects than they can simultaneously afford. Choices must be made; project prioritization happens against a global slate of opportunities. Therefore, investments in U.S.-based projects to develop technologies, scale up commercial models, and pilot new energies need to compare favorably against similar

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[2] American Gas Association, *Net-Zero Emissions Opportunities for Gas Utilities,* 2021, page 2, https://www.aga.org/wp-content/uploads/2022/02/aga-net-zero-emissions-opportunities-for-gas-utilities.pdf.

[3] The Oil and Gas Climate Initiative (OGCI) brings together 12 of the largest oil and gas companies worldwide to lead the industry’s response to climate change. OGCI members are Aramco, bp, Chevron, CNPC, Eni, Equinor, ExxonMobil, Occidental, Petrobras, Repsol, Shell, and TotalEnergies, representing about 30% of global oil and gas production.

investments in other countries. The United States is in a global competition for energy transition capital and should position its policies to recognize this reality.

Energy transition's critical path runs – and will always run – through permitted infrastructure and supportive policies. All transition paths that lead to affordable renewable energy depend on infrastructure such as grid transmission lines and charging stations, pipelines, thousands of onshore and offshore wind turbines, and liquefaction terminals. In the future, there will be new and additional infrastructure needs – CO_2 pipelines, citing of DAC and hydrogen plants, and onshore and offshore CO_2 storage locations. These infrastructure investments will require much faster U.S. regulatory review and approvals than is the case today. At present, it takes an average of ten years to permit an overhead transmission line; other infrastructure asset classes are similarly – or more – challenged.[4] To be successful, any pathway to achieve net-zero emissions will require the support of policymakers, regulators, and customers, along with investment into infrastructure and emerging technologies.

Beyond infrastructure support, key policy considerations include shaping future energy demand by expanding energy efficiency and promoting emerging technologies, supplying renewable and low-carbon fuels, scaling up geothermal, reducing emissions from energy operations and pipelines, and improving and utilizing negative emissions technologies. The preferred mix of measures will ultimately vary by region and state. Further analyses that account for highly localized considerations, including costs and impacts on consumers, communities, and the economy, will be needed to study transition paths and their overall impact to U.S. consumers.

4.6 Just Transition

Although there is no single definition of "just transition" – it varies depending on context, geography, and economic standing – it is based on a set of principles and practices. In developed countries, just transition is about ensuring that people affected by transition are considered by those making the decisions and that previous harms are remedied. By contrast, in emerging economies and communities, just transition is about access to energy and reducing reliance on wood and biomass. Achieving just transition in the United States will require addressing the environmental burdens on minority communities and the dislocations faced by workers and communities that are dependent on the current energy economy, and ensuring that the benefits of the transition are shared equitably across communities.

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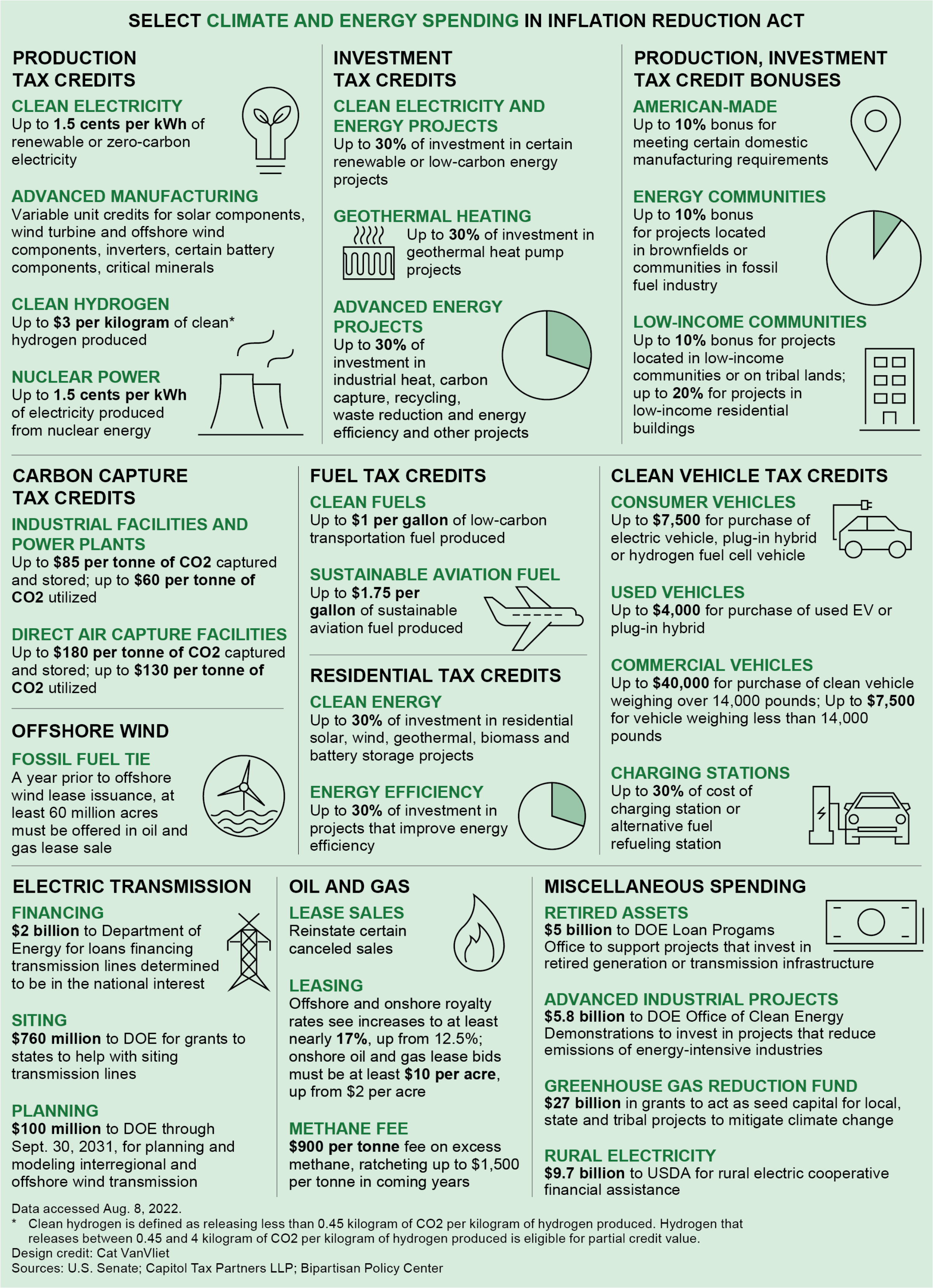
[4] National Petroleum Council, *Dynamic Delivery: America's Evolving Oil and Natural Gas Transportation Infrastructure,* 2019. https://dynamicdelivery.npc.org/

4.7 Inflation Reduction Act

In August 2022, President Biden signed the Inflation Reduction Act (IRA). This landmark legislation will significantly accelerate U.S. clean energy efforts. IRA provides nearly $370 billion in federal funding and financial incentives for clean energy (Figure 7). Incentives in the IRA are expected to lead to:

- Reduction in oil and gas-related methane emissions
- Improvement of economics for CCS, DAC, and hydrogen
- Growth in sustainable aviation fuels
- Improvement to solar and wind economics
- Build-out of manufacturing for renewable power equipment and battery supply chains
- Benefits to energy storage projects
- Increased production and demand for electric vehicles.

Further support, in particular permitting reforms, will be required to unlock the full potential.



SELECT CLIMATE AND ENERGY SPENDING IN INFLATION REDUCTION ACT

PRODUCTION TAX CREDITS

CLEAN ELECTRICITY
Up to **1.5 cents per kWh** of renewable or zero-carbon electricity

ADVANCED MANUFACTURING
Variable unit credits for solar components, wind turbine and offshore wind components, inverters, certain battery components, critical minerals

CLEAN HYDROGEN
Up to **$3 per kilogram** of clean* hydrogen produced

NUCLEAR POWER
Up to **1.5 cents per kWh** of electricity produced from nuclear energy

INVESTMENT TAX CREDITS

CLEAN ELECTRICITY AND ENERGY PROJECTS
Up to **30%** of investment in certain renewable or low-carbon energy projects

GEOTHERMAL HEATING
Up to **30%** of investment in geothermal heat pump projects

ADVANCED ENERGY PROJECTS
Up to **30%** of investment in industrial heat, carbon capture, recycling, waste reduction and energy efficiency and other projects

PRODUCTION, INVESTMENT TAX CREDIT BONUSES

AMERICAN-MADE
Up to **10%** bonus for meeting certain domestic manufacturing requirements

ENERGY COMMUNITIES
Up to **10%** bonus for projects located in brownfields or communities in fossil fuel industry

LOW-INCOME COMMUNITIES
Up to **10%** bonus for projects located in low-income communities or on tribal lands; up to **20%** for projects in low-income residential buildings

CARBON CAPTURE TAX CREDITS

INDUSTRIAL FACILITIES AND POWER PLANTS
Up to **$85 per tonne of CO2** captured and stored; up to **$60 per tonne of CO2** utilized

DIRECT AIR CAPTURE FACILITIES
Up to **$180 per tonne of CO2** captured and stored; up to **$130 per tonne of CO2** utilized

OFFSHORE WIND

FOSSIL FUEL TIE
A year prior to offshore wind lease issuance, at least 60 million acres must be offered in oil and gas lease sale

FUEL TAX CREDITS

CLEAN FUELS
Up to **$1 per gallon** of low-carbon transportation fuel produced

SUSTAINABLE AVIATION FUEL
Up to **$1.75 per gallon** of sustainable aviation fuel produced

RESIDENTIAL TAX CREDITS

CLEAN ENERGY
Up to **30%** of investment in residential solar, wind, geothermal, biomass and battery storage projects

ENERGY EFFICIENCY
Up to **30%** of investment in projects that improve energy efficiency

CLEAN VEHICLE TAX CREDITS

CONSUMER VEHICLES
Up to **$7,500** for purchase of electric vehicle, plug-in hybrid or hydrogen fuel cell vehicle

USED VEHICLES
Up to **$4,000** for purchase of used EV or plug-in hybrid

COMMERCIAL VEHICLES
Up to **$40,000** for purchase of clean vehicle weighing over 14,000 pounds; Up to **$7,500** for vehicle weighing less than 14,000 pounds

CHARGING STATIONS
Up to **30%** of cost of charging station or alternative fuel refueling station

ELECTRIC TRANSMISSION

FINANCING
$2 billion to Department of Energy for loans financing transmission lines determined to be in the national interest

SITING
$760 million to DOE for grants to states to help with siting transmission lines

PLANNING
$100 million to DOE through Sept. 30, 2031, for planning and modeling interregional and offshore wind transmission

OIL AND GAS

LEASE SALES
Reinstate certain canceled sales

LEASING
Offshore and onshore royalty rates see increases to at least nearly **17%**, up from 12.5%; onshore oil and gas lease bids must be at least **$10 per acre**, up from $2 per acre

METHANE FEE
$900 per tonne fee on excess methane, ratcheting up to $1,500 per tonne in coming years

MISCELLANEOUS SPENDING

RETIRED ASSETS
$5 billion to DOE Loan Progams Office to support projects that invest in retired generation or transmission infrastructure

ADVANCED INDUSTRIAL PROJECTS
$5.8 billion to DOE Office of Clean Energy Demonstrations to invest in projects that reduce emissions of energy-intensive industries

GREENHOUSE GAS REDUCTION FUND
$27 billion in grants to act as seed capital for local, state and tribal projects to mitigate climate change

RURAL ELECTRICITY
$9.7 billion to USDA for rural electric cooperative financial assistance

Data accessed Aug. 8, 2022.

* Clean hydrogen is defined as releasing less than 0.45 kilogram of CO2 per kilogram of hydrogen produced. Hydrogen that releases between 0.45 and 4 kilogram of CO2 per kilogram of hydrogen produced is eligible for partial credit value.

Design credit: Cat VanVliet

Sources: U.S. Senate; Capitol Tax Partners LLP; Bipartisan Policy Center

Figure 7. Select Climate and Energy Spending in Inflation Reduction Act

5. ENERGY TRANSITIONS

5.1 Energy Transitions – Evolution Not Revolution

Energy transitions have been multi-faceted and overlapping. Biomass (wood, straw, animal waste) is the energy source from which the world transitioned into coal. Yet even that initial transition is far from finished. Globally, more than 2.6 billion people do not have access to clean cooking. For these people, including much of the population in sub-Saharan Africa, the shift from biomass to liquefied petroleum gas (LPG) for cooking will be a 21st century energy transition that will reduce emissions, improve health and livelihood, and spare women the many hours spent gathering wood.

Staggering growth in energy demand appears ahead, even with continuing improvement in the efficiency by which energy is consumed. But that growth will come with an imperative – to reduce emissions. That is what has become known as the energy transition. Energy transitions are not new. But this one is different because of that imperative to reduce emissions while at the same time enabling energy consumption to continue to grow.

Two other key differences are the speed and totality at which it is aimed. In prior transitions, externalities such as the impact and cost of emissions were not considered. These differentiators make this transition more challenging than any previous energy transitions.

Because this transition is driven more by policy and market interventions aimed at reducing emissions, it is further unlike all preceding ones, which primarily were driven by market economics and technology. Previous energy transitions have unfolded over a century or more, not in a quarter of a century. Moreover, energy transitions have not reduced or replaced the existing energy base before the new energy base was ready; instead, they resulted from new sources being added atop the existing mix.[5]

Coal's share of primary energy peaked during the 1920s; however, the amount of coal the world is using will reach a new peak in absolute terms in 2022. Oil (while ascending in absolute terms) began losing share by 1980s. Natural gas use has been rising globally, driven by its low relative cost and an abundant resource base, including shale gas in the United States. Modern renewables have risen fast since the 1990s but supplied about 8% of electricity globally in 2019. Geothermal, whose share is still very small, has more potential to grow in the future.

In short, global energy systems cannot be rebuilt overnight. Capital stock, i.e., *hardware* has lifespan of decades and cannot be changed overnight, as is the case with *software*. Energy transitions take time and cannot be summarily imposed (Figure 8).

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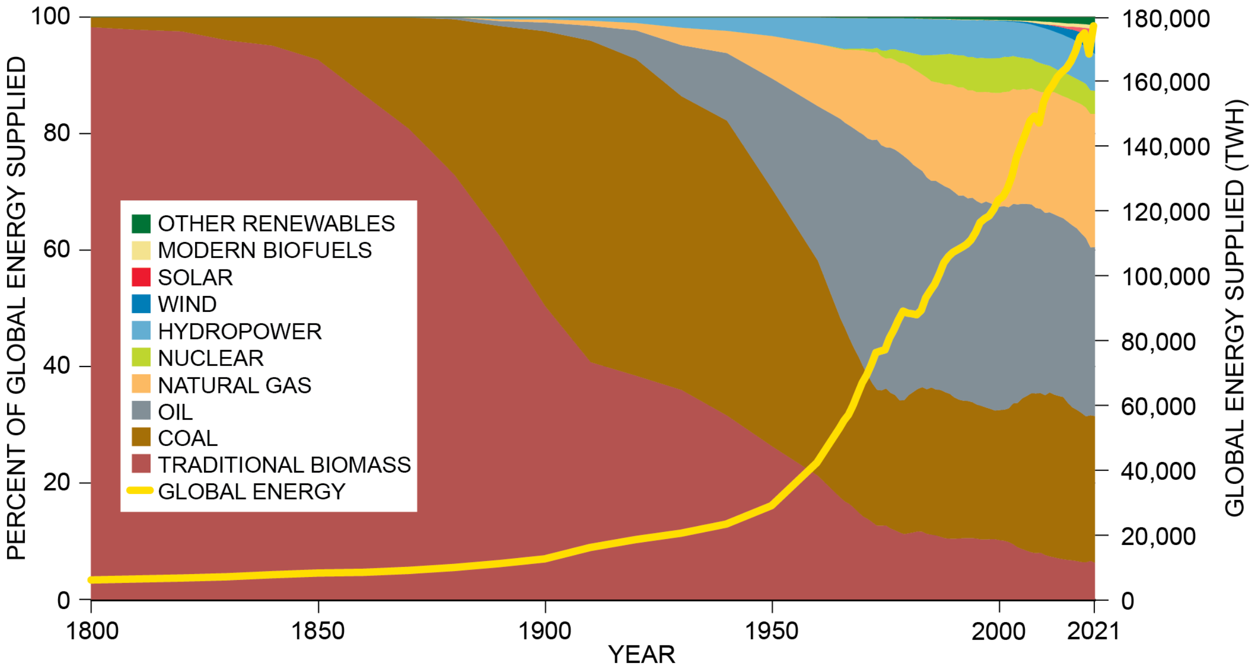
[5] Daniel Yergin, *The New Map: Energy, Climate, and the Clash of Nations* (New York: Penguin, 2021)



Source: Our World in Data (https://ourworldindata.org), based on Vaclav Smil (2017) and *BP Statistical Review of World Energy.*

Figure 8. Energy Transitions Take Time

Over the last 60 years, the combination of energy density, reliability, and affordability have favored the reliance on coal, oil, and gas. Hydrocarbons have made up 80% of the energy mix owing to their characteristics — deliverability. In terms of energy density, gasoline is ten quadrillion times more energy-dense than solar radiation, one billion times more energy-dense than wind and hydropower, and ten million times more energy-dense than human power (*International Journal of Green Energy, 5: 438–455, 2008*). Table 2 gives further indication of comparability of different energy systems.

Table 2. Energy Density of Various Energy Sources

Energy Type	Energy Density (in watts per meter square)
Hydrocarbons	500-10,000
Nuclear	500-1,000
Solar	5-20
Hydropower	5-50
Wind	1-2
Wood / Biomass	<1

As the global energy system transition from high energy density sources (hydrocarbons) to lower energy density sources (solar, wind, biomass), the land requirements for energy production, transport, and transmission will increase proportionately. This will add further challenges in countries and regions with dense populations and limited availability of land for new energy infrastructure.

5.2 Energy Transition – Challenges

The global consensus around the need for an emissions-focused energy transition has become consistently stronger. Yet challenges to achieving it have also become more evident. One challenge is obvious – the uncertain pace of technological development and deployment and the timing required to reach scale. After all, the modern solar and wind industries were born in the 1970s and 1980s but did not become economically competitive and achieve scale until the second decade of the 21st century, supported by government policies and incentives around the world.

Four other challenges are evident:

i. The return of energy security and its embrace as a prime requirement for countries
ii. Lack of consensus on how fast the transition should and can take place, in part because of its potential economic disruptions
iii. A sharpening divide between advanced and developing economies on priorities and costs in the transition
iv. Obstacles to expanding mining and building the supply chains for the minerals needed for the net-zero objective.

The need for energy security was a concern that had largely faded over the past several years. It had been a primary concern for the United States since the 1970s but had slipped away with the shale revolution. Europe became comfortable with heavy dependence on Russian natural gas, without developing corresponding energy security structures. The energy shock, the economic hardship that ensued, skyrocketing energy prices that could not have been imagined 18 months ago, and geopolitical competition and conflicts – all these have combined to bring energy security back to the fore. Experience indicates that the energy transition needs to be based in energy security — that is, adequate and reasonably priced supplies — to assure public support and avoid disruptions.

Building out energy systems with lower emissions should not conflict with ensuring that the current energy system can continue to function adequately and with continuous efforts to reduce its emissions. What can be described as “preemptive underinvestment” in conventional energy sources rests on an assumption – stated or unstated – that the alternative energy system is up and running at scale, which is not the case. The consequence of this preemptive underinvestment could be shortages, price shocks, and turbulence that undermine the energy transition. An energy transition that is subject to recurrent crises will not be one that delivers the results that are envisioned.

The second challenge goes back to the timing of the energy transition itself. How fast should it—and can it—proceed? Can 2050 goals be accelerated into 2030? The nature of what is being attempted can be underestimated considering the scale, complexity, and the interconnectedness of the global energy system. Each of the preceding transitions unfolded over a century or more, and none were the type of transition currently envisioned. "Ambition" is a word that is much used for today's energy transition. But it is notable that what is being targeted is a very big ambition, and that nothing on this scale has ever been attempted before.

Some have warned that because the scale of the transition is so large and far-reaching, the macroeconomic impact needs deeper analysis. The economist Jean Pisani-Ferry, co-founder of Bruegel – Europe's leading economic think tank – has observed that accelerating the targets for net carbon emission reductions too aggressively could create much larger economic disruptions than generally anticipated – what he called "an adverse supply shock – very much like the shocks of the 1970s." Such a transition, Pisani-Ferry wrote in 2021[6] is "unlikely to be benign and policymakers should get ready for tough choices." He subsequently added, in 2022: "Climate action has become a major macroeconomic issue … the policy conversation now needs methodical, peer-examined assessments of the potential costs and benefits of alternative plans for action."[7]

The third challenge is the emergence of a new North-South Divide — that is, a sharpening difference in perspective between developed and developing countries on how the transition should proceed. The original North-South Divide of the 1970s was a collision between developed and developing nations over the distribution of wealth and, in particular, the pricing of commodities and raw materials. That division faded with globalization and advances in technology, as reflected in the shift in nomenclature to "emerging market" nations.

The new North-South Divide goes beyond the question of "reparations" for climate damages. This divide reflects disagreement over climate and transition policies, the role of conventional energy, their impact on development, and who is responsible for cumulative and new emissions. The global commodity shocks triggered by the war in Ukraine and the interest rate increases and currency devaluations that have ensued have only deepened the pressures on developing countries.

For developing countries, too much emphasis on reducing emissions can sideline other urgent priorities—health, poverty, and economic growth. Many developing countries are basing their energy strategies on expanded use of natural gas, whether by pipeline or as liquefied natural gas (LNG). They see natural gas as critical for reducing indoor air pollution and emissions, as well as reducing the deforestation that comes with cutting trees that are used as

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[6] Jean Pisani-Ferry, "Climate Policy is Macroeconomic Policy, and the Implications will be Significant" (Peterson Institute for International Economics, 2021), https://www.piie.com/publications/policy-briefs/climate-policy-macroeconomic-policy-and-implications-will-be-significant.

[7] Jean Pisani-Ferry, "The Missing Macroeconomics in Climate Action" in S. Tagliapietra, G. Wolff, and G. Zachman, eds., Greening Europe's Post-Covid-19 Recovery, 2022, Bruegel, https://www.pisani-ferry.org/papers.

a domestic fuel. Particularly significant is the use of natural gas for meeting the growing need for electricity and as a pathway towards lower emissions and decarbonization. Gas is substituting for coal, widely used in developing countries, and thus contributing to significantly lowering emissions in a timely way. Expanded natural gas supplies are regarded as essential to fuel economic growth and industrial development, meet the need for expanded employment opportunities, and provide the energy at scale required for growing urbanization. It should be noted that in most developed economies, share of gas in primary energy mix is 20% or higher.

There is an obvious difference of perspectives when policies are being proposed by countries with per capita incomes 20 times higher than other countries. This is particularly evident in restrictions by financial institutions in developed countries on lending for energy projects in developing countries.

The fourth challenge will be assuring new supply chains for net zero. The passage in the United States of the Inflation Reduction Act, with its massive incentives and subsidies for renewable sources of energy, the RePowerEU plan in Europe, and similar initiatives elsewhere will accelerate the demand for the minerals that are the building blocks for renewable energy—which requires wind turbines, electric vehicles, and solar panels, among other things. A host of organizations—the IMF, the World Bank, the International Energy Agency (IEA), the U.S. government, the European Union, the Japanese government—have all issued studies on the urgency of those supply chains. The IEA projects that the world economy will be moving from "a fuel intensive to a mineral intensive energy system" that will "supercharge demand for critical minerals." In *The New Map,*[8] this is described as the move from "Big Oil" to "Big Shovels."

The Future of Copper: Will the Looming Supply Gap Short-Circuit the Energy Transition (S&P Global, 2022), focused on that metal because the thrust of the energy transition is towards electrification, and copper is "the metal of electrification." The study used 2050 targets stated by advanced countries and assessed what achieving those targets would require for specific applications—for instance, the different components of an offshore wind system or electric vehicles. An electric car, for example will require at least 2 ½ times more copper than a vehicle with a conventional internal combustion engine. The conclusion of this analysis is that copper supply would have to double by the mid-2030s to achieve the 2050 goals.

The chokepoint is supply. At the current rate of supply growth—which encompasses new mines, mine expansion and greater efficiency, and recycling, as well as substitution—the amount of copper available will be significantly smaller than the copper supply requirements. For instance, the IEA estimates that it takes 16 years from discovery to first production for a new mine. Some mining companies say more than 20 years. Permitting and environmental issues are major constraints around the world. Also, copper production is more concentrated

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[8] Daniel Yergin, *The New Map: Energy, Climate, and the Clash of Nations* (New York: Penguin, 2021).

than, say, oil. Three countries produced 40 percent of world oil in 2021—the United States, Saudi Arabia, and Russia. Just two countries produced 38 percent of copper—Chile and Peru.

The coming flood of "energy transition demand" will cause prices to rise and will likely create new tensions between resource-holding countries and mining companies, which in turn will slow the rate of investment. Moreover, as the race to net zero intensifies, there is a risk that the competition for minerals will become caught up in what has become known as the "great power competition" between China and the United States. The U.S. government's National Intelligence Council has already warned that access to minerals will become a major source of tension between the United States and China by the next decade.[9]

These challenges—energy security, macroeconomic impacts, the North-South Divide, and minerals—will each have significant effects on how the energy transition unfolds. All of that puts further emphasis on the nature, possibilities, and pacing of technological innovation. And that is the subject of the next section of this report, Technologies Necessary to Achieve Net Zero.

The focus in this next section is on the initiatives that the U.S. oil and gas industry is taking to lower emissions and decarbonize. While different companies are emphasizing different technologies and approaches, altogether it reflects the reality that the oil and gas industry will be an important contributor to the energy mix in the energy transition for decades to come. For instance, over the last two years, various scenarios from the International Energy Agency have shown, on a global basis, oil demand in 2050 ranging from its current level to 30 percent of its current level. Whatever the level turns out to be, the endeavors around decarbonization and the technology advances will be a significant factor in future demand for hydrocarbons.

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[9] National Intelligence Council, "Global Trends 2040, A More Contested World," 2021.

6. TECHNOLOGIES NECESSARY TO ACHIEVE NET ZERO

Technology is an integral part of providing safe, affordable, and scalable energy to society. The energy transition will be underpinned by technology development and deployment accompanied by supporting policies and infrastructure build. Many of the energy technologies deployed today were developed in the United States, many in collaboration between private companies, universities, and government labs.

Energy is unique in that it requires integration across all sciences and all engineering. The capabilities needed to progress energy solutions from discovery to scale range from basic math and chemistry to chemical and nuclear engineering, and increasingly digital. An evolving workforce with a wide range of capabilities will continue to be needed to discover, develop, and deploy energy solutions to meet society's needs while reducing emissions.

Integrating across policy, infrastructure and technology will allow a more parallel approach to the energy transition. A unique characteristic of energy is its enormous scale. Global energy consumption is about 260 million barrels of oil equivalent per day and increasing. Technologies for the energy transition will need to get on the deployment pathway towards scale. Today, the vast majority of needed technologies are not on track to meet the scale required (IEA).

The following sections will provide technology specific overviews and recommendations covering:

1. Energy Efficiency
2. Methane Abatement
3. Carbon Capture and Sequestration (CCS)
4. Direct Air Capture (DAC)
5. Hydrogen
6. Renewable Fuels
7. Geothermal

6.1 Energy Efficiency

Improved energy efficiency in oil & gas upstream, midstream, and processing is a key pathway to reduce emissions as part of the energy transition to a net-zero world. U.S. energy producers are global leaders in this arena. Industry reduced the greenhouse gas intensity of U.S. oil and natural gas production by 46%, since 2006, while nearly doubling domestic oil and gas production from 16 million barrels of oil equivalent to 30 million barrels of oil equivalent in 2020. These steps placed the United States among the lowest carbon-per-barrel producers in the world. Additional emissions reductions via energy efficiency remains a high priority for U.S. energy producers. These areas of priority are summarized in four broad categories of

Upstream Well Productivity, Methane Emissions, Electrification, and Refining Productivity. It should also be noted that end-users of oil and gas, including gas utilities and the industrial sector, are also working on methods to improve energy efficiency and reduce emissions, including efforts like promoting tighter building envelopes, efficient lighting, and waste heat capture and reuse technologies, but this section will focus solely on the development and processing of oil and gas.

6.1.1 Upstream Well Productivity

Oil and natural gas extraction is an energy-intensive process that consumes 3-4% of the overall energy produced from well (primary energy) to end-use consumer. Because the largest category of use is the energy consumed to create materials for, manufacture, and transport the rigs, pipes, cement, and other equipment, the industry has improved energy efficiency by improving productivity per well drilled, rig built, or stimulation fleet assembled.

To improve well productivity, operators have increased lateral length and improved fracturing technology, all of which allow operators to recover more resources with fewer wells, thus less embodied energy consumed per unit energy produced. Every major U.S. producing basin has seen substantial increases in per-rig production since 2007. Additionally, new per-well productivity in the Permian Basin grew five-fold since 2020, surpassing 1,000 barrels of oil equivalent resource recoverable per foot drilled (BOEF) in 2022.[10]

Digitalization has increased upstream well productivity. Advances allowed for drilling longer lateral distances in a single well bore. In the Permian Basin, average well horizontal length has increased by more than 6,000 feet since 2010, saving time and energy required to drill multiple vertical wellbores for nearly the same amount of resource.[11]

6.1.2 Methane Emissions and Field Flaring

U.S. oil and natural gas producers are taking MAJOR steps to reduce methane emissions and field flaring of gas, as these are losses of valuable product. With the addition of the methane tax introduced in the Inflation Reduction Act, methane emissions have become even more costly for operators. To stem methane emissions, over 80 companies joined together to create the Oil & Gas Methane Partnership. This voluntary organization is a pivotal step forward by industry to reduce greenhouse gas emissions. Members pledge to publicly report methane emissions from their assets, announce individual reduction targets, and track progress to these targets within three to five years. These initiatives will lead to transparency in measured levels of methane emissions, greater accountability, and progress towards a net-zero world.

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[10] Energy Information Administration, *Advances in technology led to record new well productivity in the Permian Basin in 2021,* September 2022.

[11] Ibid.

In another effort, The Environmental Partnership represents 100 companies that make up more than 70% of the U.S. onshore oil and natural gas industry, reflecting the growing commitment to driving innovation, sharing best practices and increasing transparency to reduce methane emissions in every major U.S. basin. The Partnership members implemented six best practices, in addition to sharing lessons learned and collaborating with academics and technology providers. Program participants conducted over 460,000 leak detection and repair surveys in 2021, with a leak occurrence rate of 0.05%. Since the launch of a flare management program in 2020, The Partnership has advanced best practices to reduce flare volumes, promote beneficial use of associated gas, and improve flare reliability and efficiency when flaring is necessary. In 2021, there was a 45% reduction in flare intensity and a 26% reduction in total flare volumes from the previous year.

Most field flaring results from the lack of infrastructure to which the gas can be diverted. The industry has made significant progress to build new infrastructure to reduce flaring. For example, U.S. flaring intensity has dropped by 46% since 2012, and the United States is the only country that was able to reduce flaring while substantially increasing production.[12] But more investment in new infrastructure is needed to further reduce flaring. And a faster, more efficient system to acquire permits to proceed with these investments is required.

6.1.3 Electrification of In-Field Oil & Gas Production Transport and Gas Liquefaction

To support a net-zero future, operators have been evaluating the staged electrification of equipment that has historically relied upon natural gas as a fuel. Natural gas engine efficiency has improved over time; however, it remains relatively less efficient compared to electrified engines due to thermodynamic limitations. In spread-out land operations, the electrification of field compressors and pumps that move the hydrocarbons through the pipelines can increase the efficiency of the system. Use of an electric engine to drive a compressor achieves 94-97% efficiency as compared to a field natural gas engine, topping out at around 42% efficiency.[13] If the electrical grid is powered by low-carbon generation, overall system emissions can be reduced and effectively eliminated.

Electrification is also the key to a step-change in emissions in LNG liquefaction. In general, energy efficiency improvements are primarily derived from improved heat exchanger and turbine technology. Today the liquefaction industry is looking to electrify full plant operations using e-Drives, new electric motors that could increase efficiencies to up to 95%

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[12] The World Bank, *2022 Global Gas Flaring Tracker Report*, 2022. Global Gas Flaring Reduction Partnership, https://thedocs.worldbank.org/en/doc/1692f2ba2bd6408db82db9eb3894a789-0400072022/original/2022-Global-Gas-Flaring-Tracker-Report.pdf.

[13] U.S. Department of Energy, *Premium Efficiency Motor Selection and Application Guide*, 2014.

vs. 25-30% achieved through industrial gas turbines,[14] ultimately driving up overall process efficiency of the plant from 25% in the 1970s to over 60% today using the latest technology.[15]

6.1.4 Crude Oil Refining

U.S. refineries have maintained focus on reducing energy use and improving efficiency of operations – both together have allowed emissions per barrel of oil refined to reduce. This has been enabled by process integration improvements, improved catalysts, and increasing use digital tools to better optimize operations.

6.1.5 Summary and Policy Recommendations

Energy efficiency and associated emissions reduction continue to be top-of-mind for oil and gas producers, transporters, processers, refiners, distributors, and users as the industry works to meet the hydrocarbon demand while advancing net-zero commitments. Since the early days of the shale revolution, the industry has kept production-related absolute CO_2 emissions flat and continuing to drive down the energy intensity even as the U.S. production capability has almost doubled. The industry continues to work to responsibly do more with less energy-intensive equipment, to reduce hydrocarbon losses and emissions with the most efficient fuel and power sources to help meet the energy demand of the U.S. and global economy. Moreover, these efficiency improvements are a clear demonstration of the oil and gas industry's skilled workforce to safely innovate with new technologies and digitalization, and to swiftly implement large-scale improvements through strong project management and established technical processes, concepts that are immediately transferrable to alternative technologies during the energy transition.

Policies that streamline permitting pipeline, plant, and electrical infrastructure; offer durable incentives for low carbon fuels and energy carriers like hydrogen; and establish a carbon price for emitters across the economy will assist in driving down emissions.

6.2 Methane Abatement

6.2.1 Introduction

Active abatement of methane emissions in the oil and gas sector is one of the best near-term approaches to decarbonization of the U.S. economy. Methane (from all natural and anthropogenic sources) is believed to be responsible for about 30% of the rise in global

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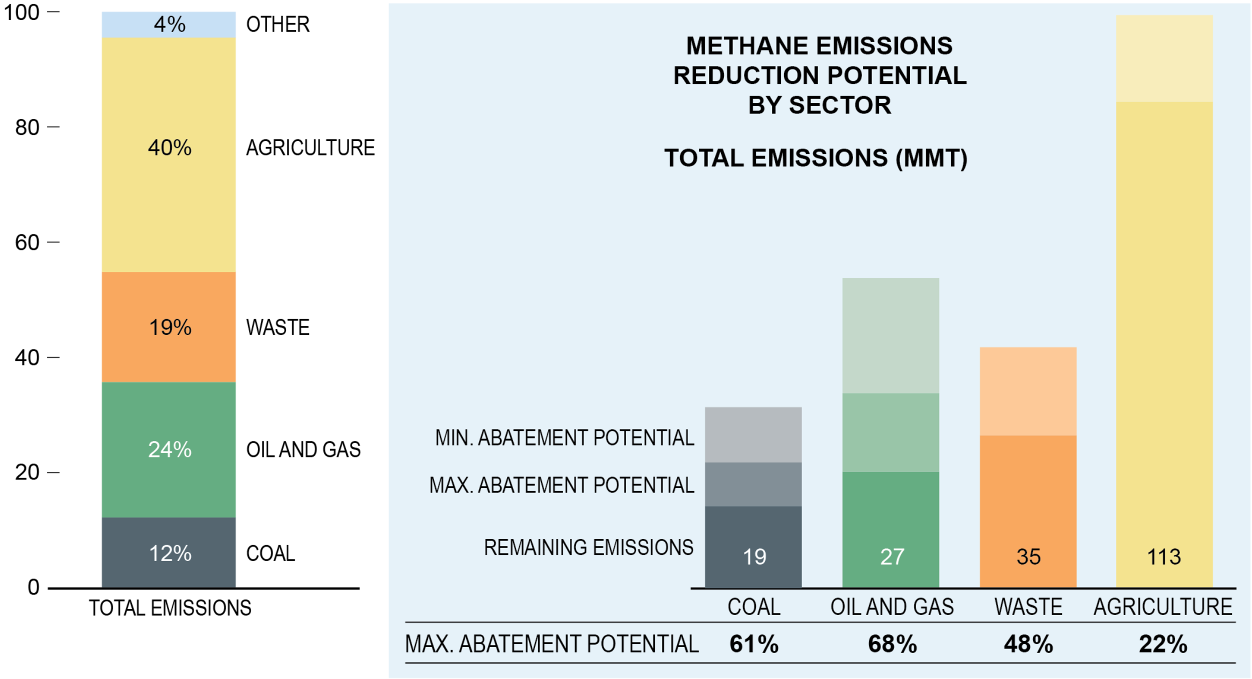
[14] Owen, W., *The future is electric*, LNG Industry, July 8, 2020, https://www.lngindustry.com/liquid-natural-gas/08072020/the-future-is-electric/.

[15] ExxonMobil LNG, Technical paper: LNG market trends in energy and execution efficiency, 2017, https://www.exxonmobillng.com/en/about-us/trending-topics/trends-in-energy-and-execution-efficiency-technical-paper.

temperatures since the industrial revolution.[16] It is a powerful climate force that remains in the atmosphere for a much shorter period than carbon dioxide yet has a greater effect on global warming. A concerted focus on reducing methane emissions can slow the rate of global warming, allowing governments and businesses time to address the more complex task of energy transition. While several large categorical sources of methane exist, the "addressability" of emissions in each category varies. As shown in Figure 9, scaling up deployment of economically and technically feasible methane abatement measures in the oil and gas sector globally can have significant near-term benefits on the rate of warming.[17]



Source: Derived from Global Methane Assessment 2021.

Figure 9. Anthropogenic Methane Emissions Sources and Reduction Potential

Over 100 countries including the United States have joined the Global Methane Pledge ("Pledge") and committed to collectively reduce global methane emissions by at least 30% from 2020 levels by 2030.[18] The Pledge is multi-sector (energy, agriculture, and waste) and states that methane abatement efforts complement, but do not replace, global efforts towards decarbonization. Also fundamental to the Pledge is a recognition that 1) many methane emissions reduction measures are readily available at often low or negative cost and that

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[16] International Energy Agency, *Global Methane Tracker 2022: Methane and climate change*, 2022. https://www.iea.org/reports/global-methane-tracker-2022/methane-and-climate-change

[17] UN Environment Programme, *An Eye on Methane: International Methane Emissions Observatory 2021 Report*, October 2021. https://www.unep.org/resources/report/eye-methane-international-methane-emissions-observatory-2021-report

[18] Climate and Clean Air Coalition, *Global Methane Pledge*, 2021, https://www.ccacoalition.org/en/resources/global-methane-pledge.

2) improvements to completeness and accuracy of methane emissions data can stimulate necessary action.

In the United States, federal regulations to limit methane emissions from new or modified oil and gas facilities have existed since 2012, and regulations on existing oil and gas facilities are pending. In 2022, the U.S. government enacted a first-ever fee on greenhouse gas emissions. Among other provisions, the Inflation Reduction Act of 2022[19] includes a methane waste emissions charge, which the U.S. Environmental Protection Agency (EPA) would impose starting in 2024 on facilities that have methane emissions intensities above certain thresholds. The amount of the charge starts at $900 for each excess ton of methane in 2024 and increases to $1,500 in 2026 and thereafter.

The oil and gas industry is also part of the solution through their unique ability to apply a highly skilled workforce and manage capital intensive, large-scale improvements to deliver cleaner, low-emission energy products. Many companies have set ambitious corporate methane emissions reduction goals and have incorporated methane emissions reductions into net-zero targets, goals, or aspirations. Many of these companies are taking an industry-wide collaborative approach to these efforts, as detailed in the Methane Abatement Topic Paper to this report.

One example is the ONE Future Coalition, a group of more than 50 natural gas companies working together to voluntarily reduce methane emissions across the natural gas value chain to 1% (or less) by 2025 and is comprised of some of the largest natural gas production, gathering and boosting, processing, transmission and storage, and distribution companies in the United States, representing more than 20% of the U.S. natural gas value chain. The industry is actively engaging in emerging initiatives to better account for and to reduce methane emissions from its operations. Over the last decade, academics, environmental NGOs, and companies have partnered to conduct in depth research into the sources and quantities of methane emissions from oil and gas operations. This suite of studies has provided valuable insights that both characterize the challenge and catalyze actionable solutions.

6.2.2 Current State of Technology (Development and Deployment)

Methane abatement technologies can be classified in two different categories. The first includes technologies that minimize emissions at the source by way of facility design and operation. The second includes technologies deployed to detect and measure methane emissions at operating sites, which enables leak remediation or focuses abatement efforts towards higher-potential emissions sources.

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[19] Congress.gov, "H.R. 5376 – Inflation Reduction Act of 2022," 2022, https://www.congress.gov/bill/117th-congress/house-bill/5376.

Selecting equipment and designing facilities to minimize emissions is often the more effective approach and is considered the first line of defense. Applying technology at the initial design stage is highly efficient from a cost and abatement standpoint. Retrofitting or upgrading existing facilities can be more challenging, but technology options do exist. Operators are increasingly incorporating methane emissions controls in their newer generation facilities as well as retrofitting existing facilities to a higher standard. Examples include advanced tank design and tankless facilities, vapor recovery units and towers, instrument air pneumatic devices, zero-bleed valves and components, infrastructure to capture equipment blowdowns, higher-efficiency flares and flare monitoring systems, and electrification of compression equipment.

For years, operators have performed traditional leak detection and repair, relying on audio/olfactory/visual processes and optical gas imaging (OGI) cameras. Oil and gas companies are now deploying advanced methane detection technologies, both at the facility level and on a regional scale as shown in Figure 10,[20] to monitor operations of their assets more effectively and to respond quickly to any occurrence of elevated methane emissions.

As capabilities evolve beyond detection, the sensors can provide additional operator insights through emissions quantification and localization. Further, they enable the development of measurement-based emissions inventories and emissions certification, both of which will increase transparency and confidence in reporting. Herein lie opportunities for continued innovation.

6.2.3 Pathways to Scale and Technical Challenges

Over the last few years, many new methane detection technologies have become available for use. These technologies have provided operators additional insights into the predominant sources of emissions and are informing mitigation today. Industry action to address these sources through design and operational modifications is currently driving down, and will continue to drive down, methane emissions. To realize further value of implementation, improvements to methane detection technology and standardization of approach are needed.

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[20] National Academies, *Improving Characterization of Anthropogenic Methane Emissions in the United States*, 2018, https://nap.nationalacademies.org/catalog/24987/improving-characterization-of-anthropogenic-methane-emissions-in-the-united-states.

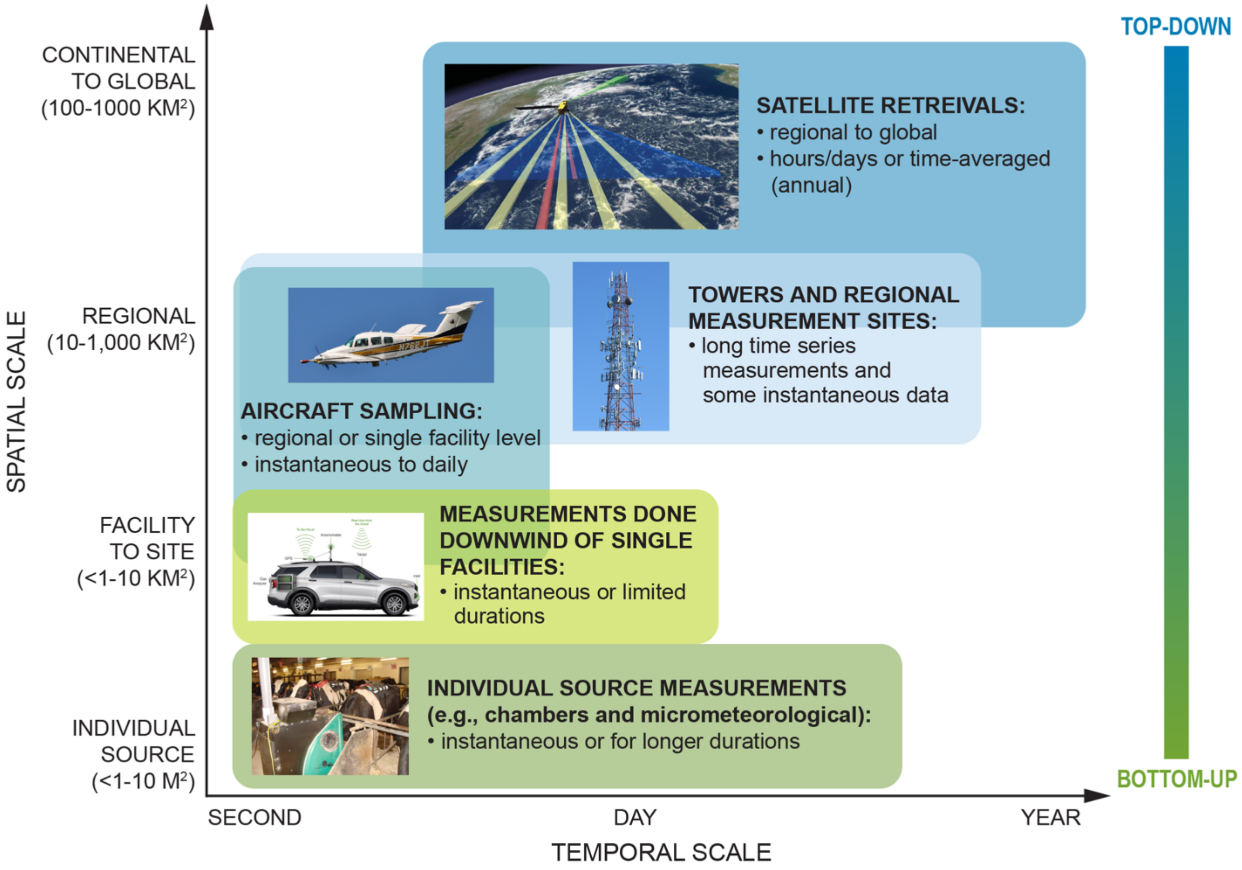

Photo credits: Aura instrument fields of view graphic: Jesse Allen, NASA Earth Observatory; Aircraft: Purdue University; Vehicle: Picarro Inc.; Measuring methane emission: Alexander N. Hristov, The Pennsylvania State University.

Source: National Academies, *Improving Characterization of Anthropogenic Methane Emissions in the United States*, 2018. https://nap.nationalacademies.org/catalog/24987/improving-characterization-of-anthropogenic-methane-emissions-in-the-united-states.

Figure 10. Methane Measurement Platforms Operating Across Spatial and Temporal Scales

Achievement of significant sensitivity as well as reasonable improvement in accuracy of methane sensors is still a fundamental issue. While these instruments are effective at measuring density within the methane plume, many of these emerging technologies are currently insufficient at estimating emissions rate (i.e., quantity). In addition, and when considering measured data or comparing these data to estimated emissions, it is imperative to account for measurement error. While some components of random error can be mitigated through averaging, the deviations from known values for methane measurements undermines confidence in results.

A variety of approaches used to derive conclusions from measured data lead to uncertainty and often incomparability. Estimated emissions rate is generated by making assumptions on the size and geometry of a given plume. Results from different measurement technologies for a given emissions detection can vary. Extrapolating measurements geographically and temporally to develop a comprehensive picture of emissions is difficult and is compounded by a lack of accepted methodology. Further, industry, non-government organizations, and regulators use models to estimate the impacts of different technologies and associated survey frequencies/detection thresholds. Discrepancies arise because the underlying emissions distributions that drive these models are different.

Finally, the field of methane and carbon accounting is relatively new. Oil and gas companies tackling this problem are currently using internal platforms and spreadsheets to develop their strategies and assess their status. Technology developers are creating software platforms, yet they are still relatively immature.

To address these concerns, there is movement towards measurement-informed methane emissions inventories. The United Nations-led Oil and Gas Methane Partnership 2.0 aims to improve the accuracy and transparency of methane emissions reporting from the oil and gas industry and create a consistent platform to track actual emissions reductions. The Gas Technology Institute-led Veritas initiative is expected to develop protocols necessary to calculate measurement-informed emissions inventories. As illustrated in the Methane Abatement Topic Paper, the goal of such programs is to improve emission-factor based inventories with both bottom-up (source-level) and top-down (site-level) measurements to ensure comprehensive emissions reporting. The oil and gas industry is actively engaging in initiatives to better account for and to reduce methane emissions from its operations. Details on leading initiatives are provided in Table A-1 of the Topic Paper.

6.2.4 Recommendations

Achieving the potential of methane detection technology to reduce emissions will depend upon collaboration between regulators, the oil and gas industry, and research and development organizations amongst other stakeholders. Each party possesses skills and resources needed to address existing challenges. The U.S. government has seen great success with previous investments in methane mitigation. The Department of Energy ARPA-E MONITOR program advanced the state-of-the-art in methane measurement and has enabled a record number of technology transitions that are being used by industry today.

The goal of new regulations for methane leak detection should be to foster superior performance. To do this while managing costs, it is necessary to encourage innovation. Regulation needs to be flexible enough to incorporate newer emissions detection technologies that may not be directly comparable to existing systems. It is also challenging to develop regulations for methane because at their core, they are based on emissions distributions. Stakeholders all use varying distributions, which can lead to frustration and confusion when modeling results do not line up. To promote dialogue between industry, regulators, and other stakeholders, there needs to be a common basis for modeling efforts so that at the very least there is a fundamental level of alignment. Finally, allowing operators the option to report measured data through the U.S. EPA Greenhouse Gas Reporting Program would provide EPA with greater insight into how that data can be relied upon for standardization in the future.

Research and development organizations can help to address challenges that exist with characterization of measured methane emissions and lack of tools to model different methane reduction strategies. Existing models are written in programming languages that require advanced skills for use and as a result, they have seen limited uptake. A practical and simple tool to evaluate different methane monitoring strategies is key for regulators and industry to design and develop tactics to meet increasingly aggressive goals. Another important advancement would be an open-source plume inversion model to enable standard quantification approaches across a wide range of methane detection technologies and platforms. While it is unrealistic to expect perfect alignment, a standard approach for quantification and estimation of emissions rates would greatly facilitate methane detection, mitigation, and reconciliation.

Reconciliation provides confidence to external stakeholders that approaches to detection and mitigation are effective and enables operators to track progress through source attribution. Emerging guidance for reconciliation can involve iteration along with multiple rounds of measurement to generate an emissions distribution. These methods are complicated and can be challenging to implement. With the existence of a universal emissions distribution, it would not be difficult to develop a set of criteria for detection threshold and sensor performance. Monte Carlo simulations or other tools can be used to understand the temporal uncertainty of emissions and the required measurement frequency. The net result is by using a standardized approach, reconciliation could be performed in a single pass instead of an elaborate open-ended process.

As technology becomes available to measure methane, a number of software platforms are being developed to digest these data. With no standardized format for methane emissions data, sensor networks deployed by oil and gas companies are often homogeneous and associated software systems are either sensor-specific or require a lot of internal integration. Given the need that companies have for methane emissions data, for mitigation and to track emissions reductions, using a single set of sensors and software system from a single provider is unrealistic and will not foster innovation nor an ecosystem. If the industry develops a common format for methane emissions data consumption, it will permit a more heterogeneous approach to sensor deployment. These commercial codes represent the future; therefore, it is important for companies, with domain knowledge of both the industry and the uncertainty in quantification ability of detection technology, and developers to partner to construct and deploy these platforms faster and allow the transition to universal code to happen at a quicker pace.[21]

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[21] The NPC study on Greenhouse Gas Emissions in the Natural Gas Supply Chain, as requested by the U.S. Secretary of Energy (letter dated April 22, 2022), was underway as this report was completed. The greenhouse gas emissions study will comprehensively address methane abatement and is planned for completion by the second quarter of 2024.

6.3 Carbon Capture and Sequestration

6.3.1 Introduction

Carbon capture and sequestration (CCS) has been identified as a needed technology by IEA, IPCC, and others. Simply put, CCS is needed at scale if climate ambitions are to be met. CCS technology exists today. Unlike some other decarbonization options, there is technology/ know-how available to deploy this at scale. Sufficient policy support and the ability to build the infrastructure will be needed to accelerate the deployment of CCS. The 2022 Inflation Reduction Act amended Section 45Q of the U.S. tax code for operators of carbon capture equipment, increasing the tax credit to $85 per ton of CO_2 stored in dedicated geological storage and $60 per ton for CO_2 stored through EOR or for CO_2 used.

The United States currently deploys approximately 80% of the world's CO_2 capture capacity. However, the 25 million tons per annum (Mtpa) of CCS capacity represents less than 1% of the U.S. CO_2 emissions from stationary sources. The United States is advantaged versus many other countries in having both access to geologic storage near large industrial hubs (e.g., the Gulf Coast) and existing infrastructure that could be repurposed for CO_2 transport and sequestration.

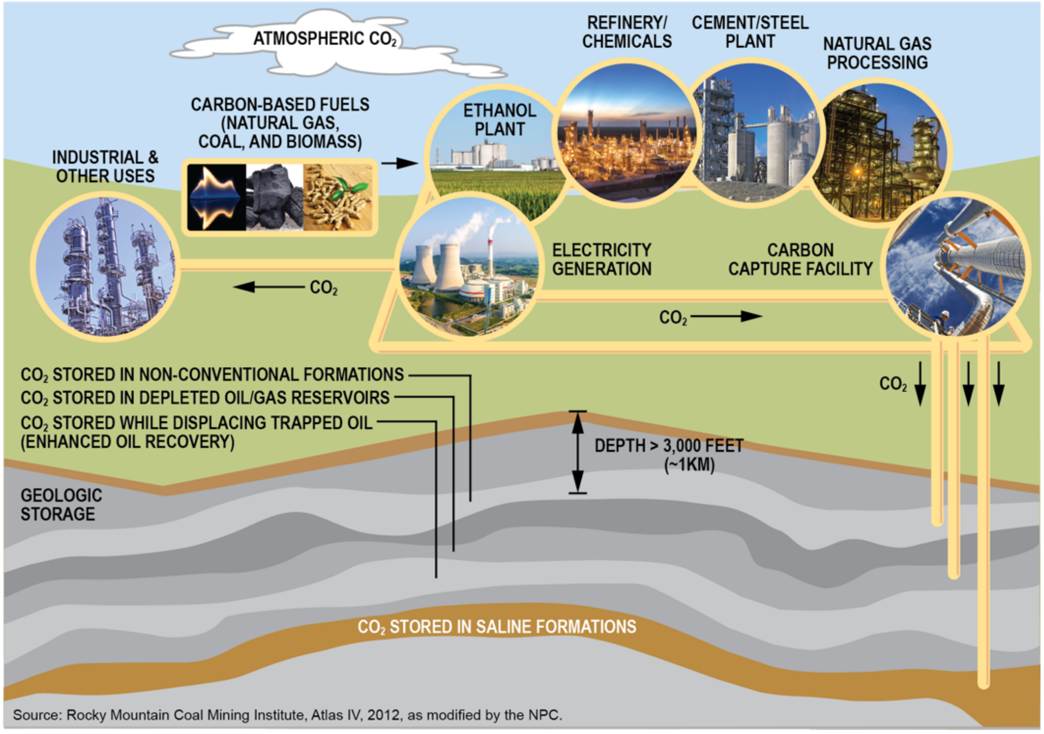
Oil and gas companies have the needed skills to deploy CCS at scale: process integration to operate complex carbon capture facilities, transport capabilities to safely transport the captured CO_2, and subsurface knowledge to manage the sequestration of the CO_2. The oil and gas industry is uniquely qualified to utilize the CO_2 in enhanced oil recovery (EOR) to improve the efficiency of oil and gas production.

Energy pathways or value chains that incorporate CCS should include the CO_2 emissions reductions in the lifecycle assessment calculations.

6.3.2 Background

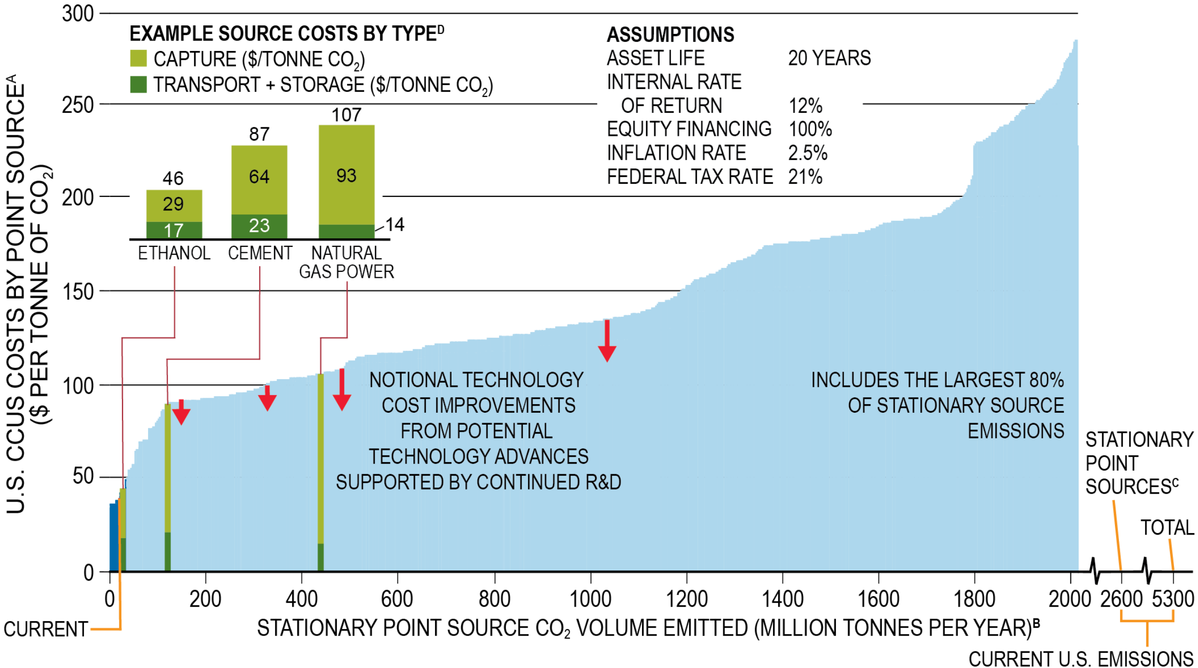
CCS contains three distinct steps: CO_2 separation from other gases, CO_2 transportation, and CO_2 storage. Figure 11, from the 2019 NPC Dual Challenge study on CCS, shows the three components.

The 2019 NPC study developed the costs associated with the capture, transport, and storage of CO_2. Emissions from the largest 80% of U.S. stationary sources were assessed. These results are presented as a CCS cost curve (Figure 12), where the cost to capture, transport, and store one ton of CO_2 is plotted against the volume of CO_2 abatement it could provide. In general, the higher CO_2 concentration sources with the lowest capture costs trend to the left of the graph, and the sources with the lowest concentration and highest cost of capture sources to the right.



Source: Rocky Mountain Coal Mining Institute, Atlas IV, 2012, as modified by the NPC.

Figure 11. Supply Chain for CCS



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.

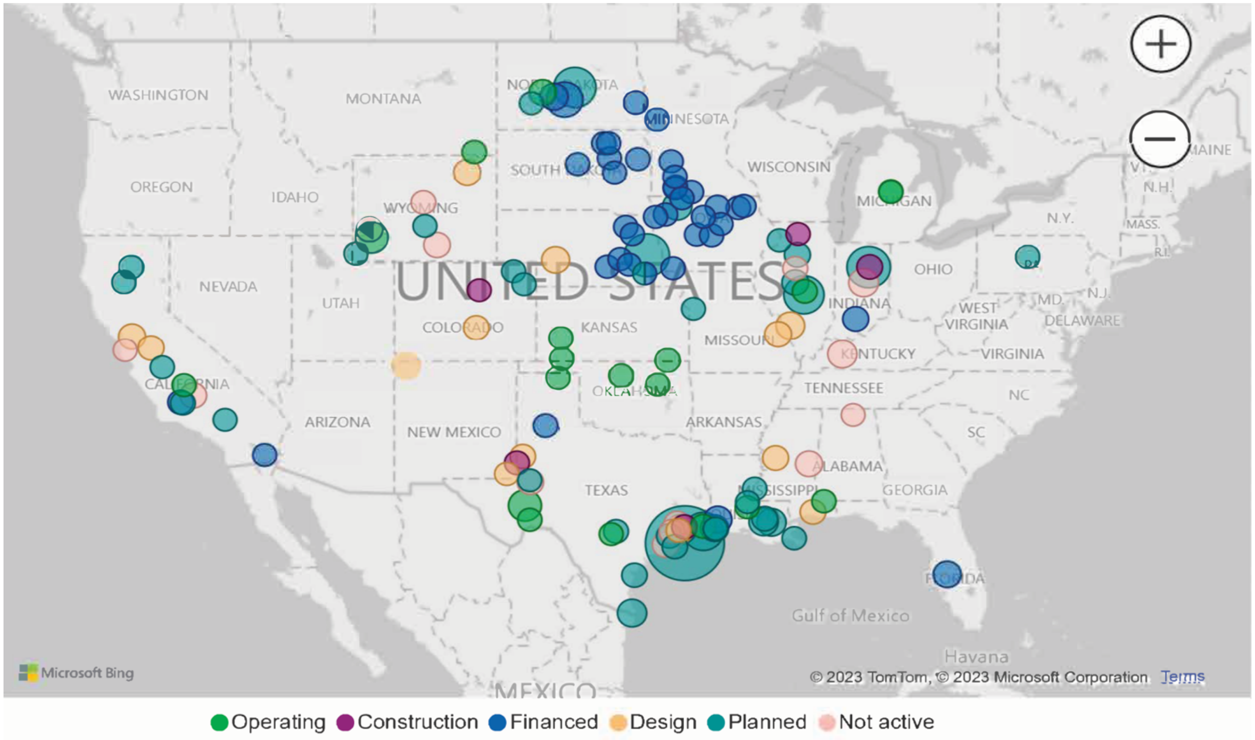
Figure 12. U.S. CCUS Cost Curve Showing Capture, Transport, and Storage Costs for the Largest 80% of U.S. 2018 Stationary Source Emissions

6.3.3 Technical Challenges

The technical challenge of carbon capture is the separation of dilute CO_2 from other gases. The concentration can range from <5% to greater than 90%, with the technical challenge increasing as the CO_2 concentration decreases. Flue gas is the result of combustion of a hydrocarbon. Depending on the industrial process, the flue gas may contain additional impurities such as sulfur or nitrogen containing compounds. These impurities need to be removed before the CO_2 can be separated. The temperature and pressure of the CO_2 containing gas will also vary, adding additional complexity to the separation. In order to address the challenges, the right combination of material and process configuration will be needed.

6.3.4 Current Status

The U.S. CCS project status is shown in Figure 13. 300MTA of total capacity is active or announced. This is far short of the capacity needed if the United States is to meet its emissions reduction targets.



Source: Copyright 2022 S&P Global Inc. All rights reserved.

Figure 13. U.S. CCS Projects

6.3.5 Pathway to Scale

The 2019 NPC study laid out three phases of deployment – activation, expansion, and at scale – that support the growth of CCS over the next 25 years, and detailed recommendations that enable each phase. While the IPCC AR6 report calls for acceleration even beyond these aggressive volumes, the 2019 study provides a valuable roadmap to achieve scale.

In the first phase, clarifying existing tax policy and regulations could double existing U.S. capacity within the next 5 to 7 years to 60MTA (Figure 14).

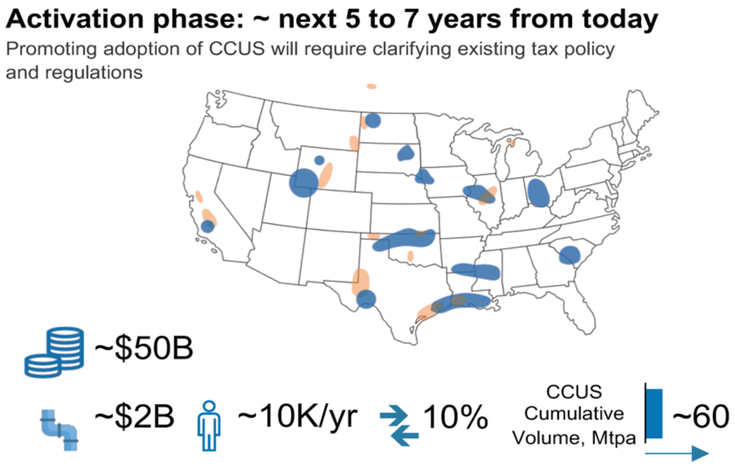


Figure 14. Activation Phase

Extending and expanding current policies and developing a durable legal and regulatory framework could enable a second phase of CCS projects (i.e., 75 to 85 Mtpa) within the next 15 years (Figure 15).

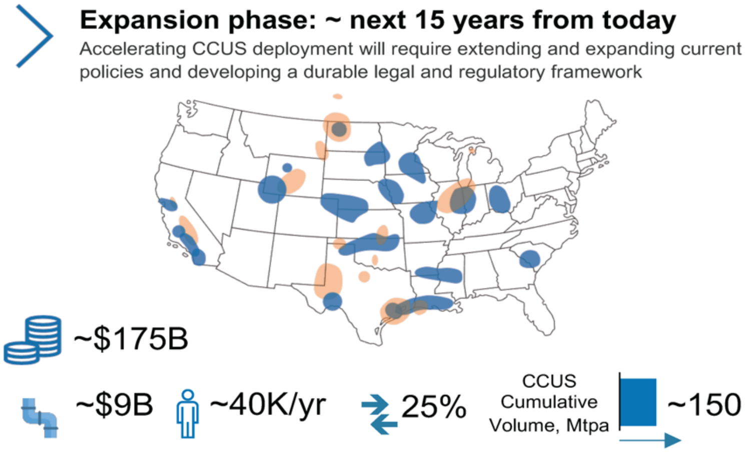


Figure 15. Expansion Phase

Achieving CCS deployment at scale (i.e., additional 350 to 400 Mtpa) within the next 25 years will require substantially increased support driven by national policies (Figure 16).

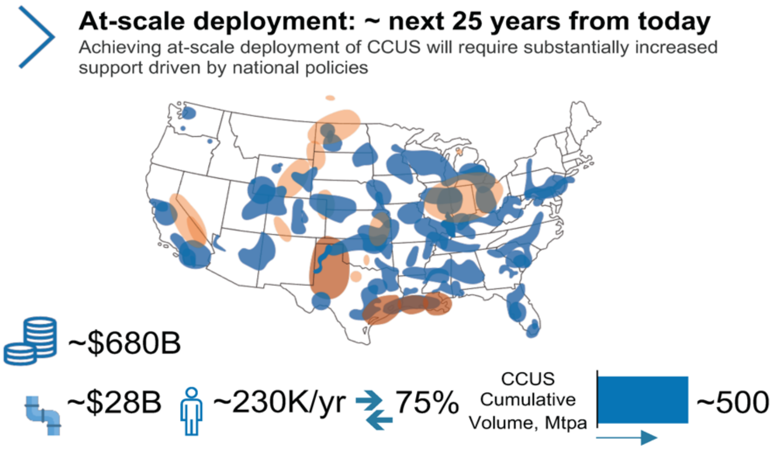


Figure 16. At-Scale Deployment

Since the 2019 NPC study was published, several CCS initiatives have been announced, including proposed CCS Hubs. However, CCS deployment at scale still needs to be accelerated to meet ambitious climate goals.

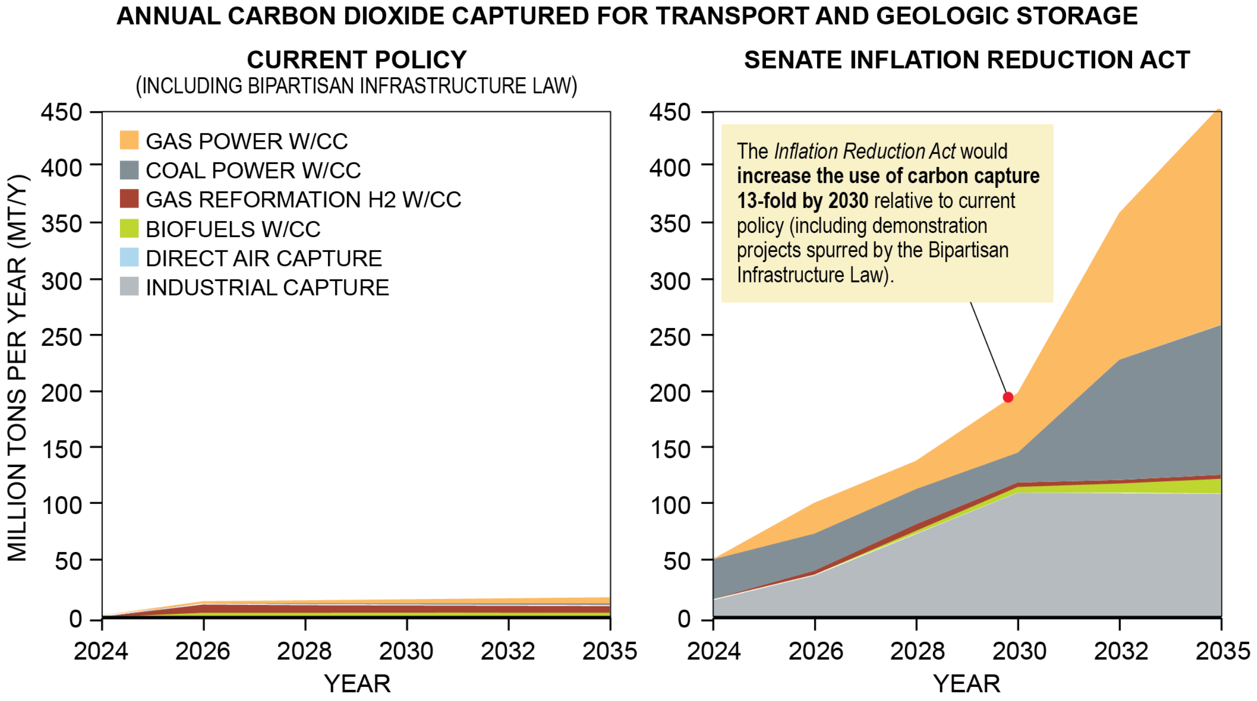
Further acceleration can be catalyzed by the recently passed IRA bill. Modelling by Princeton University shows the potential for CCS deployment by 2030 (Figure 17). Included in the modelling is more than \$20 billion in annual investment in CO_2 transport and storage, and fossil power generation w/carbon capture by 2030.

6.3.6 Recommendations

CCS technology will need to be developed and deployed at unprecedented rates over the next several decades. In order to meet this goal, several areas will need to be addressed:

1) Accelerate deployment of ready to scale technology

Unlike some other decarbonization options, there is technology/know-how available today to deploy this at scale. Sufficient policy support and the ability to get the infrastructure built will be needed to accelerate the deployment of CCS.



The *Inflation Reduction Act* would **increase the use of carbon capture 13-fold by 2030** relative to current policy (including demonstration projects spurred by the Bipartisan Infrastructure Law).

Incentives for carbon capture, storage, and use in the *Inflation Reduction Act* would build on demonstration funding in the Bipartisan Infrastructure Law to **make carbon capture a viable economic option** for the most heavily emitting industries, such as steel, cement, and refineries, as well as power generation from coal and natural gas.

The total volume of CO_2 captured for transport and geologic storage across energy and industry could reach **200 million tons per year** by 2030, if sufficient investment in transport networks and storage basins can be deployed.[1]

That includes roughly 110 million tons across industries and 90 million tons in power generation.[2] Modeled results include 6 gigawatts of carbon capture retrofits at existing coal-fired power plants and 18 gigawatts of gas power plants with carbon capture installed by 2030.

1. Growth in annual CO_2 injection capacity in storage basins is likely to constrain the pace of carbon capture deployment. This modeling assume maximum annual CO_2 injections increase to 200 Mt CO_2/y by 2030 based on expert input and Princeton *Net-Zero America* study.
2. Industrial CO_2 capture volumes are fixed exogenously based on analysis in Larson et al., 2021, "Capturing the Moment: Carbon Capture in the American Jobs Plan," Rhodium Group, April 2021. Carbon capture in fuels conversion (biofuels, hydrogen, ammonia) and power generation are optimized in RIO modeling, constrained by remaining available annual injection volume limit.

Source: Princeton University ZERO Lab (https://repeatproject.org/docs/REPEAT_IRA_Prelminary_Report_2022-08-04.pdf).

Figure 17. CO_2 Captured for Transport and Geologic Storage

2) Continue to support technology development

The NPC study showed the status of technology readiness for various CCS technologies (Figure 18). Increased government and private research, development, demonstration, and deployment are needed to improve CCS performance, reduce costs, and advance alternatives beyond currently ready to deploy technology.

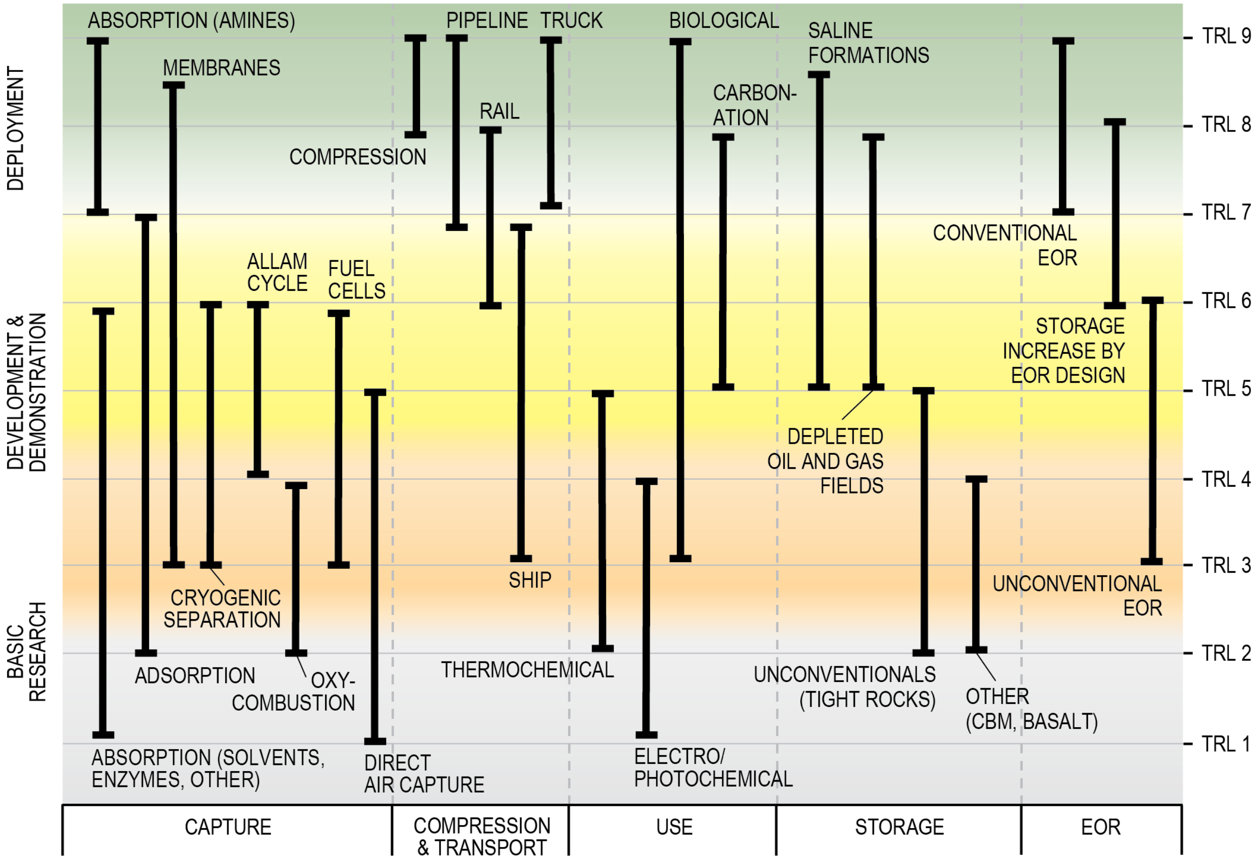


Figure 18. Technology Readiness Level (TRL) Ranges for CCUS Technologies

The oil and natural gas industry is uniquely positioned to lead CCS deployment due to its relevant expertise, capability, and resources. DOE funded projects can accelerate research, development, and deployment of materials and processes required for CCS. Parallel approaches to development of absorption and adsorption materials and processes can further widen the array of available technologies. Collaboration between industry, academia, and national labs has the potential to identify technology options that have higher potential for scale. Further, DOE National Carbon Capture Center test beds can be used to advance testing of materials and processes.

3) Invest in infrastructure

Significant increase in pipelines for transport of CO_2 will be needed. The United States has over 5,000 miles of existing pipelines for safe CO_2 transport. However, significant expansion will be required to meet the required increase in CCS capacity. Infrastructure investments can be made in parallel or in advance or project deployment.

4) Provide supportive policy

CCS has benefited from federal tax policy as well as state and regional incentives. The 2022 Inflation Reduction Act amended Section 45Q of the U.S. tax code for operators of carbon capture equipment, increasing the tax credit $85 per ton of CO_2 stored in dedicated geological storage and $60 per ton for CO_2 stored through EOR or for CO_2 used. Continued policy support will incentivize CCS deployment.

5) Workforce development

A broad range of skills will be needed to achieve the level of CCS development and deployment needed. Encouraging academic research through DOE grants, increasing education and training via community colleges, and building the labor force needed to build projects and infrastructure should all be progressed via public-private partnerships.

6.4 Direct Air Capture

6.4.1 Introduction

Direct Air Capture (DAC) is the synthetic process by which CO_2 is removed directly from the atmosphere, resulting in negative emissions. No emissions source is needed. A 2019 report by the National Academy of Sciences, Engineering, and Medicine concluded that 10 billion tons of CO_2 removal from air per year up to mid-century will be needed to meet climate goals. Other estimates are shown on Table 3.

Table 3. Estimates of Potential Requirements for Direct Air Capture
(Million Tons per Year of CO_2)

DAC estimate	2030	2050	2100
IPCC AR6 lower 2C and 1.5C average	0	~ 400	~ 3000
IEA Net Zero (by 2050)	85	980	-

The IPCC AR6 report states Pathways likely to limit warming to 2°C or 1.5°C require some amount of DAC to compensate for residual GHG emissions, even after substantial direct emissions reductions are achieved in all sectors and regions. To advance the development of this emerging and necessary industry, DOE launched Carbon Negative Shot—the U.S. government's first major effort in carbon dioxide removal (CDR) technology.

Sufficient policy support and the ability to build the infrastructure will be needed to accelerate the deployment of DAC. The 2022 Inflation Reduction Act amended Section 45Q of the U.S. tax code for operators of carbon capture equipment, establishing a tax credit of $180 per ton of CO_2 stored in dedicated geological storage and $130 per ton for CO_2 stored through EOR or for CO_2 used.

DAC has two distinct features: 1) feed is limitless, air is the feed required for DAC, and 2) process is location agnostic, DAC can be sited directly over the sequestration point avoiding some of the infrastructure logistics or can be located near power sources leveraging advantaged power to operate the process. DAC is also advantaged from a land use standpoint. A 1MTA DAC facility requires 0.5-0.75 km^2. To capture 1MTA of CO_2 using nature-based solutions would require 860 km^2 according to a World Resources Institute estimate.[22]

Power will be required to operate the DAC facility and a full lifecycle analysis of the process (including capture, transportation, and storage) should be conducted to ensure the process is negative emissions. Power requirement for 1MTA DAC is estimated at 270-280 MW.

Oil and gas companies have the needed skills to deploy DAC at scale: process integration and gas (air) handling expertise to operate complex direct air capture facilities, transport capabilities to safely transport the captured CO_2, and subsurface knowledge to manage the sequestration of the CO_2. The oil and gas industry is uniquely qualified to utilize the CO_2 in enhanced oil recovery (EOR) to improve the efficiency of oil and gas production.

6.4.2 State of Technology

There are two basic approaches to direct air capture: liquid and solid. Figure 19 shows the two approaches to DAC technologies.

Currently DAC has been demonstrated at small scale. To date, 18 units have been built, capturing 10KTA of CO_2. The largest operating facility is 4KTA. There are multiple projects under development including a 2KTA facility in Chile, a 36KTA facility in Iceland, and 500KTA facility in Texas. In order to meet the billion-ton scale challenge, technology development and deployment will need to be accelerated. The amount assumed to be deployed for NZE (by IEA) is ~85MTA (2030) and ~980MTA (2050).

6.4.3 Technology Challenges

There are three main challenges for DAC:

1) Materials: The DAC process requires materials capable of capturing CO_2 from dilute streams (400 ppm CO_2). This can be done via liquid solvents (absorption) or solid substrates (adsorption).
2) Process: The process requires moving large volumes of air; 1,650 T of air is required for 1 T CO_2 captured (assumes 100% capture).
3) Equipment: Reliability becomes a key factor for a DAC process.

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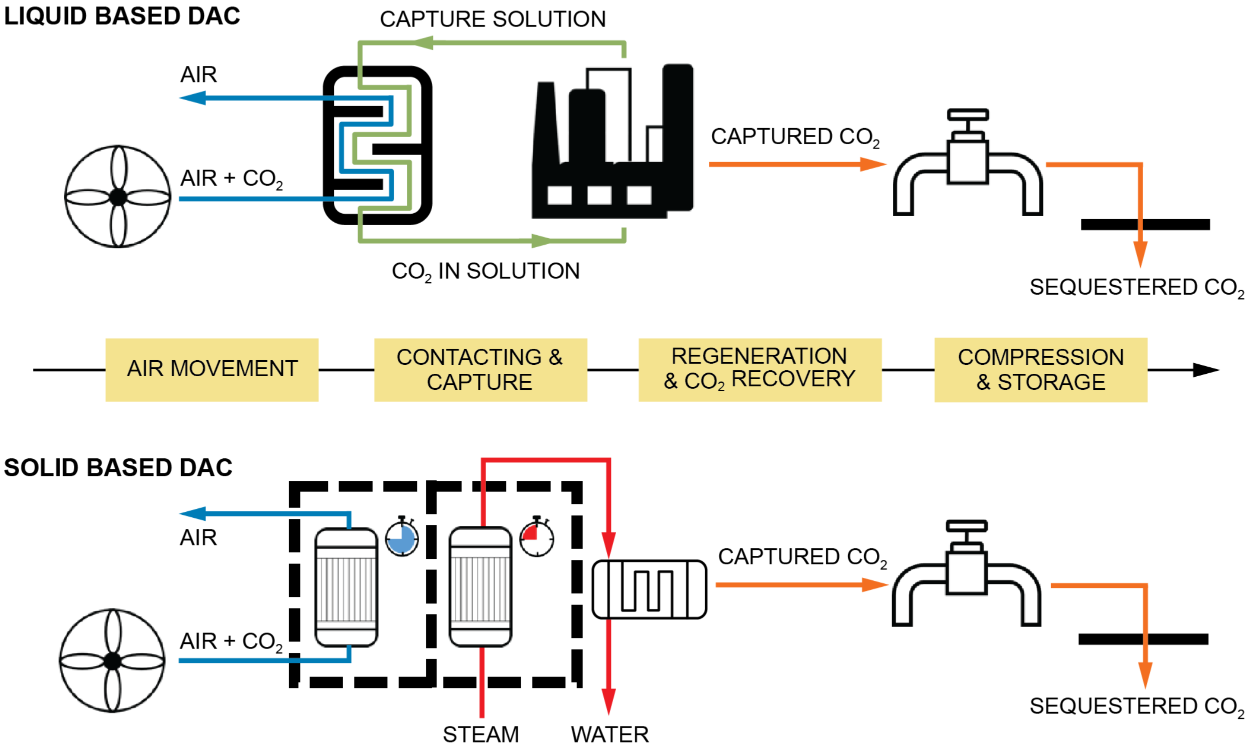
[22] World Resources Institute, *6 Things to Know About Direct Air Capture,* May 2022.



Source: ExxonMobil.

Figure 19. Direct Air Capture (DAC) Technologies

6.4.4 Costs

Preliminary estimates of the costs for DAC vary between \$250 and \$600 today depending on the technology choice, energy source, and the scale of deployment. Costs will be better understood as more units are built. The Department of Energy launched the Carbon Negative Shot in 2021, which aims to reduce the cost of carbon removal technologies that could reach gigaton scale to \$100/T CO_2 over the next decade.

6.4.5 Recommendations

1) Advance Technology

The majority of technologies are in the TRL 5-6 range. Hence, pathway to scale needs to be encouraged. This can be done through policy support to deploy units to accelerate the learning rates. The IRA bill has \$180/T credit for DAC. An increase in this could allow for additional deployments.

Advances in materials, processing, and reliability will be needed. The DOE Carbon Negative Shot can be used to fund programs ranging from academia to first deployment to increase the number of DAC options.

2) Use of DOE facilities

The DOE National Carbon Capture Center could be used as a test bed to accelerate materials discovery and process configurations. National labs can be used for materials discovery and process modelling.

3) Promote collaboration

Collaboration among academia, national labs, and industry should be encouraged to advance pathways to scale in parallel.

4) Promote policy

The 2022 Inflation Reduction Act amended Section 45Q of the U.S. tax code for operators of direct air capture equipment, establishing a tax credit of $180 per ton of CO_2 stored in dedicated geological storage and $130 per ton for CO_2 stored through EOR or for CO_2 used. Continued policy support will incentivize DAC deployment, particularly at early stages of demonstration.

5) Develop workforce

A broad range of skills will be needed to achieve the level of DAC development and deployment needed. Encouraging academic research through DOE grants, increasing education and training via community colleges, and building the labor force needed to build projects and infrastructure should all be progressed via public private partnerships.

6.5 Hydrogen

6.5.1 Introduction

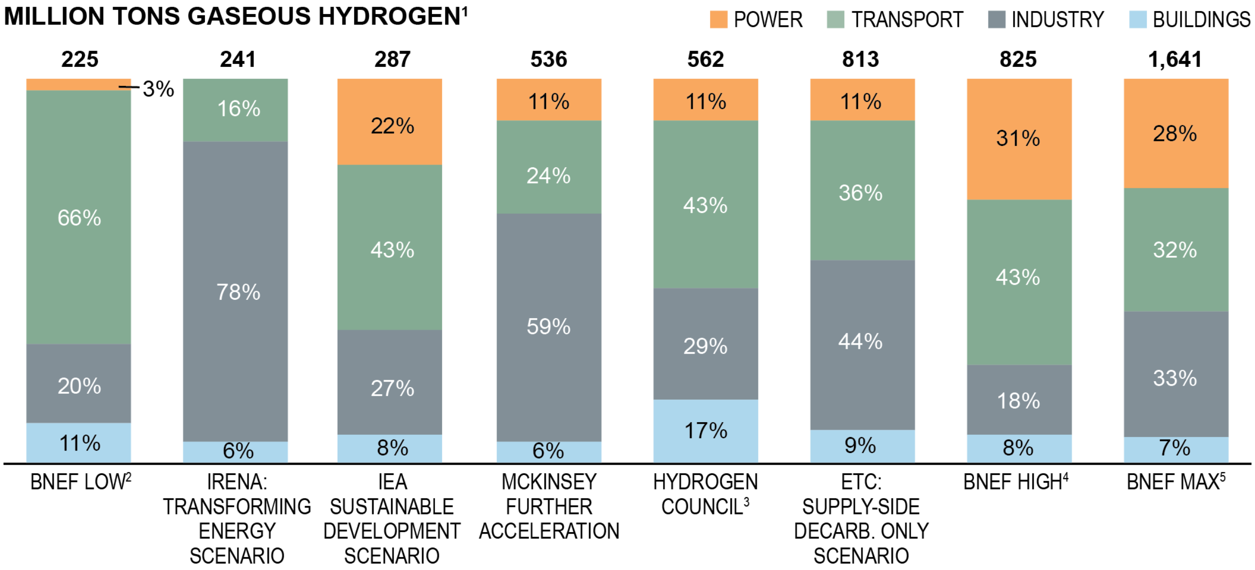
Hydrogen is a unique energy carrier in that no CO_2 is produced when hydrogen is burned.

Hydrogen production technology is readily available and being further expanded through numerous research efforts. In terms of policy support, recent passage of the Inflation Reduction Act (P.L. 117-169) will help in reducing the cost of hydrogen production and make it a more competitive offering in the consumption marketplace. The Act offers a 10-year production tax credit (PTC) for clean hydrogen production facilities. Incentives begin at $0.60/kg for hydrogen produced in a manner that captures slightly more than half of steam methane reforming carbon emissions, assuming workforce development and wage requirements are met. The PTC's value rises to $1.00/kg with higher carbon capture rates before jumping to $3.00/kg for hydrogen produced with near-zero emissions. These provisions clearly incentivize production. While these measures will stimulate the growth of supply, they have a lesser impact on hydrogen demand. To create a sustainable hydrogen ecosystem at scale where final investment decisions on new projects are taken, supply and demand need grow in tandem. It is therefore recommended to focus future federal and local policy efforts on stimulating supply and demand in a synchronized manner.

How hydrogen is produced becomes the key factor in determining its respective emissions profile; there are many generation processes or "colors" of hydrogen. While the colors are useful descriptors of the process by which the hydrogen is produced, a full lifecycle assessment of the energy pathway used to produce the hydrogen should be conducted for meaningful comparisons between pathways.

- Gray: produced from reforming (steam or thermal) methane
- Blue: gray hydrogen plus CCS
- Green: electrolysis of water using renewable power
- Pink: electrolysis using nuclear power
- Turquoise: methane pyrolysis
- Yellow: solar powered hydrogen generation.

Today, around 99% of hydrogen is produced from fossil fuels via reforming of methane. Global hydrogen demand reached 94 million tons in 2021. A variety of studies have suggested 2x-17x increase in demand by 2050, based on input assumptions (Figure 20). To be on track for net-zero emissions by 2050, approximately 200 million metric tons of hydrogen would be needed by 2030 (Hydrogen Council, Hydrogen Insights 2022).



1. Data based on EJ, converted to MMT gaseous hydrogen using McKinsey methodology.
2. Supportive for hydrogen but piecemeal policy in place.
3. Strong and comprehensive hydrogen policy in place; net zero scenario.
4. If all the unlikely-to-electrify sectors in the economy used hydrogen.
5. Scenario: Theoretical maximum: If all the unlikely-to-electrify sectors in the economy used hydrogen.

Sources: BNEF Hydrogen Economy Outlook 2020; IRENA 2020 Global Renewables Outlook (page 31); IEA Global hydrogen production in the Sustainable Development Scenario, 2019-2070; McKinsey Energy Insights Global Energy Perspective, January 2022 report; Hydrogen Council Hydrogen for Net Zero report; ETC Making the Hydrogen Economy Possible, April 2021 report.

Figure 20. Hydrogen Demand Forecast by Sector in 2050

Hydrogen has the potential to play multiple roles in the clean energy transition, in end uses such as transportation, heating, electric generation, and industrial processes. Currently, nearly all of the hydrogen consumed in the United States is used in industrial processes such as refining petroleum, treating metals, producing fertilizer, and processing foods.[23] However, hydrogen can be used in various end uses, including:

- Transportation: Hydrogen is considered an alternative vehicle fuel under the Energy Policy Act of 1992. The interest in hydrogen as an alternative transportation fuel stems from its ability to power fuel cells in zero-emission vehicles (vehicles with no emissions of air pollutants), its potential for domestic production, and the fuel cell's potential for high efficiency. Of note, hydrogen for long-haul trucking may be one of the first major markets to develop in the near term and there is a significant amount of synergy between CNG and hydrogen station construction and operation. Hydrogen can also be used in the process to make fuel by converting biomass into renewable hydrocarbon fuels. Hydrogen will be required at scale (up to hundreds of tons of per day) to be used as fuel or to produce renewable fuels. Lower emissions forms of hydrogen will have a direct impact on the carbon intensity of the final product and the overall emissions profile associated with usage of the fuel. A full lifecycle analysis of emissions should be conducted to make meaningful comparisons.
- Electricity Generation: Interest in using hydrogen as a power plant fuel is growing. Hydrogen can be burned alone or co-fired with natural gas to reduce a plant's emissions profile. Some power generation technologies do exist that can combust 100% hydrogen as a fuel source. In the U.S. power market, hydrogen blending in gas-fired turbines is already established at small scale. As an example, power is being generated by blending up to 5% of hydrogen with natural gas in Ohio. Several additional power plants have announced plans to operate gas turbines using a natural gas–hydrogen blend. Over time, small- and large-scale natural gas turbines should have the capability to decarbonize fully through hydrogen firing. Hydrogen fuel cells produce electricity by combining hydrogen and oxygen atoms. The hydrogen reacts with oxygen across an electrochemical cell similar to that of a battery to produce electricity, water, and small amounts of heat.
- Buildings: Hydrogen has the potential to be used safely in homes, businesses, and in industry. It has different flammability characteristics than methane, which means additional and different precautions are required for the safe management of the fuel.

6.5.2 Current Status

To date, roughly 680 large-scale hydrogen projects have been announced. This equates to USD 240 billion in direct investment through 2030. Even though development of hydrogen

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[23] U.S. Energy Information Administration, "Hydrogen explained, use of hydrogen," January 2022. https://www.eia.gov/energyexplained/hydrogen/use-of-hydrogen.php

projects has seen significant growth, only 10% of the announced projects have reached Final Investment Decision.[24]

Energy companies are playing a significant role in the development of low carbon hydrogen production. In the U.S. Gulf Coast region alone, more than 25 projects have been announced that focus on the development of low carbon hydrogen, and hydrogen derivatives such as ammonia, methanol, and renewable fuels. These projects could replace existing grey hydrogen, supply new demand, and are estimated to come online between 2023 and 2030. In Europe, the Port of Rotterdam has seen commitment to invest in a 200MW electrolyzer and 600MW more of announced capacity, all led by large industrial companies. Many oil and gas companies occupy unique technical and market positions with the ability to safely produce hydrogen, build out reliable supply chains, while also representing the demand side of hydrogen.

For a hydrogen economy to be established, much like natural gas, hydrogen will need to flow unrestricted across state boundaries and reach its end customers affordably and reliably. Hydrogen storage has been successfully deployed at scale (4+ BCF) in the United States for several decades. It is well understood but requires favorable local geology, only available in certain parts of the United States.

6.5.3 Challenges

Storage and Transmission

There are several challenges related to storage and transmission to be addressed. Storage of hydrogen as a gas typically requires high-pressure tanks. Storage of hydrogen as a liquid requires cryogenic temperatures because the boiling point of hydrogen at one atmosphere pressure is −252.8°C. Hydrogen can also be stored on the surfaces of solids (by adsorption) or within solids (by absorption). High density hydrogen storage is a challenge for stationary and portable applications and remains a significant challenge for transportation applications. Presently available storage options typically require large-volume systems that store hydrogen in gaseous form.

Within the United States, there are approximately 1,600 miles of existing hydrogen pipelines concentrated around large demand centers such as the Gulf Coast. For a hydrogen economy to be established, much like natural gas, hydrogen will need to be able to flow unrestricted across state boundaries and reach its end customers affordably and reliably. The technology for hydrogen transmission is readily available but building out the infrastructure will require time and capital investments far beyond that available in the H2Hubs funding under the Infrastructure Investment and Jobs Act. Early build out of transmission pipelines will hinge on a coordinated build out of supply and demand. Gaseous hydrogen is most commonly delivered

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[24] Hydrogen Council, *Hydrogen Insights 2022: An updated perspective on hydrogen market development and actions required to unlock hydrogen at scale*, 2022. https://hydrogencouncil.com/wp-content/uploads/2022/09/Hydrogen-Insights-2022-2.pdf

either by trucks or through dedicated pipelines. Use of the existing natural gas pipelines to transport hydrogen is feasible, but key concerns remain regarding hydrogen capability with existing infrastructure as well as addressing questions pertaining to regulatory structure and authority.

Process Containment

As mentioned previously, the industry has focused efforts on reducing methane emissions from process leaks and releases, and substantial progress has been made. Hydrogen processing depends on similar process connections as methane processing – with the notable difference that molecular hydrogen is about eight times smaller than a methane molecule. This molecule size difference can potentially lead to a greater tendency to leak to atmosphere. Mechanical joints are present throughout the entire hydrogen value chain, from generation (compression, electrolyzation, liquefaction), transportation pipeline systems, storage tanks, road transport, and end-user filling stations. It is important to note that the climate impact of raw hydrogen emissions is not fully understood; there is increasing research to improve understanding and that research should be continued.

Hydrogen as a Consumer Transport Fuel / Refilling Network

The hydrogen refueling station network continues to grow worldwide. By the end of 2021, there were approximately 700 hydrogen stations developed worldwide with 80 stations located in the United States. The main challenge in hydrogen mobility is achieving cost and performance parity with gasoline and diesel. This will require sufficient and convenient access to hydrogen fuel. Hydrogen will need new infrastructure for the very first vehicles, then require scaling quickly.

Hydrogen to Power

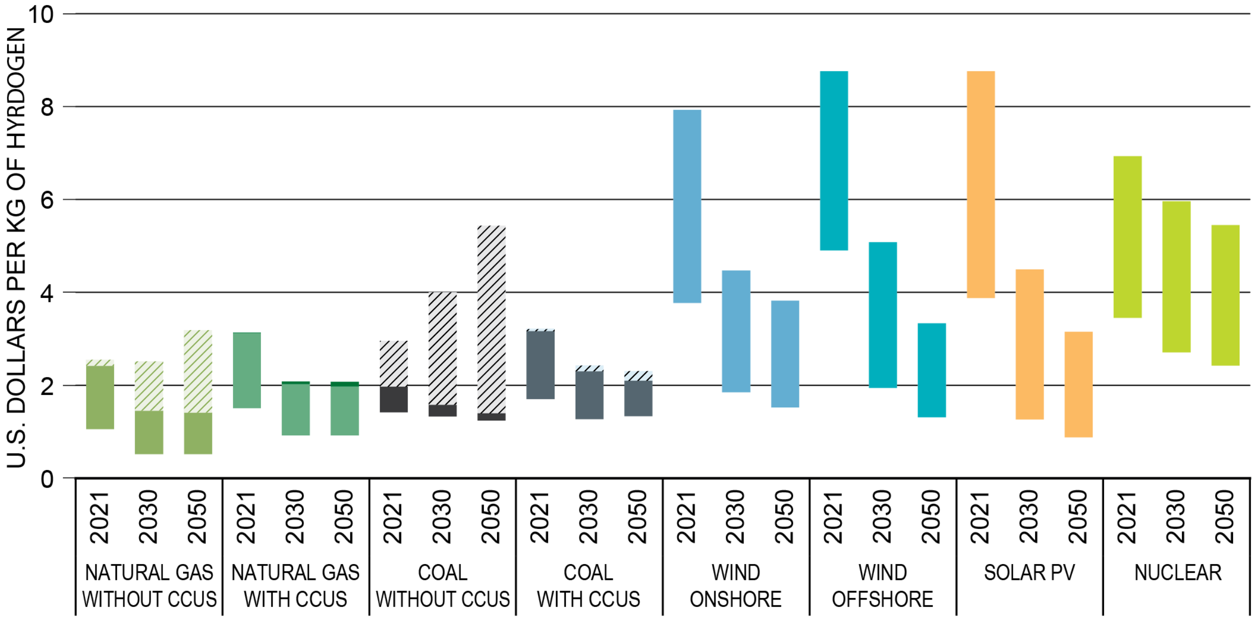
Hydrogen can be used as the primary source for power or as back-up for grid scale storage. Beside the availability of hydrogen, cost is the biggest obstacle. At the current cost structure, including 45Q and PTC economic incentives, hydrogen is still more expensive than natural gas at market. In other industries where natural gas is used as a feedstock (e.g., boilers, heaters, furnaces, etc.), a similar dilemma exists. Significant economies of scale and favorable policies and incentives are needed to realize sustainable decarbonization by supplementing natural gas with hydrogen.

6.5.4 Recommendations

One of the greatest obstacles to scaling low emission hydrogen today is production cost. As demand for low carbon hydrogen increases, the cost of hydrogen will naturally fall through economies of scale. Collaboration between government, energy companies, industry players, infrastructure providers, and original equipment manufacturers can help accelerate this by creating efficiencies, improving technology, and implementing supportive supply/demand policies. International coordination to implement a tradeable and robust certification systems is essential to build up trust amongst off-takers and can create a path for international trade in hydrogen, which in turn will help bring down the cost of hydrogen further.

It is important to note that, at present, and in the near- to mid-term future, hydrocarbon-based power generation will prove to be the most affordable "clean" option for consumers (both industrial and private) as the IEA data demonstrate in Figure 21.[25]

In addition to cost, supporting infrastructure will be needed. Critical infrastructure includes hydrogen production facilities, pipelines for transportation, and storage. This managed co-development will require coordination among public and private organizations at a local, and national, level to create efficient permitting systems that enable viable projects to make investment decisions, be built and operated, and collectively, deliver meaningful reductions in greenhouse gas emissions.



LEVELIZED COST OF HYDROGEN PRODUCTION BY TECHNOLOGY IN 2021 AND IN THE NET ZERO EMISSIONS BY 2050 SCENARIO, 2030 AND 2050

Notes: Ranges of production cost estimates reflect regional variations in costs and renewable resource conditions. The dashed areas reflect the CO_2 price impact, based on CO_2 prices ranging from USD 15/tonne CO_2 to USD 140/tonne CO_2 between regions in 2030 and USD 55/tonne CO_2 to USD 250/ tonne CO_2 in 2050.

Sources: Based on data from McKinsey & Company and the Hydrogen Council; IRENA (2020); IEA GHG (2014); IEA GHG (2017); E4Tech (2015); Kawasaki Heavy Industries; Element Energy (2018). All rights reserved.

Figure 21. Opportunities for Cost Reductions to Produce Low-Emission Hydrogen

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[25] International Energy Agency, *Global Hydrogen Review 2022*, https://www.iea.org/reports/global-hydrogen-review-2022.

As the low carbon hydrogen market is established around the country, the industries supporting it will evolve as well. This evolution will inevitably create deeper insights regarding more effective industry practices and government policy. To that extent, it is expected that a degree of flexibility will be required from public and private institutions. The H2 Hubs funding, for example, is intended to support and accelerate the hydrogen development cycle. It is recommended that the DOE allow for certain amount freedom and flexibility in organizations and companies, in coordination with the DOE, to direct resources where they have the most measurable effect on decarbonization, growing a hydrogen economy, and positively impacting local communities.

The supply chain underpinning hydrogen development will in turn support the growth of a hydrogen-anchored commerce ecosystem in the United States. This growth will inevitably create strain on resources and the ability to bring projects onstream efficiently. Beyond the borders of the United States, the effects of hydrogen supply chain constraints are already being felt. Raw material shortages, electrolyzer production capacity, and shortages of skilled human resources are affecting the industry. It is therefore recommended that government policy consider the broader, supporting value chains that help build the hydrogen ecosystem in the short term, and make it commercially sustainable in the long term.

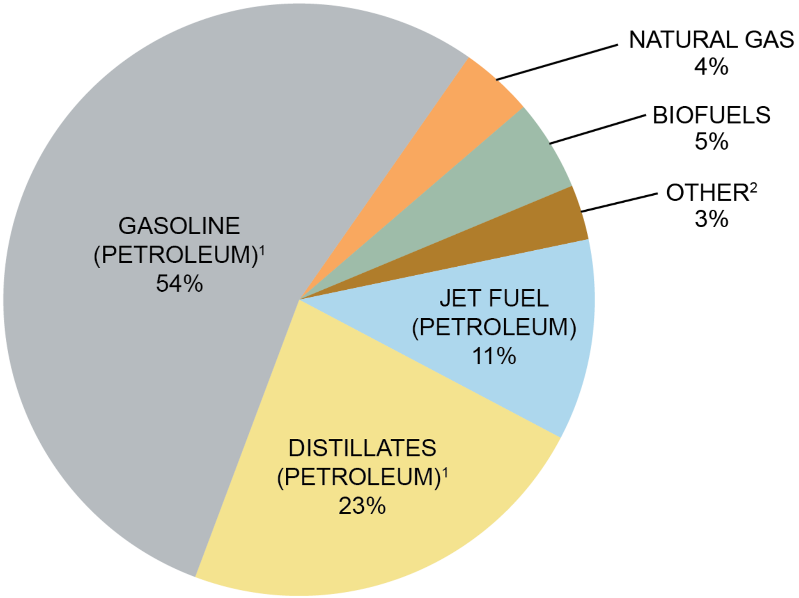
Finally, it should be noted that the National Petroleum Council study on the deployment of low carbon intensity hydrogen energy at scale, commissioned on the basis of a request from the U.S. Secretary of Energy in November 2021, is under development and is expected to be delivered in late 2023. The summary above should be viewed as an introduction to the comprehensive work underway in the 2023 NPC hydrogen study.

6.6 Renewable Fuels

6.6.1 Introduction

As in the power sector, rapid and widespread adoption of renewable, low-carbon, and negative emissions resources will be essential to the residential, commercial, industrial, and power generation sectors' achieving net-zero emissions. In addition, the transportation sector is one of the largest contributors to U.S. GHG emissions, and a range of solutions is needed if climate goals are to be reached. Liquid hydrocarbon fuels provide energy density that is needed for heavy duty (aviation, marine, trucks) transportation. Renewable fuels are lower carbon intensity fuels versus fossil based fuels and can reduce the lifecycle GHG emissions of the transportation and other sectors while meeting the world's growing need for energy. Renewable fuels can also help reduce the lifecycle carbon intensity of a wide range of end-use sectors today because they can be used in existing building appliances, industrial uses, vehicle engines and can be delivered with existing infrastructure. Common renewable fuels include ethanol, biodiesel, renewable diesel, sustainable aviation fuel (SAF), renewable gasoline, and renewable natural gas (RNG).

Renewable diesel, biodiesel, and SAF have the ability to decarbonize the hard-to-abate transportation sectors such as heavy-duty trucking and aviation, which made up ~34% of U.S. transportation demands in 2021.[26] See Figure 22 for U.S. transportation energy sources/fuels in 2021.



1. Gasoline is motor gasoline and aviation gasoline excluding fuel ethanol. Distillates exclude biodiesel and renewable diesel fuel.
2. Includes residual fuel oil, lubricants, hydrocarbon gas liquids (propane), and electricity.

Data Source: U.S. Energy Information Administration (EIA), *Monthly Energy Review,* Tables 2.5, 3.8c, and A1. April 2022, and EIA Petroleum Navigator. April 2022; preliminary data.
Note: Sum of individual components may not equal 100% because of independent rounding.

Figure 22. U.S. Transportation Energy Sources/Fuels, 2021 (Based on Energy Content)

Renewable fuels offer benefits that are key components to reduce the lifecycle carbon intensity of a wide range of end-use sectors:

- Energy diversification: Renewable fuels provide a diversity of energy solutions especially since they are produced from distributed energy sources, allowing the U.S. energy system to be resilient. A broad cross section of alternatives lessens the dependency on any one energy source and allows expanded consumer choice.
- Lower lifecycle emissions today: Near-term lifecycle GHG emissions reductions creates substantial value, and renewable fuels serve as a ready-now solution. Renewable fuels can reduce lifecycle GHG emissions now with today's technologies and through use of existing infrastructure.

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[26] U.S. Energy Information Administration, Use of energy for transportation, https://www.eia.gov/energyexplained/use-of-energy/transportation.php.

In addition, vehicles that are liquid-fueled remain the lowest total cost of ownership solution for both personal and commercial transportation,[27] despite decreasing costs of alternative technologies such as battery-electric vehicles. This status quo is expected to remain through at least 2030. Renewable fuel solutions can cost more to produce compared to petroleum fuels due to lack of scale and technology advancements. Therefore, policies that encourage renewable fuel adoption can balance fuel costs for consumers and businesses and the ability to produce renewable fuels at scale.

6.6.2 Current Status

Renewable Diesel (RD) is produced by hydrotreating biofeedstocks, such as plant or waste oils, resulting in lower GHG emissions on a lifecycle basis compared to petroleum diesel. The ease of transition to RD is an attractive lower carbon solution for consumers; it reduces emissions without range limitations, new equipment, or infrastructure modifications. RD is produced most often by hydrotreating biofeedstock oils, which can be done using existing refining infrastructure and capabilities. Increasing policy and regulatory programs have supported the expansion of RD nationwide. RD supply in the United States is likely to increase given the announced projects to build new or convert facilities to produce RD. The growth of announced Hydrotreated Vegetable Oil (HVO) renewable diesel production capacity is shown in Figure 23.

Biodiesel is produced from the same biofeedstocks as RD but uses a different process known as transesterification. The end product is a lower carbon intensity fuel, which is chemically different than petroleum diesel. As such, biodiesel can be blended with petroleum diesel or RD for use in existing internal combustion engines, typically up to 20%.

Sustainable aviation fuel is produced from biofeedstocks such as plant or waste oils and can be blended up to 50% with petroleum jet fuel. SAF is compatible with modern aircraft engines and airport fueling infrastructure. There are currently seven technology pathways approved under ASTM standards to produce SAF. SAF can significantly reduce the lifecycle carbon intensity of aviation fuel; however, it is commercially available in limited quantities. Historically, the lack of policy support to offset the cost to produce SAF have limited the production of SAF.

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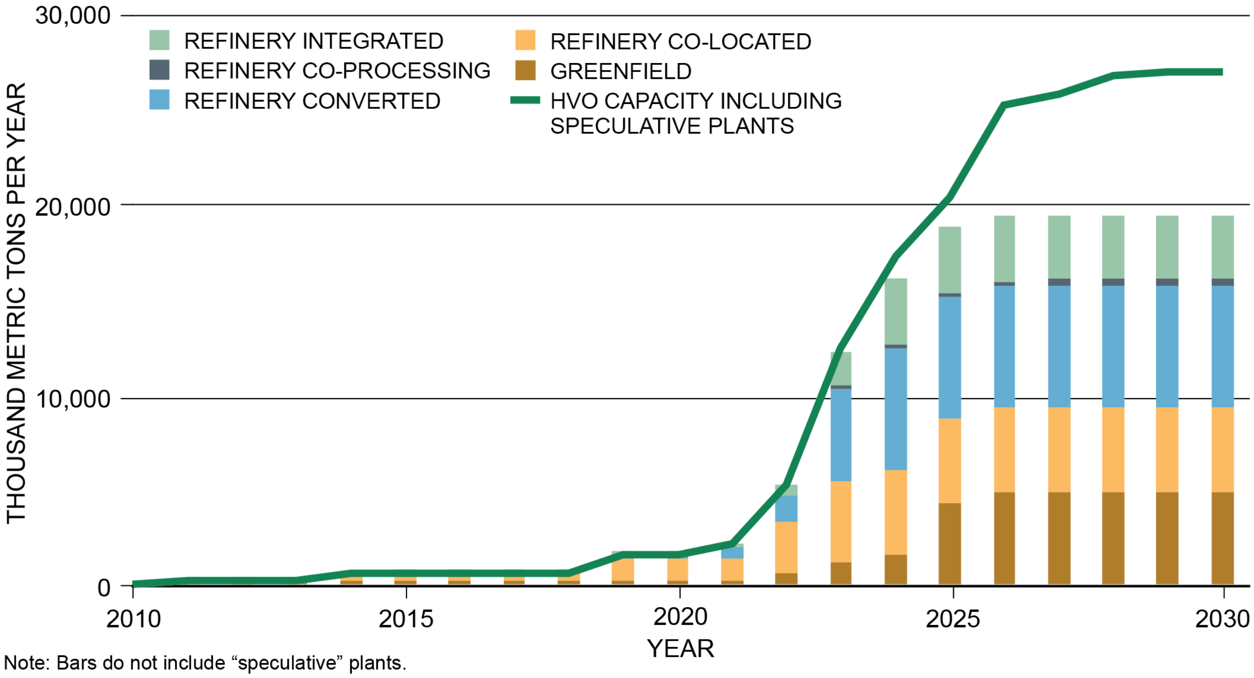
[27] Argonne National Laboratory, *Comprehensive Total Cost of Ownership Quantification for Vehicles with Different Size Classes and Powertrains,* April 2021, https://publications.anl.gov/anlpubs/2021/05/167399.pdf.



Note: Bars do not include "speculative" plants.
Source: Copyright 2022 S&P Global Inc. All rights reserved.

Figure 23. Announced Regional HVO Production Capacity by Type – North America

Renewable natural gas is a gaseous renewable fuel derived from sources such as animal manure, landfill waste, energy crops, and food waste. RNG facilities capture methane that is currently emitted to the atmosphere and convert it into a renewable fuel. RNG facilities capture naturally occurring gas from these waste sources and repurpose it, creating a beneficial and domestic source of energy. It has potential for a negative lifecycle carbon intensity under programs such as the California Low Carbon Fuel Standard. In addition, RNG provides a methane mitigation solution to vital industries like food production, wastewater treatment, and waste disposal. RNG is a drop-in fuel for existing natural gas uses and can use the existing natural gas distribution system and pipelines or be compressed or liquified and dispensed for use in compressed natural gas (CNG) vehicles. RNG vehicles have potential for negative lifecycle emissions, depending on the RNG feedstock source. RNG has reduced 660 million gallons of diesel consumed by heavy duty vehicles. By filling approximately 3 million semi-trucks or 7.3 million transit buses, 14,792 million pounds of CO_2 emissions can be reduced by converting existing waste streams into a valuable fuel source.[28] In 2020, approximately 3.5 million metric tons of CO_2 emissions were avoided by using RNG used as vehicle fuel in the United States. That's the equivalent of removing 756,000 cars from the road.[29]

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[28] The Coalition for Renewable Natural Gas, *Economic Analysis of the US Renewable Natural Gas Industry,* 2021.

[29] The Coalition for Renewable Natural Gas, *RNG: Zero Scope 1 Emissions and Negative Carbon Intensity*, 2021

It is also important to note that RNG can be created from green hydrogen. The methane produced from combining hydrogen with CO_2 (from non-fossil sources) is known as Power to Gas (P2G) and is a clean alternative to conventional fossil natural gas, as it can directly displace fossil natural gas for combustion in buildings, vehicles, and electricity generation without releasing net incremental CO_2 emissions. Methanation avoids the cost and inefficiency associated with hydrogen storage and creates more flexibility in the end use through the natural gas system. The P2G-RNG conversion process can also be coordinated with conventional biomass-based RNG production by using the surplus CO_2 in biogas to produce the methane, creating a productive use for the CO_2. A critical advantage of P2G is that the RNG produced is a highly flexible and interchangeable carbon neutral fuel. With a storage and infrastructure system already established, RNG from P2G can be produced and stored over the long term, allowing for deployment during peak demand periods in the energy system. RNG from P2G also utilizes the highly reliable and efficient existing natural gas transmission and distribution infrastructure, the upfront costs of which have already been incurred.

Renewable gasoline is a lower carbon intensity gasoline drop-in fuel that can be utilized in existing light duty vehicle internal combustion engines (ICE), which comprise more than 99%[30] of today's light-duty vehicle engines in the United States. Lower carbon intensity gasoline is produced by using blendstocks that are produced from a wide variety of bio-based resources, resulting in lower GHG emissions on a lifecycle basis compared to petroleum gasoline. Studies suggest that lower carbon intensity gasoline can potentially deliver GHG emission reduction parity with battery-powered electric vehicles on full lifecycle basis, when paired with advanced internal combustion engine (ICE) technology plus updated gasoline specifications. Although lower carbon intensity gasoline can be used in existing light-duty vehicle ICE technology, it is not widely produced today due to lack of policy support.

Ethanol is typically produced from starch- and sugar-based biofeedstocks such as sugar cane, corn, or sugar beets. Cellulosic ethanol can be produced from biofeedstocks such as crop and wood byproducts. Cellulosic ethanol has a lower carbon intensity compared to conventional ethanol but is in limited supply as technology development is needed to lower the cost to produce. Conventional and cellulosic ethanol can be used as blendstocks with conventional gasoline or can be blended with lower carbon intensity gasoline to produce a high-octane fuel that reduces energy consumption and lifecycle GHG emissions. Ethanol blend volumes in gasoline are limited by the blend wall set at 10%, which has limited the production growth of ethanol. Ethanol can also be a feedstock to produce renewable fuels such as SAF via an Alcohol-to-Jet (ATJ) pathway. The carbon intensity of the ethanol supplied today can be reduced by implementation of carbon sequestration and sustainable farming practices.

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[30] Reuters, *The long road to electric cars*, February 2022, https://www.reuters.com/graphics/AUTOS-ELECTRIC/USA/mopanyqxwva/.

6.6.3 Challenges

Broader growth in renewable fuels is challenged by biofeedstock availability at scale.

- Renewable diesel, biodiesel, and SAF demand in the United States is forecasted to more than double between 2022 and 2030,[31] supported by policy and production investments. Access to biofeedstock and development of next generation lower carbon biofeedstocks is critical to meeting renewable fuels growing demands. Therefore, an increasing number of partnerships have been formed between agriculture and energy industries to integrate biofeedstock and production capabilities.

- SAF production will grow in the United States, European Union, and Asia as policy evolves through 2030 and corporations take action to meet increasing sustainability goals. There is limited biofeedstock supply to meet the future demand for renewable fuels. Innovation in feedstock, technology investment and cross-industry partnerships are critical to enable renewable fuels at scale.

- Today, RNG supply is largely being deployed in states with policy support, like California, and the transportation market due to policy support through Lower Carbon Fuel Standard incentives. Given the large amount of organic waste streams available domestically such as landfill and manure, there is considerable potential to increase RNG supply. With policy support such as the Inflation Reduction Act (IRA) Clean Fuel Production Tax Credit, RNG could see continued growth in the United States as a fuel for a wide range of end-use sectors that currently use geologic natural gas.

6.6.4 Recommendations

The opportunity for renewable products to decarbonize the end-use sectors is significant; for example, annually, U.S. vehicles [trucks and cars] use more than 4 billion barrels of petroleum-based fuels and emit 1.6 billion tons of GHG emissions into the atmosphere.[32] There are approximately 250 million cars, SUVs, and light-duty trucks on the road today, with about 17 million new cars are sold each year.[33] At this turnover rate, it could be a decade or more before greater numbers of electric vehicles are adopted. Policy support will accelerate growth of renewable fuels.

The IRA contains several provisions that introduce or expand tax credits that incentivize the further expansion of domestic renewable fuel supply. The New Clean Fuel Production Tax Credit (45Z) allows fuels to qualify for a maximum credit of up to $1 per gallon based on the

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[31] S&P Global Commodity Insights, Top Biofuels Market Trends in 2022 and Beyond, https://www.spglobal.com/commodityinsights/en/ci/Info/0322/top-biofuels-market-trends-2022-beyond.html.

[32] U.S. Department of Energy, Co-Optimization of Fuels & Engines, *The Road Ahead: Toward a Net-Zero-Carbon Transportation Future,* June 2022, https://www.energy.gov/sites/default/files/2022-06/beto-co-optima-fy15-fy21-impact.pdf.

[33] Reuters, *The long road to electric cars,* February 2022, https://www.reuters.com/graphics/AUTOS-ELECTRIC/USA/mopanyqxwva/.

fuel's overall emissions intensity. The bill also introduces a new production tax credit for SAF (40B) between $1.00-$1.75 per gallon based on the fuel's emissions reduction qualities with the credit available through 2026. The IRA also extends current tax credits for second generation biofuels and the current $1 per gallon credit for both bio and renewable diesels through 2024. While IRA credits will be helpful in stimulating further capacity expansion in renewable fuels, the potential sunsetting of these credits creates some uncertainty for the sector. The IRA also extends the investment tax credit (Section 48) to include qualified renewable and biogas projects that begin construction before 2025. While the tax credits in IRA provide a positive signal to renewable fuels producers, further credit extensions or additional long-term policy certainty may be required to incent further expansion of renewable fuels capacity.

RNG is carbon neutral, or sometimes carbon negative, versatile, and fully compatible with the U.S. pipeline system, so it can lower emissions in homes, businesses, and heavy industries, such as manufacturing. Utilities throughout the country are starting to offer RNG to their customers as another option to lower household emissions. The United States possesses the most extensive gas pipeline delivery network in the world, and using this system to deliver new forms of energy such as RNG is a critical component of our nation's ability to reach ambitious GHG reduction goals. Although the availability of renewable gas is relatively limited at present in most regions, low-carbon fuel producers have shown the ability to ramp up production relatively quickly when a market is developed for the RNG. For example, a 2019 study performed on behalf of Argonne National Laboratory estimated that 157 RNG production facilities would be operating in the United States at the end of 2020 (up 78% from 2019), 76 projects under construction (up 100%), and an additional 79 projects in the planning process.

Progress is possible now with renewable fuels. Renewable fuels are a cost-efficient solution that can be used today in the existing building and industry end uses, vehicle fleets, and infrastructure, can lower emissions now, and can provide energy diversification.

Biofeedstocks supply is expected to tighten further given the announced renewable fuels production capacity growth in the mid-2020s. Policy can increase biofeedstocks available to produce renewable fuels by providing near-term approvals of new waste and emerging feedstock sources. Also, policies that recognize and incentivize sustainable farming practices can allow lower carbon intensity biofeedstocks to be available today and promote agricultural innovations. These farming practices further reduce GHG emissions, which should be reflected.

Broader acceptance of feedstock and technology pathways to process feedstocks will reduce the cost to produce renewable fuels. For example, co-processing is a cost-efficient means of producing renewable fuels with petroleum feeds (crude oil) using existing refining facilities. Policies that include technology solutions such as co-processing can allow for higher volumes of renewable fuels to be available in the market today with limited infrastructure modifications required.

Policies with a technology inclusive and full-lifecycle approach can provide a means to achieve climate and air quality goals with affordable, reliable solutions that can make progress possible now. Policy can create hurdles to meeting climate goals by limiting certain technologies and solutions. Therefore, it is critical that an all-inclusive, broad-based policy approach is taken to make impactful lifecycle GHG emissions reduction now and reduce uncertainties associated with a single technology focus.

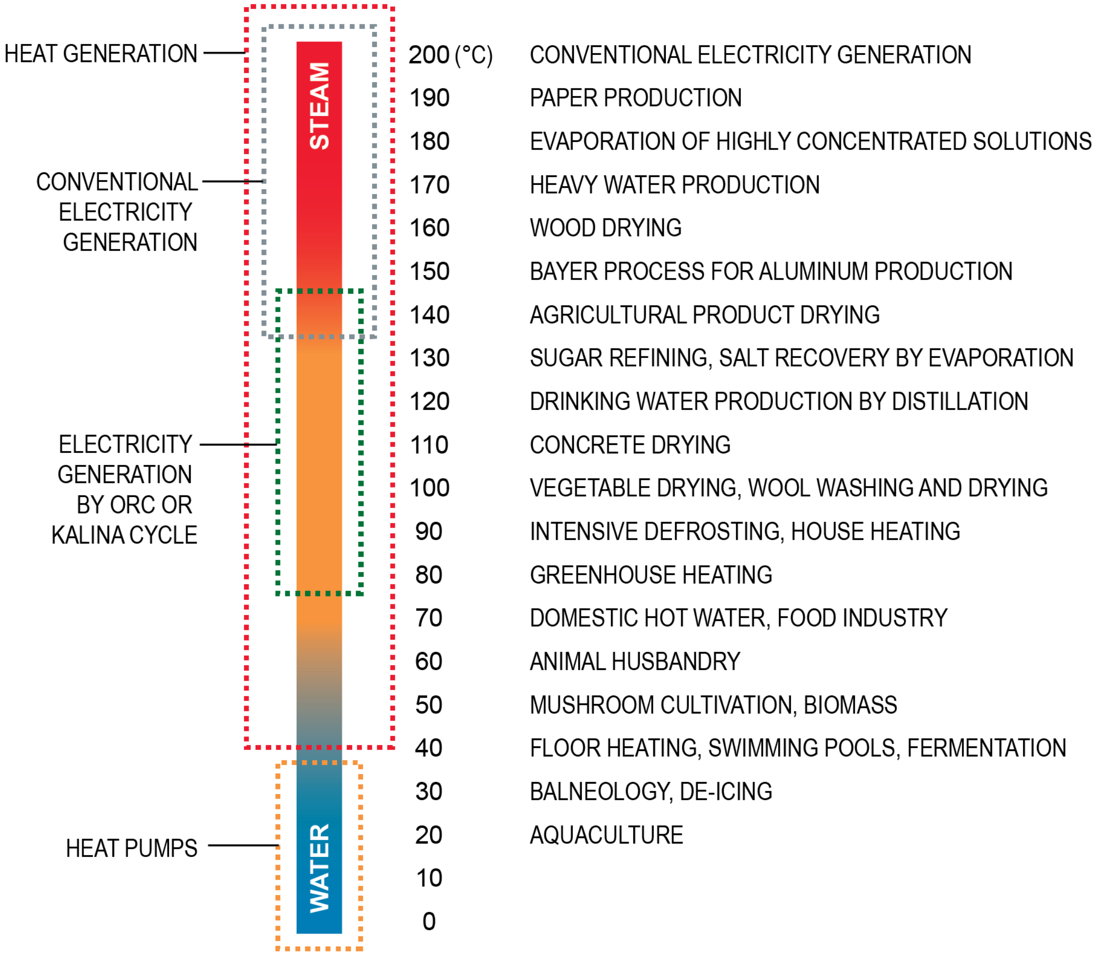
To succeed in achieving climate and air quality goals, all viable pathways should be explored, including electrification, hydrogen, and renewable fuels that are lower carbon intensity fuels – focusing not only on solutions that are long-term and complex, but also those that are near-term, accessible, and affordable to everyone.

6.7 Geothermal

6.7.1 Introduction

Geothermal energy is not a new idea. It's been used since Roman times, and scientists and practitioners have known about its potential since the early 1900s. There is an increasing recognition that geothermal energy could play a substantial role in the energy transition. Geothermal is a resilient and renewable energy source that has bipartisan support because it provides not only clean, firm, stable baseload power partner (thus serving as a ready complement to wind and solar energy, while stabilizing electricity grids) but is also used to supply carbon-free heating and cooling in buildings, industrial/process heat, and heat for agricultural applications, such as greenhouse heating and food processing. Figure 24 shows examples of applications for geothermal energy at various temperatures. Geothermal energy also facilitates transportation: geothermal fluids often contain attractive amounts of dissolved Lithium, which is filling a growing need for EV batteries. There is a growing recognition of the value of geothermal energy, and people and industries want more of it.

The total installed geothermal power capacity worldwide is about 16 GW, all of which is supplied from naturally occurring "conventional" geothermal resources that have the right combination of high temperature and high permeability, enabling high well productivities. This combination of attributes has enabled geothermal projects to compete with power produced from other sources. 3.8 GW of geothermal power is installed in the western United States, where subsurface temperatures are hotter than in the rest of the nation. Geothermal power has not been developed at scale because of limited public-sector support, competition from lower-cost fuels, and importantly, this geologic constraint on conventional geothermal resources. Enhanced (or Engineered) Geothermal Systems (EGS), an "unconventional" geothermal resource type that focuses on engineered strategies, aims to improve subsurface permeability and thus access the omnipresent heat of the earth in hot rock at attractive depths. In the 2010s, public investment in geothermal (primarily by the U.S. Department of Energy) increased somewhat (to $84 million in 2019), and the focus shifted to unconventional geothermal. Recognizing that high permeability is not found everywhere but hot rock can be found



Source: Modified from Watson et al., "Repurposing Hydrocarbon Wells for Geothermal Use in the UK: The Onshore Fields with the Greatest Potential," *Energies,* 2020.

Figure 24. Geothermal Applications

everywhere in the subsurface, the U.S. Department of Energy's Geothermal Technologies Office (DOE-GTO) has made EGS its top priority. DOE-GTO's FY2023 budget request is $202 million, compared allocated budgets of just over $100 million in 2020, 2021 and 2022. These amounts are orders of magnitude lower than funding allocations for wind, solar and fossil fuels (and for most other energy technologies).

The passage of the Inflation Reduction Act of 2022 provides valuable incentives for renewable energy, including geothermal. Although the legislation has a first focus on the short term (for projects that begin construction before 2025), the legislation restores federal tax credits to the full rate for new renewable energy projects for 2025 and beyond in the Clean Energy Investment Tax Credit (CEITC) and the Clean Energy Production Tax Credit (CEPTC). The CEITC provides a two-tier investment tax credit for the eligible costs of qualified facilities (including geothermal) placed in service after December 31, 2024, at rates corresponding to the 30% ITC (6% "base"/30% maximum). For electricity produced at qualified facilities that are placed in service after December 31, 2024, and sold to unrelated taxpayers (like a utility), the CEPTC provides a two-tier, inflation-adjusted tax credit equal to the corresponding PTC amounts of 0.3 cents/kWh “base”/1.5 cents/kWh maximum, as adjusted for inflation (which for taxable year 2022 is equal to 2.6 cent/kWh). Both tax credits will phase down to 75% of the relevant credit amount for projects that begin construction in the second year following the later of (i) 2032 or (ii) the calendar year in which Treasury determines that the annual greenhouse gas emissions from the production of electricity in the United States are equal to or less than 25% of those emissions for calendar year 2022. A further reduction to 50% of the credit amount will occur in the following year, and no credits will be allowed for projects that begin construction thereafter. Both credits are also subject to prevailing wage and apprenticeship requirements, and could benefit from incremental credit amounts if one or more of the domestic content, the energy community, or the low-income community rules are met.

After a decades-long hiatus, oil and gas is re-engaging with geothermal energy in many locations (including their traditional domain), bringing expertise, technology, and the ability to scale, and renewed interest in this adjacent technology. Several majors and many minors and NOCs are now active in the geothermal space. Recognizing this, DOE-GTO’s GEODE (Geothermal Energy from Oil and gas Demonstrated Engineering) initiative seeks to expand geothermal energy deployment in the United States by leveraging technologies and workforce from oil and gas. The mission of the consortium will be to: 1) adapt and transfer technologies from oil and gas to geothermal; 2) generate heat and power from oil and gas fields; 3) resolve regulatory and permitting barriers; and 4) develop geothermal opportunities that utilize the skilled oil and gas workforce.

In 2008, the United States Geological Survey (USGS) presented an updated evaluation of geothermal energy, focusing on power production.[34] USGS concluded that the potential capacity of developable, power-grade geothermal resources that have already been identified in the United States is at least 5 GW, and that such resources that have not specifically been identified represent another 30 GW. USGS estimates that more than 500 GW are potentially available from our earth in the form of hot, low-permeability rock (i.e., EGS). DOE GTO’s GeoVision report is more conservative, estimating that technologies and methodologies used to explore, discover, access, and manage geothermal resources will enable up to 60 GW of geothermal power generation by 2050.

USGS and DOE-GTO projections aside, the demand for geothermal is high today, not only from utility companies, but also from corporations, communities, and individuals, all of whom are making deliberate choices about the provenance of the electricity they consume. However, geothermal power accounts for less than 1% the U.S. electricity market today and has had little or no support for policy, tax incentives, appropriations, permitting improvements, and more. This situation means that geothermal cannot ramp up fast enough because polices are

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[34] Williams et al., *A Review of Methods Applied by the U.S. Geological Survey in the Assessment of Identified Geothermal Resources,* 2008.

not being put in place fast enough. In addition to benefits related to technology and the ability to scale, the reunion of oil and gas and geothermal could change this situation for the better through influence and advocacy for a directly adjacent energy source.

6.7.2. Summary of Geothermal Technologies (Description, Potential to Scale, Technical Challenges, and Recommendations)

1) Borehole Heat Exchangers (BHEs). This is a relatively old technology that is used almost exclusively for heating. BHEs are closed systems that consist of either a U-shaped pipe (sometimes two in tandem) or a coaxial arrangement of pipes that are designed to capture heat from the earth at depths up to a few hundred meters. They neither produce nor inject formation fluids but rely on conductive heat transfer resulting from fluid circulation within a closed system. The pipes are grouted in place to enable good thermal contact between the BHE and the earth. Deep BHEs may be installed in existing wells and become particularly efficient in combination with solar installations. *Potential to Scale:* Medium to High, readily deployable. *Technical Challenges: None*, this is a simple, long-proven, and practical technology.

2) Ground Source Heat Pumps (GSHPs). GSHP systems are used to heat and cool buildings by exchanging heat with the earth at relatively shallow levels, ranging from just a few meters to a few hundred meters, depending on energy demand. One of the simplest and most deployable uses of geothermal energy, GSHPs work best in areas with seasonal needs for heating in winter and cooling in summer. The change from heating to cooling mode is readily managed with smart feedback and control technology. Some systems shut down between seasons when neither heating nor cooling are needed.

GSHP systems are deployed to manage energy in single residences and larger buildings, including office buildings, apartment complexes, university campuses and industrial parks. For more complex industrial projects with both heating and cooling needs, system-wide energy load balancing can be facilitated using GSHPs. The current geopolitical situation limiting the availability of natural gas is directly leading to increased deployment of GHSPs, particularly (but not only) in Europe.

While GSHPs may be considered a “low tier” use of geothermal energy, they are a key element for energy transition. Companies like Dandelion are advancing residential deployment, and utility companies are adding district heating and cooling projects that use systems of networked GSHPs, starting in densely populated, mixed-use communities.

Potential to Scale: Very Large and can contribute significantly to decarbonizing space heating and cooling. *Technical Challenges: Few.* GSHPs use well-understood and flexible technology that is increasingly being adopted at various scales. The challenge is to deploy at scale in major population centers, at a reasonable price. *Recommendation:* Supportive policy to increase rate of deployment and continue the urban renewal trend in American cities. Municipalities and utilities should be involved and investing.

3) <u>Direct Utilization of Geothermal Fluids</u>. Unlike BHEs and GSHPs (which are closed-loop solutions), warm and hot geothermal fluids are typically used in open-loop scenarios, i.e., they are extracted, used, and often reinjected back into the formation from whence they came, at a suitable distance to minimize cooling of the production well(s). Geothermal fluids can be used in various useful ways, ranging from aquaculture to food drying, home heating, industrial heat, and supplying absorption chillers, depending on temperature.

Since 1969, 50 separate geothermal heating networks have supplied (and continue to supply) the equivalent of 250,000 homes in the greater Paris area. Produced from limestones at a depth of 1,500 – 2,000 m in a large sedimentary basin, the water is too brackish to be potable, but has temperatures ranging from 60 to 80°C – perfect for district heating on a large scale. After passing through heat exchangers, the cooled geothermal fluid is injected back into the same formation at a suitable distance from the production area.

*<u>Potential to Scale</u>: Large***,** across the country (warm and hot waters are present in many places, not only in the west). *<u>Technical Challenges</u>:* Competing interests for water (particularly if the geothermal fluids are not highly mineralized); limited yield from warm or hot aquifers; distance from source to use point, requirements for new infrastructure to deliver warm or hot water; and ability to deploy at scale. *<u>Recommendation</u>:* Inspire public and private investment to accelerate deployment. Municipalities and utilities should be involved and investing.

4) <u>Conventional Geothermal Power</u>. The word "conventional" connotes the presence of the two key elements needed to develop successful geothermal power projects: heat and permeability in the same place. This synergy occurs in tectonically and volcanically active regions of the earth, providing the combination that enables geothermal developers to drill into hot, naturally fractured rock. Nearly all of the 16 GW of installed geothermal power plants today are supplied by these natural, conventional geothermal resources.

Most power plants – regardless of the fuel that supplies them – utilize steam as the motive fluid for the turbine-generator. The same applies to high-temperature geothermal fluids with temperatures of about 220°C or more; however, instead of being fueled by a boiler, natural steam produced from geothermal wells serves as both the "fuel" and the motive fluid for power generation. For lower-temperature resources, a different heat-to-power conversion strategy is needed: the Organic Rankine Cycle (ORC). There are many remaining resources available for development in the United States that would utilize either or both types of power plants. Regardless of power generation technology, conventional geothermal power plants share a common characteristic: remarkably high availability. Once the wellfield has been developed, the majority of the fuel supply is in place. Make-up wells are needed periodically and operators plan for them (and their cost) in advance.

Technical Challenges:

- Long permitting timelines.
- Difficulty identifying highly permeable areas to enable per-well hot water flow rates of at least 30,000 BWPD (and ideally much more).
- A long initial period (several years) that precedes the initiation of a revenue stream (because nearly all the fuel for the project lifetime is developed up-front).
- Geographic limitations (power-grade conventional resources are only present in the western United States).
- Competition from sources that are "cheaper" because CO_2 emissions are not accounted for.
- Potentially, a lack of transmission access (a problem that is not unique to geothermal but affects most renewable technologies).

Potential to Scale: USGS estimates that there remains at least 5 GW of identified but undeveloped conventional geothermal resources in the western United States, and that there are 30 GW of conventional resource that have not yet been discovered. Significant new geothermal development underway as a result of the CPUC mandate for a GW of clean, firm, 24x7 power (geothermal) to be produced in California or wheeled in from nearby states. Deep basin geothermal is being seriously evaluated. Communities are committing to clean power (including geothermal).

Recommendations:

- Initiate a new cost-shared exploration drilling to kick off a new wave of development, with costs shared between the public and private sectors.
- Make rapid progress to shorten permitting timelines.
- Continue and expand the engagement between geothermal and oil and gas. Even with oil and gas re-entering the geothermal market, top-down support is needed to innovate and scale.
- Develop new technology to discriminate regions of high and low permeability in the subsurface, which will increase drilling success rates, reduce costs and hasten project development, and encourage more projects.

5) Unconventional Geothermal Power. In contrast to conventional geothermal projects, unconventional projects do not rely entirely upon nature to provide commercially productive conditions (i.e., high temperature and good permeability in the same place). The following section describes the two main unconventional approaches: Enhanced (or Engineered) Geothermal Systems (EGS) and Advanced Geothermal Systems (AGS).

5.1) Enhanced (or Engineered) Geothermal Systems (EGS). The initiation of EGS strategies coincided with the shale revolution in the oil and gas sector, and the two domains have a common challenge: to improve permeability and increase fluid production rates. In shale, this is achieved by hydraulic fracturing, with leak-off into the shale that opens many smaller fractures, from which oil or gas drains into large fractures that intersect the production well. In contrast, EGS requires more than an attractive production rate: effective heat transfer is also required. The typical propped mode 1 fracture used in shale projects is too permeable to enable much heat transfer; the injected water will rapidly cool the fracture surfaces. In EGS, injected water must pass through a complex fracture network with enough fracture surface area and residence time to enable the injected fluid to pick up heat along a slow, tortuous path from the injection well to the production well. Several EGS demonstration projects have been undertaken, and significant advancement are being made at the EGS underground laboratory near Milford Utah (Frontier Observatory for Research in Geothermal Energy, or FORGE). The FORGE project was deliberately set up to preclude very high temperature resources, thus enabling the use of a significant amount of existing oil and gas technology.

Potential to Scale: Very Large considering the vast heat reserves of the earth (USGS estimates that electrical generation capacity of the available EGS resource base in the United States is more than 500 GW; DOE-GTO estimates that 60 GW of EGS power could be produced by 2050). Achieving scale requires advancing down the learning curve. A typical EGS demonstration project might deal with 1 or 2 deep test wells, never reaching the point where a learning curve becomes apparent. However, at least one EGS operator is following a "basin approach" to improve subsurface understanding, accelerate drilling and optimize stimulation efficiency. Operators with experience in tight shale projects could pivot to EGS.

Technical Challenges: Many, hence the EGS Energy Earthshot's goal of reducing the cost of EGS to $45 per MW-hour by 2035. This will be achieved by focusing on:

- Reducing the cost of drilling materials and equipment
- Advancing engineering techniques that enable deep, large-diameter wells to be drilled quickly, resulting in more wells being drilled and project moving up the learning curve
- Developing new techniques to interrogate the subsurface to identify the best drilling locations
- Improving understanding of subsurface fluid flow to ensure that fluids go where they should while remaining contained within a specific subsurface volume.

Recommendations:

1) Continue collaborative R&D between national labs, universities, and industry to address challenges.

2) Develop a nationwide EGS Favorability Map that takes into account conditions related to earth stresses, formation characteristics, and temperature gradient.

3) Develop best practices for creating the right fracture network in areas of differing favorability.

4) Continue support from DOE to improve EGS stimulation success by undertaking more stimulations, including interventions in sub-commercial wells adjacent to operating conventional geothermal fields.

5.2) Advanced Geothermal Systems (AGS). AGS refers to closed-loop systems that are similar in concept to borehole heat exchangers, but reach greater depths and higher temperatures. Relying solely on conductive heat transfer (like borehole heat exchangers), these systems can be thought of as "radiators in reverse" that capture (rather than dissipate) heat. One type of closed loop (AGS) technology (in the testing phase) is a deep borehole heat exchanger that has a central tube filled with a CO_2-water mixture is the heat transport mechanism. Another AGS technology system has a vertical injection well drilled to a suitable depth to reach the desired formation temperature, then diverts the injected fluid into a series of smaller-diameter pipes (laterals) that are angled downward. At the deepest point, the system of laterals doubles back on itself to initiate upward flow in angled-upward pipes, driven by a thermal siphon.

Potential to Scale: Large, if the technology can be proven and the price point is acceptable. *Technical Challenges: Many.* Well construction is difficult and costs will increase substantially with the depth of the vertical production and injection wells and the orientation (angle) of the laterals in the second example above. AGS is in the RD&D phase, with demonstration projects underway in several places. *Recommendations:* Evaluate this technology after the demonstration projects are completed and operational.

6) Thermal Storage (Earth Battery). The earth is a good insulator, making heat storage is an interesting option. Storage locations include shallow earth-covered vaults, drawn-down aquifers, depleted reservoirs, caverns, and mines. If the subsurface is hot enough, geothermal power (from binary plants) could be generated during specific times of the day to when other renewables are not available. Using concentrated solar power (CSP) to heat water and store it until needed is an interesting hybrid solution.

Potential to Scale: Medium to Large. Pilot projects are underway in Europe (mainly), and the potential to store heat can contribute to decarbonizing the heating sector. *Technical Challenges: Some*, depending on the specifics of the location. Open spaces in the subsurface (caverns, mines) may not be appropriate for this technique, and intragranular pore space may be too limited. There could be competition from others who would like to use the same pore space (*e.g.*, for CO_2 or H_2 storage). Mines or caverns might be too leaky, with the stored fluid gradually leaking off. *Recommendation:* Undertake detailed analyses and preliminary simulations to determine the optimal conditions for storing and extracting heat.

7) Hybrid Solutions. The Geothermal Topic Paper to this report evaluates and discusses 7 hybrid (geothermal +) technologies; all except the last two are either in development or already operating today.

1) Geothermal + Oil and Gas
2) Geothermal + Solar
3) Geothermal + Green Hydrogen
4) Geothermal + Minerals
5) Geothermal Heat for Direct Air Capture Units
6) CO_2 Plume Geothermal + CCS
7) Wind + Geothermal

Appendices

Appendix A: Request Letter and Description of the NPC

Appendix B: Study Group Rosters

Appendix A

The Secretary of Energy
Washington, DC 20585

July 29, 2022

Mr. Darren W. Woods
Chair, National Petroleum Council
Chairman and Chief Executive Officer
Exxon Mobil Corporation
5659 Las Colinas Boulevard
Irving, Texas 75039

Dear Mr. Woods:

Thank you for arranging an administrative meeting with the National Petroleum Council (NPC) at my request on July 1. In this meeting I shared my deep concern over the current crude oil and refined products supply and demand imbalance caused by multiple factors, underscoring the outsized impact from the unprecedented invasion of Ukraine. This imbalance continues to create upward pressure on oil prices, resulting in significant financial pain at the pump for the American people. President Biden is committed to alleviating this burden and taking steps to shore up supply, including calling on industry to increase private inventories to protect the American people. I appreciated your perspectives on how the NPC could help provide expert recommendation and analysis to help prepare and address this ongoing challenge.

As we focus on increasing the financial pressure on Vladimir Putin, we are dually focused on mitigating the negative impacts on the domestic economy. We recognize that U.S. refiners, producers, and the full supply chain are experiencing constraints, and as we look at the situation comprehensively, I informed you of the following areas that I am interested in receiving formal advice:

- How can we increase supply? Where is there efficiency and/or opportunity to increase current supplies of crude oil and refined products?

- What are current constraints and market hurdles to getting affordable products to U.S. consumers?

- How are companies reevaluating traditional emergency preparedness? Given the current tight market, how is industry making sure inventories are well supplied should there be a critical disruption from major and/or multiple storms, a cyber-attack, or other unforeseen events that would cause refineries or pipelines to shut down? What additional actions can the government be taking in coordination with industry to help enhance preparedness?

- Where is industry taking steps and grasping opportunities to prepare for a net-zero economy? Right now, we are seeing impacts from an unmanaged transition.

> What actions are being taken by industry to move to a more managed energy transition? What actions can the government take to support a more managed transition?

I request the NPC to:

1. Provide within 30 days a written list of: (i) the ways industry is preparing to secure consistent, physical supply for the American people; and (2) near-term actionable steps the Administration can consider to help increase physical supply of oil and refined products while continuing safe, efficient operations and maintenance of production facilities.

2. Conduct analysis and issue a report within 120 days examining and providing an analysis of the changing global crude supply and how it will positively and/or negatively impact U.S.-based producers, suppliers and refiners; note expected supply challenges in the near term and medium term that should be evaluated further; and provide an update on ongoing work related to the steps the industry is taking to be an active player in a net-zero economy by 2050.

For the purposes of the study, I am designating Deputy Secretary David Turk as the official to whom the NPC reports and to represent me at NPC meetings. The Assistant Secretary for Fossil Energy and Carbon Management, Brad Crabtree, will work with Deputy Secretary Turk to provide the NPC with the information it needs to expedite the analysis and advice from the NPC.

In order to receive advice from the NPC in a time frame that will allow for consideration and action, I appreciate your written response to the near-term recommendations, and I will request the convening of a full NPC meeting following the 120 days to brief me on the results of this study.

Sincerely,

Jennifer Granholm

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 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.

Examples of studies undertaken by the NPC at the request of the Secretary include:

- *Principles, and Oil & Gas Industry Initiatives and Technologies for Progressing to Net Zero* (2022)
- *Petroleum Market Developments – Progress and Actions to Increase Supply and Improve Resilience* (2022)
- *Meeting the Dual Challenge: A Roadmap to At-Scale Deployment of Carbon Capture, Use, and Storage in the United States* (2019)
- *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* (2018)
- *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)
- *Facing the Hard Truths about Energy: A Comprehensive View to 2030 of Global Oil and Natural Gas* (2007)
- *One Year Later: An Update On Facing the Hard Truths About Energy* (2008)
- *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).

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 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

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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.

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 broad and diverse participation informs and enhances its studies 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, and its Subcommittee and Subgroups, as a recognition of their contributions.

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