

TASK FORCE

The Donald C. Hellmann Task Force Program



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Global Trends in Energy and Emissions:
Key Points for Policy Decision-Making

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Introduction

Executive Summary

How much progress is the world actually making in the shift away from fossil fuels and toward reducing global emissions? The energy transition, as this shift has been called, is decidedly underway: since 2001, more than \$4 trillion of global investment has gone into expanding renewable energy.¹ What, however, do global energy trends tell us has been achieved?

This Task Force will assemble an accurate picture of global energy use and emissions for regions across the world, focusing on major emitting nations such as China, the European Union, India, Russia, and the United States. Aimed at giving realistic, usable advice to policy decision-makers, this report will analyze trends in light of recent energy policy decisions to identify the degree to which progress toward emissions reductions has or has not occurred and are set to occur in the next few decades.

Land Acknowledgment

This Task Force acknowledges the Coast Salish peoples of this land, the land which touches the shared waters of all tribes and bands within the Duwamish, Puyallup, Suquamish, Tulalip, and Muckleshoot nations.

Global Emissions

Throughout the last 150 years, the widespread usage of electricity and energy production has become increasingly essentialized. In a continuously developing world, the production of energy and mitigation of climate-driven concerns are at the forefront of conversations regarding the future. This report looks at the means of energy production available and upcoming technologies, distinguishing the realities in energy production from popularized hopes, exploring the geopolitical and political advantages and disadvantages of each.

Entering into a discussion about energy production and global emissions, it is essential to first set the scene for global energy demands and emissions.

Global Energy Consumption and Production

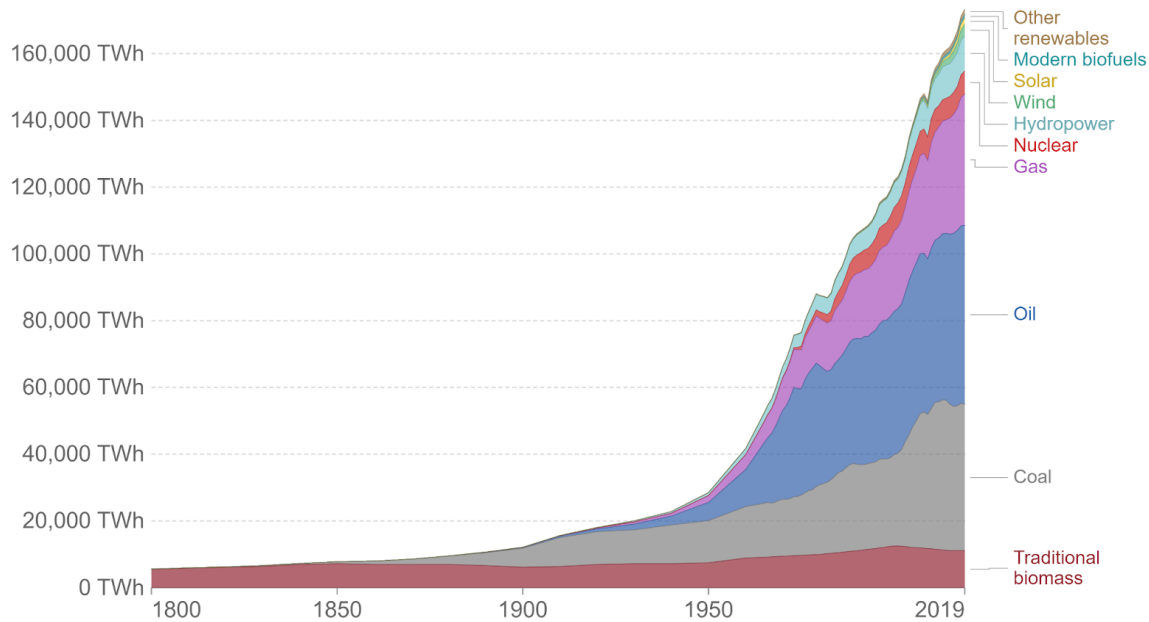
Global demand for energy is increasing over time, as countries that have already developed have increased consumption, and as other nations move toward increasing development. According to Figure 0.1, between 1800 and 1875, global energy consumption remained relatively low at around 10,000 terawatt-hours (TWh)—from primarily biomass sources. From 1900 to 1950, energy consumption grew past 20,000 TWh before spiking at 160,000 TWh in 2019.

¹ Madhumitha Jaganmohan, “Clean Energy - Global Investment 2019,” Statista, January 27, 2021, <https://www.statista.com/statistics/186807/worldwide-investment-in-sustainable-energy-since-2004/>.

With the exponential increases in energy consumption during the last 150 years, developments in energy production have had to progress quickly; Figure 0.1 also displays the variation in energy creation.

Global primary energy consumption by source

Primary energy is calculated based on the 'substitution method' which takes account of the inefficiencies in fossil fuel production by converting non-fossil energy into the energy inputs required if they had the same conversion losses as fossil fuels.



Source: Vaclav Smil (2017) & BP Statistical Review of World Energy

OurWorldInData.org/energy • CC BY

Figure 0.1. Chart by Our World in Data with data collection from Vaclav Smil & BP Statistical Review of World Energy

Over time, coal, oil, and gas (fossil fuels) have become the primary means of energy production, with other forms making strides in recent years. Until around 1870, the primary form of energy consumption came from the use of traditional biomass, which has remained relatively steady over time. While coal and oil have revolutionized global energy access, today it is understood that the burning of carbon-based sources is a major contributor to global climate change and endangers the health of populations where fossil fuels are procured and burned.

In 2021, the International Energy Agency (IEA) emphasized the impact that COVID-19 has had on energy demand and CO₂ emissions. In 2019, major decreases in energy consumption and carbon emissions were experienced globally, as much of the world went into lockdown. In 2022, the world has reopened with tenacity, as global energy demand was projected to increase by 4.6% in 2021.² This increase will push energy demand beyond pre-pandemic consumption levels, ultimately leaving demand 0.5% higher than in 2019.³ The dramatic difference in demand

² Laura Cozzi et al., “Global Energy Review 2021,” IEA (International Energy Agency, April 2021), <https://www.iea.org/reports/global-energy-review-2021?mode=overview>, 4.

³ Cozzi et al., “Global Energy Review 2021,” 4.

is driven largely by developing economies, while advanced economies are set to remain 3% below pre-pandemic demand, according to the 2021 report.⁴

Other key findings from the IEA report included increased demand for carbon-based energy, coupled with high-carbon emissions. Demand for coal was set to rise 4.5% in 2021, with consumption growth occurring largely in Asia.⁵ Further, natural gas experienced major demand increases, with 3.2% growth driven by demand in Russia, the Middle East, and Asia.⁶ As a result of the fast-growing demand for carbon-based energy, energy-related CO₂ emissions were set to rise nearly 5% globally in 2021.⁷

Net Zero Emissions by 2050

In 2021, the IEA released a roadmap toward achieving net zero emissions of CO₂ by 2050 (NZE 2050) and keeping global warming to about 1.5°C. With a few exceptions, this goal was accepted at the 2021 United Nations Climate Change Conference (COP26) by both developed and developing nations. The IEA outlined a framework for actions that included more than 400 milestones toward decarbonization.

According to the IEA, the next thirty years should include plans for tripling clean energy investment to \$4 trillion and driving huge leaps in non-carbon energy innovation by 2030.⁸ By 2035, they postulate that there will be a rapid shift away from fossil fuels and that in 2040 electricity will be the core of global energy systems, which will have net zero emissions during generation. In 2045, new low-emission industries will grow, and by 2050, the energy sector will be based primarily on renewable energy.⁹ The IEA report also provided a comprehensive and detailed plan for achieving this timeline, with smaller milestones outlined by year. This list includes 60% of global car sales going electric by 2030 as well as overall net zero emissions electricity in advanced economies by 2035 and net zero emissions electricity globally in 2040.¹⁰

The IEA's roadmap to NZE 2050 is ambitious, but it serves as an outline for the kinds of drastic actions that must be taken to reduce carbon emissions. Further, the roadmap to NZE 2050 provides insight into the necessary steps and landmarks that should be achieved, despite whether or not they follow the IEA's timeline. Both advanced and growing economies have an essential role to play in revolutionizing global energy systems. The NZE 2050 report reiterates that cooperation between countries will be key to reducing emissions in the coming decades. Development toward carbon neutrality must take economic development and a rising standard of living into account. It is important that advanced economies work to support developing economies in the process of making economic advancement while working toward carbon

⁴ Cozzi et al., "Global Energy Review 2021," 4.

⁵ Cozzi et al., "Global Energy Review 2021," 4.

⁶ Cozzi et al., "Global Energy Review 2021," 5.

⁷ Cozzi et al., "Global Energy Review 2021," 5.

⁸ Stephanie Bouckaert et al., "Net Zero by 2050," IEA (International Energy Agency, May 2021), <https://www.iea.org/reports/net-zero-by-2050>.

⁹ Bouckaert et al., "Net Zero by 2050," 20.

¹⁰ Bouckaert et al., "Net Zero by 2050," 20.

neutrality. Vice versa, it is essential that advancing economies maintain stable governmental systems that will support the growth of low to no-carbon energy systems.

Implications of Energy Related Carbon Emissions

In the report *Climate Change 2021*, the Intergovernmental Panel on Climate Change (IPCC) introduced five scenarios based on “climate models participating in the Coupled Model Intercomparison Project Phase 6 (CMIP6) of the World Climate Research Programme.”¹¹ This is illustrated in Figure 0.2.

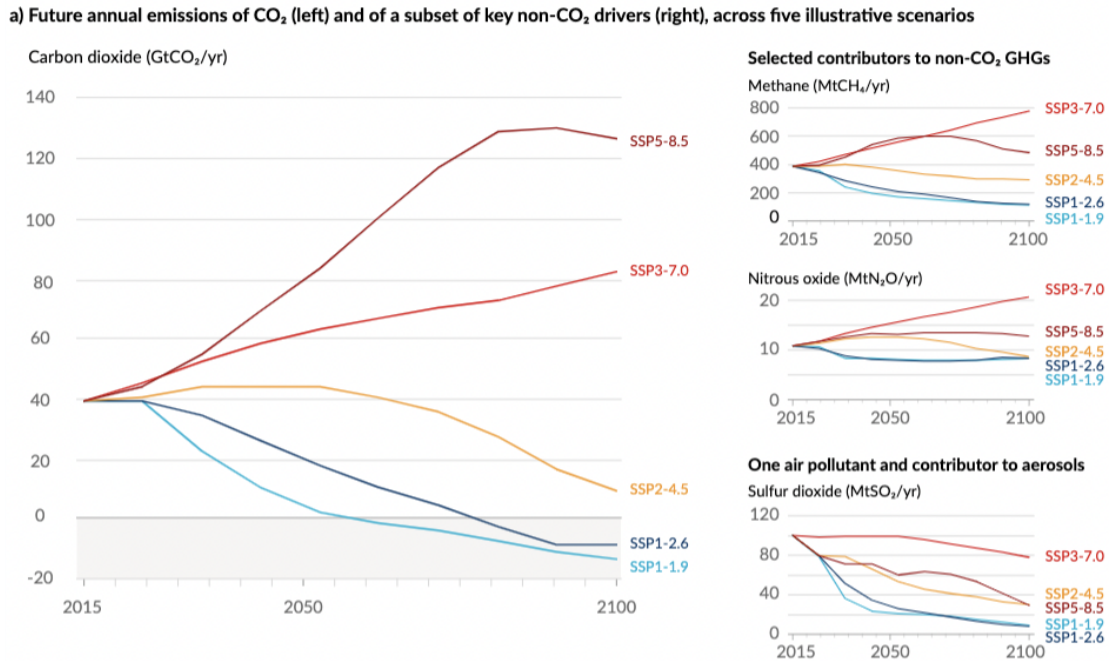


Figure 0.2. Future annual CO₂ emissions across all five scenarios. Chart and data by the IPCC. According to the IPCC report, “Global surface temperature will continue to increase until at least the mid-century under all emissions scenarios considered.”¹² Furthermore, “Global warming of 1.5°C and 2°C will be exceeded during the 21st century unless deep reductions in CO₂ and other greenhouse gas emissions occur in the coming decades.”¹³

Drivers of Carbon Emissions

According to the IPCC Sixth Assessment, it is “unequivocal” that human activity has produced increasing concentrations of GHG emissions – so much as to cause rapid, pervasive warming throughout the Earth’s atmosphere, oceans, biosphere, and cryosphere around the globe.¹⁴ Human influence, mainly atmospheric aerosols (particulate air pollutants and smoke) and well-mixed GHGs (CO₂, CH₄ methane, and N₂O nitrous oxide, in descending order of

¹¹ IPCC, 2021: *Climate Change 2021: The Physical Science Basis*. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.

¹² IPCC, 2021: *Climate Change 2021: The Physical Science Basis*.

¹³ IPCC, 2021: *Climate Change 2021: The Physical Science Basis*.

¹⁴ IPCC, 2021: *Climate Change 2021: The Physical Science Basis*, 5.

atmospheric concentration), have caused the climate to warm at rates unprecedented in thousands of years.¹⁵ In 2019, the atmospheric concentration of CO₂ was the highest in at least two million years, and since 1750, has had greater increases than naturally occurring fluctuations between glacial periods across millennia. Tied to this trend, global surface temperatures have increased faster in the last fifty years than over any other fifty-year period in the last 2000 years.¹⁶

The rapid, far-reaching, and potentially critical changes to the Earth's climate, caused by excessive CO₂ emissions resulting from human activity, cannot be easily or quickly remediated. In addition to the immediately observable effects of rising global temperature, this anthropogenic, or human-induced climate change means that in every region across the planet, climate extremes – including heatwaves, droughts, heavy precipitation, and hurricanes/tropical cyclones – have become increasingly severe and frequent in only the last several decades.¹⁷ Land and ocean carbon sinks, which act as natural cushioning against these outcomes, are predicted to become less effective at slowing CO₂ accumulation in the atmosphere over time, and changes to oceans and to ice sheets caused by GHG emissions are irreversible for centuries to millennia in the future.¹⁸ Actions pertaining to the climate now and in the near future bear enormous significance on the trajectory of the well-being – and continued existence – of the Earth's environment and life forms.

Chapter 1: Carbon Sources

Chapter 1.1: Coal as a Carbon Energy Source

Overview and Introduction

Coal is the world's most highly polluting, carbon-intensive fuel among carbon energy sources.¹⁹ Nonetheless, coal remains the most widely used energy source for the generation of electricity globally.²⁰ Coal's preeminence derives from the geological reality that coal resources are more widely distributed than any other carbon energy source, with commercial abundance in over one hundred countries. Thus, governments of these nations perceive coal as a particularly accessible, affordable, and secure energy source in comparison to alternatives.²¹ These facts complicate the picture for emissions reduction, as coal continues to be the largest source of global carbon emissions, and subsequently, climate change, as Figure 1.1.1 demonstrates. However, it also provides the basic need for secure energy supply in many poor and emergent states.

¹⁵ IPCC, 2021: Climate Change 2021: The Physical Science Basis, 8.

¹⁶ IPCC, 2021: Climate Change 2021: The Physical Science Basis

¹⁷ IPCC, 2021: Climate Change 2021: The Physical Science Basis

¹⁸ IPCC, 2021: Climate Change 2021: The Physical Science Basis, 20.

¹⁹ Hannah Ritchie and Max Roser (2020) - "CO₂ and Greenhouse Gas Emissions". Retrieved from: <https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions> [Online Resource]

²⁰ "Coal." The National Academies of Science, Engineering, and Medicine. Last modified 2022. <http://needtoknow.nas.edu/energy/energy-sources/fossil-fuels/coal/>.

²¹ "Coal." The National Academies of Science, Engineering, and Medicine..

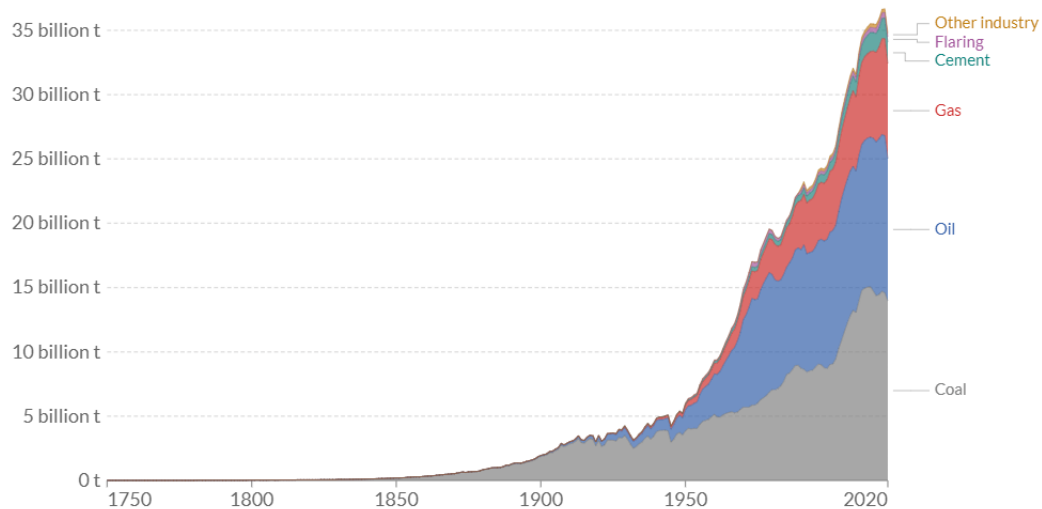


Figure 1.1.1 “CO₂ Emissions by Fuel Type, World” (Source: Our World in Date, CO₂ Emissions, by Fuel)²²

Coal is defined as rock containing 50% or more of its mass as carbon.²³ Coal is generated from vegetal matter accumulated in swamp and wetland environments that are subjected to pressure and heat over time.²⁴ Such environments have been especially abundant and widespread at various periods in the geologic past, leading to its global distribution contemporarily. Coal is an extractive resource, obtained primarily through mining.²⁵ Surface mining is employed when the resource is at shallow levels, roughly 61 to 91 meters below the Earth’s surface.²⁶ Such “strip mining” employs heavy machinery to remove overburden in order to access coal deposits.²⁷ More than two-thirds of U.S. coal mining is done in this way. Surface mining disrupts the ecology and environment of the extraction site greatly, before and after extraction. Underground mining, or deep mining, is used when coal seams are too deep to be accessible through surface mining.²⁸ This necessitates the creation of large underground shafts and elevators and involves explosives and special machinery to excavate the coal. Underground mining is generally more costly, labor-intensive, and involves a higher degree of risk to life and limb. Post-extraction for both modes of coal mining entails transportation via trucks, trains, and ships to move coal from extraction sites to consumer end-nodes, such as coal-fired power stations. Once extracted, coal is ground into small pieces and transported via truck, train, and ship, entailing further emissions along the many steps of the commodity chain.

Coal is divided into four main ranks: anthracite, bituminous, subbituminous, and lignite.²⁹ Ranks are determined by the quantity and types of carbon found in coal, which in turn, are determined by the

²² Hannah Ritchie and Max Roser (2020) - "CO₂ and Greenhouse Gas Emissions". Retrieved from: <https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions> [Online Resource]

²³ James D. Agresti, Steven Bukovec and Rachel McCutcheon, “Energy Facts: Coal,” *Just Facts*, last modified August 25, 2021.

²⁴ Agresti, Bukovec and McCutcheon, “Energy Facts: Coal.”

²⁵ Agresti, Bukovec and McCutcheon, “Energy Facts: Coal.”

²⁶ U.S. Energy Information Administration. "Coal Explained: Mining and Transportation of Coal." In *Energy Explained*, US EIA. U.S. Energy Information Administration, 2020. Last modified December 10, 2020.

²⁷ U.S. Energy Information Administration. "Coal Explained: Mining and Transportation of Coal."

²⁸ U.S. Energy Information Administration. "Coal Explained: Mining and Transportation of Coal."

²⁹ "Coal Explained." U.S. Energy Information Administration. Last modified October 19, 2021. Accessed February 2, 2022.

amount of pressure and heat applied over time.³⁰ About 1% of coal in the United States is anthracite, which contains over 85% carbon and burns most efficiently.³¹ Bituminous is about 45 to 85% carbon and is used in electricity generation and steel production.³² Subbituminous coal contains a lower heat rating and carbon content at 35 to 45% while representing about half of U.S. production, mainly from strip mines in Wyoming.³³ Lignite, or “brown” coal—which comprises 9% of U.S. production—has the lowest energy content and is used in electricity generation.³⁴

In addition to coal’s direct use as an energy source via combustion, coal yields two other energy sources. Most coals naturally contain a significant amount of methane gas, which can be produced via drilling even at shallow levels of under 152 meters. Such drilling has been used to reduce the amount of methane in underground mines, thus improving safety and adding to the overall value of a mine. Over the past several decades, coalbed methane has become an important resource in a number of countries. It is conceivable that this resource could become a lower-carbon replacement for coal itself in some places. A second additional energy source can be produced when coal is itself gasified. This occurs when subbituminous or lignite coal is subjected to high temperatures in a vessel with low levels of oxygen, yielding “syngas,” a combination of carbon monoxide and hydrogen. Processes for converting syngas into fuels, fertilizer, and petrochemicals are well-known, though more costly, than production from oil and natural gas. Nonetheless, the use of coal gasification to potentially lower emissions is being pursued in the United States. A facility located in North Dakota converts lignite coal to synthetic natural gas.³⁵ The world’s top emitter, China, has been exploring coal-bioenergy gasification systems with carbon capture and storage systems that would facilitate both carbon mitigation and air pollution abatement.³⁶

Coal Power Station Technology

There are several technical terms and technologies that are relevant to coal, its emissions, and coal-fired power stations. For instance, many forecasts and scenarios outlining the future of emissions and coal consumption employ terms like “unabated” and “abated” coal. “Unabated” refers to the industrial processes existing in the absence of applied extraneous pollution controls. As it relates to coal, it signifies coal power generation without carbon capture and storage or carbon capture, utilization, and storage (CCS/CCUS) technologies.³⁷ Thus, abated coal power refers to generation with additive controls with the goal of reducing harmful pollution.³⁸ More efficient abated power stations such as supercritical and ultrasupercritical types have become increasingly used in more modern stations.³⁹ Both of these

³⁰ "Coal Explained." U.S. Energy Information Administration.

³¹ U.S. Department of the Interior. "What Is Coal Used For?" U.S. Geological Survey. <https://www.usgs.gov/faqs/what-coal-used>.

³² "Coal Explained." U.S. Energy Information Administration.

³³ "Coal Explained." U.S. Energy Information Administration.

³⁴ "Coal Explained." U.S. Energy Information Administration.

³⁵ "Coal Explained." U.S. Energy Information Administration.

³⁶ Lu, et al. “Gasification of coal and biomass as a net carbon-negative power source for environment-friendly electricity generation in China”. *Proceedings of the National Academy of Sciences*.

³⁷ Littlecott, Chris, Hanna Hakko, and Leo Roberts. "Explained: What Does 'Unabated Coal' Mean?" E3G. Last modified June 24, 2021.

³⁸ Littlecott, Hakko, and Roberts. "Explained: What Does 'Unabated Coal' Mean?"

³⁹ Donev, Jason, Bethel Afework, Jordan Hanania, and Kailyn Stenhouse. "Supercritical Coal Plant." In *Energy Education*. N.p.: University of Calgary, 2018.

types of coal plants differ from older, conventional plants by using water in a supercritical state, with characteristics of both liquid and vapor.⁴⁰ The capital inputs needed for these types of plants are greater than conventional plants, however, higher efficiency reduces emissions and fuel costs.⁴¹ The IEA reports, “CCUS can be retrofitted to existing power and industrial plants that could otherwise emit 600 billion tonnes of CO₂ over the next five decades,” and within their “sustainable development scenario,” they attribute roughly 15% of emissions reductions by the year 2070 to CCUS technologies, serving an important technological role in a given energy transformation.⁴²

Integrated coal gasification combined cycle (IGCC) power plants are another emergent technology relating to coal power generation. IGCC power generation refers to a process by which electricity is generated through the gasification of coal using a gas turbine combined cycle (GTCC) system, and additionally through an exhaust heat recovery steam generator.⁴³ IGCC coal power generation entails several benefits over its conventional coal-fired thermal counterparts, such as increased efficiency, coal type flexibility, lower nitrogen and sulfur oxides and dust pollution, and lower CO₂ emissions.⁴⁴ Emission-reducing technologies like CCUS and IGCC power generation will be crucial in the future of global coal use.

Emissions Relating to Coal Use

In addition to being the most carbon-intensive fuel source, coal combustion results in several other negative emissive byproducts, including but not limited to: sulfur dioxide (SO₂), which creates acid rain and respiratory illnesses; nitrogen oxides (NO_x), which produces smog and also contributes to respiratory ailments; particulates that contribute to smog, haze, lung problems, and respiratory diseases; CO₂, which is the primary greenhouse gas (GHG) contributing to climate change; mercury and other heavy metals which negatively impacts biological development; and lastly, ash pollution.⁴⁵ Existing technology has the ability to, in part, “clean” coal, which in the form of abated coal power generation, removes and reduces SO₂, NO_x, particulate matter, and ash. This, however, does not change the reality that coal is the most carbon-intensive form of energy production, and has contributed greatly to climate change, as demonstrated by Figure 1.1.2, displaying the carbon intensity based on pounds of CO₂ emitted per million British thermal units (Btu).

Coal (anthracite)	228.60
Coal (bituminous)	205.40
Coal (lignite)	216.24
Coal (subbituminous)	214.13

⁴⁰ Donev, Jason, Afework, Hanania, and Stenhouse. "Supercritical Coal Plant."

⁴¹ "Clean Coal' Technologies, Carbon Capture, and Sequestration." World Nuclear Association. Last modified November 2021.

<http://www.world-nuclear.org/information-library/energy-and-the-environment/clean-coal-technologies.aspx>.

⁴² IEA (2020), CCUS in Clean Energy Transitions, IEA, Paris

<https://www.iea.org/reports/ccus-in-clean-energy-transitions>.

⁴³ Mitsubishi Power. "Integrated Coal Gasification Combined Cycle (IGCC) Power Plants." Edited by Mitsubishi Power. <https://power.mhi.com/products/igcc>.

⁴⁴ Mitsubishi Power. "Integrated Coal Gasification Combined Cycle (IGCC) Power Plants."

⁴⁵ U.S. Energy Information Administration. "Coal Explained: Mining and Transportation of Coal." In *Energy Explained*, US EIA. U.S. Energy Information Administration, 2020. Last modified December 10, 2020.

Diesel fuel and heating oil	163.45
Gasoline (without ethanol)	155.77
Propane	138.63
Natural gas	116.65

Figure 1.1.2 “Pounds of CO₂ Emitted per Million Btu of Energy for Various Fuels” (Source: U.S. EIA⁴⁶)
Coal emissions, regardless of their rank, are more carbon-intensive than their competitors, while additionally emitting ash, small particulate matter, and other greenhouse gasses- furthering the claim of coal as a key driver of climate change.

As mentioned throughout this report, China alone comprises a majority of coal consumption, and consumption in postindustrial economies is trending downwards. A majority of coal emissions currently come from East and South Asia, geographically. Figure 1.1.3 demonstrates these trends over the past two decades.

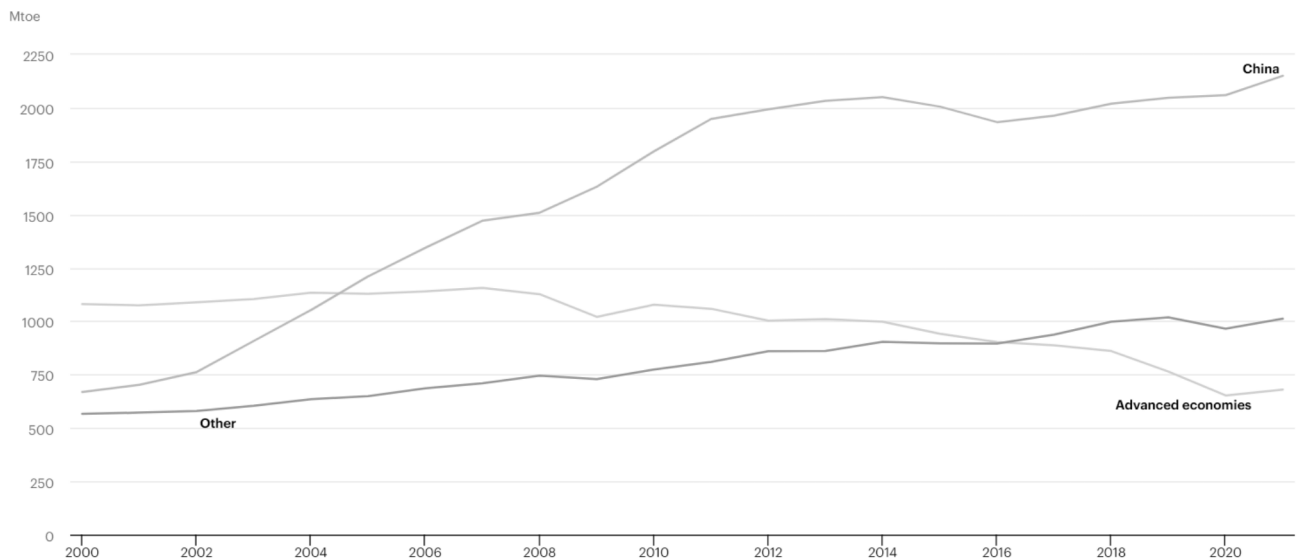


Figure 1.1.3 “Coal Consumption by Region 2000 to 2021” (Source: IEA Global Energy Review, Coal, 2021⁴⁷)
In terms of coal emissions, China is significant enough to warrant its own category, along with categories of advanced economies, and the rest of the world. Since 2000, postindustrial, advanced economies have declined in their coal emissions—however, this is more or less offset by the growth of coal emissions in the rest of the world. So while postindustrial economies and the rest of the world have proportionally decreased and increased respective coal emissions—effectively offsetting each other—China has increased their coal emissions by three-fold since 2000. In short, coal is more carbon-intensive and harmfully emissive than its competitors, while contemporary coal emissions are largely centralized in South and East Asia.

Importance of Coal

⁴⁶ U.S. EIA. "FAQs: How Much Carbon Dioxide Is Produced When Different Fuels Are Burned?" U.S. Energy Information Administration. Last modified October 28, 2021. <https://www.eia.gov/tools/faqs/faq.php?id=73&t=11>.

⁴⁷ IEA (2021), *Global Energy Review, Coal, 2021*, IEA, Paris <https://www.iea.org/reports/global-energy-review-2021>

On the subject of global coal use in 2021, IEA Executive Director Fatih Birol stated that “Coal is the single largest source of global carbon emissions, and this year’s historically high level of coal power generation is a worrying sign of far off track the world is in its efforts to put emissions into decline towards net zero.”⁴⁸ Birol’s quote is reflective of the reality that coal has been the most dominant and carbon-intensive energy source since the early nineteenth century.⁴⁹ Contemporary coal use is concentrated in the Global South, representing 85% of global consumption, while China and India alone represent 60% of total consumption, as Figure 1.1.3 demonstrates.⁵⁰ Coal’s embedded prevalence can be explained by several key realities and benefits it has over both its carbon and non-carbon energy counterparts. Chiefly, and as aforementioned, coal is globally abundant, with a majority of countries having commercially viable quantities. It is also comparatively accessible, requiring relatively simple mining and logistical infrastructure for extraction, transportation, and consumption.⁵¹ This relative accessibility is compounded by surging energy demands and ongoing industrialization in the Global South, as over one billion people have gained access to electricity in the past three decades has largely been driven by coal.⁵² For these developing countries, coal brings immediate benefits, such as electricity and power to fuel economic development, while the costs of pollution and environmental degradation are experienced later on. While contemporary coal use is declining in post-industrial economies, there nonetheless exists centuries of coal’s legacy. Thus, coal is deeply globally embedded into the market economy, labor market, sociopolitical, and cultural life.

At COP26, prominent coal consumers like China, India, and others altered the framing of future coal use and development from “phase out” to “phase down”, signifying that these states view coal as part of their development strategy for the foreseeable future.⁵³ Coal’s global significance in its use and emissions results from: its relative accessibility, simplicity, and its abundance, as well as its immediate advantages over delayed costs, strong financial backing and geopolitical significance, and its general societal embeddedness.

Future of Coal Use

Contemporarily, coal is used primarily in emerging economies, and remains a highly emitting carbon energy source. Coal use is highly concentrated in the Global South, particularly China and India, comprising well over a simple majority between the two, as shown by Figure 1.1.3. Trends shown in Figure 1.1.3 will likely not face drastic alterations in the immediate short-term, meaning that the key actor in the future of coal emissions is China. In addition to domestic Chinese coal consumption, China invests and finances coal greatly as part of its international Belt and Road Initiative (BRI), promoting infrastructure and development across Afro-Eurasia. Coal consumption and subsequent emissions will likely continue trending downwards in postindustrial economies.

⁴⁸ IEA (2021), *Coal 2021*, IEA, Paris <https://www.iea.org/reports/coal-2021>.

⁴⁹ IEA (2021), *Coal 2021*.

⁵⁰ IEA (2021), *Coal 2021*.

⁵¹ Tänzler, Dennis, and Noah Gordon. "The New Geopolitics of a Decarbonizing World." Wilson Center. Last modified September 30, 2020. <https://www.wilsoncenter.org/article/new-geopolitics-decarbonizing-world>.

⁵² Tänzler, Dennis, and Noah Gordon. "The New Geopolitics of a Decarbonizing World."

⁵³ Tänzler, Dennis, and Noah Gordon. "The New Geopolitics of a Decarbonizing World."

Geopolitical Challenges of Coal

There are several key geopolitical issues relating to coal use and reducing emissions. First, the role of emerging, industrializing economies and state actors cannot be ignored. 85% of all coal use is now in the Global South.⁵⁴ En masse, China and India are responsible for about 60% of global coal consumption.⁵⁵ Besides China and India, other emergent economies such as Indonesia, Vietnam, Mongolia, Turkey, Pakistan, and South Africa all have economic development strategies presently reliant on coal use.⁵⁶ Figure 1.1.3 displays this—modern coal use by country in graphical form. Coal, as an energy source, provides several benefits for less-developed nations as opposed to its competitors. Coal requires relatively simple infrastructure, is widespread and abundant (while accessible), sources multiple fuels (making it versatile), and is prevalent amid surging electricity and industrialization demands in the Global South.⁵⁷ Altogether, this makes coal an attractive fuel source for promoting development and economic growth. In short, though postindustrial economies of the Global North are no longer prevalent in coal consumption, they are not absolved of their historic coal use. Many states, such as Australia, remain coal suppliers. Nevertheless, coal use today is heavily concentrated in developing economies.

Second, coal, as a traded commodity, like other carbon energy sources such as gas or oil, is vulnerable to dynamic market forces including production, price, crucially demand, and—to a lesser extent—supply. As a commodity, coal has strong financial backing. Within China, coal has particularly strong financial backing.⁵⁸ Coal energy development is intrinsic to China's Afro-Eurasian-centric BRI international development plan, in which China develops infrastructure and other works, including coal power generation, to developing countries across Afro-Eurasia. Thus, demonstrating that coal has strong international financial backing as a commodity.

Third, coal is a widely-distributed resource globally, with many countries having readily available access to it. Though, the United States, Russia, Australia, China, and India hold over three-quarters of the world's known coal deposits.⁵⁹ Domestic commercial abundances do more than facilitate coal extraction and power, they allow for energy security. Energy security refers to the idea of uninterrupted availability of energy sources.⁶⁰ The concept of energy security is not hypothetical—in fact, energy has and continues to be employed as a geopolitical weapon, as demonstrated off and on in recent decades by Russia and Ukraine.⁶¹ Thus, states seek to use what they have in terms of energy resources to avoid geopolitical reliance. As states will often use what they have in terms of energy

⁵⁴ U.S. Department of the Interior. "What Is Coal Used For?" U.S. Geological Survey. <https://www.usgs.gov/faqs/what-coal-used>.

⁵⁵ "What Is Coal Used For?" U.S. Geological Survey.

⁵⁶ Wade, Will. "The World's Three Biggest Coal Users Get Ready to Burn Even More." *Bloomberg*, March 19, 2021.

⁵⁷ Wade, Will. "The World's Three Biggest Coal Users Get Ready to Burn Even More."

⁵⁸ Wang, Christoph Nedopil. "Brief: Coal Phase-out in the Belt and Road Initiative (BRI): An Analysis of Chinese-backed Coal Power from 2014-2020." Green Finance and Development Center. Last modified June 16, 2021.

<https://greenfdc.org/coal-phase-out-in-the-belt-and-road-initiative-bri-an-analysis-of-chinese-backed-coal-power-from-2014-2020/>.

⁵⁹ Wang, Christoph Nedopil. "Brief: Coal Phase-out in the Belt and Road Initiative (BRI): An Analysis of Chinese-backed Coal Power from 2014-2020." Green Finance and Development Center.

⁶⁰ "Energy Security." International Energy Agency. Last modified 2022. <https://www.iea.org/topics/energy-security>.

⁶¹ Gardener, Andrew. "Russia Cuts Gas off to Ukraine". *Politico*, June 16, 2014.

resources, coal will almost certainly hold space as a backup energy source, filling the energy gaps that renewable cannot currently fill with continuity. Coal is geopolitically challenging and entrenched, as it is heavily consumed in the developing Global South, a financially-backed abundant commodity, and provides a sense of energy security for many states.

Denouement and Bottom Line

Coal, for economic good or environmental ill, is ostensibly not leaving the energy scene for the foreseeable future, particularly in developing economies and in the Global South. Coal consumption in postindustrial western countries is declining, which in regards to emissions, is a good sign and should be encouraged with continuity. The West's historic use of coal and Asia's use of coal today must be pored and addressed in a just manner. The United Kingdom, United States, India, and China are all either historic or ongoing coal-use polluters, yet little common ground has been met in emissions reductions. The West must play a larger role as a historic polluter and aggregate metropole in reducing and replacing coal's financial backing, and offering substantive, sustainable development models moving forwards. Unlike other forms of carbon energy, coal lacks the downstream versatility of something like oil, which is used in plastics. Coal is used primarily for electricity and power generation, which has existing replacements, whereas oil's relation to plastics has less of a suitable alternative. This means that coal's use today has few aspects that are truly irreplaceable. Coal emissions must be reduced. If coal energy is pursued by China and India it must be abated; existing plants should be retrofitted with emissions-reducing technology, and should ultimately be phased out of wealthy countries with all deliberate speed.

Chapter 1.2: Carbon Energy: Oil

Introduction

Liquid petroleum, which generates the most carbon emissions after coal, remains the largest source of energy currently utilized worldwide. As shown in Figure 1.1.1, this has been the case for decades, and though oil's dominance has decreased significantly, especially in 2020, demand has grown rapidly in 2021 and 2022 as the developed world has sought to recover from the COVID-19 pandemic.⁶² In 2020, oil made up more than 31% of the global energy mix, with coal second at 27%, and both natural gas and non-carbon sources (nuclear, hydropower, and renewables) at 25%.⁶³ The distribution across different fuel sources is very dependent on energy production and the mix of sources in each country.⁶⁴ In the United States and the United Kingdom, for example, oil followed by gas are the largest contributors. In China and India, coal is much more dominant, whereas in Russia, it is gas. While a large element of which energy

⁶² "U.S. Energy Information Administration - EIA - Independent Statistics and Analysis," Short-Term Energy Outlook - U.S. Energy Information Administration (EIA) (U.S. Energy Information Administration, February 8, 2022), https://www.eia.gov/outlooks/steo/report/global_oil.php.

⁶³ Bernard Looney, "Statistical Review of World Energy: Energy Economics: Home," BP global (BP), accessed February 14, 2022

<https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html>.

⁶⁴ Hannah Ritchie and Max Roser, "CO₂ Emissions by Fuel," Our World in Data (OurWorldInData.org, May 11, 2020), <https://ourworldindata.org/emissions-by-fuel>.

sources a country is based on their geography and what is naturally available to them on a large scale, there is also the consideration of price and accessibility to these sources. Though the United States has access to coal, they can shift their energy consumption to other sources due to private company investments as well as human capital.

A key reason for oil's prominent level of use is the diversity of fuels and products it yields. Crude oil is a mixture of many hydrocarbon fractions whose separation by refining yields dozens of individual fuels plus lubricants, asphalt, and starting material for petrochemicals. Its fuels power the overwhelming majority of the world's land, air, and sea transportation. As this renders oil fundamental to any economy, global trade, and every nation's military, it has been for decades a key national security concern. This reality seems unlikely to change to a profound degree with the advent of electric light-duty vehicles. Electrification for heavy-duty vehicles—including construction, mining, agricultural, and military equipment—will take longer to achieve and requires future advances in battery technology, proving to be a point of contention for the transition away from oil.

Current World Trends in Consumption and Emissions

The global trade of oil is a large part of many nations' economies. Oil continues to run the vast majority of world transport, which makes it essential to any modern economy and to every modern military. As a result, the oil market and its determinations of supply and demand are also related to the national security of most countries.⁶⁵ Major exporters include the Organization of the Petroleum Exporting Countries (OPEC), Russia, Canada, and Kazakhstan, while the major importers are the EU, China, India, Japan, South Korea, and emerging economies. In overall production, the United States leads by 194 Mt according to provisional 2020 data, which is more than the seventh world producer of the United Arab Emirates.⁶⁶ It is also one of the top three importers with an import stat of 202 Mt, according to provisional data from 2019, with China dominating imports with almost 300 more Mt.⁶⁷

The overall world production of oil is quite high. There are different views about future consumption, which have come to focus on the idea that there will be a peak in global oil demand coming as soon as 2025.⁶⁸ Figure 1.2.1 displays this prediction, suggesting that world production will begin to flatten out by the end of 2023, despite additions to world stocks (stored oil).

Figure 1.2.1 shows global production returning to 2019 levels in 2022, and that production will exceed consumption for most of the year. Such forecasts, even covering only a few months into the future, are highly uncertain. This is due to the large number of factors that can affect levels of supply in the short term, such as severe weather, civil conflict, geopolitical

⁶⁵ "Oil and Gas in Everyday Life," IOGP, accessed February 13, 2022, <https://www.iogp.org/oil-natgas-in-everyday-life/>.

⁶⁶ IEA, "Supply – Key World Energy Statistics 2021 – Analysis," accessed February 13, 2022, <https://www.iea.org/reports/key-world-energy-statistics-2021/supply>.

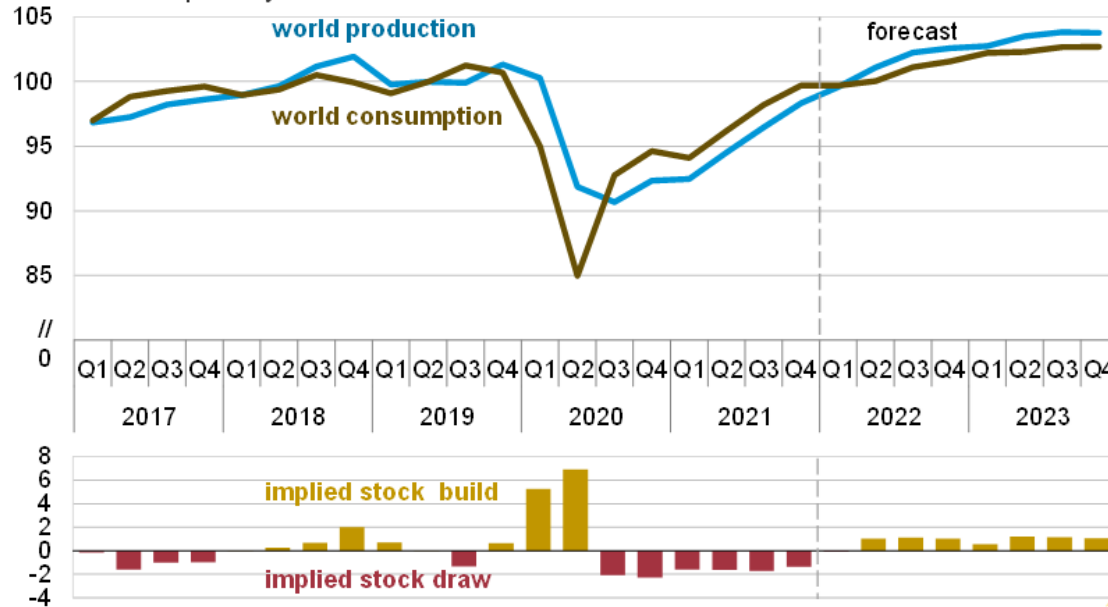
⁶⁷ Ibid.

⁶⁸ IEA, "Fuels: Old and New – World Energy Outlook 2021 – Analysis," (IEA, 2021), <https://www.iea.org/reports/world-energy-outlook-2021/fuels-old-and-new>.

tensions, energy decisions of major states, and more. British Petroleum (BP) and other scenario reports have discussed the complications that come with predicting oil demand and consumption. According to the report, “the point at which oil demand is likely to peak is very uncertain and depends on many assumptions.”⁶⁹ Everything that encompasses oil is highly unpredictable, which is due to the fact that it is a commodity market, and the dependency many countries have on oil production and use. Consumption and dependency on oil are not dwindling anytime soon, which points to the increasing amount of emissions oil will be producing.

World liquid fuels production and consumption balance

million barrels per day



Source: U.S. Energy Information Administration, Short-Term Energy Outlook, February 2022



Figure 1.2.1 World oil production and consumption, 2017-2022, with forecasts to 2023. (Graph from EIA⁷⁰)

Recent Discoveries and Development

Oil occurs in commercial volumes in many parts of the world, and its accessible abundance today is greater than previously predicted. The key reason for this is the enhanced extraction capabilities that have come from multi-stage hydraulic fracturing, or “fracking.” This can be described as “the process of injecting liquid and materials at high pressure to create small fractures within tight shale formations to stimulate the production and safely extract energy from an underground well after the drilling has ended and the rig and derrick are removed from the site. The process takes about three to five days, on average, to complete from start to finish.”⁷¹

⁶⁹ “SIPA Center on Global Energy Policy,” Columbia (Columbia University, June 29, 2021), <https://www.energypolicy.columbia.edu/research/report/will-covid-drive-early-peak-transportation-activity-and-oil-demand/>; Spencer Dale and Bassam Fattouh, “BP Statistical Review of World Energy 2020,” BP (BP PLC, 2018), <https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2020-full-report.pdf>.

⁷⁰ EIA, “U.S. Energy Information Administration - EIA - Independent Statistics and Analysis.”

⁷¹ “Fracking: What Is Fracking?: Shale Oil and Natural Gas: IPAA,” Independent Petroleum Association of America (IPAA, July 24, 2018), <https://www.ipaa.org/fracking/>.

This process is used around the world; in recent years there has been an immense number of oil exploration, proven oil reservoirs, and extraction, proving that the world is not going to run out of oil anytime soon.⁷²

Some areas of the world that have had recent oil discoveries include offshore Guyana by Exxon and the North Sea discovery at the Johann Sverdrup field by Equinor. Most discoveries are made by private companies such as Exxon, Shell, COPL, and Equinor, as such companies have extensive experience in many parts of the world, as well as the most sophisticated technology and highly trained people.⁷³ Additionally, the price of oil exploration is quite expensive; though oil extraction and production is relatively cheap, the process of searching for and producing wells is quite expensive. Usually, private companies will take this on as a form of investment in the future profit of said oil reservoir discoveries. The discovery of oil at “Johan Svredrup is the third largest oil field on the Norwegian continental shelf, with expected resources of 2.7 billion barrels of oil equivalent (boe)” and the Guyana discovery by Exxon was offshore and will be adding to their previous recoverable resources by an estimate of 10 billion boe.⁷⁴ This extended discovery for Guyana is highly important, because as a developing country, there is a space for extended security that could be based around the military or energy security.

For development in the oil industry, there has been tremendous growth within Russia, OPEC, and the United States consistently over the past couple of decades. These countries are the main oil suppliers for Europe, and as seen recently, have been major players in maintaining security for nations. The United States was one of the major producers in 2020, with a production of 18.61 million barrels per day making up 20% of the world’s total, and even has various untapped wells.⁷⁵ Followed by Saudi Arabia, Russia, Canada, and China.⁷⁶ So when geopolitical issues arise, the United States is able to utilize its power as an oil producer to support allies and protect itself. However, when looking into Era 2, 2007-2070, developing areas within Asia and South America are where most development will start to occur.⁷⁷ China is the number one importer, which is important to note as it is highly dependent on others for oil, meaning the country is lacking security.⁷⁸ The world will see more expansion in oil investment occurring in these countries. It can be seen in these countries already, but more so as they make discoveries, start to extract, and become less dependent on imports. This development is

⁷² “The Earth Is Not Running out of Oil and Gas, BP Says,” Energy Knowledge (Energy Institute, March 11, 2015), <https://knowledge.energyinst.org/search/record?id=105045#:~:text=BP%20has%20said%20that%2C%20despite,would%20almost%20double%20by%202050.&text=With%20new%20exploration%20and%20technology,leap%20to%207.5%20trillion%20boe>.

⁷³ “Discoveries - Oil & Gas Journal,” Oil & Gas Journal (OGJ) (Endeavor Business Media, 2022), <https://www.ogj.com/exploration-development/discoveries>.

⁷⁴ “ExxonMobil Discovers More Oil Offshore Guyana,” accessed February 14, 2022, [https://www.ogj.com/exploration-development/discoveries/article/14223129/exxonmobil-discovers-more-oil-offshore-guyana](https://www.ogj.com/exploration-development/discoveries/article/14223129/exxonmobil-discovers-more-oil-offshore-guyana;).; “Johan Sverdrup - the Third Largest Oilfield on the NCS,” Johan Sverdrup - The third largest oilfield on the NCS (Equinor ASA, January 28, 2021), <https://www.equinor.com/en/what-we-do/johan-sverdrup.html>.

⁷⁵ EIA, “Frequently Asked Questions (Faqs)” (2020), <https://www.eia.gov/tools/faqs/faq.php?id=709&t=6>.

⁷⁶ Ibid.

⁷⁷ IEA, “Supply – Key World Energy Statistics 2021 – Analysis”

⁷⁸ IEA, “Supply – Key World Energy Statistics 2021 – Analysis,” accessed February 13, 2022, <https://www.iea.org/reports/key-world-energy-statistics-2021/supply>.

important, as some of these nations are among the poorest in the world, and oil is seen as a treasured resource, meaning that these countries will not be moving away from oil anytime soon.

Will We Ever See a World Without Oil?

The current world standing of oil is of the utmost importance. Oil means consumption of products, transportation, military prowess, and much more. Oil takes many forms and is entrenched in almost every aspect of life. It was estimated that 99.0 million barrels per day (b/d) of petroleum and liquid fuels were consumed globally in January 2022, an increase of 6.6 million b/d from January 2021. It is forecast that global consumption of petroleum and liquid fuels will average 100.6 million b/d for all of 2022, up 3.5 million b/d from 2021, and above the 2019 average of 100.3 million b/d. Global consumption of petroleum and liquid fuels are predicted to increase by 1.9 million b/d in 2023.⁷⁹ While advanced nations have the ability and privilege of moving toward a mixed usage of energy sources, not all developing countries have the ability to do the same. Less advanced countries—such as those in Africa and South America—rely on oil to help develop and grow their economy. Due to expenses, lack of human capital, and lack of accessibility of alternative carbon-neutral energy sources, these countries rely heavily on oil and coal, some of the sources with the highest emissions.⁸⁰

One of the major reasons that oil will never be fully dismissed or phased out in exchange for an alternative source is because it is the driver of militaries and is a major aspect of national security. In the current political climate, it is clear that pipelines connecting access to oil are major stressors and political chokeholds. The issues of oil, national security, and political warfare were evident in the United States in 2021 with the Colonial Pipeline.⁸¹ Unlike much of Europe, the United States is a large producer of domestic oil shares, so there is less concern, but it is very rare that the production of crude oil within the United States would outweigh its consumption needs within.⁸² There are many ways that oil can fuel international conflict, such as through resource wars, petro-aggression, oil-market domination, and oil transit routes.⁸³ Transit routes can include pipelines but it can also be transit paths via sea or land. In China, it can be seen that the country is trying to become more self-sufficient by establishing dominance in the South China Sea, though this is causing geopolitical tensions for other surrounding countries. As countries that rely on imported oil, losing access to this is a big point of contention.

Changes need to be made on the front side of the oil industry, and that starts with the major producers—specifically supermajors such as BP, Shell, Equinor, Total, Eni, and Exxon. The pressure for change is being pushed by shareholders who want companies to acknowledge

⁷⁹EIA, “U.S. Energy Information Administration - EIA - Independent Statistics and Analysis.”

⁸⁰Rosamond Hutt, “Which Economies Are Most Heavily Reliant on Oil?,” World Economic Forum (World Economic Forum, May 10, 2016), <https://www.weforum.org/agenda/2016/05/which-economies-are-most-reliant-on-oil/>.

⁸¹David E. Sanger and Nicole Perloth, “Pipeline Attack Yields Urgent Lessons about U.S. Cybersecurity,” The New York Times (The New York Times, May 14, 2021), <https://www.nytimes.com/2021/05/14/us/politics/pipeline-hack.html>.

⁸²EIA, “U.S. Energy Information Administration - EIA- Independent Statistics and Analysis.”

⁸³Jeff D Colgan, “Oil, Conflict, and U.S. National Interests,” Belfer Center for Science and International Affairs (Harvard University, October 2013), <https://www.belfercenter.org/publication/oil-conflict-and-us-national-interests>.

climate change and implement adaptations to offset its effects. Both “Shell and BP faced shareholder rebellions at their annual meetings this month when significant minorities voted for tougher emissions reductions. Chevron faced a similar vote in May, 2021.”⁸⁴ This push back from shareholders and climate activists focused on the lack of responsibility being held by the companies in terms of the emission goals, specifically the responsibility attached to their scope 3 emissions.⁸⁵ Scope 3 emissions are the indirect “emissions from both upstream suppliers and downstream consumers of the company’s products and services.”⁸⁶ The goal of lower emissions is a goal set by supermajors, many of whom have said they will achieve net zero emissions by 2050. Some have committed to absolute reductions from their operations and use of oil while omitting emissions from sales, while others are only pledging to reduce their operational emissions intensity. There are even cases of companies, such as Shell, planning to use nature-based solutions—this can include planting trees to assist in removing carbon dioxide from the air. Companies have focused on expanding out of oil and moving away from fossil fuels to help offset their carbon footprint. This is being done through the purchasing of renewable energy firms, electric vehicle (EV) charging companies, and more.⁸⁷

Main Concerns Associated with Oil

There are many concerns associated with crude oil, from its production, use, and reliance. A specific concern facing oil is the safety of exploration, extraction, and production. Compared to other sources, it is much more dangerous. The dangers of extraction come from drilling and serving wells, which involve different types of equipment and materials that can include vehicle collisions, getting stuck in machines, explosions and fires, falls, ergonomic hazards, high pressure lines and equipment, and/or electrical and other hazardous energy.⁸⁸ Human error is a big fault within rig systems, so many have moved toward offshore drilling and rigs, which eliminates human errors, but also leaves more room for machinery errors.

Another concern with oil, as previously mentioned, is that it generates the largest carbon emissions after coal, and remains the largest source of energy currently utilized worldwide.⁸⁹ With oil consumption and production only increasing, emissions and emission control will continue to be one of the main concerns.⁹⁰ This will include the increase of use within the transport industry, military use, and electricity. Oil is “providing close to 40% of all of the nation's [the United States] entire power needs. Though most oil is used for transportation or

⁸⁴ “Oil Majors' Net Zero Plans Still Far from Paris Targets,” Carbon Tracker Initiative (CTI), May 25, 2021, <https://carbontracker.org/oil-majors-net-zero-plans-still-far-from-paris-targets/>.

⁸⁵ James Bacchus, “Oil Firms Face More Legal Fights on Climate Change - Here's Why,” World Economic Forum (World Economic Forum, June 4, 2021),

<https://www.weforum.org/agenda/2021/06/oil-shell-exxon-chevron-court-shareholders-climate/>.

⁸⁶ Ibid.

⁸⁷ CTI, “Oil Majors' Net Zero Plans Still Far from Paris Targets,”

⁸⁸ “Department of Labor Logo United States Department of Labor,” Oil and Gas Extraction - Hazards | Occupational Safety and Health Administration (United States Department of Labor), accessed February 14, 2022, <https://www.osha.gov/oil-and-gas-extraction/hazards>.

⁸⁹ Ritchie and Roser, “CO2 Emissions by Fuel.”

⁹⁰ EIA, “U.S. Energy Information Administration - EIA - Independent Statistics and Analysis.”

home heating purposes, a small percentage is still used as a fuel for electricity generating plants.”⁹¹ With oil being usable for electricity use, many developing countries will have a hard time moving away from oil, as providing electricity to their citizens is a high priority that can drastically improve the quality of life. Even if electricity is a small portion of oil use, the pollution from this is of high concern, as “burning oil to generate electricity produces significant air pollution in the forms of nitrogen oxides, and, depending on the sulfur content of the oil, sulfur dioxide and particulates.”⁹² Oil is not just a driver in the production of electricity, but also in the transport industry, and it will be difficult to replace oil with another energy source. Though many companies, countries, and governments are looking at EVs as a solution to offset carbon emissions from transport, commercially and domestically, this will not fix everything. Like crude oil, EVs are on the commodity market and therefore face a lot of volatility from consumers. There is still currently a lack of buy-in from consumers, which could stem from the lack of infrastructure in place to support the transition over to EVs. Overall, oil is a major part of the global economy and structure, and it will continue to be in the future.

Chapter 1.3: Natural Gas as a Carbon Energy Source

Overview

Natural gas has grown rapidly in the past two decades as a multi-use energy source worldwide for power generation, petrochemicals, heat production in industry, business, and residences. The growth of liquified natural gas (LNG) is due to increased abundance and a global gas market where emerging and developing countries such as Turkey, Mozambique, Ghana, and the Ivory Coast have discovered new reserves, and in some cases, become exporters. Additionally, natural gas has grown as a means of reducing coal consumption and CO₂ emissions, especially from major energy consumers such as China, the United States, and European countries. Among the fossil fuels, natural gas has the lowest carbon intensity, emitting less CO₂ per unit of energy generated than other fossil fuels, and unlike oil, requires limited processing to prepare for end use.

These favorable characteristics have enabled natural gas to penetrate many markets.⁹³ However, there have been discussions as to whether LNG should be designated as “low carbon” or not with respect to a “net zero scenario.” Even though the European Union, China, and India have recently accepted such a designation, there is evidence that natural gas, if overused, could actually produce more methane and CO₂ emissions than oil.

Extraction and Uses of Natural Gas

Natural gas is primarily composed of methane, but may also contain ethane, propane, and

⁹¹ “Electricity: from Oil,” Electricity from oil (Pace University), accessed February 14, 2022, http://www.powerscorecard.org/tech_detail.cfm?resource_id=8.

⁹² Ibid.

⁹³ Ruszel, Mariusz. "The development of global LNG exports." In *The Future of Energy Consumption, Security and Natural Gas*, pp. 1-20. Palgrave Macmillan, Cham, 2022, 3.

heavier hydrocarbons.⁹⁴ Small quantities of nitrogen, sulfur compounds, carbon dioxide, oxygen, and water may also be found in natural gas.⁹⁵ However, when natural gas is liquified, non-methane components such as water and carbon dioxide are removed to prevent solids from forming when cooled to -160°C.⁹⁶ As a result, LNG is made up primarily of methane. There are four different stages to the production and distribution of LNG:

Exploration and Production

Today, the top four exporters of LNG are the United States, Qatar, and Australia, with the top importer being China. The United States is projected to be the largest producer of LNG in 2022. The U.S. Energy Information Administration projected dry gas production would rise to 2.64 billion cubic meters per day (bcmd) in 2021 and 2.72 bcmd in 2022—up from 2.59 bcmd in 2020.⁹⁷ Many other countries play smaller, albeit significant—as well as growing—roles as natural gas producers and LNG exporters. Countries such as Angola and Venezuela are striving to reach their full potential in the global LNG marketplace, and countries like Saudi Arabia and Iran, which have vast reserves of natural gas, could also participate as LNG exporters.⁹⁸

Natural gas occurs in pores and fractures within shale, sandstone, and other types of sedimentary rock.⁹⁹ When these pores are connected, allowing gas to flow through the rock to a drilled wellbore and up to the surface, production is called “conventional.” When pores are poorly connected and must be stimulated to create the flow of gas, the production is “unconventional.” Another common term for this situation is “tight gas,” and if the rock is mostly shale, “shale gas.” Additionally, natural gas can also be found within deposits of crude oil, which is referred to as “associated natural gas.”¹⁰⁰

Technological advances in the past two decades have greatly expanded the ability to drill long horizontal wells in gas-rich zones and stimulate tight formations and those composed of shale by fracturing them. This process involves pumping water, chemicals, and sand down a well under high pressure. Called multi-stage hydraulic fracturing, or “fracking,” this process creates flow pathways and releases the natural gas from the rock, allowing it to flow to the surface.¹⁰¹ There, gas is put into gathering pipelines and sent to natural gas processing plants, where non-methane components are removed.

Liquefaction

⁹⁴ Montgomery, Scott L. *The powers that be: Global energy for the twenty-first century and beyond*. University of Chicago Press, 2010, 83.

⁹⁵ Foss, Michelle Michot. "Introduction to LNG." *Center for Energy Economics*. Available: http://www.beg.utexas.edu/energyecon/lng/documents/CEE_INTRODUCTION_TO_LNG_FINAL.pdf [accessed 20150819] (2007), 14.

⁹⁶ Ibid.

⁹⁷ Reuters, “US Natural Gas.”

⁹⁸ Foss, “Introduction,” 16.

⁹⁹ “U.S. Energy Information Administration - EIA - Independent Statistics and Analysis.” Natural gas explained - U.S. Energy Information Administration (EIA). Accessed February 15, 2022.

<https://www.eia.gov/energyexplained/natural-gas/>.

¹⁰⁰ Ibid.

¹⁰¹ Ibid.

For marine transport, natural gas is cooled to liquid form at a temperature of -160°C . During liquefaction, any contaminants found in produced gas are removed to avoid freezing and damaging equipment and to meet pipeline specifications at the delivery point.¹⁰² The liquefaction process can be designed to purify LNG to almost 100% methane through refrigerant cooling. The natural gas is liquified for shipping at a temperature of approximately -160°C , as its volume is reduced by a factor of 600. In other words, LNG at -160°C uses 1/600th of the space required for a comparable amount of gas at room temperature and atmospheric pressure.¹⁰³

Shipping

When LNG is shipped worldwide, it is transported in tankers (double-hulled ships) that are specially designed and insulated to prevent leakage or ruptures in an accident. The typical LNG carrier can transport 125,000-138,000 cubic meters (CM) of LNG, and the typical carrier measures some 274 meters in length, about 42 meters in width, 11 meters in water draft, and costs about \$160 million.¹⁰⁴ LNG tankers generally pollute less than other shipping vessels because they burn natural gas in addition to oil as a source of fuel for propulsion.

Distribution

In order to prepare LNG for residential and commercial use, it must be returned to its gaseous state through a regasification plant. On arrival at the receiving terminal in its liquid state, LNG is pumped first to a double-walled storage tank—similar to those used in the liquefaction plant—at atmospheric pressure, then pumped at high pressure through various terminal components where it is warmed in a controlled environment.¹⁰⁵ Then, the LNG is warmed by passing through pipes heated by direct-fired heaters, seawater, or through pipes that are in heated water.¹⁰⁶

Energy potential

Until recently, the debate about the future of energy in the United States has focused on oil, with natural gas often being overlooked. However, this view has changed during the past decade due to the substantial new supplies that have been unlocked by shale gas development, reducing domestic prices, and allowing U.S. companies to become major exporters. Additionally, the demand for natural gas is growing; according to the U.S. Energy Information Administration, LNG consumption rose from 2.35 BCM per day in 2020 to 2.36 BCM in 2021 before sliding to 2.35 BCM in 2022. That compares with a record high of 2.41 BCM per day in 2019.¹⁰⁷

Rapid growth in natural gas production has had positive effects for the United States. Since 2017, it has eliminated the need for significant imports and has altered the global geopolitics of natural gas by supplying European and Asian allies with increasing volumes of

¹⁰² Foss, "Introduction," 17.

¹⁰³ Foss, "Introduction," 17.

¹⁰⁴ Foss, "Introduction," 19.

¹⁰⁵ Foss, "Introduction," 21.

¹⁰⁶ Ibid.

¹⁰⁷ "U.S. Natural Gas Output and Demand to Rise in 2021." Reuters. Thomson Reuters, December 7, 2021.

LNG, thereby decreasing their reliance on Russia and OPEC.¹⁰⁸ In addition, there has been a growing recognition that the lower carbon content of natural gas relative to oil and coal can play a significant role in reducing CO₂ emissions. For example, a typical coal-burning power plant in 2013 was approximately 33% efficient in converting heat energy into electrical power.¹⁰⁹ A gas-fired plant was approximately 42% efficient, and a natural gas combined-cycle power plant was 60% efficient.¹¹⁰

Dangers and Prices of Natural Gas

Another reason why natural gas is an appealing energy source is because it is nowhere near as dangerous as oil. LNG is non-explosive, non-toxic, and is only flammable in very narrow concentrations. It is only flammable in concentrations between 5-15% because more than 95% of air dilutes the gas so it will not ignite, and concentrations less than 85% have too little oxygen to keep a flame going.¹¹¹ Additionally, there is no natural gas equivalent to the Exxon Valdez oil spill, and in the past eighty years, there have only been two major natural gas explosions. The first was in 1944 in a Cleveland facility, where 136 people died;¹¹² this was due to a poorly built storage tank. The other large explosion occurred in Skikdia, Algeria in 2004 when a leaked vapor cloud was set on fire by a faulty boiler. Conversely, Japan is an excellent example of how safe transporting natural gas is, as they have never suffered from a major fire despite having twenty-three ports and tankers docking every twenty hours.

Environmental Footprint

The environmental impacts of shale development can be challenging because such development requires the drilling and fracking of many wells and the use of large volumes of water. There is also evidence of surface water contamination and natural gas migration into freshwater zones.¹¹³ While such occurrences are rare and almost certainly result from substandard well completion practices, they occur more often than conventional oil/gas operations, since so many more wells are drilled. Moreover, they have affected private landowners in areas not used to oil/gas drilling.

There are additional environmental challenges in the area of water management, particularly the effective disposal of fracture fluids. Concerns with this issue are particularly acute in regions that have not previously experienced large-scale oil and gas development,

¹⁰⁸ Foss, "Introduction," 20.

¹⁰⁹ "The National Academies Presents: What You Need to Know about Energy." Our Energy Sources, Natural Gas -. Accessed February 15, 2022. <http://needtoknow.nas.edu/energy-sources/fossil-fuels/natural-gas/#:~:text=Natural%20gas%20provides%2029%25%20of,homes%20in%20the%20United%20States.&text=It%20is%20also%20more%20energy,plant%20was%20about%2042%25%20efficient.>

¹¹⁰ Ibid.

¹¹¹ Montgomery, *Global*, 4; Montgomery, *Global*, 5.

¹¹² Biamonte, Emilio. "Controlling the Risks from Liquefied Natural Gas." *The Geneva Papers on Risk and Insurance* 7, no. 23 (1982): 75–88. <http://www.jstor.org/stable/41950030>, 75.

¹¹³ Vengosh, Avner, Robert B. Jackson, Nathaniel Warner, Thomas H. Darrah, and Andrew Kondash. "A critical review of the risks to water resources from unconventional shale gas development and hydraulic fracturing in the United States." *Environmental science & technology* 48, no. 15 (2014): 8334.

especially those overlying the massive Marcellus Shale, as well as those that do not have a well-developed subsurface water disposal infrastructure. It is essential that both large and small companies follow the industry's best practices: that water supply and disposal are coordinated on a regional basis and that improved methods are developed for the recycling of returned fracture fluids. A second problem in the domain of water disposal has been the generation of earthquakes from the injection of wastewater at high volumes. While this can be reduced by moderating disposal volumes to some degree, a better solution is to recycle such water for repeated use.

Additionally, between 2010 and 2020, growth in CO₂ emissions from natural gas was greater than that for oil, which is a much richer source of carbon.¹¹⁴ Moreover, methane emissions from gas production and pipeline leakage have also increased, generating significant concern, since methane has a global warming potential twenty-five times that of CO₂.¹¹⁵

Supply and Demand of Natural Gas

Despite natural gas being the least carbon-rich of all fossil fuels, it is still a hydrocarbon, and therefore a source of emissions. Even though it has the ability to buy the world time to find and develop non-carbon energy sources, it is not a solution to climate change.¹¹⁶ More and more countries are discovering and producing their own natural gas, such as Abu Dhabi's new discovery of up to 42,475 MCM of raw natural gas.¹¹⁷ At the end of 2020, the United States had 12.6 trillion CM of natural gas reserves, Venezuela had 6.3T CM, Russia had 37.4T CM, Turkmenistan had 13.6T CM, Iran had 32.1T CM, Qatar had 24.7T CM, and China had 8.4T CM.¹¹⁸

In terms of consumption, the United States consumed 832 billion cubic meters of natural gas in 2020, Europe consumed 541.1B CM, Russia consumed 411.4B CM, Iran consumed 233.1B CM, and China consumed 330.6B CM.¹¹⁹ This is significant because there are abundant supplies of natural gas in the world, and many of these can be developed and produced at a relatively low cost.¹²⁰ In North America, shale gas development over the past decade has substantially increased assessments of resources producible at modest cost. This has made the price of natural gas in the United States among the lowest in the world. With growing LNG exports in 2021 and 2022, volumes available for domestic use have decreased and prices have risen. Yet they remain a fraction of those in most parts of the world.¹²¹ For example, U.S. prices

¹¹⁴ "Importance of Methane." EPA. Environmental Protection Agency, November 15, 2016. https://19january2017snapshot.epa.gov/gmi/importance-methane_.html.

¹¹⁵ Ibid.

¹¹⁶ Montgomery, *Global*, 2.

¹¹⁷ "Eni Discovers Gas Offshore Abu Dhabi | Oil & Gas Journal." AcceBP Energy Reportd February 15, 2022. <https://www.ogj.com/exploration-development/discoveries/article/14233101/eni-discovers-gas-offshore-abu-dhabi>.

¹¹⁸ "Energy Economics: Home." BP global. Accessed February 15, 2022. <https://www.bp.com/en/global/corporate/energy-economics.html>, 34.

¹¹⁹ BP, "Energy Economics," 38.

¹²⁰ "How Natural Gas Can Displace Competing Fuels - UNECE." Accessed February 27, 2022.

https://unece.org/DAM/energy/se/pdfs/CSE/PATHWAYS/publ/NG_Displace_Competing_Fuels.pdf; xv.

¹²¹ "U.S. Energy Information Administration - EIA - Independent Statistics and Analysis." Three countries provided almost 70% of liquefied natural gas received in Europe in 2021 - Today in Energy - U.S. Energy Information Administration (EIA). Accessed March 1, 2022. <https://www.eia.gov/todayinenergy/detail.php?id=51358>.

of natural gas in 2020 were \$1.99 per Btu, natural gas in the Netherlands cost \$3.42 per Btu, Japan's natural gas cost \$7.81, and German imported natural gas was \$4.06.¹²²

In the U.S. electricity supply sector, reducing CO₂ emissions lies with the substitution of natural gas for coal, especially in older, less efficient units. Substitution through increased utilization of existing combined-cycle natural gas power plants provides a relatively low-cost, short-term opportunity to reduce U.S. power sector CO₂ emissions by up to 20% while also reducing the emissions of criteria pollutants and mercury.¹²³

Additionally, U.S. administrations and Congress have viewed European energy security as a U.S. national interest, which is why the U.S. has sanctions on Nord Stream 2, the new natural gas pipeline being built by Russia to connect domestic supplies of natural gas to Europe. During the George W. Bush administration, this issue was viewed in geopolitical terms, and the administration sharply criticized Russia for using energy supplies as a political tool to influence other countries.¹²⁴ While supplying natural gas to Europe from the Caspian region and Central Asia has been a goal of multiple U.S. administrations and the EU, it is far from being achieved in volumes significant to counter Russian exports.¹²⁵

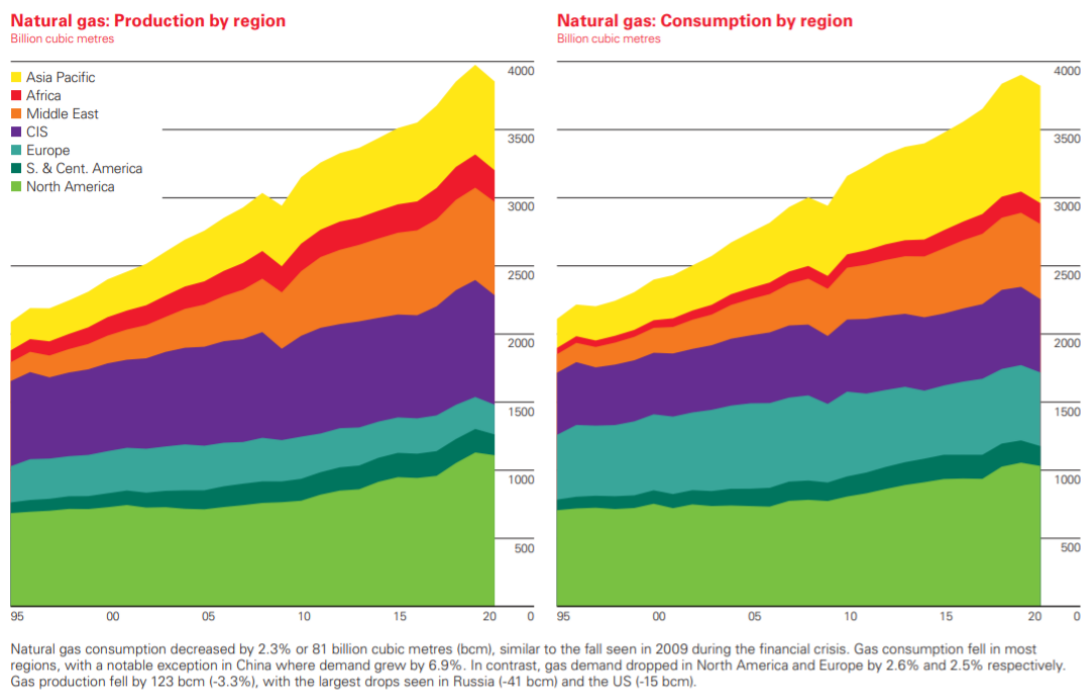


Figure 1.3.1. The two charts compare natural gas production by region (left) to natural gas consumption by region (right). Source: BP 2021 *Statistical Review of World Energy*.

¹²² BP, "Energy Economics," 41.

¹²³ UNECE, "Natural Gas," xv.

¹²⁴ Belkin, Paul, Jim Nichol, and Steven Woehrel. "Europe's energy security: options and challenges to natural gas supply diversification." *Congressional Research Service* (2013): 9.

¹²⁵ *Ibid.*

While the United States has become a producer of natural gas, the EU is one of the greatest importers of natural gas, and their consumption is expected to grow, whereas its domestic natural gas production is expected to decline.¹²⁶ Though second to Norway as a supplier to Europe, Russia remains one of Europe's most important natural gas suppliers, and with the completion of Nord Stream 2, their reliance on Russian natural gas is expected to increase. However, Europe finds itself in a difficult situation, because although it would be in their best interests to explore alternative sources for its natural gas needs, it is uncertain whether Europe as a whole can, or is willing to, replace a significant quantity of imports from Russia.

Future Natural Gas Initiatives/Plants

Natural gas will continue to grow as an energy source, especially considering its increased dependence from Europe. The United States and other significant producing countries of natural gas will continue to develop this energy source and export it to countries such as China. In 2020, the United States experiences an annual growth rate of inter-regional trade for natural gas of 11.6%. There were 68.2 BCM of NG pipeline imports, 1.3 BCM of LNG imports, 76.1 BCM of pipeline exports, and 61.4 BCM of LNG exports.¹²⁷

The main obstacle for the United States and other countries in operating a global gas market is not the lack of supply, but rather the deliverability of natural gas. In order to collect and distribute natural gas, there needs to be an increase in investment, exploration, technology, and infrastructure.¹²⁸ This is similar to other fossil fuels that require specialists who know where to look, what the best method of extraction is, and how to transport it in the safest and cheapest way possible. There also needs to be additional investment in natural gas made in 2022, as most scenarios spanning the next several decades show natural gas consumption growing at least until 2030-2035.¹²⁹

Efforts to develop the use of natural gas are being made in marine transportation, more specifically, in tankers and cargo ships. Shipping is a significant contributor to global GHG and air pollutant emissions via huge amounts of SO_x, CO₂, particulate matter (PM), carbon monoxide (CO), and NO_x.¹³⁰ According to the International Maritime Organization (IMO), ships are responsible for 4%, 2.6%, and 6.6% of the global SO_x, CO₂, and NO_x emissions, which respectively come from diesel fuel.¹³¹ As a result, switching from diesel-powered ships to dual-fuel engines would produce environmental benefits for reducing CO₂, NO_x, SO_x, PM, and CO emissions by 20.1%, 85.5%, 98%, 99%, and 55.7% with cost effectiveness of \$109, \$840, \$9,864, \$27,761, and \$4,307 per ton, respectively.¹³² In addition, a dual-fuel engine would

¹²⁶ Belkin, "Europe," 10.

¹²⁷ BP, "Energy Economics," 42.

¹²⁸ Montgomery, *Global*, 87.

¹²⁹ BP, "Energy Economics," 38.

¹³⁰ Elkafas, Ahmed G., Mohamed M. Elgohary, and Mohamed R. Shouman. "Numerical analysis of economic and environmental benefits of marine fuel conversion from diesel oil to natural gas for container ships." *Environmental Science and Pollution Research* 28, no. 12 (2021): 15210.

¹³¹ *Ibid.*

¹³² Ruszel, "Development," 20.

comply with the current and future IMO regulations regarding air pollutant emissions, improve the ship energy efficiency index by 29.6% with annual fuel cost savings of \$4.77 million.¹³³

Concluding Statement

Trade-in LNG has more than tripled between 2000 and 2020, and it is estimated—despite COVID-19—to be a further increase from 485 BCM in 2019 to 585 BCM in 2025.¹³⁴ Due to this increase, the growing oversupply of natural gas on the global market will increase the competition among exporters and contribute to lower gas prices for end-users and more flexible contracts. At the same time, LNG may become more competitive than gas delivered through pipelines, given further planned investments in the construction of LNG export infrastructure. For this reason, the most competitive supplier will be the one that reduces the price of supplied LNG by lowering production and transportation costs. By 2025, the United States will become the largest exporter of LNG, while China will become the largest LNG importer and will therefore avoid being as dependent on Russia’s natural gas supply. Additionally, COVID-19 will create an opportunity for energy company stock acquisitions and the consolidation of the strongest players on the LNG market, who will look to improve their position.

Chapter 2: Non-Carbon Sources

Chapter 2.1: Renewables

Introduction

Renewable energy, often labeled “clean energy” or “green energy,” is energy from sources that are naturally replenishing.¹³⁵ Major types of renewable energy sources include solar, wind, geothermal, biomass, and hydropower. This chapter will dive into energy from solar, wind, geothermal, and biomass sources, with hydropower will be mentioned in a future chapter. As renewable resources are virtually inexhaustible, renewable energy technologies globally are a key part of reducing emissions from electricity generation. NZE 2050 has set a goal of generating as much as 70% of global electricity from renewable sources by mid-century. Solar becomes the largest source, accounting for one-fifth of the total energy supply.¹³⁶ Yet there are major questions about relying so heavily on weaker and intermittent sources like solar and wind when other non-carbon sources and decarbonization approaches exist.

Renewable energy, like all energy sources, involves trade-offs. Though often thought of as “clean energy,” renewables produce an enormous amount of waste. As the renewable energy market increases, this has the potential to become a limiting factor if not solved via recycling. Global solar photovoltaic (PV) panel waste is anticipated to reach 8 million metric tons by 2030

¹³³ Ibid.

¹³⁴ Ruszel, “Development,” 10.

¹³⁵ EIA, “What is renewable energy?,” last updated May 20, 2021, <https://www.eia.gov/energyexplained/renewable-sources/>

¹³⁶ IEA, “Net Zero 2050 A Roadmap for the Global Energy Sector,” last revised October 2021, https://iea.blob.core.windows.net/assets/deebef5d-0c34-4539-9d0c-10b13d840027/NetZero2050-ARoadmapfortheGlobalEnergySector_CORR.pdf

and 78 million metric tons by 2050.¹³⁷ A report by the IEA and the International Renewable Energy Agency (IRENA) highlighted the importance of recycling and repurposing solar PV panels at the end of their 30-year lifetime. In addition to solar energy, all other renewable energy produces a significant amount of waste, so the discussion of their recycling and repurposing is as important as the capacity-building, innovation, and investment of renewable energy.

Recycling industries are expected to generate employment opportunities in developing and emerging countries, as waste collection and recycling services are often operated by informal sectors. IEA and IRENA suggest that solar PV waste management systems could increase employment, especially in the repair/reuse and recycling/treatment industries.¹³⁸

Solar Energy

As discussed above, solar energy is anticipated to be a much larger source of energy by 2050.¹³⁹ In the pathway to NZE 2050, solar and wind energy generation is predicted to grow rapidly in this decade, reaching an annual addition of 630 gigawatts (GW) of solar PV and 390 GW of wind by 2030.¹⁴⁰ As of 2020, China had the largest electricity generation from solar with 261.10 terawatt-hours, followed by the EU at 144.96 TWh, and the United States at 132.63 TWh.¹⁴¹ Whether the world is able to achieve NZE 2050, these numbers are almost certain to grow considerably. Although China had the largest primary energy consumption in 2019 as well as fossil fuel consumption, it also generated the largest amount of electricity from solar in 2019, which was double that of the United States.^{142;143}

However, solar has grown rapidly in the United States. In 2020, electricity from solar energy was twenty-three times what it had been in 2011. There were 2 million solar PV systems installed in 2019 and an additional million installations in the summer of 2021.¹⁴⁴ Solar power is forecasted to make up 46% of the new utility-scale electric generating capacity in the United States in 2022 followed by natural gas at 21% and wind at 17%. Additionally, 21.5 GW is expected to be added to the nation's utility-scale solar generating capacity, surpassing 2021's 15.5 GW of capacity additions. The largest planned solar addition will take place in Texas, accounting for 28% of the national total, followed by California at 4 GW.¹⁴⁵ Though Texas is

¹³⁷ IEA and IRENA, "End-of-Life Management: Solar Photovoltaic Panels," June 2016, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2016/IRENA_IEAPVPS_End-of-Life_Solar_PV_Panels_2016.pdf

¹³⁸ IEA and IRENA, "End-of-Life Management," 14

¹³⁹ IEA, "Net Zero 2050," 18

¹⁴⁰ IEA, "Net Zero 2050," 14

¹⁴¹ Our World in Data, "Solar power generation," retrieved February 13, 2022, https://ourworldindata.org/grapher/solar-energy-consumption?tab=chart&country=IND~CHN~AUS~USA~ZAF~ESP~OWID_WRL~European+Union+%2827%29

¹⁴² Our World in Data, "Primary energy consumption," accessed February 11, 2022, <https://ourworldindata.org/grapher/primary-energy-cons?tab=table>

¹⁴³ Our World in Data, "Fossil fuel consumption"

¹⁴⁴ Environment America Research & Policy Center, "Renewables on the Rise 2021: The rapid growth of renewables, electric vehicles and other building blocks of a clean energy future," 1, November 2021, <https://environmentamerica.org/sites/environment/files/Renewables-On-The-Rise-21.pdf>

¹⁴⁵ EIA, "Solar power will account for nearly half of new U.S. electric generating capacity in 2022," January 10, 2022 <https://www.eia.gov/todayinenergy/detail.php?id=50818>

expected to have the most utility-scale solar electric generator additions in 2022, the largest market for solar power in the United States will be California, providing nearly a quarter of the nation's electricity.¹⁴⁶ California's Million Solar Roofs Initiative, adopted in 2006, was largely completed within a decade and accelerated California's solar growth and capacity. The California state government also adopted policies to ensure that homeowners and businesses that invested in solar power were fully compensated for their efforts toward contributing to environmental and social benefits. Furthermore, California requires all new homes in the state to have solar PV panels.¹⁴⁷ Although other states have also increased solar electricity generation over the last several decades, California's growth rate from 2011 to 2020 was about five times that of Texas—the second most rapid rate of solar electricity growth.¹⁴⁸

As noted, there are advantages and disadvantages to solar energy in terms of current technology. According to the U.S. Department of Energy (DOE), in addition to the environmental benefits of solar PV, the benefits of residential solar electricity include saved costs, increased home value, and non-limiting locations.¹⁴⁹ As the cost of solar PV has rapidly fallen over the past decade, switching residential electricity to solar has become a viable choice for more American families. Solar electricity enables financial returns and lower monthly utility bills. Savings depend on the residence's electricity consumption, solar energy system size, hours of daily sunlight, size and angle of solar PV on roofs, and local electricity rates. Having solar PV panels on roofs can lower monthly utility bills and make long-term, low-risk investments. The number of residential solar PV panels is anticipated to increase globally from 25 million in 2020 to 240 million in 2050.¹⁵⁰ In addition, studies show that solar PV panels may increase the value of a home by about \$15,000 on average.¹⁵¹

On the other hand, the twenty to thirty-year lifetime of solar panels—as well as the waste produced by solar PVs—serve as major disadvantages.¹⁵² The IEA and IRENA estimate that PV waste will globally emerge around 2030, with regions like the EU experiencing a large volume of PV waste even earlier.¹⁵³ End-of-life management such as recycling and reuse, as well as solar PV installation, needs to be well-addressed in order to be prepared for the upcoming wave of solar PV deployment. The technologies needed to increase solar PV lifetime and solar PV waste management need further development.

Wind Energy

NZE 2050 envisions generating nearly 70% of total electricity from solar and wind by 2050. From 2030 to 2050, 340 GW of electricity generation from wind will be added annually. China had the largest electricity generation from onshore and offshore wind resources in 2019 at

¹⁴⁶ Environment America Research & Policy Center, "Renewables on the Rise 2021"

¹⁴⁷ Environment America Research & Policy Center, "Renewables on the Rise 2021"

¹⁴⁸ Environment America Research & Policy Center, "Renewables on the Rise 2021"

¹⁴⁹ U.S. Department of Energy, "Benefits of residential solar electricity," <https://www.energy.gov/energysaver/benefits-residential-solar-electricity>

¹⁵⁰ IEA, "Net Zero 2050," 146

¹⁵¹ U.S. Department of Energy, "Benefits of residential solar electricity"

¹⁵² IEA and IRENA, "End-of-Life Management," 11

¹⁵³ IEA and IRENA, "End-of-Life Management," 19

1004 TWh, which was nearly 3% of the country's total energy consumption.¹⁵⁴ In the United States, energy consumption by wind power was at 740 TWh, accounting for 2.85% of the United States' total energy consumption.¹⁵⁵

Since the United States has one of the fastest-growing wind markets in the world, the DOE has conducted a variety of both onshore and offshore research and development projects.¹⁵⁶ In 2008, the DOE released *20% Wind Energy by 2030*, a report examining the costs, major impacts, and challenges likely to arise from attempting to generate 20% of the nation's electricity demand from wind by 2030.¹⁵⁷ The DOE's Wind Energy Technologies Office (WETO) later published *Wind Vision: A New Era for Wind Power in the United States* in 2015 and *Wind Vision Detailed Roadmap Actions: 2017 Updates* to further evaluate the future pathway of the wind energy industry.^{158;159} According to *Wind Vision*, the wind industry has scaled up its domestic manufacturing capacity and lowered wind power costs by more than 30% since 2008. In some aspects, the growth of wind power exceeded assumptions made in the 2008 report.¹⁶⁰ *Wind Vision* clarified that wind power would need to provide 10% of the U.S. electric demand by 2020, 20% by 2030, and 35% by 2050. In 2020, wind power provided more than 10% of electricity in sixteen states and more than 30% in Iowa, Kansas, Oklahoma, South Dakota, and North Dakota.¹⁶¹

Advantages of wind power include cost-efficiency, economic benefits, new employment, reliability, and sustainability.¹⁶² Land-based utility-scale wind power is, in fact, one of the cheapest energy sources available today. Because wind is inexhaustible and electricity from wind is sold at a fixed rate, the price of electricity would be more certain and would be sustainably generated. The DOE also anticipates that the wind industry will employ 100,000 workers and will potentially create over 600,000 jobs in manufacturing, installation, maintenance, and supporting services by 2050.¹⁶³ Considering that energy from wind is produced and consumed domestically, the supply and price of electricity will not be affected by political affairs.

¹⁵⁴ Our World in Data, "China: Energy Country Profile," <https://ourworldindata.org/energy/country/china>

¹⁵⁵ Our World in Data, "United States: Energy Country Profile,"

<https://ourworldindata.org/energy/country/united-states>

¹⁵⁶ U.S. Department of Energy, "Wind,"

<https://www.energy.gov/science-innovation/energy-sources/renewable-energy/wind>

¹⁵⁷ U.S. Department of Energy, "20% Wind Energy by 2030: Increasing Wind Energy's Contribution to U.S. Electricity Supply," July 2008, <https://www.energy.gov/sites/default/files/2013/12/f5/41869.pdf>

¹⁵⁸ U.S. Department of Energy, "Wind Vision: A New Era for Wind Power in the United States," April 2015, https://www.energy.gov/sites/prod/files/WindVision_Report_final.pdf

¹⁵⁹ U.S. Department of Energy, "Wind Vision: Detailed Roadmap Actions: 2017 Updates," May 2018, https://www.energy.gov/sites/default/files/2018/05/f51/WindVision-Update-052118-web_RMB.pdf

¹⁶⁰ U.S. Department of Energy, "Wind Vision: A New Era," xxxiv-xxxv

¹⁶¹ U.S. Department of Energy, "Wind Market Reports: 2021 Edition," 7-8, August 2021, https://www.energy.gov/sites/default/files/2021-08/Land-Based%20Wind%20Market%20Report%202021%20Edition_Full%20Report_FINAL.pdf

¹⁶² U.S. Department of Energy, "Advantages and Challenges of Wind Energy,"

<https://www.energy.gov/eere/wind/advantages-and-challenges-wind-energy>

¹⁶³ U.S. Department of Energy, "Advantages and Challenges"

On the other hand, major challenges include cost bias, limited location, noise and aesthetic pollution, lack of profitability, and impact on the local habitat.¹⁶⁴ Although the cost of wind power has dramatically declined over the past few decades, the wind industry needs to compete with the lowest-cost source of energy. Compared to solar power, wind power is not variable in size and is thus limited in the locations where a wind turbine can be installed. There are also concerns regarding visual impacts on the landscape and noise produced by turbine blades. Installation of wind plants may affect the local habitat, as birds are sometimes killed by turbine sources.

Geothermal Energy

Geothermal resources are widely distributed and occur in many parts of the world. They occur in large portions of the western United States, in countries bordering the Pacific Ocean, portions of South and Southeast Asia, Australia and New Zealand, Central Asia, East Africa, and the eastern Mediterranean.¹⁶⁵ To date, these resources have only been locally developed, where hydrothermal heat is accessible at the surface. While there are reasons underlying this, they do not erase the fact that geothermal represents a very large, mostly untapped source of renewable energy.

Geothermal energy is baseload and domestic and has a small environmental footprint. Compared to solar PV, geothermal power plants emit four times fewer GHGs on a lifecycle basis. While utility-scale solar PV and wind turbines require large amounts of land, geothermal power plants only use 404m² per GW hour. In addition, as geothermal resources are “always on,” its energy is secure, reliable, flexible, and constant, while the electric supply from solar and wind is dependent on weather.¹⁶⁶ Enhanced Geothermal Systems (EGS) has a great potential to expand the use of geothermal energy in larger areas of the western United States as well as new geographic areas of the nation.¹⁶⁷ EGS is also expected to accelerate the growth in the non-electric sector for district-heating systems and other direct-use applications.¹⁶⁸

Despite these advantages, geothermal has so far attracted much smaller levels of investment, with few exceptions (e.g. Iceland, El Salvador, and Kenya) and remains a small contribution to the total electricity generation. A significant challenge is the high drilling costs associated with exploration and development.¹⁶⁹ Initial costs for a field and plant in the United States is around \$2,500 per installed kW.¹⁷⁰ The cost of solar PV and wind plants has fallen in the

¹⁶⁴ U.S. Department of Energy, “Advantages and Challenges”

¹⁶⁵ Statista, “Global geothermal energy produced in 2020, by country,”

<https://www.statista.com/statistics/514488/geothermal-generation-worldwide-by-key-country/>

¹⁶⁶ U.S. Department of Energy, “GeoVision: Harnessing the Heat Beneath Our Feet,” May 2019, x-xii

<https://www.energy.gov/sites/default/files/2019/06/f63/GeoVision-full-report-opt.pdf>

¹⁶⁷ Office of Energy Efficiency & Renewable Energy, “How an Enhanced Geothermal System Works,”

<https://www.energy.gov/eere/geothermal/how-enhanced-geothermal-system-works>

¹⁶⁸ U.S. Department of Energy, “GeoVision,” 19

¹⁶⁹ Susan Hamm, “Geothermal Energy: Solutions for a Zero-Emissions Sustainable Energy Future,” *Office of Energy Efficiency & Renewable Energy*, https://www.energy.gov/sites/default/files/2021-06/ARMA_Hamm%202021.pdf

¹⁷⁰ Office of Energy Efficiency & Renewable Energy, “Geothermal FAQs,”

https://www.energy.gov/eere/geothermal/geothermal-faqs#cost_to_develop_geothermal_power_plant

last few decades, which has enabled people and manufacturers to adopt renewable energy—though the installation cost of geothermal energy is still high. A Report by the DOE highlighted that technology improvements could reduce costs and risks associated with geothermal developments and increase the geothermal electric power generation.¹⁷¹ Since geothermal power can generate 8.5% of all U.S. electricity generation with the cost reduction, technology improvements are critical for increasing the electric generation by geothermal power and achieving commercial EGS.¹⁷²

Biomass Energy

Among the bioenergy technologies, wood is still the largest source of biomass energy.¹⁷³ On the pathway to NZE 2050, the traditional use of biomass is anticipated to decrease gradually leading up to 2030, when it will be replaced by liquefied petroleum gas, biogas, electric cookers, and improved bioenergy stoves. By providing a renewable source for cooking to households and villages in rural areas, about 500 million households will use biogas in 2030, consequently raising the demand for biomethane.¹⁷⁴ Biogas is an energy-rich gas composed primarily of methane, carbon dioxide, and the same compound found in natural gas.¹⁷⁵ However, it continues to be an important source of energy, especially in emerging markets and developing countries. Additionally, 750 million people in developing countries will not have access to electricity, and billions will have to rely on the traditional use of bioenergy for cooking.¹⁷⁶

In 2020—excluding its traditional use for cooking approximately 10% of the global primary supply of modern bioenergy was consumed as liquid biofuels for road transport, and 6% was consumed as biogases for power and heat.¹⁷⁷ Biofuels are transportation fuels like ethanol and biomass-based diesel fuel and are used to meet transportation needs by converting biomass into liquid. As the use of fossil fuels is expected to decline rapidly on the way to NZE 2050, low-emission fuels such as biogases, hydrogen, and hydrogen-based fuels will consequently grow.

In 2020, biomass energy generated nearly 5% of total primary energy use in the United States.¹⁷⁸ Biomass sources include wood and wood processing wastes, agricultural crops and waste materials, biogenic materials in municipal solid waste, animal manure, and human sewage. 39% of total renewable energy use is generated from biomass energy, consisting of 22% from wood and waste and 17% from biofuels.¹⁷⁹ In September 2021, the DOE announced that over

¹⁷¹ U.S. Department of Energy, “GeoVision,” xii

¹⁷² U.S. Department of Energy, “GeoVision”

¹⁷³ NREL, “Biomass Energy Basics,” <https://www.nrel.gov/research/re-biomass.html>

¹⁷⁴ IEA, “Net Zero 2050 A Roadmap for the Global Energy Sector,” 77-78

¹⁷⁵ EIA, “Biomass explained,” last updated November 3, 2021, <https://www.eia.gov/energyexplained/biomass/landfill-gas-and-biogas.php>

¹⁷⁶ IEA, “Net Zero 2050,” 37-38

¹⁷⁷ IEA, “Net Zero 2050,” 106-107

¹⁷⁸ EIA, “Table 1.3 Primary Energy Consumption by Source,”

<https://www.eia.gov/totalenergy/data/browser/index.php?tbl=T01.03#/?f=A&start=1949&end=2020&charted=11-13>

¹⁷⁹ EIA, “U.S. renewable energy consumption by source and sector, 2020,”

https://www.eia.gov/totalenergy/data/monthly/pdf/flow/renewable_energy_2020.pdf

\$64 million was funded for twenty-two biofuels research projects to help accelerate the United States' path to NZE 2050.¹⁸⁰ These projects will support the Sustainable Aviation Fuel Grand Challenge, which aims at reducing the cost, enhancing sustainability, and expanding the production and use of Sustainable Aviation Fuel (SAF). Memorandum of Understanding set a commitment of achieving a minimum 50% reduction in life cycle GHG emissions and meeting a goal of supplying sufficient SAF to meet 100% of aviation fuel demand by 2050.¹⁸¹

Chapter 2.2: Nuclear Energy

Introduction

Nuclear energy is one of the most crucial non-carbon sources of electricity in the world. Energy originates from the splitting of uranium atoms in a process called fission. This generates heat to produce steam, which is used by a turbine generator to generate electricity. Uranium is a naturally-occurring radioactive element, and it can be recovered by conventional mining of rock¹⁸². Nuclear energy could be a key part of the solution for carbon emissions and rising energy demands benefitting both national and public interests. However, the initial investment for nuclear energy is high compared to other energy sources, and cooperation among citizens, the private sectors, and the state and federal government, is crucial.

Civilization consumes around 23,398 terawatt-hours of electricity in a year.¹⁸³ This energy demand is forecasted to increase from 40% to 50% in the next thirty years. Currently, the world generates 84% of its electricity from oil, coal, and gas. The environmental consequences of relying on these energy sources are now known to be extremely serious. Aside from air, water, and soil pollution, the burning of fossil fuels, especially coal, results in emitting CO₂ into the air, exacerbating climate change. Climate change affects environmental conditions, food and water supplies, weather patterns, sea levels, and many other factors that threaten all types of organisms, not least human beings. In 2020, the world has emitted about 37 billion tons of additional CO₂ into the atmosphere. Though roughly half of this is absorbed by the oceans and other terrestrial systems, the other half remains in the atmosphere for centuries. Even if all countries and industries were to stop their emissions today, climate change will still occur in the future.¹⁸⁴ Lowering emissions a large amount will significantly reduce the amount of such change, and thus the scale and intensity of negative impacts. Therefore, it is essential to prioritize lowering carbon emissions.

¹⁸⁰ Office of Energy Efficiency & Renewable Energy, "U.S. Department of Energy Announces More Than \$64 Million for Biofuels Research to Reduce Transportation," September 9, 2021, <https://www.energy.gov/eere/bioenergy/articles/us-department-energy-announces-more-64-million-biofuels-research-reduce>

¹⁸¹ Office of Energy Efficiency & Renewable Energy, "U.S. Department of Energy"

¹⁸² "Radioactive Waste From Uranium Mining and Milling." EPA United States Environmental Protection Agency. EPA. Accessed February 15, 2022. <https://www.epa.gov/radtown/radioactive-waste-uranium-mining-and-milling>.

¹⁸³ Alves, Bruna. "Net Electricity Consumption Worldwide in Select Years from 1980 to 2019." Statista. Statista, February 14, 2022. <https://www.statista.com/statistics/280704/world-power-consumption/>.

¹⁸⁴ Goldstein, Joshua S., and Staffan A. Qvist. *A Bright Future: How Some Countries Have Solved Climate Change and the Rest Can Follow*. Public Affairs, 2019, 5.

Nuclear energy can be a core solution to climate change and global carbon emissions. Since the first nuclear power plant began operations in the 1950s, the technology has provided an enormous amount of low-carbon energy to civilized society. Yet the technology has continued to spark fear and opposition due to concerns about safety and radiation that are exaggerated and non science-based. Such fears have been heightened by news coverage and anti-nuclear exploitation of three major accidents: Three Mile Island (United States), Chernobyl (Soviet Union, today Ukraine), and Fukushima (Japan). The 2011 power plant failure in Fukushima especially influenced policymakers to reconsider the dependence on nuclear energy.

In the United States, twelve nuclear power reactors have permanently closed since 2012, and another seven reactor retirements have been announced through 2025, a total generation capacity of 7% of U.S. nuclear capacity.¹⁸⁵ The major factor that contributed to the shutdowns is the cost of major repairs or operating losses. Most of Europe is moving toward a mixed usage of different sources of energy, with nuclear at 26%, renewables at 30%, and fossil fuels at 44%.¹⁸⁶ Since the 1980s, France has relied on nuclear for 70% of its energy as a way to achieve independence from fossil fuels. France is now one of the lowest carbon emitting countries. In February 2022, French President Emmanuel Macron announced that France will construct six new nuclear reactors to reach carbon-neutral status by 2050.¹⁸⁷ While some European countries—such as the United Kingdom and the Netherlands—are increasing the capacity of nuclear energy, a few other European nations— like Germany and Belgium—are heading in the opposite direction. After Fukushima, former German Chancellor Angela Merkel proposed shutting down all seventeen nuclear plants, of which generate 12% of Germany’s electricity. Belgium is also planning to denuclearize by 2025, even though they rely on nuclear power for more than 50% of their energy.

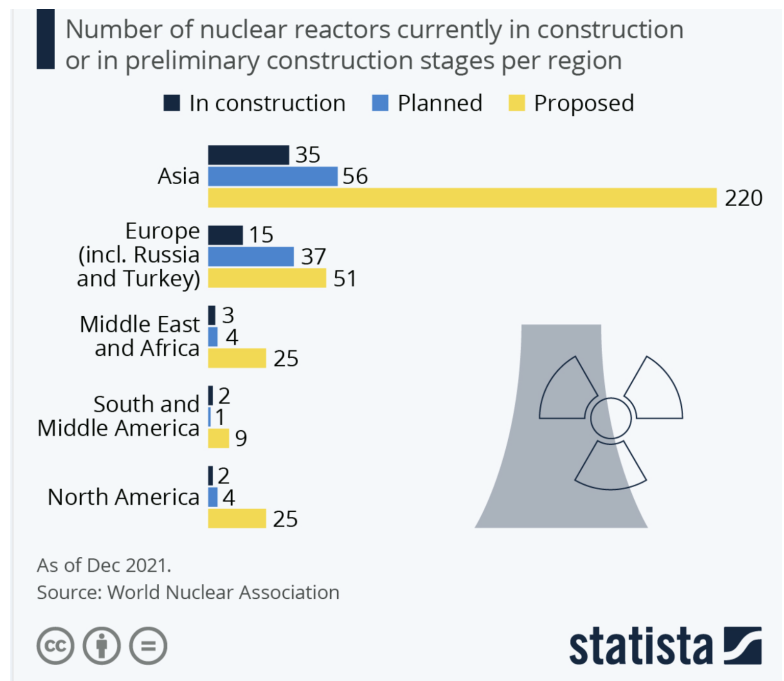


Figure 2.2.1 Number of Nuclear Reactors Currently in Construction or In Preliminary Construction Stages Per Region Graph by Statista; Data Adapted From World Nuclear Association

¹⁸⁵ Holt, Mark, and Phillip Brown, R46820 U.S. Nuclear Plant Shutdowns, State Interventions, and Policy Concerns § (2022).

¹⁸⁶ “Eurostat.” Electricity Production, Consumption and Market Overview. Eurostat, January 27, 2022. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Electricity_production%2C_consumption_and_market_overview#Electricity_generation.

¹⁸⁷ Lough, Richard, and Benjamin Mallet. “Macron Bets on Nuclear in Carbon-Neutrality Push, Announces New Reactors.” Reuters. Thomson Reuters, February 10, 2022. <https://www.reuters.com/business/energy/macron-bets-nuclear-carbon-neutrality-push-announces-new-reactors-2022-02-10/>.

While some European nations have policies in place for nuclear power phase-out, China, Russia, India, as well as countries in the Middle East, Africa, and Southeast Asia, are constructing or planning to build nuclear power plants to meet increasing energy demand. As of January 2022, China had fifty-three operating nuclear power units, eighteen under construction, and over 200 more planned or proposed.¹⁸⁸ Although China is currently relying heavily on coal, the government is aiming to reach carbon neutrality by 2060, with nuclear a key non-carbon source of power and heat. Russia operates thirty-seven reactors, with three under construction and another forty-eight planned.

Both countries are pursuing advanced reactor technologies and have large-scale programs underway for nuclear exports. Nuclear electricity production in the United States accounts for 20% of national electricity. Although the Russian government is seeking to enhance the efficiency of natural gas utilization and coal quality, Russia recently agreed to create six nuclear reactors in India, and is also building reactors in Bangladesh, Turkey, Belarus, Iran, and Egypt.

Nuclear energy development in the Middle East is still in its early stages. As an oil and gas producing region, shifting away from fossil fuels seems difficult. However, a strong reason in favor of nuclear energy is that these nations would rather save their oil and gas for export than burn it for electricity. There are six countries in the region with nuclear power ambitions: Iran, the United Arab Emirates (UAE), and Turkey, who have existing reactors or one or more in construction, while Egypt will begin building its first reactor in 2022¹⁸⁹; Saudi Arabia, and Jordan will likely follow in the next several years.¹⁹⁰ In 2020, the UAE brought the first of four large (1.4 GW capacity) reactors online, which together will supply as much as 25% of the nation's electricity by the end of 2023. Iran already has one operational nuclear power plant, with an additional reactor under construction. Of the remaining Middle Eastern countries, Turkey has a four-reactor site being built, with plans for two other similar sites to be completed by the early 2030s.

As shown in Figure 2.2.1, reactors have been proposed in most areas of the world, with Asia having particularly large ambitions. Southeast Asia, for example, is one of the fastest-growing economic regions worldwide, yet it has no commercial nuclear power plants. However, according to a recent report from the Association of Southeast Asia Nations (ASEAN), the prospects for putting the region's first nuclear power plant into operation could take place by 2030, with two more by 2035.¹⁹¹

Nuclear energy currently provides about 10% of the world's electricity from about 437 reactors. In the United States, nuclear energy provides 20% of electricity. Despite the fact that some

¹⁸⁸ "World Nuclear Power Reactors & Uranium Requirements." World Nuclear Association. World Nuclear Association, January 2022.

<https://world-nuclear.org/information-library/facts-and-figures/world-nuclear-power-reactors-and-uranium-requirements.aspx>.

¹⁸⁹ "Construction of 1st Reactors of Dabaa Plant in Egypt to Start next July: Rosatom." EgyptToday. EgyptToday, January 19, 2022.

<https://www.egypttoday.com/Article/3/112018/Construction-of-1st-reactors-of-Dabaa-plant-in-Egypt-to>.

¹⁹⁰ Thomas, Joelle. "Refuting the Case for Nuclear in the Middle East." Energy Transition. The Global Energiewende, April 23, 2021.

<https://energytransition.org/2021/04/refuting-the-case-for-nuclear-in-the-middle-east/>.

¹⁹¹ Manpati, Tipakson. "Nuclear Power Trend in Southeast Asia and Its Contested Discourses on Climate Change: Heinrich Böll Foundation: Southeast Asia Regional Office." Nuclear Power Trend in Southeast Asia and Its Contested Discourses on Climate Change. Heinrich Böll Stiftung Southeast Asia, November 9, 2020.

<https://th.boell.org/en/2020/11/09/nuclear-power-trend-southeast-asia>.

nations in Europe have plans for denuclearization, the global demand for nuclear energy remains high. Currently, about one hundred power reactors are on order or planned, and over 320 more are proposed.¹⁹²

Capacity of Nuclear Energy

The capacity factor—the percentage of total capacity actually generated—of nuclear energy is the highest of any energy source and comes with a smaller environmental footprint. Another strength of nuclear energy is outstanding reliability. The average capacity factor of a nuclear energy plant is 93.5%, while geothermal is 74%, and hydropower has 42% of its capacity.¹⁹³ A nuclear plant requires fewer maintenance and refueling cycles compared to natural gas and coal plants, an advantage that is set to increase considerably with current reactor and fuel designs that will allow operation for more than two years without refueling. In addition, plant operations are less influenced by seasonal or environmental variations, unlike renewable energy, which is heavily dependent on weather conditions. Updated standards now in use in most nations make plant operations almost wholly independent of weather, including major storms, such as hurricanes and related flooding.

Finding clean energy sources requires the consideration of environmental footprints. Large land use for solar energy will have an impact on soil, water, and air resources. In the process of construction of solar facilities, large areas of land require clearing and grading, resulting in soil compaction which potentially alters drainage channels; and increases runoff and erosion. Land clearing and grading also affect native vegetation and wildlife in many ways, including loss of habitat. Other impacts from solar power include potentially causing interference with aircraft operations if reflected light beams are misdirected into aircraft pathways. This might not occur at small-scale energy plants, though large-scale solar energy plants will have significant impacts on both nature and humanity.¹⁹⁴

¹⁹²WNA, “Plans For New Reactors Worldwide”.

¹⁹³“Nuclear Power Is the Most Reliable Energy Source and It’s Not Even Close.” Energy.gov. U.S. Department of Energy, March 24, 2021.

<https://www.energy.gov/ne/articles/nuclear-power-most-reliable-energy-source-and-its-not-even-close>.

¹⁹⁴“Solar Energy Development Environmental Considerations.” Solar Energy Development Programmatic EIS. Information Center. Accessed February 15, 2022. <https://solareis.anl.gov/guide/environment/>.

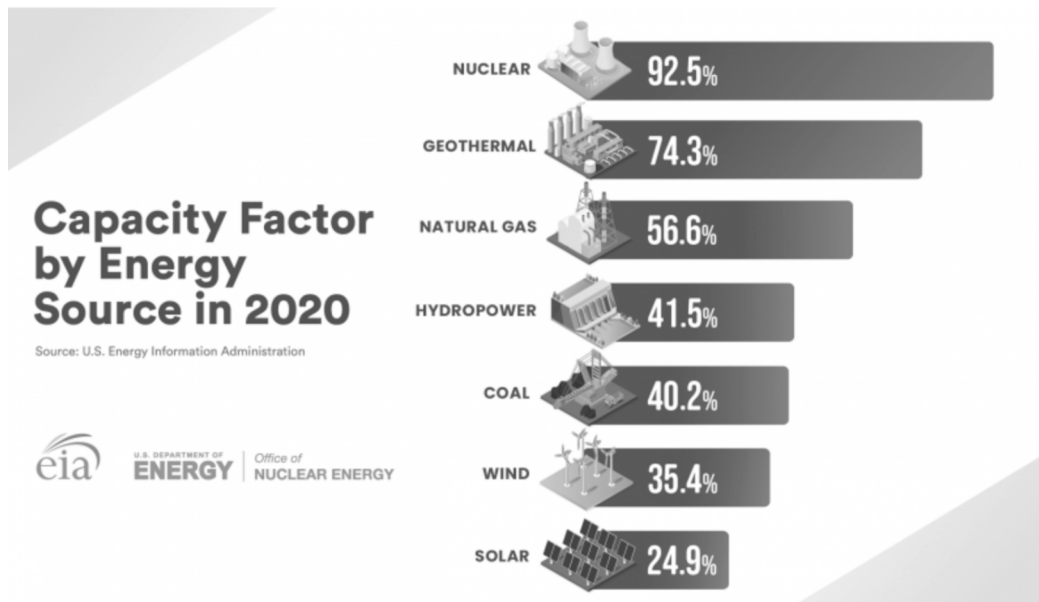


Figure. 2.2.2 Nuclear Has The Highest Capacity Factor. Graph by Office of Nuclear Energy; Data Adapted From U.S. Energy Information Administration

Many nations are considering increasing their reliance on hydropower. It is more reliable than other renewable energy sources and generates much larger quantities of energy. However, land use for hydropower plants is enormous — among all energy resources, it has the greatest land usage. In addition, the construction of dams has a major impact on aquatic ecosystems. Although there are several methods to minimize this impact, fish and other organisms can be injured and killed by turbine blades.¹⁹⁵

On a large scale, to generate 1,000 megawatts of electricity, a nuclear energy facility requires about 1.3 square miles. By contrast, a solar farm requires about 45 to 75 square miles, and a wind farm requires 260 to 360 square miles of land.¹⁹⁶ Figure 2.2.3 shows how much space is required to power a flat screen TV.

In order to generate the power for a single TV screen, hydropower requires more than one double tennis court's worth of space, and wind and solar also require much larger space than nuclear power. Such a large usage of land in the United States could cause conflict with Indigenous peoples. Their land ownership is protected by law, and no private company or government can legally take their land and resources.

¹⁹⁵ “Environmental Impacts of Hydroelectric Power.” Union of Concerned Scientists. Union of Concerned Scientists, March 5, 2013.

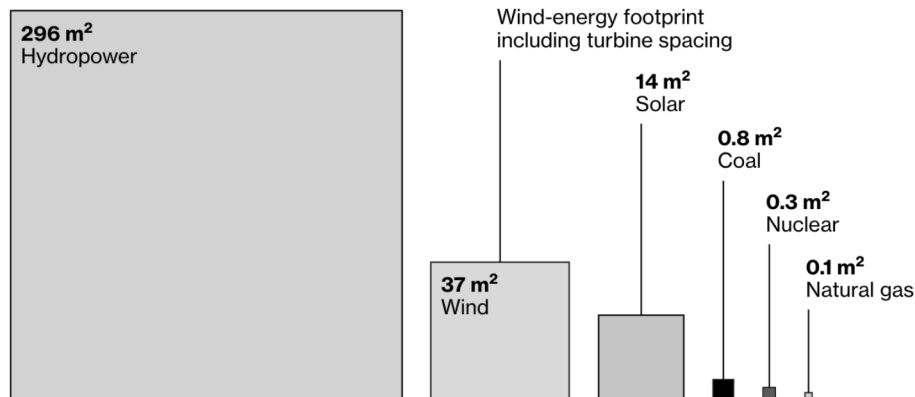
<https://www.ucsusa.org/resources/environmental-impacts-hydroelectric-power#:~:text=Flooding%20land%20for%20a%20hydroelectric,way%20for%20reservoirs%20%5B3%5D>.

¹⁹⁶ “Land Needs for Wind, Solar Dwarf Nuclear Plant's Footprint.” Land Needs for Wind, Solar Dwarf Nuclear Plant's Footprint. Nuclear Energy Institute, July 9, 2015.

<https://www.nei.org/news/2015/land-needs-for-wind-solar-dwarf-nuclear-plants>.

Power Densities: Renewables Need More Space

Land area needed to power a flat-screen TV, by energy source



Note: Assumes 100-watt television operating year-round
Source: van Zalk, John, Behrens, Paul, 2018, The Spatial Extent of Renewable and Non-Renewable Power Generation

Figure 2.2.3 Power Densities Graph by Bloomberg; Data Adapted From The Spatial Extent of Renewable and Non-Renewable Power Generation

Safety and Ethics

According to a recent survey, 49% of Americans favor the use of nuclear energy, while 49% are opposed. In addition, 47% of Americans believe nuclear power plants are safe.¹⁹⁷ The majority of Americans believe nuclear power is dangerous, despite the fact that the fatality rate of other energy sources is much higher than that of nuclear energy. A study on the number of deaths per terawatt-hour of electricity generated, which is the same as roughly the amount of power consumed by as 187,000 citizens in Europe, shows that nuclear energy death rates are almost 98% fewer than energy from fossil fuels.

The data combines death rates from accidents and air pollution from major energy sources including fossil fuels, nuclear, and biomass. As Figure 2.2.4 indicates, nuclear belongs in the same risk category as solar and wind. Nuclear energy is responsible for no fatalities. In none of the three major accidents over the past 75 years were there large numbers of deaths due to radiation. In fact, no such deaths occurred in two of the three; only Chernobyl saw such fatalities, specifically among first responders to the core-generated fires who were not informed of the radioactivity danger and wore no protective clothing. According to detailed studies by United Nations scientific agencies, the greatest number of fatalities resulted from the ordered evacuations, which removed many people from critical care and nursing home facilities.¹⁹⁸

¹⁹⁷Reinhart, R.J. "40 Years after Three Mile Island, Americans Split on Nuclear Power." Gallup. Gallup, November 20, 2021. <https://news.gallup.com/poll/248048/years-three-mile-island-americans-split-nuclear-power.aspx>.

¹⁹⁸Ritchie, Hannah. "What Was the Death Toll from Chernobyl and Fukushima?" Our World in Data. Our World in Data, July 24, 2017. <https://ourworldindata.org/what-was-the-death-toll-from-chernobyl-and-fukushima>.

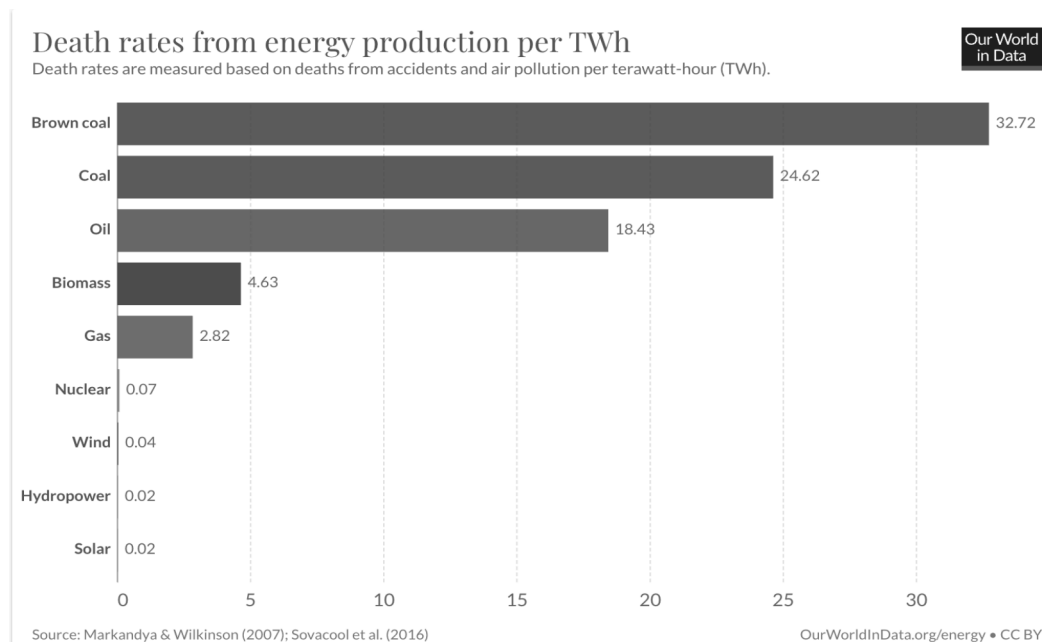


Figure 2.2.4 Death Rates From Energy Production per TWh. Graph by Our World in Data; Data Adapted From Markandya & Wilkinson (2007); Sovacool et al. (2016)

Exporting nuclear technology to developing countries is a considerable choice for the United States due to the fact that developing nations rely heavily on fossil fuels, and replacing them with nuclear energy solves energy shortages and rising CO₂ emissions. The global nuclear power market is a matter of national interest and security for the United States. Estimates from the U.S. Department of Commerce (DOC) project that the United States is absent from a global nuclear reactor market that is forecasted to be worth between \$500 billion and \$740 billion over the next several decades.¹⁹⁹ Meanwhile, Russia is expanding its global nuclear influence with \$133 billion worth in foreign orders for reactors. China is also constructing four reactors abroad with prospects for sixteen more. Russia and China are conducting projects, and thus are gaining influence on the nuclear sector. The United States should consider greater involvement in exporting nuclear energy, which also leads to job creation. According to the DOC, every \$1 billion of exports by U.S. companies represents 5,000 to 10,000 jobs.²⁰⁰ The possibility of exporting nuclear technology to create nuclear weapons is unlikely given the Treaty of the Non-Proliferation of Nuclear Weapons and the U.N. Treaty on the Prohibition of Nuclear Weapons.

Nuclear power plants are one of the most highly secured places in a country. It is a robust structure protected by armed security guards, physical barriers, intrusion detection, and surveillance systems to defend against possible threats. Most power plants collaborate with military and local law

¹⁹⁹ Sallee, Kyle. "Regaining American Competitiveness in the Global Nuclear Power Market." American University. American University, Washington, D.C., February 5, 2021. <https://www.american.edu/sis/centers/security-technology/regaining-american-competitiveness-in-the-global-nuclear-power-market.cfm>.

²⁰⁰ NEI, "Nuclear Energy's Economic Benefits - Current and Future

enforcement.²⁰¹ In the United States, nuclear power plants are often protected by the Department of Homeland Security, Defense, Energy, the FBI, and local police. However, when it comes to cyberspace, nuclear power plants can be targeted, as process control systems in nuclear power plants have evolved from early analog systems to digital ones. In September 2019, the Kudankulam Nuclear Power Plant in India was the victim of a cyber attack, though damage to the main operating system was avoided. There have been constant updates and innovations in technology (both hardware and software). A nuclear power plant in Switzerland created a private cloud program with malware protection and maintained their system with their own IT team. However, such with a cat and mouse game, hackers always find ways into a system. There are still many obstacles ahead in terms of cyber security, and this limits the potential of nuclear technology. A data breach involving sensitive commercial or nuclear information could cause significant reputational damage or loss of regulatory and public confidence.²⁰²

New Era of Nuclear Energy

Generation III Reactor

Nuclear reactors are entering a new era. The French government has decided to build six new European Pressurized Reactors (EPR-2), which is an optimized version of the standard EPR. This reactor has an operating life of at least sixty years and is much more durable and easy to construct. Compared to an EPR, the cost of an EPR-2 was reduced by about 30% and the total capacity of the reactor is 1.6 GW, making it one of the best nuclear reactors in the world.²⁰³

Generation IV Reactor

Fast Neutron Reactors (FNR) are a technological step beyond conventional power reactors. This reactor uses plutonium as its basic fuel, and the system has the potential to extract sixty times more energy compared to existing reactors. It also contributes to a significant reduction in the burden of radioactive waste.²⁰⁴ However, these technologies are still under development. Furthermore, since plutonium is a highly toxic material, FNR power plants require stringent safety and security, sustainable development, proliferation resistance, and public acceptance. Therefore, FNRs are currently economically infeasible, and further research is needed.

Small Modular Nuclear Power Reactors

The future of nuclear power plants could be smaller and operable at a local scale rather than generating power from a central power system. The construction cost of conventional nuclear power plants is about \$6 billion to \$9 billion and takes over five years to build. On the other hand, the construction cost for small modular reactors (SMR) is about \$1 billion and takes fourteen months to build. The power output of an SMR is as small as under 300 MW and 700 MW for medium reactors.

²⁰¹ “Backgrounder on Cyber Security.” U.S.NRC. United States Nuclear Regulatory Commission, July 13, 2021. <https://www.nrc.gov/reading-rm/doc-collections/fact-sheets/cyber-security-bg.html>.

²⁰² WNA, “Security of Nuclear Facilities and Material.”

²⁰³ WNA, “Advanced Nuclear Power Reactors”.

²⁰⁴ Patel, Sonal by POWER. “Rapid Advancements for Fast Nuclear Reactors.” POWER . Power Magazine, March 24, 2019. <https://www.powermag.com/rapid-advancements-for-fast-reactors/>.

SMRs are expected to have greater simplicity of design. Due to the fact that most of the construction is largely placed in factories, the period of construction would be much shorter, which significantly reduces the cost. In addition, SMRs can readily slot into brownfield sites in place of decommissioned fossil fuel plants, reducing its enormous environmental footprint.²⁰⁵ SMRs can be exported to other countries, because their small size and passive safety features are compatible for countries with smaller grids and less experience with nuclear power. In 2020, the U.S. Nuclear Regulatory Commission (NRC) approved the design of SMRs from Portland-based company NuScale Power. The company is expected to sell anywhere from 674 to 1,682 reactors between 2023 and 2042, and the capacity of the reactor is more than 80 GW. The first reactors are expected for delivery at the Idaho National Laboratory by 2027 and are scheduled to be operational by 2029²⁰⁶.

Storage and Disposal of Radioactive Waste

Radioactive waste management is a large concern for the public due to the fact that nuclear waste is highly toxic and can take up to 1,000 years to decay. However, like all industries, the thermal generation of electricity produces waste. For instance, fossil fuels produce CO₂, and renewables like solar and wind energy produce silicons and unrecyclable steel. Waste from those energy sources is not well-managed in ways that safeguard human health and minimize the impacts on the environment. Conversely, nuclear waste is well-managed and stored in locations where it does not harm any species on this planet. In addition, the amount of waste from nuclear energy is much less than some renewable energies. The International Renewable Energy Agency estimated that solar panels produced 250,000 metric tons of waste in 2018 alone.²⁰⁷ In contrast, the amount of used fuel discharged from 1954 to 2013 was 367,600 metric tons of waste.²⁰⁸ The amount of waste from nuclear energy is significantly lower than from solar energy, which helps reduce damage to the environment and the environmental footprint.

Deep geological disposal is largely the preferred option for nuclear waste management. One such facility is located in Finland. It is about 427 meters underground and 32 kilometers (20 miles) long. The facility can store up to 6,500 tons of used fuel and is expected to start operations in 2023.²⁰⁹ Nuclear waste will be stored in containers surrounded by two-inch-thick copper. After the waste has been filled, the entire facility will be packed with clay and eventually abandoned. While the United States has advanced plans for the disposal of used fuel, there has been a delay due to political

²⁰⁵ WNA, “Small Nuclear Power Reactors”.

²⁰⁶ Levitan, Dave. “First U.S. Small Nuclear Reactor Design Is Approved.” *Scientific American*. Scientific American, September 9, 2020. <https://www.scientificamerican.com/article/first-u-s-small-nuclear-reactor-design-is-approved/>.

²⁰⁷ Folk, Emily. “Waste in the Renewable Energy Industry and How We Can Sustainably Power Our World.” *Renewable Energy Magazine*, at the heart of clean energy journalism. *Renewable Energy Magazine*, January 14, 2021. <https://www.renewableenergymagazine.com/emily-folk>.

²⁰⁸ “Renewable Technologies Can’t Escape the Issue of Waste Management.” *Nuclear Newswire*. *Nuclear Newswire*, February 3, 2021.

<https://www.ans.org/news/article-2599/renewable-technologies-cant-escape-the-issue-of-waste-management/>.

²⁰⁹ “Construction of Test Disposal Tunnel under Way at Onkalo.” *WNN*. *World Nuclear News*, March 1, 2021. <https://www.world-nuclear-news.org/>.

polarization. Public acceptance is the remaining issue for the disposal facilities, not technological feasibility.²¹⁰

Concluding Statement

Nuclear energy is:

- The most reliable energy source; with capacity of 92.5%
- One of the safest energy sources along with renewable energy.
- The lowest carbon emitting energy source.
- The lowest environmental footprint within the non-carbon energy source.
- Over \$500 billion market opportunity, which leads to job creation.
- Innovation within the nuclear energy sector is growing, and Generation IV or SMRs could be a new era of nuclear technology.

The clock is ticking. In the book *A Bright Future*, it is stated that the consequences of CO₂ emissions can affect all ecosystems on the Earth. There are two kinds of effects from climate change: those recognizable in the past five years, such as rising sea levels and temperature, as well as a greater frequency of large hurricanes, floods, droughts, and wildfires, and the tipping points that cause truly catastrophic shifts.²¹¹ Rafael Marino Grossi, the director general of the IEA, said during the COP26 that several developed and developing countries were considering either expanding or introducing nuclear power to help achieve both climate change and sustainable development goals. Grossi also noted that nuclear power is a “present solution” that provides almost one third of the world’s low carbon electricity.²¹² In addition, Dr. Fatih Birol, executive director of the IEA, stated that “Nuclear is the number one source of clean electricity. And it has been so for the last three decades. Therefore, when we think of electricity security [and] clean electricity to reach our climate targets, nuclear power should have an integral part in the countries where governments and citizens are part of the solution.”²¹³ Nuclear energy must be included in the energy solution to net zero emissions, and we must act immediately.

Due to technological advancements, global electricity demand is increasing annually. Nuclear energy is the most desirable energy source because of its capacity, reliability, safety, and ability for innovations. The U.S. nuclear sector is expected to decrease by 2050 due to a lack of federal and public support. At the same time, China and Russia are expanding their nuclear energy sectors—therefore increasing their influence in the global energy market. As a global leader, the United States must expand and lead the nuclear energy sector to remain competitive with other nations.

2.3 Non-carbon Sources: Hydropower

²¹⁰WNA, “Radioactive Waste - Myths and Realities.”

²¹¹ Goldstein, Joshua S., and Qvist, Staffan A. *A Bright Future*, 208.

²¹² IAEA, “IAEA's Grossi Calls for Nuclear Power for Net Zero Emissions as Climate ‘Clock is Ticking.’”

²¹³ “Nuclear Is Integral to Clean Energy Transition, Says IEA's Birol.” *World Nuclear News*. World Nuclear Association, March 4, 2021.

<https://world-nuclear-news.org/Articles/Nuclear-is-integral-to-clean-energy-transition-say>.

Introduction

Hydropower continues to dominate the non-carbon energy market, producing more electricity than all other non-carbon sources combined at 4,418 TWh worldwide in 2020.²¹⁴ Many countries favor including hydropower as part of their energy portfolios because of its efficiency, reliability, and ability to reduce and prevent emissions. It is estimated that the use of hydropower has avoided one hundred billion tonnes of carbon dioxide emissions over the past fifty years.²¹⁵ Continued advances in hydropower technology and market formation can be considered evidence that hydropower plants will be critical to the overall goal of decarbonizing power grids, especially in emerging economies, and thus decelerating the impacts of climate change worldwide.

Three Main Types of Hydropower Plants

There are three different kinds of hydropower plants: reservoir, “run-of-river” (ROR), and pumped storage plants. Reservoir power plants, also known as impoundment facilities, utilize a dam to store water in a reservoir. Stored water is directed to flow through turbines, whose spin is transmitted to a generator to produce electricity.²¹⁶ The installed cost of a reservoir power plant is around \$1,000-\$5,000 per kW.²¹⁷ One advantage of reservoir power plants is that their stored water makes them less reliant on the variability of flows in a given season or day.²¹⁸ Additionally, reservoir power plants monitor flood control and provide irrigation services.²¹⁹ One study concluded that dams significantly help with the “frequency, duration, and timing of annual flooding events.”²²⁰ Reservoir power plants also provide recreational value to local communities, such as fishing, swimming, and boating.²²¹

Reservoir power plants come with disadvantages as well. The most notable disadvantage is the disruption to the natural habitat and nearby communities. It is reported that dams have forced around 40 to 80 million people worldwide to physically relocate.²²² Building dams that drive resettlement can cause major unrest among people who cannot find other places to live.

²¹⁴ IEA, “Hydropower,” (2021), accessed January 24, 2022, <https://www.iea.org/reports/hydropower>

²¹⁵ Clean Energy Council, “Hydropower: The Backbone of a Reliable Renewable Energy System,” November 17, 2021,

<https://assets.cleanenergycouncil.org.au/documents/resources/reports/Hydropower-The-Backbone-of-a-Reliable-Renewable-Energy-System.pdf>, 11

²¹⁶ Water Power Technologies Office, “Types of Hydropower Plants,” Energy.gov, accessed January 24, 2022, <https://www.energy.gov/eere/water/types-hydropower-plants>

²¹⁷ Dylan Fitzgerald, “Affordable,” National Hydropower Association, September 12, 2019, <https://www.hydro.org/waterpower/why-hydro/affordable/>

²¹⁸ IEA, “Hydropower - Fuels & Technologies,” (2022), January 7, 2022, <https://www.iea.org/fuels-and-technologies/hydropower>

²¹⁹ IEA, “Hydropower - Fuels & Technologies”

²²⁰ Julien Boulange et al., “Role of Dams in Reducing Global Flood Exposure under Climate Change,” *Nature Communications* 12, no. 1 (January 18, 2021), <https://doi.org/10.1038/s41467-020-20704-0>

²²¹ Water Power Technologies Office, “Benefits of Hydropower,” Energy.gov (Office of Energy Efficiency & Renewable Energy), accessed February 13, 2022, <https://www.energy.gov/eere/water/benefits-hydropower>

²²² Vijay Dwivedi, Sanjeev Kumar Gupta, and Sachchida Nand Pandey, “A Study of Environmental Impact Due to Construction and Operation of Dam,” in *ResearchGate* (Mathura, 2010): 4-5, accessed January 26, 2022, https://www.researchgate.net/publication/331222795_A_Study_of_Environmental_Impact_Due_to_Construction_and_Operation_of_Dam

Furthermore, dams endanger aquatic wildlife and their migratory patterns.²²³ Another negative factor associated with dams is their potential to accumulate dead vegetation, garbage, and fertilizer runoff, all of which can impact the health of nearby residents.²²⁴ While related concerns are wholly justified, such environmental impacts can be mitigated by careful planning and design in correspondence to stakeholder considerations. For example, the sensor fish device—a project funded by the DOE’s Water Power Technologies Office (WPTO)—aims to measure the physical activity of fish passing through hydropower plants such as dam turbines.²²⁵ This provides researchers and hydropower plant operators insight into the fish experience, and aids in determining whether to adjust pressure, acceleration, strain, turbulence, and other forces so that the fish population is not negatively affected. Another example is how artificial intelligence (AI) can be employed to both minimize environmental impact and optimize hydropower production. A group of international researchers from a *Nature Communications* study in 2019 utilized data from a sophisticated computational model to determine that lowland dams in Brazil tend to have large reservoirs with high levels of carbon concentration. In contrast, countries, such as Bolivia, Ecuador, and Peru, with higher elevation and steep topography emit less carbon concentration.²²⁶ Maximizing current technologies opens the capability to protect the environment and maintain hydroelectric output.

The second type of hydropower plant is the “run-of-river” (ROR) facility, sometimes referred to as a diversion facility. As the name suggests, a ROR diverts part of a river with a canal and/or penstock to a set of turbines, thus relying on the natural downward flow of the river to generate electricity.²²⁷ A penstock is a closed, tunnel-like pathway that directs the flow of river water. ROR power plants can be built within three to four years.²²⁸ The installed cost of a ROR power plant is about \$1,500-\$6,000 per kW.²²⁹ Most RORs do not have a dam. This can be viewed as an advantage over its reservoir counterpart as it eliminates the scale of environmental damage caused by dam construction and operation.

One disadvantage to ROR power plants are their higher vulnerability to seasonal changes in river volume and, more seriously, periods of drought. Although some ROR plants have pondage, or short-term water storage, the volume is limited and lacks the capacity to compensate for an entire season of low river discharge.²³⁰ ROR facilities also produce less power than other types of hydropower plants, which causes further uncertainty regarding supply needed to meet given demands. Overall, this type of hydropower plant can be less reliable than a reservoir facility and often requires one or more forms of backup, adding to total related costs.

²²³ Dwivedi, Kumar Gupta, and Nand Pandey 4-5

²²⁴ Dwivedi, Kumar Gupta, and Nand Pandey 4-5

²²⁵ Hoyt Battey, “Making Hydropower More Eco-Friendly,” Energy.gov, October 22, 2014, <https://www.energy.gov/eere/articles/making-hydropower-more-eco-friendly>

²²⁶ Anuradha Varanasi, “How AI Could Help Bring a Sustainable Reckoning to Hydropower,” Popular Science, February 25, 2022, <https://www.popsoci.com/environment/greenhouse-gas-hydropower-dam/>

²²⁷ Water Power Technologies Office, “Types of Hydropower Plants”

²²⁸ “How Long Does It Take to Build a Hydroelectric Power Station?,” AQPER, accessed February 28, 2022, <https://www.aqper.com/en/how-long-does-it-take-to-build-a-hydroelectric-power-station>

²²⁹ Dylan Fitzgerald, “Affordable”

²³⁰ IEA, “Hydropower - Fuels & Technologies”

The third type of hydropower plant is pumped storage hydropower (PSH). PSH facilities possess both an upper and lower reservoir. During periods of high demand, the upper reservoir releases water to the lower reservoir to run turbines for added electricity generation.²³¹ At times of high water and large power production, PSHs pump water from the lower to the upper reservoir to store energy for future use. The installed cost of a PSH is around \$1,010-\$4,500 per kW.²³² These plants are also able to store energy generated from other non-carbon sources, such as solar, wind, and nuclear.²³³ This defines a distinct advantage, as it represents a cheaper and more long-lived alternative to battery storage for these technologies. As a report from Australia's Clean Energy Council claims, hydropower is the "only low-carbon electricity-generating technology that can provide system flexibility within a range of sub-seconds to hours while also cost-effectively storing energy for days to months during periods of limited energy."²³⁴ Another benefit of PSHs is that it has a high "return on energy." Research from the Swiss Academy of Engineering Sciences suggests that PSH power plants return "186 times the energy required to build it."²³⁵

PSHs have their disadvantages as well. For example, PSHs require specific topographic settings, where a large vertical change takes place over a relatively short horizontal distance.²³⁶ As a result, PSHs are constrained as a global source of non-carbon power.

General Advantages and Disadvantages of Hydropower

Because hydropower relies solely on water, it is easily replenishable, making it a renewable source. Also, using hydropower to generate electricity does not emit as many greenhouse gasses or contribute to as much pollution, unlike fossil fuel counterparts such as coal, oil, and natural gas. In addition, incorporating hydropower into the United States' energy portfolio makes it less reliant on international energy sources due to hydropower's domestic abundance. Hydroelectric power is also flexible. Regardless of the level of demand, hydropower has the ability to generate electricity to the grid quickly. This makes hydropower a reliable source, especially as a backup power for intermittent energy sources.²³⁷

Similar to reservoir power plants, the major drawback against hydropower is the use of dams. While hydropower is meant to serve as a better alternative for energy use, it also has the potential to impose negative impacts on the environment, like the construction of dams and decomposition of flooded organic material, which produces methane and further emits greenhouse gasses. ROR power plants cause less environmental damage than reservoir and PSH plants because they do not require the presence of a dam. Nevertheless, ROR facilities rely heavily on seasonal changes and are not as efficient in terms of total output. Furthermore, any type of hydropower plant comes with a significant financial investment upfront. Despite having a

²³¹ Water Power Technologies Office, "Types of Hydropower Plants"

²³² Dylan Fitzgerald, "Affordable"

²³³ Water Power Technologies Office, "Types of Hydropower Plants"

²³⁴ Clean Energy Council, "Hydropower: The Backbone of a Reliable Renewable Energy System," 9

²³⁵ Clean Energy Council, "Hydropower: The Backbone of a Reliable Renewable Energy System," 11

²³⁶ Water Power Technologies Office, "Types of Hydropower Plants"

²³⁷ Water Power Technologies Office, "Benefits of Hydropower"

lifespan of up to one hundred years, countries must consider the material, labor, operational, and maintenance costs associated with any hydropower facility. Another element to consider is how climate change can affect the future of hydropower. Even though hydropower is considered a renewable energy source, local weather and precipitation trends affect the overall supply of water. Climate-related trends in the United States include megadrought conditions in the Southwest, such as large portions of California, where hydropower has suffered major declines since 2010.²³⁸ As of June 2021, the U.S. Energy Information Administration (EIA) stated that 100% of California is experiencing some form of drought, with about 33% of the state classified as undergoing “exceptional drought,” which is the most intense level. Usually, melted water from the mountains supply water to California’s reservoirs during the spring and summer seasons. Due to the severe impact from megadroughts, however, melted water was not able to reach the designated reservoirs because it was absorbed by parched soil and streams along the way.²³⁹

Global Trends of Hydropower Use

Hydropower has emerged as the world’s most popular renewable energy source. As of 2021, hydropower comprised about one-sixth of the world’s total power generation, only behind coal and natural gas.²⁴⁰ According to a report published by the International Hydropower Association (IHA), hydropower ranks within the following regions of the world in terms of highest to lowest hydropower capacity up to 2020:

Highest capacity actor refers to countries with the highest total installed hydropower capacity; emerging actor refers to the country that demonstrates strong potential regarding current hydropower capabilities; metrics relate to total installed hydropower capacity up to 2020

1. East Asia and the Pacific (501 GW)

a. Highest capacity actor: China (370,160 MW) → In 2020 alone, China contributed 13.76 GW of new hydropower capacity. This was achieved through the completion of the Jixi project and others. The Wudongde plant, which was scheduled to be completed by July 2021, was projected to become China’s fourth-largest and the world’s seventh-largest hydropower plant. China strongly emphasizes the production of PSH facilities.

b. Emerging actor: Japan (50,016 MW)

2. Europe (254 GW)

a. Highest capacity actor: Norway (32,995 MW)

b. Emerging actor: Turkey (30,984 MW) → Within a span of a year, Turkey’s hydropower capacity grew by 10% in 2020. One of the most notable hydropower plants in the country is the Ilisu facility, which generates 1,224 MW. This is

²³⁸ Lindsay Aramayo, “California’s Hydroelectric Generation Affected by Historic Drought,” U.S. Energy Information Administration, July 7, 2021, <https://www.eia.gov/todayinenergy/detail.php?id=48616>

²³⁹ Lindsay Aramayo, “California’s Hydroelectric Generation Affected by Historic Drought”

²⁴⁰ Rystad Energy, “Hydropower Cements Its Place As The World’s Most Popular Renewable Energy,” OilPrice.com, February 7, 2022, <https://oilprice.com/Alternative-Energy/Renewable-Energy/Hydropower-Cements-Its-Place-As-The-Worlds-Most-Popular-Renewable-Energy.html>

significant because the construction was completed after thirteen years, which started in 2007. Ilisu provides electricity for over a million homes and irrigation for thousands of farmers in the region.

3. North and Central America (205 GW)

a. **Highest capacity actor: The United States (102,000 MW)** → Stanford University's initiative called the "Uncommon Dialogue" aims to find ways that decarbonize the country's electrical grid, as well as preserve the biodiversity and ecosystems of rivers.

b. **Emerging actor: Canada (82,000 MW)** → Back in April 2020, the government proposed a \$14 billion budget for green programs throughout 2021-2022. Within this budget, about \$33.15 million was allocated for hydropower-related projects, which could advance the Atlin Hydro expansion in Yukon and feasibility study of the Kivalliq HydroFibre Link in Nunavut.

4. South America (177 GW)

a. **Highest capacity actor: Brazil (109,271 MW)** → Due to ongoing droughts across the entire country, Brazil's government has declared a hydrological crisis. Since Brazil relies on over 60% of hydropower for its electricity, Brazil's current status symbolizes the effects from climate change on its hydropower supply. To find other solutions, Brazil has stood out as a global leader in hybrid energy projects, such as installing solar floating photovoltaic panels on reservoirs.

b. **Emerging actor: Venezuela (15,393 MW)**

5. South and Central Asia (155 GW)

a. **Highest capacity actor: India (50,549 MW)** → India granted approval and commissioned various hydropower projects, including Dibang (2,880 MW), Bodhghat (500 MW), and more.

b. **Emerging actor: Russia (49,912 MW)** → Russia commissioned four hydropower plants in 2020.

6. Africa (38 GW)

a. **Highest capacity actor: Ethiopia (4,074 MW)** → The country continued with the construction of its Great Ethiopian Renaissance Dam (GERD), which is set to produce 6,350 MW, despite facing legal challenges with Egypt and Sudan regarding the amount of water being retained in the reservoir.

b. **Emerging actor: Angola (3,836 MW)** → Angola itself added 401 MW of total installed capacity in 2020.²⁴¹

2020 marked a 1.6% increase from 2019 in total installed hydropower capacity worldwide.²⁴² To put this metric into perspective, the average yearly growth in installed capacity from 2016 to 2020 equaled 1.8%.²⁴³ Despite records of increasing capacity, experts argue that

²⁴¹ International Hydropower Association, "2021 Hydropower Status Report: Sector Trends and Insights," 2021, <https://www.hydropower.org/publications/2021-hydropower-status-report>, 23-45

²⁴² International Hydropower Association, "2021 Hydropower Status Report: Sector Trends and Insights," 8

²⁴³ International Hydropower Association, "2021 Hydropower Status Report: Sector Trends and Insights," 8

countries must continue to be more aggressive with their growth strategies in order to meet NZE 2050 goals. To accomplish this, the yearly growth rate must reach around 2.3%, which is equivalent to 1,300 GW generated by 2050.²⁴⁴

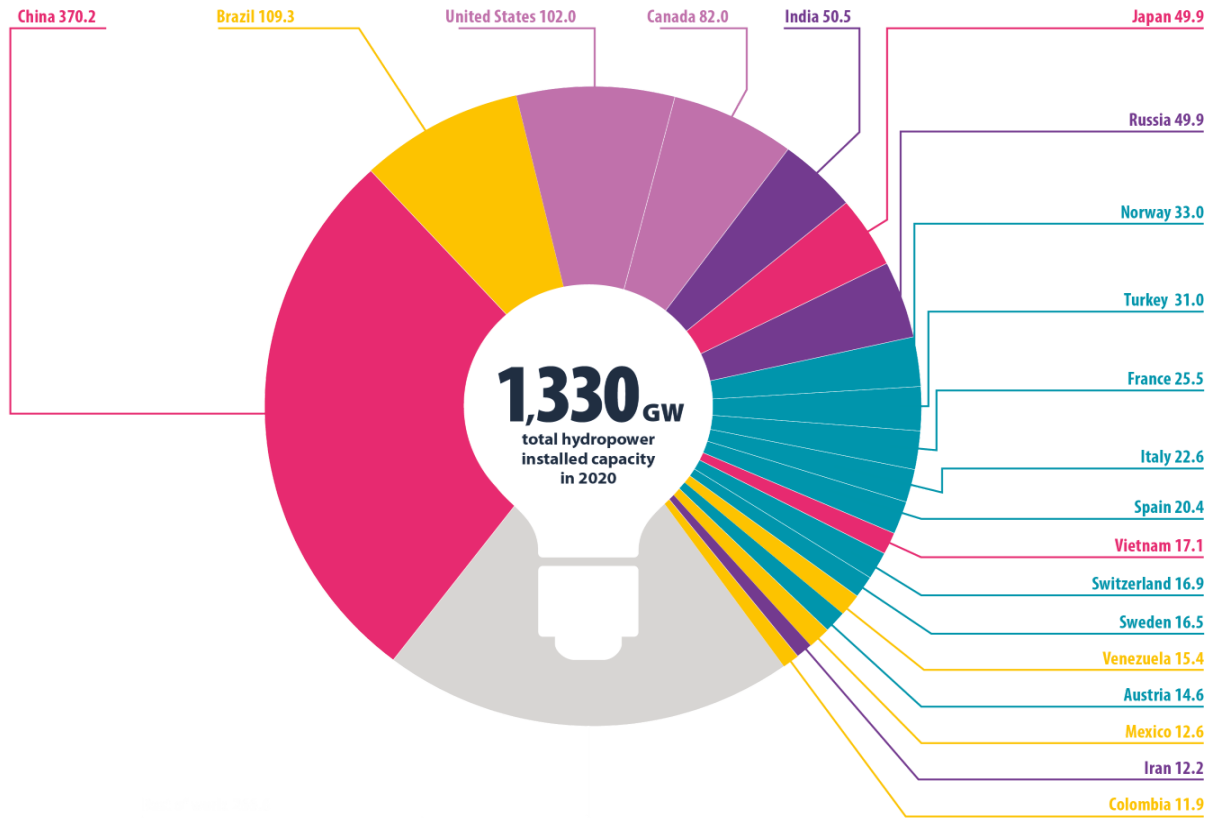


Figure 2.3.1: Total Hydropower Installed Capacity Growth by Country (2020)²⁴⁵

The COVID-19 Pandemic and the Hydropower Industry

The COVID-19 pandemic has impacted the global hydropower industry in ways that exemplify how such crises can cause serious setbacks for the transition to non-carbon sources. In terms of short-term effects, the IHA outlined that “widespread uncertainty, currency volatility, and liquidity shortages” have put financing and refinancing for hydropower plants at major risk.²⁴⁶ Furthermore, construction of upcoming hydropower plants have been delayed due to social distancing regulations and supply chain disruptions.²⁴⁷ Several public initiatives and programs that support the hydropower sector have also been put on hold due to the redistribution

²⁴⁴ International Hydropower Association, “2021 Hydropower Status Report: Sector Trends and Insights,” 8

²⁴⁵ International Hydropower Association, “2021 Hydropower Status Report: Sector Trends and Insights,” 7

²⁴⁶ International Hydropower Association, “Strengthening Sustainable Hydropower to Support the Covid-19 Recovery,” May 28, 2020, <https://www.hydropower.org/publications/iha-position-paper-strengthening-sustainable-hydropower-to-support-the-covid-19>, 3

²⁴⁷ International Hydropower Association, “Strengthening Sustainable Hydropower to Support the Covid-19 Recovery,” 3

of government attention to immediate forms of public assistance, such as unemployment benefits, vaccine development, and more. As of now, it is too early to determine the long-term effects on the hydropower industry from the pandemic. However, it is imperative to highlight how the pandemic has made individuals realize the extent of their reliance on electricity. In the case of the United States, specifically, COVID-19 forced white collar employees to communicate through Zoom meetings, transitioned students to the online learning environment, and challenged people to find alternative ways to operate online. The pandemic has further underscored the importance of securing the electrical grid and diversifying energy resources.

The Relationship Between Hydropower and Climate Change

While hydropower is classified as a “renewable” source of energy, this label could become misleading if climate change were to have a stronger impact in the near future. For example, South and Southeast Asia credit almost 14.5% of their total electricity generation to hydropower, which is about 117 GW of total installed hydropower capacity.²⁴⁸ However, due to the “rising temperatures, extreme rainfall patterns, melting glaciers, and increasing occurrence of extreme weather events,” hydropower can become an unreliable source of energy if the effects of climate change are not sufficiently mitigated.²⁴⁹ This is imperative for South and Southeast Asian countries to address, as hydropower enables them to meet electricity demands, aids economic development, and assists in the transition to non-carbon energy sources.

Some South and Southeast Asian countries are already enduring the effects of climate change in relation to their hydropower resources. One example is Vietnam, where a series of landslides occurred due to severe rainfall in October 2020. The landslides caused the Thua Thien Hue hydropower plant to suspend its operations and killed several of its workers.²⁵⁰ Another example from India occurred in February 2021, when a glacial burst triggered a flash flood that caused the Dhauliganga Hydropower Plant to halt operations.²⁵¹

Climate change has also affected hydropower operations in Latin America. In this region, hydropower dominates as the main source of electricity generation at 45%.²⁵² In Peru, the Callahuanca hydropower plant—which was constructed in 1938—was shut down temporarily in 2017 when a series of landslides and flooding significantly damaged 95% of the total infrastructure and equipment.²⁵³ The scale of the impact caused severe blackouts where the grid was connected to the plant. While the Callahuanca plant was fixed and modernized with new generators, turbines, and control systems—eventually reopening in 2019—this does not avoid the fact that climate change imposes dire consequences if not specifically addressed. Moving forward, the United States must take these incidents seriously, especially since certain parts of

²⁴⁸ IEA, “Climate Impacts on South and Southeast Asian Hydropower,” December 2021, <https://www.iea.org/reports/climate-impacts-on-south-and-southeast-asian-hydropower>, 2

²⁴⁹ IEA, “Climate Impacts on South and Southeast Asian Hydropower,” 2

²⁵⁰ IEA, “Climate Impacts on South and Southeast Asian Hydropower,” 10

²⁵¹ IEA, “Climate Impacts on South and Southeast Asian Hydropower,” 10

²⁵² IEA, “Climate Impacts on Latin American Hydropower,” January 2021, <https://www.iea.org/reports/climate-impacts-on-latin-american-hydropower>, 2

²⁵³ IEA, “Climate Impacts on Latin American Hydropower,” 15

the country have already been impacted by climate change (i.e. megadroughts in California) that could be detrimental to the nation's hydropower supply.

Hydropower versus Nuclear Energy

Hydropower and nuclear energy are often compared to each other because of their larger presences in the non-carbon energy market. In contrast to intermittent energy sources such as solar and wind, hydropower and nuclear are baseload technologies that provide continuous power on a twenty-four hour, seven days a week basis.

One differentiating factor between both non-carbon sources is their respective lifespans. For hydropower, a typical plant—if properly maintained—can last one hundred years.²⁵⁴ For nuclear, lifespan depends on which generation of technology was used to build a plant. Most nuclear plants were built between the early 1970s and 1990s; these were licensed for forty years, but a sizable number have been, and continue to be, relicensed for up to eighty years.²⁵⁵ Reactors that use more advanced technology starting in the late 1990s are typically licensed for sixty years, but this could possibly be extended between eighty to one hundred years if current trends are to be repeated in the future.²⁵⁶ Life spans are important to consider because they allow countries to understand how much power can be generated as well as to calculate how much it would cost to replace such technology once it has expired.

Additionally, both energy sources come with significant environmental impacts. For hydropower, dams disrupt the local ecology and can negatively impact human life, while nuclear waste is toxic and its disposal has proven to be a difficult social problem due to public fear.²⁵⁷ Another element is the amount of land used for each power plant. According to research from Bloomberg, hydropower requires 296 square meters of land area, whereas nuclear power plants need 0.3 square meters to produce enough electricity to power a flat-screen television.²⁵⁸ Since hydropower plants demand large sections of land, some countries may feel restricted in terms of how much space they have and whether they can build such structures. Therefore, countries may resort to nuclear power plants if they are limited in space.

Another factor to consider is reliability. Due to evidence concerning how climate change can affect the supply of hydropower, countries may feel more comfortable using nuclear energy since weather and climate do not factor into their electricity generation. Moreover, another difference between both non-carbon sources is the consideration of geographic conditions.

²⁵⁴ “Hydropower: Setting a Course for Our Energy Future,” *Hydropower: Setting a Course for Our Energy Future* (Washington, DC, 2004), <https://www.nrel.gov/docs/fy04osti/34916.pdf>

²⁵⁵ Office of Nuclear Energy, “What's the Lifespan for a Nuclear Reactor? Much Longer Than You Might Think,” Energy.gov, April 16, 2020, <https://www.energy.gov/ne/articles/whats-lifespan-nuclear-reactor-much-longer-you-might-think>

²⁵⁶ “Advanced Nuclear Power Reactors,” World Nuclear Association, April 2021, <https://world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/advanced-nuclear-power-reactors.aspx#:~:text=It%20is%20designed%20for%2060%20year%20life%20and%2090%25%20capacity%20factor>

²⁵⁷ Michael Wolfe, “The Comparison Between Hydropower & Nuclear Energy,” Bizfluent, September 26, 2017, <https://bizfluent.com/about-6160410-comparison-between-hydropower-nuclear-energy.html>

²⁵⁸ Dave Merrill, “The U.S. Will Need a Lot of Land for a Zero-Carbon Economy,” Bloomberg.com (Bloomberg, June 3, 2021), <https://www.bloomberg.com/graphics/2021-energy-land-use-economy/>

Regarding hydropower plants, they require specific topographic settings. For example, PSH plants need both an upper and lower reservoir, which imposes difficulty for countries that do not satisfy those geographical requirements. Another geographical element is weather and climate patterns. Hydropower plants would not be successful in deserts or semi-arid regions. In contrast, there is more flexibility for nuclear power plants, as they can be constructed in more spaces without regard to physical locations.

These differences are not to say that hydropower is a better option than nuclear energy or vice versa. Rather, as countries accelerate their plans to decarbonize their electrical grids, they must take all of these factors into consideration and employ such a source wherever they feel is the most appropriate in terms of energy security and prosperity.

Aging Hydropower Plants

Countries must prioritize the maintenance of aging hydropower plants to avoid disruptions in their power supplies and progress toward decarbonization. In terms of global comparison, around 40% of all hydropower plants worldwide—which is 476 GW of power—are at least forty years old.²⁵⁹ This is a result of the widespread hydropower construction wave that occurred between the 1960s and 1980s in many advanced countries. Regionally speaking, about 70% of hydropower plants in North America are forty years old or older.²⁶⁰ When hydropower facilities reach between forty-five and sixty years of their lifespan, countries must consider implementing upgrades to improve electricity generation and increase flexibility. According to the IEA, through the modernization process, upgraded hydropower plants have the ability to increase their output by 5 to 10%.

An integral part of the modernization process is the digitalization of hydropower facilities. According to a study conducted by Accenture, improved systems of forecasting and data analytics can enable hydropower plant operators to maximize power production and profitability due to reduced costs in material, labor, and maintenance.²⁶¹ Forecasting includes external factors (e.g. weather and water inflows), internal factors (e.g. reservoir levels), and market conditions (e.g. price, demand, and supply). Regarding data analytics, hydropower facility operators can examine past trends of weather and market conditions to determine the best time periods and methods of optimized electricity production. As hydropower plants undergo digitization, it is imperative for operators to be aware of the new challenges and concerns that arise with the integration of technology, such as data privacy, critical infrastructure protection, and information security compliance. Therefore, operators must establish designated timelines to review and audit their upgraded systems.

Concluding Statement

²⁵⁹ IEA, “Hydropower”

²⁶⁰ IEA, “Hydropower”

²⁶¹ Maria Agostini et al., “Hydro's Digital Generation: Transforming the Future of Hydropower” (Accenture, 2020), https://www.accenture.com/_acnmedia/PDF-121/Accenture-Hydro-Digital-Generation-USLdig.pdf, 7

While hydropower presents a variety of options as well as its benefits and drawbacks, expediting the growth of the hydropower sector is a crucial component in promoting energy security, increasing job opportunity, and decarbonizing the world's electrical grids. As countries begin and further their construction plans, they must consider both the environmental and social implications that come with hydropower plants, especially the presence of dams. Furthermore, it is important to upgrade existing hydropower plants in accordance with modern environmental and technological standards so that current supplies of hydropower are not disrupted by preventable measures.

2.4 Future Technologies

Hydrogen and Fuel Cells

Although not quite as mainstream as other non-carbon sources, countries should consider investing time and resources into hydrogen. Hydrogen is proven to be very beneficial in providing electricity; it is versatile and represents another means toward diversifying the world's energy portfolio.

Hydrogen fuel can be produced via four different methods. First, it can be created through a thermal process called steam reforming. This refers to high-temperature steam reacting with a hydrocarbon fuel to create hydrogen. Common hydrocarbons include “natural gas, diesel, renewable liquid fuels, gasified coal, and gasified biomass.”²⁶² In the United States, 95% of all hydrogen sources are produced through steam reforming with natural gas.²⁶³ The second way hydrogen fuel is produced is through the electrolytic process, which refers to the physical separation of hydrogen and oxygen atoms in an electrolyzer.²⁶⁴ The third method consists of solar-driven processes, which come in three different forms: photobiological, photoelectrochemical, and solar thermochemical. Photobiological processes utilize the natural photosynthetic activity of bacteria and green algae to produce hydrogen. Photoelectrochemical activity happens when specific semiconductors separate water into hydrogen and oxygen atoms. Solar thermochemical optimizes concentrated solar power to force the separation of water molecules, even with other materials like metal oxides.²⁶⁵ The last method related to hydrogen fuel production occurs through biological processes with the use of microbes such as bacteria and microalgae.²⁶⁶

Steam reforming has gained traction worldwide for electricity generation as it serves as an alternative way to source power through non-carbon technology. Hydrogen power is especially favorable within the trucking industry, as its refueling time and driving range are just

²⁶² Hydrogen and Fuel Cell Technologies Office, “Hydrogen Fuel Basics,” Energy.gov, accessed February 5, 2022, <https://www.energy.gov/eere/fuelcells/hydrogen-fuel-basics>

²⁶³ Hydrogen and Fuel Cell Technologies Office, “Hydrogen Fuel Basics”

²⁶⁴ Hydrogen and Fuel Cell Technologies Office, “Hydrogen Fuel Basics”

²⁶⁵ Hydrogen and Fuel Cell Technologies Office, “Hydrogen Fuel Basics”

²⁶⁶ Hydrogen and Fuel Cell Technologies Office, “Hydrogen Fuel Basics”

as strong and reliable as gasoline.²⁶⁷ Replacing lithium batteries and diesel fuel with hydrogen fuel has the potential to significantly eliminate annual greenhouse gas emissions. Since heavy-duty transportation vehicles make up 23% of total transportation emissions, this shift can have a significant impact on both the industry and the environment.²⁶⁸

Along with transportation, hydrogen is also used in many industrial processes. This includes refining petroleum and producing fertilizers.²⁶⁹ Hydrogen fuel has also been experimented in the realm of space exploration. Since the 1950s, NASA has utilized liquid hydrogen as rocket fuel. From these examples, it is evident that hydrogen is a versatile energy source that can be beneficial to decarbonizing the electrical grid and diversifying energy options.

Hydrogen has grown globally. As of October 2021, seventeen governments have released hydrogen strategies and more than twenty governments have publicly stated their intentions to develop similar strategies.²⁷⁰ Besides utilizing fossil fuels like natural gas, countries are also continuing to research and find ways to produce fuel from alternative sources. For example, Europe is leading the way in electrolyser capacity deployment, which equates to about 40% of total global installed capacity. The IEA also suggests that Australia's progress can catch up to Europe's within a few years.²⁷¹

In terms of regional consumption, the United States accounts for 13% of global hydrogen demand. Two-thirds of it is used in the country's refining sector and the rest is used for ammonia production. The United States has been a long supporter of including hydrogen in its energy portfolio. Throughout the past few years, the country has launched initiatives, such as the H₂@Scale (2016), DOE Hydrogen Program Plan (2020), and the Hydrogen Energy Earthshot (2021) to further scale its hydrogen output.²⁷²

The Relationship Between Hydrogen and Fuel Cells

Fuel cells derive chemical energy from hydrogen and other fuels to produce electricity. Simply put, the function of fuel cells is similar to batteries: they both produce electricity and heat as long as fuel is supplied.²⁷³ Investing in and maximizing the use of fuel cells will be critical in meeting goals of NZE 2050 because of their versatility. Their capabilities range from powering industrial buildings to supplying energy for everyday devices, such as a laptop. Fuel cells are highly favorable because they are able to convert chemical energy in the fuel into electrical

²⁶⁷ David A Cullen and Karren L More, "Heavy-Duty Vehicles an Ideal Entry into Hydrogen Fuel Cell Use," Oak Ridge National Laboratory, April 23, 2021,

<https://www.ornl.gov/news/heavy-duty-vehicles-ideal-entry-hydrogen-fuel-cell-use>

²⁶⁸ Cullen and More, "Heavy-Duty Vehicles an Ideal Entry into Hydrogen Fuel Cell Use"

²⁶⁹ U.S. Energy Information Administration, "Hydrogen Explained," eia.gov, January 20, 2022,

<https://www.eia.gov/energyexplained/hydrogen/use-of-hydrogen.php#:~:text=Hydrogen%20fuel%20cells%20produce%20electricity%20by%20combining%20hydrogen%20and%20oxygen,a%20wide%20range%20of%20application>

²⁷⁰ IEA. Rep. *Global Hydrogen Review 2021*, October 2021.

<https://www.iea.org/reports/global-hydrogen-review-2021>, 5

²⁷¹ IEA, "Global Hydrogen Review 2021," 5

²⁷² IEA, "Global Hydrogen Review 2021," 176

²⁷³ Hydrogen and Fuel Cell Technologies Office, "Fuel Cells," Energy.gov, accessed February 23, 2022,

<https://www.energy.gov/eere/fuelcells/fuel-cells>

energy with an efficiency of 60% or more.²⁷⁴ Furthermore, the only emission component of fuel cells is water, thus making fuel cells appealing because they do not emit as much greenhouse gas emissions compared to other energy sources.

The relevancy of fuel cells can be demonstrated in the transportation sector. Since 2008, the cost of automotive fuel cells has fallen by almost 70% due to the technological advancements and increasing sales of fuel cell electric vehicles (FCEV). Countries like South Korea, the United States, China, and Japan have been leading this effort, selling over 43,000 vehicles since mid-2021.²⁷⁵

Nuclear Fusion

Nuclear fusion technology has been widely researched since the 1970s. Fusion powers the sun and other stars, which as hydrogen atoms fuse to form helium, with some of the original matter being converted into energy. Normally, fusion is not possible, as extreme temperatures of around 50 million °C are required for nuclei to collide. However, scientists have found that increasing temperature causes ions to move faster, eventually reaching speeds high enough to bring close enough together that they create energy.²⁷⁶ Nuclear fusion generates four times as much energy as conventional nuclear fission reactors. In addition, fusion reactors create less toxic radioactive materials, thus, fusion reactors are the future of nuclear energy.

A challenge that fusion reactors are currently facing is related to economics. The energy density of fusion reactions in gas is much less than for fission reactions in solid fuel, and the heat yield per reaction is seventy times lower. Therefore, thermonuclear fusion will always have a much lower power density than nuclear fission, which means reactors need to be larger and more costly than a nuclear fission reactor of the same power output.²⁷⁷

As of today, there is no commercialized fusion reactor, yet there is much new activity and investment in experimental programs, both on a national and international level. International Thermonuclear Experimental Reactor (ITER) is the largest international nuclear fusion research and engineering project in the world, with thirty-five nations collaborating. The DEMONstration Power Plant known as Demo, is expected to demonstrate large-scale production of electrical power on a continual basis. The first phase of operation is expected to begin after 2040. This year, scientists in the United Kingdom announced new milestones. A team at the Joint European Torus (JET) facility generated 55921 Btu (59 megajoules) of sustained energy during an experiment in December 2021.²⁷⁸ A challenge for nuclear fusion is the magnetic field of a fusion device which encloses the hot plasma and keeps it away from the vessel walls to avoid inefficient

²⁷⁴ Hydrogen and Fuel Cell Technologies Office, “Fuel Cells”

²⁷⁵ IEA, “Global Hydrogen Review 2021,” 6

²⁷⁶ “Fission vs. Fusion – What's the Difference?” Nuclear Information Center. Duke Energy, January 30, 2013. <https://nuclear.duke-energy.com/2021/05/27/fission-vs-fusion-whats-the-difference-6843001>

²⁷⁷ “Nuclear Fusion Power.” World Nuclear Association. WNA, August 2021.

<https://www.world-nuclear.org/information-library/current-and-future-generation/nuclear-fusion-power.aspx>

²⁷⁸ Koshy, Jacob. “Scientists Set New Record in Creating Energy from Nuclear Fusion.” The Hindu. The Hindu, February 10, 2022.

<https://www.thehindu.com/sci-tech/science/scientists-in-britain-smash-fusion-energy-record/article38403008.ece>

energy losses from plasma particles drifting outward. The German stellarator Wendelstein 7-X proved its confinement efficiency, as the twisted magnetic coils of the device successfully controlled plasma energy loss, which indicated that stellarator fusion devices could be suitable for commercial power plants.²⁷⁹ In addition, the DOE used a powerful laser to heat and compress hydrogen fuel and initiate a fusion reaction. The experiment produced 1280 Btu (1.35 megajoules) of energy and was a huge step forward for the fusion community. The research of fusion reactors will continue to grow, and scientists have the ambition to build commercial nuclear fusion reactors by 2030.

Electricity Storage

Electric storage plays an important role in balancing supply (electricity generation) and demand (consumer use).²⁸⁰ Although supply is relatively fixed over short periods of time, demand varies daily. Developing the technology is necessary for electricity storage to meet the gap between supply—specifically secure supply—and demand. Electricity storage devices can make intermittent renewable energy supplies (e.g. from solar and wind) more stable and reliable.²⁸¹ As renewable energy becomes more prevalent in the world, electric storage technology will become more central to the discussion of stable supplies of electricity. Also, electric storage may provide economic reliability and environmental benefits in some cases, such as helping the utility grid work more efficiently, provide sufficient amounts of electricity during peak demand periods, and encourage the use of more renewable resources.

Types of electricity storage include pumped hydroelectric, compressed air, flywheels, batteries, and thermal energy storage.²⁸² Pumped hydroelectric stores energy in the form of water in an upper reservoir. In periods of high electricity demand, power is generated by releasing the water through turbines. On the other hand, when there is low demand—such during nights or weekends—the upper reservoir is recharged by pumping water from the lower reservoir back to the upper reservoir.²⁸³ Compressed air uses air to store electricity. When demand is high, the pressurized air is released to generate electricity through an expansion turbine generator. A flywheel is a type of rotor, and electricity is used to increase the speed of the flywheel. Just as they are used in day-to-day life, large batteries can store large amounts of electricity.²⁸⁴ Lithium ion, lead acid, lithium iron, or other battery technologies can be used. In thermal energy storage, electricity is used to produce thermal energy, which can be stored until needed. In addition to these electricity storage technologies, new ones are now being developed, including flow batteries, supercapacitors, and superconducting magnetic energy storage.²⁸⁵

²⁷⁹ Radel, Ross. “Germany’s Wendelstein 7-X Stellarator Proves Its Confinement Efficiency.” Nuclear News Wire. American Nuclear Society, August 17, 2021.

<https://www.ans.org/news/article-3166/germanys-wendelstein-7x-stellarator-proves-its-confinement-efficiency/>

²⁸⁰ U.S. EPA, “Electricity Storage,” <https://www.epa.gov/energy/electricity-storage#about>

²⁸¹ Office of Electricity, “Energy Storage,” <https://www.energy.gov/oe/energy-storage>

²⁸² U.S. EPA, “Electricity Storage”

²⁸³ ESA, “Pumped Hydropower,” <https://energystorage.org/why-energy-storage/technologies/pumped-hydropower/>

²⁸⁴ U.S. EPA, “Electricity Storage”

²⁸⁵ U.S. EPA, “Electricity Storage”

The DOE announced that electricity storage capacity was approximately 25 gigawatts, with 94% of the total being pumped by hydroelectric storage and 6% by other types of energy storage such as batteries, thermal energy storage, compressed air, and flywheels.²⁸⁶ This amount is expected to grow on the pathway to NZE 2050 as renewable energy becomes a major source of energy.

Chapter 3: Possibilities for Direct Carbon Mitigation

Chapter 3.1: Carbon Capture Utilization and Storage

Introduction

CCS is a technology that directly removes carbon from the atmosphere and transports it via ship, road, or pipeline to an underground storage facility. An alternate approach, CCUS, allows for captured carbon to be reused in industrial processes such as fertilizer, food, and biofuel production.²⁸⁷

The need for carbon capture technology became prominent in the light of the Paris Agreement's goals to limit future temperature increase to 1.5 °C. Accounting for over 200 million tons of CO₂ captured and injected underground to date, the CCS industry is among the most feasible instruments included in the nationally determined contributions (NDCs) of many countries. Governments and the private sector are displaying their interest in the technology and providing their support via research and development (R&D). From 2020 to 2021 alone, the capacity of CCS facilities grew 32%, cumulatively with those in development by 48%.²⁸⁸

In response to growing climate pressures and continued dependence on carbon sources, CCS offers a timely solution to reducing CO₂ emissions, potentially on a major scale. First, the rate of switching to alternative non-carbon energy sources is not nearly enough to fully replace them. Second, growing economies have shown that they will continue using whatever energy sources they domestically possess (which are predominantly fossil fuels), to satisfy both demands for economic development and energy security. Last, the recent pandemic demonstrated a deeper carbon dependence that might grow even larger given the tendency to rely on natural gas and coal during emergencies. This point was confirmed by the energy crisis in Europe during the fall and winter of 2021 and 2022, when a shortage of natural gas and wind power led to a greater use of coal.²⁸⁹ Carbon dependency will not disappear in the near future and, at varying levels among different nations, will continue for decades. CCS/CCUS is therefore recognized as a potentially necessary and effective tool for mitigating carbon emissions.

²⁸⁶ U.S. EPA, "Electricity Storage"

²⁸⁷ IEA, "About CCUS," (2021), assessed February 10, 2022, <https://www.iea.org/reports/about-ccus>

²⁸⁸ Turan et al., "Global Status of CCS 2021," (2021): 10, accessed February 10, 2022, <https://www.globalccsinstitute.com/wp-content/uploads/2021/10/2021-Global-Status-of-CCS-Global-CCS-Institute-Oct-21.pdf>

²⁸⁹ Wald, *The EU Contributed to Its Own Energy Crisis, but Diversification Can Solve It*, Atlantic Council (2021), accessed February 20, 2022, <https://www.atlanticcouncil.org/blogs/energysource/the-eu-contributed-to-its-own-energy-crisis-but-diversification-can-solve-it/>.

In addition, certain industries that rely heavily on fossil fuel energy and are emissions intensive such as chemicals, iron and steel, and cement—will remain challenging to the non-carbon energy transition.²⁹⁰ These industries will therefore benefit greatly from CCS/CCUS technologies, whether for an intermediate period or in the long run. With CCS in place, jobs connected with these hard-to-abate industries could be preserved, minimizing political risks, and new jobs within CCS/CCUS technologies as a growing field will emerge.²⁹¹ Thus, decarbonizing the industry sector within its realistic measures is only possible with CCS technologies in place.

Science: CCS/CCUS Technology

As demonstrated in Figure 3.1.1, the standardized CCUS procedure includes four steps:

1. **Capture:** CO₂ is separated from other gasses produced in industrial processes, such as those at coal and natural gas-fired power generation plants or steel or cement factories. The most advanced and widely adopted capture technologies are chemical absorption, adsorption, and physical separation; other technologies include membrane separation, chemical looping, hydrating, and biofixation.²⁹² Post-combustion capture using amines is among the most prominent commercialized CCUS technology.²⁹³

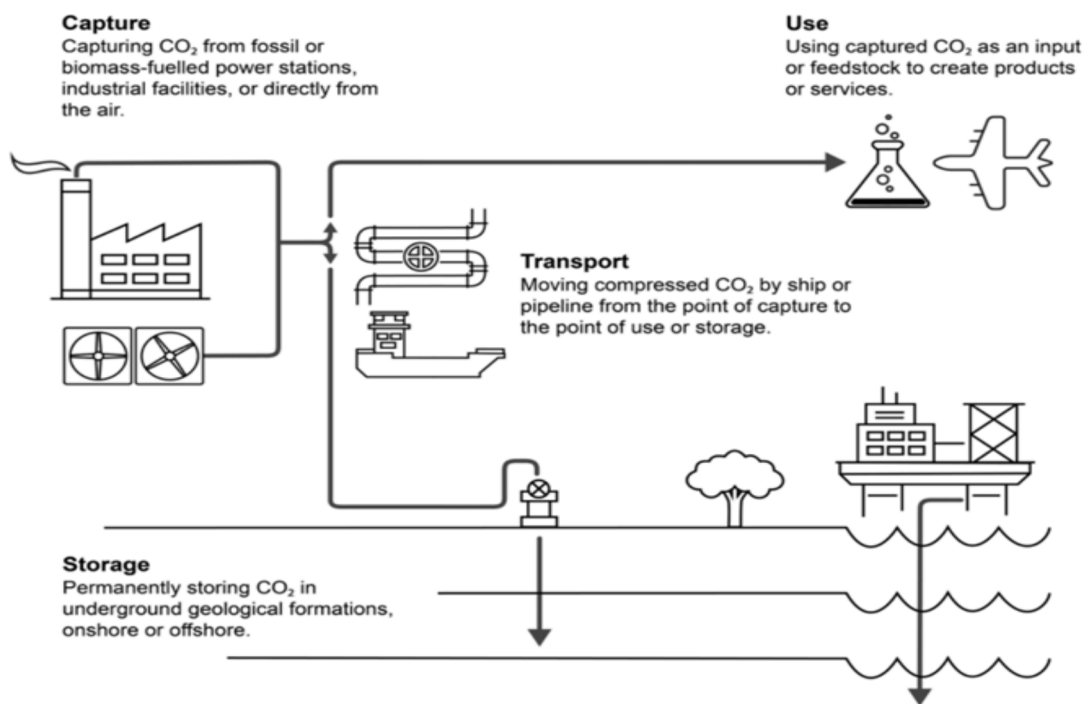


Figure 3.1.1 Standard CCUS procedure (IEA²⁹⁴)

²⁹⁰ Gül et al., “Energy Technology Perspectives 2020,” (2020): 22, accessed February 11, 2022, https://iea.blob.core.windows.net/assets/181b48b4-323f-454d-96fb-0bb1889d96a9/CCUS_in_clean_energy_transitions.pdf

²⁹¹ Turan et al., “Global Status of CCS 2021,” 10.

²⁹² “About CCUS.”

²⁹³ Rahimpour, Farsi, and Makarem, *Advances in Carbon Capture*, 37.

²⁹⁴ “About CCUS.”

2. **Transport:** CO₂ is then compressed and transported to a site for storage. The two main options for the large-scale transport of CO₂ are via pipeline (the cheapest way) and ship (more expensive but also more flexible), although for short distances and small volumes of CO₂, it can also be transported by truck or rail (at higher cost per ton of CO₂).²⁹⁵
3. **Usage (this stage is only considered in CCUS technologies):** this stage provides a profitable alternative to producing chemicals and fuels while mitigating climate change.²⁹⁶ CO₂ is used as an input to a range of products and services and can be used directly (non-conversion: where CO₂ is not chemically altered) or through the transformation of CO₂ to a useful product (conversion: through chemical and biological processes) as displayed in Figure 3.1.2. Methanol production using CO₂ and hydrogen is one of the most successful applications that involve conversion—not only because the conversion rate is relatively high (>60%), but also because methanol usage to generate power is a potential future for use of CO₂ flue gas emissions. Methanol can be directly blended in fuel, while Methyl tertbutyl ether can be used for biodiesel production. CO₂ can also be used directly in transcritical and supercritical processes, enhanced oil recovery, and even in the medical field.²⁹⁷

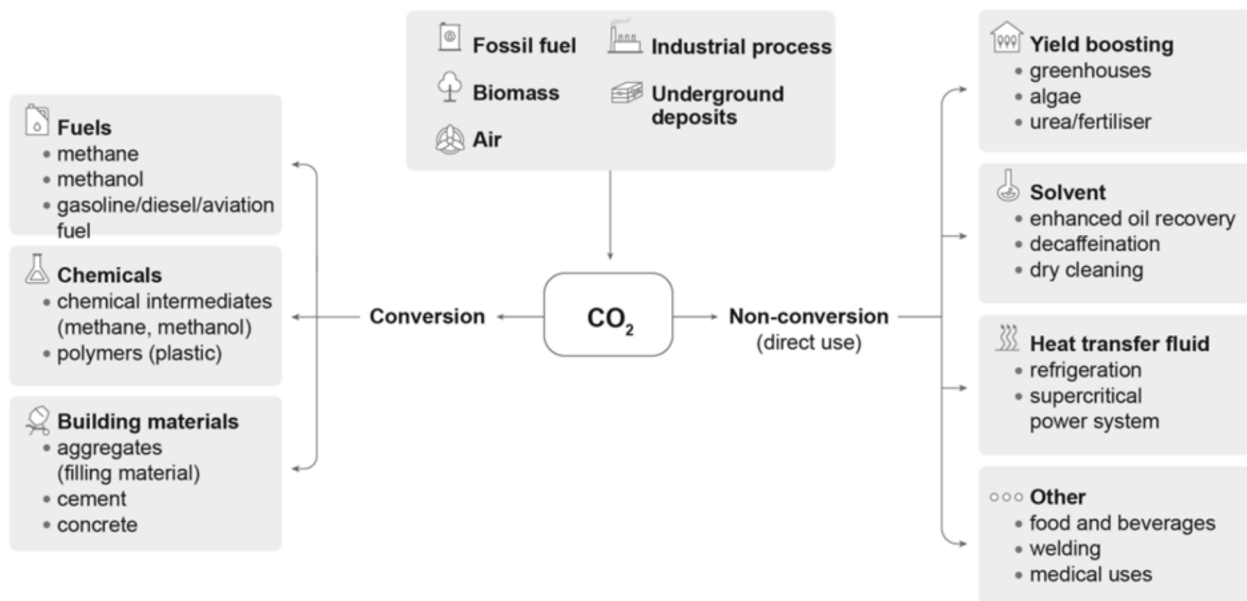


Figure 3.1.2. Classification of pathways for CO₂ use (IEA²⁹⁸)

4. **Storage:** involves the injection of captured CO₂ into a deep underground geological reservoir of porous rock that is at least 800 meters deep and sealed by impermeable rock

²⁹⁵ “About CCUS.”

²⁹⁶ Rahimpour et al., *Advances in Carbon Capture*, 32.

²⁹⁷ IEA. “Putting CO₂ to Use.”(2019): 6, accessed February 12, 2022,

https://iea.blob.core.windows.net/assets/50652405-26db-4c41-82dc-c23657893059/Putting_CO2_to_Use.pdf;

Rahimpour et al., *Advances in Carbon Capture*, 33.

²⁹⁸ “About CCUS.”

layers (e.g. shale) above and below.²⁹⁹ The CO₂ could be stored in several types of reservoirs. The most common are deep saline formations and depleted oil and gas reservoirs, both having a porous structure and high trapping capacity. The process of storage involves injecting CO₂ into the reservoir in a compressed state. Depending on geologic conditions, the CO₂ will remain entrapped in the reservoir by a combination of the mentioned seals, as well as chemical processes like dissolving in brine and formation of carbonate minerals.³⁰⁰ Research is also ongoing on the potential for using porous or fractured basalt as storage reservoirs.³⁰¹ Overall, global CO₂ storage resources are plentiful. In a review by the Global CCS Institute on sedimentary basins, two important observations were made:

- 1) Suitable basins with storage reservoirs exist in nations that are generally near emission-intensive regions. Parts of Europe, the United States, the Middle East, Russia, and some areas in Southeast Asia fit this category.
- 2) More work on basin assessment is needed. It will ensure a larger storage potential and suitable ranking to enable the full-scale deployments of CCS.³⁰²

Current/Future Global State and Partnerships

Figure 3.1.3 depicts globally **existing CCS/CCUS facilities** that capture **36.6 megatons (Mt) CO₂** annually in industry and fuel transformation. The most prominent examples include:



Figure 3.1.3 World map of CCS facilities at different stages of development.³⁰³

²⁹⁹ “About CCUS.”

³⁰⁰ Turan et al., “Global Status of CCS 2021,” 70.

³⁰¹ “About CCUS.”

³⁰² Turan et al., “Global Status of CCS 2021,” 70.

³⁰³ Turan et al., 12.

- The Gorgon CCS project in Australia launched in 2019 by Chevron (capacity to capture up to 4 Mt CO₂ per year from natural gas processing).³⁰⁴
- Qatar launched a 2 Mt CO₂ per year capture facility in 2019.
- The CNPC Jilin Oil Field started commercial operations in China in 2018 (capturing up to 0.6Mt CO₂ per year from a natural gas processing plant). In 2021, China also began its offshore project developments.³⁰⁵

With climate goals in mind, various new projects began their **development** globally:

- China: the Sinopec Qilu Petrochemical project (projected to capture up to 1Mt of CO₂) is currently under construction.
- Norway: Norcem’s Brevik plant, the world’s first application of CCUS at a cement facility, is beginning construction.
- The Equinor, Shell, and Total partnership is developing the Northern Lights project, which will provide CO₂ transport and storage for multiple industrial hubs located around the North Sea.
- **In the United States** alone, over fifty carbon capture projects have been announced between January 2020 and August 2021, which have the potential to double global industrial CCUS capacity.³⁰⁶

These are only a few examples of both developed and developing projects that together estimate to capture **149.3 Mt CO₂**, as demonstrated in Table 3.2.4:

	Operational	In construction	Advanced Development	Early Development	Operation Suspended	Total
Number of facilities	27	4	58	44	2	135
Capture capacity (Mtpa)	36.6	3.1	46.7	60.9	2.1	149.3

Table 3.2.4 Commercial CCS facilities in September 2021 by number and total capacity³⁰⁷

CCS projects become more diverse, both in size and the areas of industries they cover. Size-wise, and on par with individual larger capture plants, networks like the United States’ Summit Carbon Solutions are **making smaller capture viable**. In the past, small capacity facilities would be difficult to justify, but with the creation of solid networks, CCS has expanded its possibilities. For example, it has allowed the expansion of the Norcem Brevik project (part of the Langskip network) into a new sector—cement manufacturing. As a significant global emitter with limited decarbonization options, the cement sector’s use of CCS is an indispensable step toward net zero.³⁰⁸ Network development allows for shared transportation that the Porthos

³⁰⁴ Turan et al., 32.

³⁰⁵ Fajardy, “CCUS in Industry and Transformation,” (2021), accessed February 12, 2022, [CCUS in Industry and Transformation – Analysis - IEA](#)

³⁰⁶ Fajardy, “CCUS in Industry and Transformation.”

³⁰⁷ Turan et al., “Global Status of CCS 2021,” 14.

³⁰⁸ Turan et al., 15–16.

network in Rotterdam demonstrated through the shared pipeline for its four new blue hydrogen projects: Air Products, Air Liquide, ExxonMobile, and Shell. Due to emerging networks trends, various partnerships have developed between oil and gas companies, technology, shipping, electricity generators and distributors, and financial service providers:

- ExxonMobil Low Carbon Solutions (ELCS) was established in 2021 to commercialize CCS technologies and develop new CCS projects. The plans for 20 new CCS developments were announced with a \$3 billion budget to invest by 2025.
- Siemens and Aker Carbon Capture have partnered to develop CCS technology to capture CO₂ from gas turbines and gas powered generation.
- G2, NETPower, Siemens, and EJM are working together to capture CO₂ at a liquefied natural gas plant in the United States.
- LaFargeHolcim and Schlumberger have partnered to develop capture plants at cement facilities in Europe and the United States.
- Italian oil major ENI is also moving into CCS in a big way. Its Ravenna Hub in Italy is set to use depleted natural gas fields for CO₂ storage.
- In 2021, Shell expanded its activities in CCS when it became a founding partner of the Porthos network blue hydrogen project feeding CO₂ to a shared CO₂ infrastructure.
- BP continues to develop CCS projects under its leadership of the United Kingdom's Net Zero Teesside network, along with partners ENI, Equinor, Shell, and Total.
- The Greensand project brought together Ineos, Maersk Drilling, and Wintershall DEA to develop a CCS network in Denmark with storage in the North Sea.
- Valero, Black Rock, and Navigator partnered to develop a CO₂ pipeline project in the U.S. Midwest to transport CO₂ from bioethanol plants.³⁰⁹

All these (and many more) CCS partnerships demonstrate the importance of networks and cooperation that allow for a reduction in CO₂ emissions and financial costs from transportation and storage. These partnerships will also work toward **minimizing the risk for investment** in CCS technologies for emerging economies. At the moment, funding gaps make it almost impossible for developing countries to finance CCS technologies on the same level that developed countries do. Developing and transitioning economies are considered high risk investment areas and will benefit from network cooperation.

U.S. Financial Tangibility

As demonstrated earlier in Figure 3.2.3, over half of existing CCS/CCUS facilities are located and projected to be built in the United States. Among the most successful existing facilities is Shute Creek, Wyoming (which has captured more than 110 Mt CO₂ since 1986), the Great Plains Synfuel Plant (with over 40 million tons of CO₂ captured and stored), and the Terrell Natural Gas Processing Plant (20 million tons), and the Enid Fertilizer Plant (11 million

³⁰⁹ Turan et al., 18.

tons).³¹⁰ The projects in development within the United States are estimated to quadruple the global capture capacity. This places the United States on the leaderboard with both trendsetting powers and global responsibilities.

In the United States, the largest variety of CCS technologies are setting up a global agenda:

- Relatively low CO₂ capture costs from bioethanol production and the opportunity to access California LCFS via the production of low carbon ethanol has enabled the proposed development of two large-scale CCS network projects in the U.S. Midwest: 1) **Summit Carbon Solutions** announced a project that would link more than thirty biorefineries with a total CO₂ capture of about 8 metric tons per annum (Mtpa). This project would potentially be both the largest CCS network and the largest bioenergy with CCS (BECCS) project in the world. 2) **Navigator CO₂ Ventures**, in collaboration with **Valero and BlackRock**, has proposed a CCS network spanning more than 1,200 miles across five states in the U.S. Midwest. The Heartland Greenway Pipeline would transport CO₂ from biorefineries and other industrial facilities in Iowa, Illinois, Nebraska, Minnesota, and South Dakota to a geological storage site in Illinois with a capacity of up to 5 Mtpa.
- Industrial emissions range between 20 to 30% in the iron and steel industry and 14 to 33% in the cement industry. As demand for carbon capture has begun to grow, especially in these **hard-to-abate sectors**, several proactive projects were announced for CCS implementation. This demonstrates that the behavior of buyers has changed notably with consideration to the carbon footprint of products and services and their supply chains.
- **Large-scale, low-carbon fuel projects** also emerged as a market approach with the announced integration of CCS into planned LNG projects.
- Technologies that **capture CO₂ directly from flue gas streams** using solid adsorbents received support from the public and private investments. Two at-scale projects in the United States utilizing pre-combustion CCS technology have been announced.
- CCS technologies capable of delivering negative emissions, including both direct air capture (DACCS) and BECCS were supported by **corporate net zero pledges** from a broad set of industries, including major technology and online retail. Investments by technology companies in carbon removal technologies are an example of this trend.³¹¹

The growing trend in CCS development in the United States resulted from many enabling factors. Being the cradle country of CCS technologies (begun in Texas in 1972) and recently returning to the Paris Agreement, CCS in the United States has received enhanced government climate change attention, finalizing tax regulations and increasing investments,

- The DOE also emphasized the importance of CCS as part of its transition to a hydrogen economy in its hydrogen strategy.³¹²

³¹⁰ Turan et al., 27.

³¹¹ Turan et al., 26–30.

³¹² Lawson, “Carbon Capture Versus Direct Air Capture,” (2021), accessed February 18, 2022, 5 (congress.gov); “Hydrogen Strategy. Enabling A Low-Carbon Economy,” (2020): 6, accessed February 13, 2022, [USDOE FE Hydrogen Strategy July2020.pdf \(energy.gov\)](#)

- Most significantly, in December 2020 the U.S. Energy Act of 2020 was passed, with a \$6 billion budget for CCS R&D projects within the DOE and the Environmental Protection Agency (EPA):
 - Six commercial-scale demonstrations (natural gas, coal, industrial) at \$2.6 billion
 - Large-scale pilot projects for DOE R&D at \$910 million
 - Large-scale carbon storage and validation program at \$800 million
 - Front end engineering and design (FEED) studies at \$200 million
 - Other activities at \$1 billion
- 45Q tax credits were finalized:
 - Clarifications about geological storage certification: geological storage credit values were significantly raised;
 - Aggregation of multiple projects: network promotion;
 - Reduction of the lookback period or credit reclaim;
 - A broader definition of carbon utilization, including providing a direct pay option;
 - Providing an extension for construction deadline (to ten years);
 - Allowing for credit to more easily offset tax obligations for multinational corporations.
- Other changes include:
 - Financing CO₂ infrastructure and storage and funding to permit these projects;
 - Modifications to existing 48A tax credits for CCS equipment on coal-fired power plant redevelopments;
 - Enabling the use of a tax-advantaged, master limited partnership structure;
 - Purchase of tax-exempt private activity bonds to finance CCS modernization.³¹³

CCS/CCUS Limitations and Opportunities

When looking at challenges facing the development of CO₂ capture and utilization, it is important to compare the general effects of CCS technologies in relation to the existing world carbon economy. Given its effectiveness and rising potential, the CCS industry is on the rise. The expectation defined by the IEA is that these technologies will take care of 15% of the world's emissions reductions between now and 2050. This equates to 2,000 large-scale facilities being deployed by 2050—around 100 facilities commissioned each year.³¹⁴ The largest challenge here is the capital requirement. Around \$1,300 billion is needed, which means unprecedented levels of financing will have to fall on both the governmental and private sectors.³¹⁵ Small-scale facilities will require not only financial support, but larger networking, allowing for risk and cost reduction in the long run. This is especially important for developing economies, where the risk of investment is high and the possibilities for curbing emissions are limited.

³¹³ Turan et al., “Global Status of CCS 2021,” 27.

³¹⁴ “Carbon Capture and Storage: Challenges, Enablers and Opportunities for Deployment,” (2020), accessed February 13, 2022, [Carbon capture and storage: Challenges, enablers and opportunities for deployment - Global CCS Institute](#)

³¹⁵ Turan et al., “Global Status of CCS 2021,” 50.

Apart from commercial challenges, there are concerns about the safety of CCS technologies:

1. **Capture:** the key is to minimize the consumed energy of the separation. In the process of CO₂ desorption from a solvent, the amount of energy used largely depends on the chemical composition of the solvent and the type of energy used. Ongoing research is working to optimize these factors to make sure that their processing “fees” do not overshadow their benefits. Other challenges that should be addressed include capital expenditure, CO₂ uptake limits, the life cycle of solvent, disposal, and environmental effects.³¹⁶
2. **Utilization:** integration of materials, processes, delivery, and transformation. The caveat is that this phase cannot replace the CO₂ storage stage in delivering significant emissions reductions. This is because use opportunities have a smaller scale and a limited scope for negative emissions. They are still very young technologies and require further R&D and market development. In producing fuels, the conversion is still energy-intensive and therefore less attractive. Using CO₂ for fuel production in many cases only delays its emissions rather than removing them. Similar to the capture stage, more R&D is needed for solvent improvement and infrastructure development.³¹⁷
3. **Storage:** the criticism of the potential storage leakage was disputed by both Global CCS Institute and IEA reports.³¹⁸ The largest limitation in storage is its uneven distribution throughout the globe. Network formation and carbon markets can incentivize developing CCS projects globally.³¹⁹

Concluding Statement

CCS trends are on the rise and projected to grow steadily into the future with unchanging industry emissions and global carbon dependency. There are no reasons to dismiss the need for carbon or the technologies that could assist with bringing them down until the world is ready for a transition to a NZE future. However, CCS and CCUS technologies would most likely not be a sole solution to resolving emissions problems. IEA projections for 2030 amount to 1149 Mt CO₂ to achieve NZE, whereas carbon capture projects—both existing and developing—will only reach 81 Mt CO₂ by 2030.³²⁰ As Pacala and Socolow first acknowledged in 2004, CCS should be used in combination with other mitigation options in order to achieve significant emission reductions.³²¹ Removing CCS from the list of potential solutions will complicate, prolong, and significantly raise the cost of cutting emissions. It goes without saying, being a comparatively young technology, that CCS would require multilevel support from world governments and the private sector in the shape of: financial support: between \$655 billion and \$1,280 billion;

³¹⁶ Rahimpour, Farsi, and Makarem, *Advances in Carbon Capture*, 42–43.

³¹⁷ Rahimpour, Farsi, and Makarem, 37.

³¹⁸ “Carbon Capture and Storage: Challenges, Enablers and Opportunities for Deployment.”; “About CCUS.”

³¹⁹ Turan et al., “Global Status of CCS 2021,” 22.

³²⁰ “About CCUS.”

³²¹ Pacala and Socolow, “Stabilization Wedges,” (2004), accessed February 14, 2022, <https://doi.org/10.1126/science.1100103>.

internalizing CCS/CCUS technologies into NDC projects; building networks that will support both developed and growing economies; continuing R&D, especially in the capture and usage phases.

Chapter 3.2: Direct Air Capture

Background: Direct Air Capture

Direct air capture is the technological process that involves removing CO₂ from a flow of air and storing it into a formation or utilizing it elsewhere.³²² A fairly recent technology, the first DAC—built by Swiss company Climeworks—began operations in Himil, Switzerland, in 2017. Since then, more plants have opened throughout Europe, the United States, and Canada. While the process is indeed working to mitigate carbon from the air, there are several drawbacks to the existing technology. Thus, it is essential to comprehensively inspect all facets of DAC for cost-benefit analysis in order to evaluate the role it can play in policy aiming to lower global emissions.

How It Works

In direct air capture, air is extracted from the atmosphere, typically around large emitting industries; through a series of chemical reactions, CO₂ is extracted. There are two types of DAC plants: high temperature aqueous solution-based (HT DAC) and low temperature solid sorbent-based (LT DAC). The first of these requires air to pass through a series of chemical solutions at a high temperature that extract the CO₂. LT DAC plants have solid sorbent filters that bind with CO₂. When these filters are heated up, CO₂ is released.³²³ The released CO₂ is put through a pipeline and injected into an underground rock layer or stored for later use, such as for carbonation or in synthetic fuel. The processed air, now free of CO₂, is released back into the atmosphere.

Current Status of DAC

There are currently nineteen DAC plants operational throughout the world, all of which are located in advanced nations. The three major companies involved are Climeworks in Switzerland, Carbon Engineering in Canada, and Global Thermostat in the United States. Most DAC plants are small-scale and sell the CO₂ to soda companies for beverage carbonation, but there is a large-scale project called Orca operating in Iceland which injects captured CO₂ into basalt formations.³²⁴ The first of its kind, this plant is designed so that the CO₂ will calcify into rocks in about twenty years. It extracts around 4000 tons of CO₂ a year, which is insignificant compared to global emissions of about 37 billion tons per year. This is an indicator that DAC is still in its early phase of development. The United States has plans to open a more large-scale

³²² Sara Budinis, “Direct Air Capture – Analysis,” IEA, November 1, 2021, <https://www.iea.org/reports/direct-air-capture>.

³²³ Budinis, “Direct Air Capture – Analysis,”

³²⁴ Budinis, “Direct Air Capture – Analysis,”

plant capable of capturing one Mt CO₂ per year; it is slated to become operational in 2024.³²⁵ Even so, to reduce global emissions at a significant level, much larger plants will be needed.

Status of the Leading DAC Companies

	Cimeworks	Global Thermostat	Carbon Engineering
Location	Switzerland	United States	Canada
System type	Solid sorbent	Solid sorbent	Liquid solvent
Thermal energy needs	80-120°C / 176-248°F	80-100°C / 176-212°F	90°C / 165°F
Thermal energy source	Non-fossil energy resources (geothermal, waste heat, etc.)	Energy resource agnostic	Natural gas with CCS
Projects	Commercial operation with 16 plants globally with a collective capacity of 2,000 tonnes of CO ₂ captured from air per year	Pilot plants in Oklahoma and Colorado	Pilot plant in British Columbia; in the process of building a facility in the Permian Basin that will be capable of 1 million tonnes of CO ₂ per year
Investments	Around \$170 million in equity investment since founding in 2009, including \$110 million in the most recent round of funding this year Investors include Zurich Cantonal Bank, Horizon 2020, and others	Partnered with companies including ExxonMobil, NRG, BASF Investments from Zero-Carbon Partners, Goldman Sachs, and others	Received investments of \$68 million in most recent round of funding in 2019 Investors include BHP, Chevron, Bill Gates, Oxy Low Carbon Ventures, and others

Source: Cimeworks 2020, Carbon Engineering 2020, Global Thermostat 2020, Bipartisan Policy Center 2019, Beuttlner et al. 2019



Figure 3.2.1 Current status of the top DAC companies and statistics about their operation (Credit to World Resources Institute)

Land and Water Requirements for DAC

The land requirements for DAC are minimal, which makes it a very accessible tool for carbon-negative options. It is possible for there to be virtually no added land requirements for building DAC plants, which are essentially units of fans built near or within existing industrial and geological-sites. In cases where waste heat sources - such as from power plants or industrial facilities - exist, this would greatly reduce upfront and operational costs. This also has a neutral effect on the surrounding area in terms of agriculture and other land uses.³²⁶

Plants using solid sorbents only require one contractor, so they take up less space and take in less CO₂, whereas liquid systems are larger.³²⁷ Water demand from DAC is also a consideration and depends on the type of system. Liquid solvent systems require about zero to fifty tons of water to capture one ton of carbon, depending on the temperature and humidity of

³²⁵ Budinis, “Direct Air Capture – Analysis,”

³²⁶ Katie Lebling et al., “Direct Air Capture: Resource Considerations and Costs for Carbon Removal,” World Resources Institute, January 6, 2021, <https://www.wri.org/insights/direct-air-capture-resource-considerations-and-costs-carbon-removal>.

³²⁷ Mahdi Fasihi, Olga Efimova, and Christian Breyer, “Techno-Economic Assessment of CO₂ Direct Air Capture Plants,” *Journal of Cleaner Production* (Elsevier, March 14, 2019), <https://www.sciencedirect.com/science/article/pii/S0959652619307772>.

the location, while solid systems only use about 1.9 tons of water per one ton of carbon.³²⁸ Some companies, like Climeworks, have developed technology using cellulose filters that bind the captured CO₂ molecules to moisture, thus capturing and producing water, minimizing loss.³²⁹

Energy Requirements for DAC

DAC does have a high energy demand, mainly related to regeneration - the separation of the CO₂ process that uses heat. Typically, DAC is reliant on electricity powered by fossil fuels. The amount of energy needed is dependent on the type of energy system. Solid systems, which operate at a lower temperature, are less energy intensive and require about 8 GJ/t CO₂. Liquid systems require more thermal energy, about 10 GJ/tCO₂, because of their higher temperature requirements.³³⁰ Currently, most systems rely on fossil fuels to power the process, which is not the most efficient in terms of reaching the desired goal of reducing emissions. However, there is a concentrated push by experts to ensure future DAC plants will run on renewable energy, which will help mitigate this gap in achievement.

Cost of DAC

The cost of DAC is relatively high compared to other carbon mitigation methods. Currently, costs are about \$250 to \$600 to capture one ton of carbon, compared, for example, to reforestation, which costs about \$50 per ton of carbon captured.³³¹ The high cost of DAC is associated with energy use needed per unit of CO₂ recovered, and its efficiency is fairly low due to the relatively low absolute concentration of CO₂ in the air (approximately 415 parts per million).³³²

Overall, DAC is still in its infancy. There are only a few companies that are involved at this stage, so no market yet exists. Despite a potential role of real importance in decarbonization, financial support remains minimal. Indeed, this lack of significant support may be the largest hurdle now facing this technology. Additionally, there is a limited market for the carbon that plants sell.³³³ The largest existing market for captured carbon is enhanced oil recovery (EOR), in which CO₂ gas is injected into oil reservoirs in order to increase production. EOR, however, is highly sensitive to oil prices, which are notoriously volatile.³³⁴ More broadly, capturing carbon to reduce emissions while enhancing oil production is contradictory in the context of climate

³²⁸ Fasihi, Efimova, and Breyer, “Techno-Economic Assessment of CO₂ Direct Air Capture Plants”

³²⁹ Lebling, McQueen, Pisciotta, and Wilcox. “Direct Air Capture: Resource Considerations and Costs for Carbon Removal.”

³³⁰ Soheil Shayegh, Valentina Bosetti, and Massimo Tavoni, “Future Prospects of Direct Air Capture Technologies: Insights from an Expert Elicitation Survey,” *Frontiers* (Frontiers, January 1, 2021), <https://www.frontiersin.org/articles/10.3389/fclim.2021.630893/full#B41>.

³³¹ Lebling, McQueen, Pisciotta, and Wilcox. “Direct Air Capture: Resource Considerations and Costs for Carbon Removal.”

³³² Shayegh, Bosetti, and Tavoni, “Future Prospects of Direct Air Capture Technologies: Insights from an Expert Elicitation Survey,”

³³³ Lebling, McQueen, Pisciotta, and Wilcox. “Direct Air Capture: Resource Considerations and Costs for Carbon Removal.”

³³⁴ Lebling, McQueen, Pisciotta, and Wilcox. “Direct Air Capture: Resource Considerations and Costs for Carbon Removal.”

mitigation. For DAC to become sustainable, attracting more financing, developing into a serious contributor to mitigation, and different kinds of carbon capture uses—and thus markets—are necessary.

Future Plans for DAC

The general consensus, as indicated by the Paris Accords in 2015, accepted a need for carbon-negative technologies in order to successfully achieve net zero emissions by 2050. Direct air carbon technology is a promising method to accomplish this, with several hints of further global investment and development. In terms of the future of DAC technology, scientists have made several projections in terms of cost, energy use, commercialization, and widespread utilization. Under the net zero by 2050 scenario, DAC needs to capture up to 85 Mt CO₂ per year by 2030, as shown in Figure 3.2.2, and approximately 980 Mt CO₂ per year by 2050. Figure 3.2.2 makes clear that reaching these levels requires extensive upscaling of DAC.³³⁵

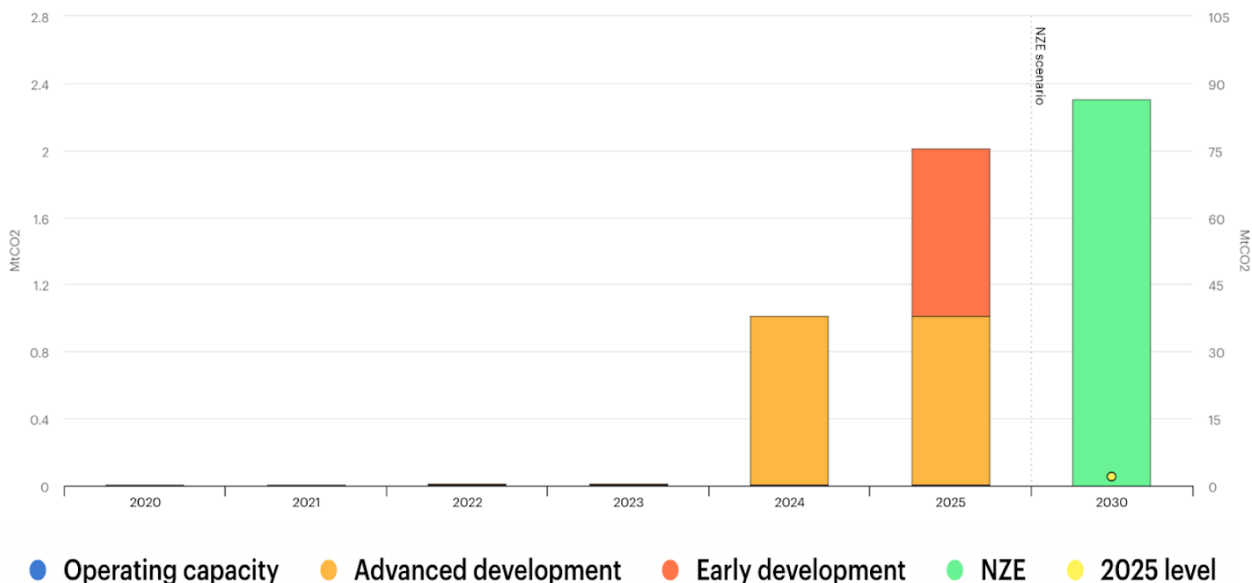


Figure 3.2.2 Projected harvest of CO₂ by Direct Air Capture by 2030 (Credit to: IEA)

Aiding the possibility of such upscaling, the cost of DAC is expected to drop significantly from \$600 to about \$200 per ton.³³⁶ The drop in cost for DAC comes from its industrialization and a “learning by doing” process that has been successful for many other forms of environmental engineering.³³⁷

In terms of actual plans for DAC, there has been a noticeable shift in attention and investment. As of October 2021, the U.S. Department of Energy has allocated \$14.5 million of

³³⁵ Budinis, “Direct Air Capture – Analysis,”

³³⁶ Shayegh, Bosetti, and Tavoni, “Future Prospects of Direct Air Capture Technologies: Insights from an Expert Elicitation Survey,”

³³⁷ McQueen, Noah, Katherine Vaz Gomes, Colin McCormick, Katherine Blumanthal, Maxwell Pisciotta, and Jennifer Wilcox. “IOPscience.” Progress in Energy. IOP Publishing, April 16, 2021. <https://iopscience.iop.org/article/10.1088/2516-1083/abf1ce>.

funding to the research and deployment of DAC technology.³³⁸ This funding, albeit insignificant compared to other funding allocations, will be used to drastically scale up carbon capture connected to low-carbon energy in the United States. Government funding for DAC remains limited, but private investment is the main source of funding. More companies have demonstrated an interest in investment or partnerships with DAC corporations. For example, Microsoft has pledged to remove all their historical carbon emissions by 2050, and has pledged \$1 billion to research and development into the limited technology.³³⁹

Analysis of Benefits

DAC has several benefits that would contribute toward zero emissions and green energy. The main benefit is at its core—it removes CO₂ from the atmosphere, which has a higher staying power than other gasses that contribute to climate change and rising temperatures. Compared to other carbon-negative technologies, DAC has variable benefits that make it accessible and efficient. First, DAC plants can be constructed and utilized in a large variety of locations, as they do not need to be attached to a power source, and are thus more accessible. They have a smaller land footprint than other carbon sequestration techniques like bioenergy with carbon capture and storage.

Analysis of Present Limitations

There are some limitations that inhibit the widespread use and accessibility of direct air capture. DAC uses large fans and other technology that require a lot of energy to power; a 2020 study posited that DAC plants use between 46% and 121% of the world's energy. Fossil fuels currently provide this energy, which is counterproductive to the goal of reducing emissions and also requires money to purchase. Because of this, DAC is expensive, therefore inaccessible and unattractive for businesses.³⁴⁰ Not only is it expensive, but there are limited opportunities for return on input in terms of markets. Aside from beverages, foods, and some greenhouse industries—which are small—there is not a substantial market for CO₂. In general, there is not a demand for purchasing CO₂, which makes the benefit and recovery marginal.³⁴¹ A number of environmental risks, such as pipeline leakages, interruption to natural environments, or seismic activity could occur.³⁴²

The Role of DAC in Policy

³³⁸ “Doe Announces \$14.5 Million Supporting Direct Air Capture and Storage Coupled to Low Carbon Energy Sources.” Energy.gov, October 26, 2021. <https://www.energy.gov/articles/doe-announces-145-million-supporting-direct-air-capture-and-storage-coupled-low-carbon>.

³³⁹ Justine Calma, “Microsoft Wants to Capture All of the Carbon Dioxide It's Ever Emitted,” The Verge (The Verge, January 16, 2020), <https://www.theverge.com/2020/1/16/21068799/microsoft-carbon-capture-climate-change>.

³⁴⁰ Anja Chalmin, “Direct Air Capture: Recent Developments and Future Plans,” Geoengineering Monitor, October 24, 2019, <https://www.geoengineeringmonitor.org/2019/07/direct-air-capture-recent-developments-and-future-plans/>

³⁴¹ Chalmin, “Direct Air Capture: Recent Developments and Future Plans,” Geoengineering Monitor, October 24, 2019

³⁴² Hiyori Yoshida, “Direct Air Capture: Costs, Benefits, and the Future,” Risk Management and Decision Processes Center, September 13, 2021, <https://riskcenter.wharton.upenn.edu/lab-notes/directaircapture/>.

At its present level of development, DAC will not be impactful on its own, as it lacks the ability to reduce carbon drastically enough to meet the necessary standards. Significant advancements in technology need to be made before it will be usable on a large scale. DAC would work best in conjunction with other emissions reduction efforts. The combination of DAC and other carbon sequestration methods is extremely impactful, such as the use of CO₂ to make synthetic fuels.³⁴³ The IEA has also slated DAC as a key tool toward the goal of net zero, and has stated that international cooperation regarding this is integral.³⁴⁴ Additionally, DAC requires more supplementary policies surrounding carbon markets (and DAC in general) in order to generate large-scale deployment of this technology in the United States.

Policy Suggestions

Below is a comprehensive list of suggestions to fully enhance the efficiency of DAC. Policies are both U.S.-centric and internationally-focused, under the assumption that climate change and energy issues are not confined to the United States.

- ***Direct more federal funding*** to the research and development of new DAC programs, gradually increasing funding to \$240 million.³⁴⁵
- ***Enact policies that will increase the demand*** for DAC and CO₂
 - Federal procurement processes to generate competition for CO₂
 - Improving upon the 45Q tax credit to incentivize more companies to participate in DAC
 - Establish a federal mandate for DAC based fuels.³⁴⁶
- ***Create opportunities*** for DAC in infrastructure, climate, and policy framework

Concluding Statement

While still currently in its early stages, direct air capture bodes a promising future if enough research and funding is invested in it. Realistically, the use of fossil fuels will not decrease dramatically enough in the near future to meet emissions goals and create substantial change. Thus, solutions like DAC and CCUS are very critical in reducing emissions and regulating climate change. More support is needed from the government, specifically support for DAC on the front and back end of the issue. Policy and redistribution or allocation of funding is needed to stimulate research and investment in DAC in order to mitigate the gaps, such as large energy consumption, that exist in it today. Additionally, policy is required to create and expand markets for captured CO₂ to incentivize private investment.

³⁴³ Giulia Realmonte et al., “An Inter-Model Assessment of the Role of Direct Air Capture in Deep Mitigation Pathways,” Nature News (Nature Publishing Group, July 22, 2019), <https://www.nature.com/articles/s41467-019-10842-5>.

³⁴⁴ “Net Zero by 2050 - .NET Framework” (IEA), accessed February 15, 2022, <https://iea.blob.core.windows.net/assets/4719e321-6d3d-41a2-bd6b-461ad2f850a8/NetZeroBy2050-ARoadmapfortheGlobalEnergySector.pdf>, 188.

³⁴⁵ John Larsen et al., “Capturing Leadership: Policies for the US to Advance Direct Air Capture Technology,” Rhodium Group (Rhodium Group, LLC, June 23, 2020), <https://rhg.com/research/capturing-leadership-policies-for-the-us-to-advance-direct-air-capture-technology>

³⁴⁶ Larsen et al., “Capturing Leadership: Policies for the US to Advance Direct Air Capture Technology”

Chapter 3.3: Geoengineering

Climate geoengineering is the planned, direct intervention of the Earth's natural systems with the goal of mitigating climate change. Geoengineering utilizes one or more of several advanced technological processes to reduce the heating of oceans, soils, and the atmosphere. It is used to manipulate the Earth's environment to mitigate the effects of climate change and slow global warming. Geoengineering methods are divided into three main categories: natural climate solutions, carbon dioxide removal (CDR), and solar radiation management (SRM).³⁴⁷ All have advantages and limitations that need to be considered carefully.



Figure 3.3.1. The above figure shows the variety of geoengineering projects implemented worldwide. (Credit to: ETC Group and the Heinrich Boell Foundation, link to interactive map: <https://map.geoengineeringmonitor.org/>)

Geoengineering is already being tested and implemented in various projects around the globe, both at local and regional levels, as illustrated in Figure 3.3.1. Given the expansive opportunities, analyses of the different projects and their advantages, disadvantages, as well as costs, are needed to determine the most effective approaches.

Ecosystem Restoration

Ecosystem restoration is the process of human intervention toward recovery of an ecosystem that has been degraded or damaged by climate change.³⁴⁸ The goal is to initiate

³⁴⁷ "Climate Engineering Solutions to Climate Change and Global Warming," Geoengineering.global, June 30, 2021, <https://geoengineering.global/climate-engineering/>.

³⁴⁸ "Home," Go to Restoration Resource Center, accessed February 14, 2022, <https://www.ser-rrc.org/what-is-ecological-restoration/>.

restoration so that an ecosystem can reestablish its original self-sustaining conditions. Projects within restoration such as afforestation are believed to act as carbon sinks, thereby adding to climate change mitigation. Ecosystem restoration is heavily involved in reaching the U.N. Sustainable Development Goals. The largest restoration project is the Great Green Wall, which aims to green the entire width of Africa by planting trees and greenery across the Sahel from Senegal to Djibouti.³⁴⁹ The goal of this initiative is to restore damaged land and bring people together to sustainably develop a vast area that has lost much of its original plant cover due to a combination of overuse by humans and drought related to climate change. It is led by the Food and Agriculture Organization (FAO) of the U.N. and the U.N. Environment Programme (UNEP), which have established the framework for the project and provided funding.³⁵⁰ There are a plethora of projects dedicated to restoring ecosystems across the globe, from forest restoration in the Lacandon forest in Mexico to coral reef restoration in Bali.

Advantages, Disadvantages, and Cost of Ecosystem Restoration

Restoration is often praised as a carbon-negative initiative because of its ethical nature in restoring the environment to its original, pre-industrialization form. However, ecological restoration alone is not the key to carbon mitigation, as there are many limitations and stipulations involved. The process is very delicate, because human error in intervention could lead to unforeseen consequences. For example, in China, the overuse of shrubbery in arid landscapes has led to a compromised environment.³⁵¹ Additionally, the ever-changing social and economic dynamics of countries makes it difficult to gauge restoration's long-term potential of continued capital and physical investment in projects.³⁵² In terms of cost, many projects vary by type of environment and who is involved, though a study by the International Institute for Sustainability demonstrated that in most cases, the impact of ecological restoration outweighs the cost, as demonstrated in Figure 3.3.2.³⁵³ Overall, ecosystem restoration has many co-benefits that create a thriving environment. Thus, it is a highly attractive policy option if coupled with aggressive energy reform.³⁵⁴

³⁴⁹ “The World's Biggest Ecosystem Restoration Project,” UNEP, April 23, 2020, <https://www.unep.org/news-and-stories/story/worlds-biggest-ecosystem-restoration-project>.

³⁵⁰ “The World's Biggest Ecosystem Restoration Project,” UNEP

³⁵¹ Rattan Lal, “Ecological Restoration,” *Ecological Restoration*, 2016, <https://www.sciencedirect.com/topics/earth-and-planetary-sciences/ecological-restoration>.

³⁵² Lal, “Ecological Restoration”

³⁵³ Bernardo BN Strassburg and Agnieszka E Latawiec, “The Economics of Restoration: Costs, Benefits, Scale and ...” (*International Institute for Sustainability*, March 2014), <https://www.cbd.int/doc/meetings/ecr/cbwecr-sa-01/other/cbwecr-sa-01-iis-en.pdf>.

³⁵⁴ Emma W Littleton et al., “IOPscience,” *Dynamic modeling shows substantial contribution of ecosystem restoration to climate change mitigation* (IOP Publishing, December 14, 2021), <https://iopscience.iop.org/article/10.1088/1748-9326/ac3c6c/meta#erlac3c6cs4>.

	Biome/Ecosystem	Typical cost of restoration	Estimated annual benefits from restoration (avg. scenario)	Net present value of benefits over 40 years	Internal rate of return	Benefit/cost ratio
		US\$/ha	US\$/ha	US\$/ha	%	Ratio
1	Coral reefs	542,500	129,200	1,166,000	7%	2.8
2	Coastal	232,700	73,900	935,400	11%	4.4
3	Mangroves	2,880	4,290	86,900	40%	26.4
4	Inland wetlands	33,000	14,200	171,300	12%	5.4
5	Lakes/rivers	4,000	3,800	69,700	27%	15.5
6	Tropical forests	3,450	7,000	148,700	50%	37.3
7	Other forests	2,390	1,620	26,300	20%	10.3
8	Woodland/shrubland	990	1,571	32,180	42%	28.4
9	Grasslands	260	1,010	22,600	79%	75.1

Figure 3.3.2. A cost benefit analysis of different types of ecosystems and their restorations. (Credit to: IIS)
Blue Carbon

Blue carbon refers to carbon captured by global oceans and coastal ecosystems. Greenery and biological life in the ocean has the power to capture and hold carbon—known as a “carbon sink”—and store it below the Earth’s surface.³⁵⁵ These sea plants, albeit smaller in square footage compared to the Earth’s forest, sequester carbon at a much faster rate, as well as store it for millions of years.³⁵⁶ Blue carbon is comparable to a natural form of carbon sequestration, as the ecosystem restoration of coastal areas and wetlands greatly improves the ability for the oceanic capture and hold of carbon. Additionally, the destruction of coastal ecosystems emits all carbon that has been stored there. The International Blue Carbon Initiative is the largest international organization that aims to protect tidal marshes, wetlands, and seagrasses through restoration activities and research.³⁵⁷

Advantages, Disadvantages, and Cost of Blue Carbon

One of the main attractions of blue carbon is that it is a nature-based solution, meaning that it contributes to climate regulation in three important ways: through emissions reduction, carbon capture and storage, and via socio-economic benefits.³⁵⁸ It greatly helps communities affected by climate change restore their ecosystems as well as from further damages, as wetlands are a guard against floods and other climate disasters.³⁵⁹ However, blue carbon is not seen as a truly viable option for large-scale carbon mitigation. The theoretical ability to restore carbon at

³⁵⁵ “What Is Blue Carbon?,” NOAA's National Ocean Service (National Ocean Service, June 1, 2013), <https://oceanservice.noaa.gov/facts/bluecarbon.html>.

³⁵⁶ “What Is Blue Carbon?,” NOAA's National Ocean Service

³⁵⁷ “The Blue Carbon Initiative,” The Blue Carbon Initiative, accessed February 16, 2022, <https://www.thebluecarboninitiative.org/>.

³⁵⁸ Ralph Chami et al., “The Role of Blue Carbon in Climate Change Mitigation and Carbon Stock Conservation,” *Frontiers* (Frontiers, September 7, 2021), [https://www.frontiersin.org/articles/10.3389/fclim.2021.710546/full#:~:text=These%20include%20providing%20storm%20protection,sinks%20beyond%20marine%20angiosperm%](https://www.frontiersin.org/articles/10.3389/fclim.2021.710546/full#:~:text=These%20include%20providing%20storm%20protection,sinks%20beyond%20marine%20angiosperm%20)

³⁵⁹ Chami et al., “The Role of Blue Carbon in Climate Change Mitigation and Carbon Stock Conservation”

such a high level is disputed by low efficacy of implementation.³⁶⁰ Effective mitigation using blue carbon to a degree that would be impactful toward negative emissions would be a multidecadal process, assuming it is being implemented at the highest capacity.³⁶¹ Additionally, blue carbon initiatives have not been proven to be entirely cost-effective, as they can range from \$240 to \$30,000 without very positive and effective outcomes.³⁶²

Space-based Geoengineering

Space-based or solar geoengineering involves mitigating the effects of climate change by reducing the amount of sunlight hitting the Earth.³⁶³ Methods for blocking or reflecting the sun's radiation include placing sunshades, mirrors, reflectors, and clouds of sunblocking particles into space or the upper atmosphere. Researchers propose positioning objects at the L1 Lagrange point, where gravity is equidistant from the Earth and sun, thus requiring very little energy to keep objects in place.³⁶⁴ Currently, there are no active geoengineering initiatives in space, only the Deep Space Climate Observatory (DSCOVR) satellite launched by NOAA, which sits at the L1 Lagrange point—though simply for observation and research purposes.

Advantages, Disadvantages, and Cost of Space-based Geoengineering

Space-based geoengineering has a very delicate balance between benefits and drawbacks due to lack of actual testing. Most analyses must be reliant on theoretical approaches, scientific proposals, and research. The major advantage of proposed space-based geoengineering is the exponential effects that redirecting high levels of solar energy would have on global warming in a very short timespan.³⁶⁵ Space-based geoengineering, if done properly, would greatly improve the climate situation. A few stipulations place limitations on the successful implementation of geoengineering. One is the inevitability of objects in space becoming compromised, thus requiring the utilization of lunar or asteroid resources.³⁶⁶ Additionally, solar modification must continue. If stopped, the detrimental consequences would include global warming accelerating at greater rates than prior to modification.³⁶⁷ Moreover, it may not mitigate all the effects of greenhouse gas emissions, and could even implicate existing ecosystems due to the way sunlight impacts rainfall.³⁶⁸ Space-based geoengineering would also be very expensive, estimated to be about \$5 trillion over twenty-five years.³⁶⁹

³⁶⁰ Jean-Pierre Gattuso et al., "The Potential for Ocean-Based Climate Action: Negative Emissions Technologies and Beyond," *Frontiers* (Frontiers, January 25, 2021), <https://www.frontiersin.org/articles/10.3389/fclim.2020.575716/full>.

³⁶¹ Gattuso et al., "The Potential for Ocean-Based Climate Action"

³⁶² Gattuso et al., "The Potential for Ocean-Based Climate Action"

³⁶³ "Space-based Geoengineering," *Geoengineering.global*, April 10, 2021

³⁶⁴ "Space-based Geoengineering," *Geoengineering.global*

³⁶⁵ C R McInnes, "Space-Based Geoengineering: Challenges and Requirements," September 15, 2009, <https://pure.strath.ac.uk/ws/portalfiles/portal/86085955/Data.pdf>, 573-574.

³⁶⁶ McInnes, "Space-Based Geoengineering"

³⁶⁷ Tara Yarlagadda, "1 Big pro and 4 Cons of Solar Geoengineering," *Inverse* (Inverse, April 7, 2021), <https://www.inverse.com/science/solar-geoengineering-pros-and-cons>.

³⁶⁸ Yarlagadda, "1 Big pro and 4 Cons of Solar Geoengineering"

³⁶⁹ "Space-based Geoengineering," *Geoengineering.global*, April 10, 2021

Albedo Modification

Albedo modification is a climate engineering approach with the potential to reverse global warming by increasing the Earth's ability to reflect solar radiation back out into space.³⁷⁰ Albedo is the measure of sunlight reflected by a surface compared to the amount absorbed by that surface. Light surfaces have a high albedo, which leads to cooling effects, as the short-wave radiation from the sun is reflected back instead of penetrating the surface and heating it.³⁷¹ Since the 1960s, there have been proposals to artificially manipulate land, ocean, and cloud albedo through geoengineering.³⁷²

The effectiveness of the albedo modification in lowering land and water temperatures was proven through various climate models. Temperature reduction in general is feasible, considering continuous investments into manufacturing albedo effects. Reducing sea surface temperatures would reduce the risk of coral bleaching events, help maintain favorable conditions for coral reefs, and could lessen the loss of sea ice. The most prominent examples of albedo modification technologies include stratospheric aerosol injection and marine cloud brightening, which will be discussed in more detail later on?.

However, these albedo modification strategies do not address other effects of greenhouse gasses like ocean acidification.³⁷³ Absorbing a quarter of emitted CO₂ a year, the oceans are undergoing chemical change. Thus, solely relying on albedo modification is not enough. Overall, albedo modification methods cannot be a substitute for cutting CO₂ emissions but may be a feasible supplement to other carbon sequestration and geoengineering approaches.

Stratospheric Aerosol Injection

Stratospheric aerosol injection (SAI) is a geoengineering approach that uses tiny reflective particles (aerosols) to modify the planet's albedo. This SRM strategy involves spraying reflective sulfate aerosol particles into the stratosphere via high altitude airplanes, tethered balloons, or artillery.³⁷⁴

SAI is highly controversial and faces large amounts of criticism. This approach is designed to mimic the cooling effects of large volcanic eruptions.³⁷⁵ Every so often, large volcanic eruptions release massive amounts of sulfur dioxide (SO₂) into the stratosphere. The SO₂ is then oxidized in the atmosphere into sulfuric acid, which has low enough vapor pressure to form a cloud of droplets. Only strong volcanic eruptions eject sulfur into the stratosphere to impact the climate. They do this by scattering incoming short-wave radiation back into space,

³⁷⁰ National Research Council (U.S.), *Climate Intervention*, (2015): 32, assessed February 14, 2022.

³⁷¹ Yip, "Albedo," (2021): 475, assessed February 14, 2022,

³⁷² Cziczo et al., "Unanticipated Side Effects of Stratospheric Albedo Modification Proposals Due to Aerosol Composition and Phase," (2019):1, assessed February 14, 2022, .

³⁷³ Cziczo et al., "Unanticipated Side Effects of Stratospheric Albedo Modification Proposals Due to Aerosol Composition and Phase," 2.

³⁷⁴ Robock, "CHAPTER 7. Stratospheric Aerosol Geoengineering," (2014): 162, assessed February 13, 2022, <http://ebook.rsc.org/?DOI=10.1039/9781782621225-00162>.

³⁷⁵ Kravitz et al., "Holistic Assessment of SO₂ Injections Using CESM1(WACCM): Introduction to the Special Issue," (2019): 444, assessed February 13, 2022, <https://onlinelibrary.wiley.com/doi/10.1029/2018JD029293>.

cooling the surface.³⁷⁶ One of the brightest examples is the eruption of Mount Pinatubo in the Philippines. On June 15, 1991, the volcano injected a 20-million ton SO₂ cloud into the stratosphere at an altitude of nearly 20 miles. According to a United States Geological Survey (USGS) survey, it managed to cool the Earth's surface by as much as 0.6 °C in the next 15 months after the eruption, the Pinatubo Effect, as it was called, was strong but temporary.³⁷⁷

In addition, SAI emulates volcanic eruptions by continuously delivering sulfur twenty km above ground. In many climate models, SAI completely stops global warming by reflecting sunlight radiation. However, if SAI is halted for any reason, it may result in rapid global warming at a rate much higher than pre-SAI.³⁷⁸

Among the many potential **risks** associated with this method, the most explicit are:

- Potential drought increase in certain monsoon regions. This effect is the same as the aftermath of large volcanic eruptions.³⁷⁹
- Sulfuric acid is dangerous for human health and ecosystems.³⁸⁰
- The impact of more diffuse and less direct radiation on Earth's surface will give the sky a permanently hazy appearance. This will cause unquantified psychological effects, disturb solar electricity generation, and disrupt the biosphere.³⁸¹

Cost-benefit Analysis of SAI

When calculating the costs of SAI implementation, the most significant expenses fall under delivery. As mentioned earlier, planes, tether balloons, guns, and other airships are utilized for this purpose.

System type	Altitude (kft)	Altitude (km)	RDT&E and acquisition costs (\$B)	Recurring cost per kg (less RDT&E, acquisition costs)	Yearly total cost including depreciation and interest (\$B)
Boeing 747 Class	45	13.7	\$0.8	\$1.00	\$1.1
Modified Gulfstream Class	60	18.3	\$3.2	\$2.15	\$2.9
New design airplane	40	12.2	\$2.0	\$0.30	\$0.6
New design airplane	60	18.3	\$2.1	\$0.35	\$0.7
New design airplane	70	21.3	\$5.6	\$0.56	\$1.5
New design airplane	80	24.4	\$7.8	\$0.60	\$1.9
New design airplane	100	30.5	\$11	\$0.75	\$2.6
Gun (Mark 7 16")	91	27.7	\$0.34	\$137	\$137
Gun (Modernized Mark 7)	91	27.7	\$0.55	\$18.90	\$19
Hybrid airship	66	20.0	\$4.0	\$0.35	\$1
Hybrid airship	82	25.0	\$5.9	\$0.40	\$1.4
Hybrid airship	98	30.0	\$7.5	\$0.80	\$2
Rocket	100	30.5	\$2300	\$263	\$390
Floating slurry pipe	70	21.3	\$24	\$0.25	\$4
Floating gas pipe	70	21.3	\$59	\$0.63	\$10

³⁷⁶ Robock, "CHAPTER 7. Stratospheric Aerosol Geoengineering," 164.

³⁷⁷ "Sulfate Aerosols Can Cool the Climate and Deplete Earth's Ozone Layer," (2015), assessed February 13, 2022, Volcanoes Can Affect Climate | U.S. Geological Survey (usgs.gov).

³⁷⁸ Robock, "CHAPTER 7. Stratospheric Aerosol Geoengineering," 171.

³⁷⁹ Robock, "CHAPTER 7. Stratospheric Aerosol Geoengineering," 173.

³⁸⁰ Robock, "CHAPTER 7. Stratospheric Aerosol Geoengineering," 165.

³⁸¹ Robock, "CHAPTER 7. Stratospheric Aerosol Geoengineering," 176.

Figure 3.3.3 Summary of different delivery systems of SAI. Annual 1Mt/yr³⁸²

Demonstrated in Figure 3.3.3, yearly costs of SAI implementations for a 1 Mt annual mass delivery rate vary between \$1 to \$2 billion, including interest rates and depreciation costs. To put these into perspective, the cost of climate damages emissions mitigation are commonly estimated to be 0.2 to 2.5% of global GDP in 2030,³⁸³ equivalent to roughly \$200 to \$2,000 billion per year.³⁸⁴ This means that the most expensive part of SAI deployment is less than 1% of potential damages. However, it is crucial to understand that costs associated with its risk side-effects are almost impossible to calculate.

Marine Cloud Brightening

Marine cloud brightening (MCB) is a climate engineering approach that increases the reflectivity or albedo of marine clouds by seeding them with seawater aerosol.³⁸⁵ MCB is among one of the most easily implemented, potentially very effective and environmentally-friendly geoengineering approaches. It also has the benefit of reducing tropospheric ozone pollution.³⁸⁶

MCB applications emerged based on the research of cloud physicist Dr. Sean Towmey, who explained how smaller water droplets in a larger quantity increase cloud albedo. Aerosols with seawater are sprayed, and when they evaporate, leftover particles are carried by the wind to clouds, acting as cloud condensation nuclei. These nuclei are responsible for creating smaller droplets in a larger amount that increase the cloud albedo effect.^{387,388}

Technical Feasibility of MCB

Proceedings of the National Academy of Sciences (PNAS) identifies several critical caveats that need to be addressed for MCB to be deemed technically feasible:

Generation and delivery of appropriately-sized particles. Aerosols should maintain specific properties to form cloud droplets that are effective at reflecting solar radiation. These properties include appropriate size, minimal variations, and the ability to overcome buoyancy and maintain size distribution. Both R&D and advanced technologies are required to test these properties and implement MCB under various conditions.³⁸⁹

Local cloud adjustments. MCB technology requires several adjustments in order to be applicable in different locations. Particles that are too large or too small may dissipate clouds,

³⁸² McClellan et al., “Cost Analysis of Stratospheric Albedo Modification Delivery Systems,” (2012): 6, assessed February 16, 2022, <https://iopscience.iop.org/article/10.1088/1748-9326/7/3/034019>.

³⁸³ Metz et al., Intergovernmental Panel on Climate Change, *Climate Change 2007*.

³⁸⁴ McClellan et al., “Cost Analysis of Stratospheric Albedo Modification Delivery Systems,” 6.

³⁸⁵ Latham et al., “Global Temperature Stabilization via Controlled Albedo Enhancement of Low-Level Maritime Clouds,” assessed February 14, 2022, <https://royalsocietypublishing.org/doi/10.1098/rsta.2008.0137>.

³⁸⁶ Diamond et al., “Opinion,” (2022): 5, assessed February 14, 2022, <http://www.pnas.org/lookup/doi/10.1073/pnas.2118379119>.

³⁸⁷ Twomey, “The Influence of Pollution on the Shortwave Albedo of Clouds,” (1977): 1149, assessed February 14, [http://journals.ametsoc.org/doi/10.1175/1520-0469\(1977\)034<1149:TlOPOT>2.0.CO;2](http://journals.ametsoc.org/doi/10.1175/1520-0469(1977)034<1149:TlOPOT>2.0.CO;2).

³⁸⁸ Latham et al., “Global Temperature Stabilization via Controlled Albedo Enhancement of Low-Level Maritime Clouds.”

³⁸⁹ Diamond et al., “Opinion,” 3–5.

leading to the offsetting of the necessary brightening effect. Thus, remote sensing and ground truthing measurements should be obtained for better models and projections.

Spatiotemporal scale of susceptible clouds. For MCB to have a global impact, suitable cloud formation should be present consistently throughout large proportions of the world. In practice, cloud susceptibility varies greatly, thus deeper local knowledge should be cultivated through research and observations. As of today, only the areas with particularly heat-sensitive ecosystems (such as coral reefs) are among the most researched territories, since they have demonstrated consistent conditions for testing MCB technologies.

Signal detection. Observation of the effects of MCB largely depends on data collected from space and a flexible timescale which allows for adjustments in response to new conditions or concerns. Since the signals from MBC are relatively small and timeframes are relatively large (spanning years to decades), the question emerges whether this technology could be deployed in a timely manner.

Impacts on marine ecosystems and coastal communities. The effects of salt as part of injected aerosols are minimal and should not interfere with important chemical processes or impact coastal ecosystems negatively. However, the chemical effects of MCB are still under research, as it is unknown how light dynamics affect ecosystems around MCB deployment. Salt deposition may also affect ecosystem functions as well as coastal infrastructure. Collaboration between physical scientists, ecologists, social scientists, and ethicists is required to fully understand the potential impacts of MBC on marine ecosystems and coastal communities.³⁹⁰

Large-scale circulation and precipitation response. The implementation of cloud brightening could lead to potentially large-scale circulation responses with unanticipated consequences.³⁹¹ Darkening clouds in other locations, for example, could make an entire process counterproductive. Studies have identified that cloud brightening can negatively impact rainfall patterns in sensitive areas such as the Amazon—a major sink for CO₂.³⁹² Assessing the risks of MCB and defining what regions are “vulnerable,” and thus of greatest concern, as well as what level of risk are “unacceptable,” will require a holistic collaboration among the fields of ecology, social science, and ethics, as well as stakeholder communities.³⁹³

Financial uncertainty. The cost of MCB is largely unknown. The Royal Society estimates £25 million (\$33.5 million) and a further three years of research are necessary. Beyond these figures, the Royal Society projects around £30 million (\$40 million) for tooling, which will allow a large number of spray vessels to be built rapidly in the event of a global emergency.³⁹⁴

Concluding Statement

³⁹⁰ Zarnetske et al., “Potential Ecological Impacts of Climate Intervention by Reflecting Sunlight to Cool Earth.”

³⁹¹ Twomey, “The Influence of Pollution on the Shortwave Albedo of Clouds,” 1152.

³⁹² Jones et al., “Climate Impacts of Geoengineering Marine Stratocumulus Clouds,” (2013): 8, assessed February 13, 2022, <http://doi.wiley.com/10.1002/jgrd.50762>.

³⁹³ Diamond et al., “Opinion,” 6.

³⁹⁴ Salter et al., “Sea-Going Hardware for the Cloud Albedo Method of Reversing Global Warming,” (2008): 4003, assessed February, 16, 2022, <https://royalsocietypublishing.org/doi/10.1098/rsta.2008.0136>.

With all the benefits and disadvantages in mind, geoengineering is still in dire need of research and a global level of cooperation. In particular, proper financing and accounting for traditionally underserved communities are critical for legitimate climate intervention research. Advancements in the technical field are quite promising, bringing the scientific community closer to understanding climate engineering potential. However, responsible research programs must guarantee that all social feasibility checkpoints are promptly addressed. It is crucial to holistically view the effects and consequences of all geoengineering methods in order to combat climate change without creating “sacrifice zones”—places with the disproportional burden of severe climate events as a consequence to modifying natural ecosystems or albedo effect. It is also clear that none of the methods are effective enough to negate anthropogenic emissions on their own. The system of several approaches would be more effective, given that safety is guaranteed.

Chapter 4: Current Realities in the Geopolitics of Energy

Introduction

According to the IEA, by April 2021, the EU and forty-four other nations have pledged a net zero emissions by a 2050 target. The pledges comprise nearly 70% of world carbon emissions.³⁹⁵ Such a goal appears lofty, however, much as with international climate agreements, the effort to transition away from carbon-based energy is a complicated affair. Global energy realities present political obstacles to a consensus-based international movement to address climate change.

The capability for nation-states to develop domestic non-carbon energy is highly variable and unequal. Moreover, new resources of carbon fuel have emerged in abundance, including for underdeveloped and emerging nations. This presents a distinct challenge to international climate diplomacy, whose goal may be to convince these nations to leave such abundance in the ground. These aims are also not helped by the fact that Russia, the United States, the EU, and China are all large sources of carbon-based energy themselves. Still, the path to non-carbon energy must be led by those who have the capital and capacity to lead the transition.

At present, the production of both oil and natural gas has continued to increase. Despite real growth in non-carbon energy technologies, they remain comparatively small when placed beside the levels of extraction and usage in the carbon energy sector.³⁹⁶ These increases are unlikely to stop. The largest expansion in global energy consumption since the 1970s has continued to be in Asia, as China, India, and other states have developed their economies. These nations are poised to ensure that demand for oil, gas, and coal is unlikely to undergo rapid and dramatic decline without profound changes.

³⁹⁵ IEA. “Net Zero by 2050 – Analysis.” International Energy Agency, October 2021. <https://www.iea.org/reports/net-zero-by-2050>.

³⁹⁶ IEA. “Key World Energy Statistics 2021 – Analysis.” International Energy Agency, September 2021. <https://www.iea.org/reports/key-world-energy-statistics-2021>.

Sustainable development of a non-carbon energy sector is dependent on geography. Wind and solar energy require particular weather conditions and large amounts of available land. Weather, climate, and topography are factors that determine the possibility for hydropower, while geothermal relies on specific conditions of geology and precipitation. Nuclear power, on the other hand, requires large amounts of investment and technological expertise, which often only exists in developed countries. The reality of non-carbon energy is therefore unequally distributed. Developing it at a high level, though improving energy self-reliance, also comes with reliance on non-domestic entities who are needed to invest in and build the relevant technologies.

The energy transition therefore will bring its own geopolitical impacts. While the United States may lose strategic advantage in decreasing demand for carbon sources, Russia and Organization of Petroleum Producing Countries (OPEC) will suffer a much greater loss due to their own deep dependence on exports of oil and gas. To date, China has benefited significantly from its global sales of solar and wind technology, even as it remains the world's largest oil importer.³⁹⁷ At the same time, Russia and China are positioned to gain considerable advantage by the export of nuclear power technology, compared with the United States and Europe.

One can look to the future of addressing climate change with hope as new technologies and alternatives surface. However, geopolitics will play a vital role in the success of non-carbon energy. The aforementioned points represent some of the challenges and complexities already evident. They offer strong evidence of the need for international diplomacy, cooperation, and commitment to change. The transition away from carbon is not a matter of if, but how and when.

The New Carbon Rush

There has been hope that dwindling carbon fuel reserves would naturally incentivize nations to look elsewhere for their energy. However, recent discoveries and the implementation of new technological processes have revealed that the supply is anything but dwindling.³⁹⁸ If nations are to effectively reduce carbon fuel use, there must be a focus on the fact that in the future, fossil fuel sources may be cheaper and in more ready supply than ever before. Because of the incentive for energy independence and rapidly growing demand for power and heat, new reserves of oil and gas—as well as existing reserves of coal—will remain attractive for developing nations in particular. The new carbon rush in these countries represents a fundamental roadblock in the transition away from carbon fuels.

Oil and gas in particular, have grown rapidly in production in the United States. The United States reported a 19% decrease in proved oil reserves in 2019. Similarly, natural gas reserves declined by 4%.³⁹⁹ Looking to Figure 4.1, one may observe that reserves of both oil and

³⁹⁷ IEA. “Key World Energy Statistics 2021 – Analysis.”

³⁹⁸ Global Change Data Lab. (2021, July 8). *Oil reserves*. Our World in Data. Retrieved February 23, 2022, from https://ourworldindata.org/grapher/oil-proved-reserves?country=~OWID_WRL

³⁹⁹ Grape, S. G. (2022, January 13). U.S. Crude Oil and Natural Gas Proved Reserves, *Year-end 2020*. Energy Information Administration. Retrieved February 23, 2022, from <https://www.eia.gov/naturalgas/crudeoilreserves/>

natural gas have sharply increased since 1997. In Figure 4.2, the change corresponds with an increase in oil production since 2010.⁴⁰⁰

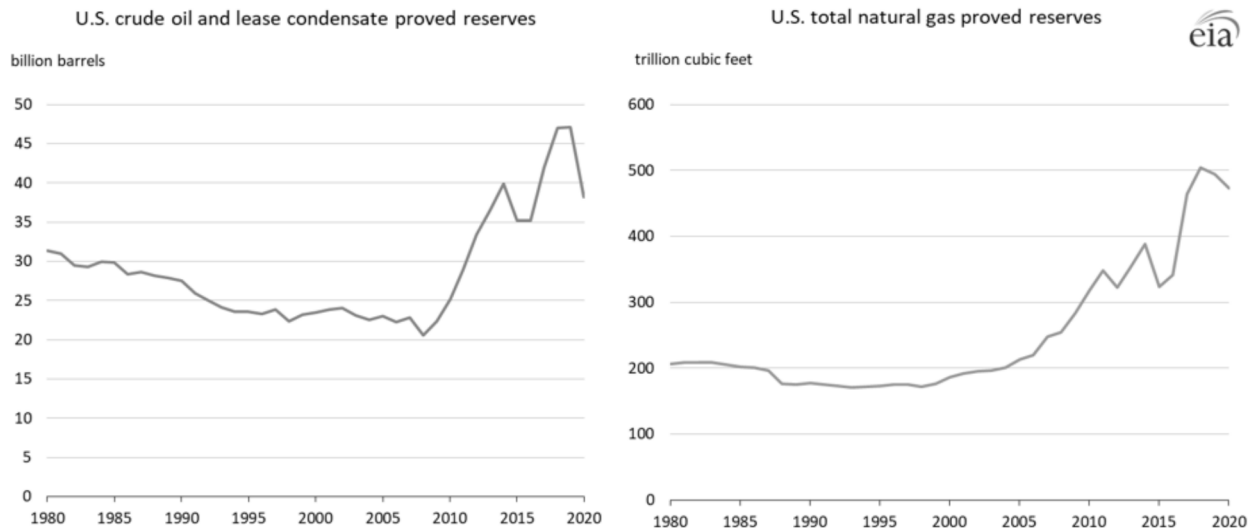


Figure 4.1: U.S. Proved Reserves 1980-2020 (U.S. Energy Information Administration: U.S. Crude Oil and Natural Gas Proved Reserves)

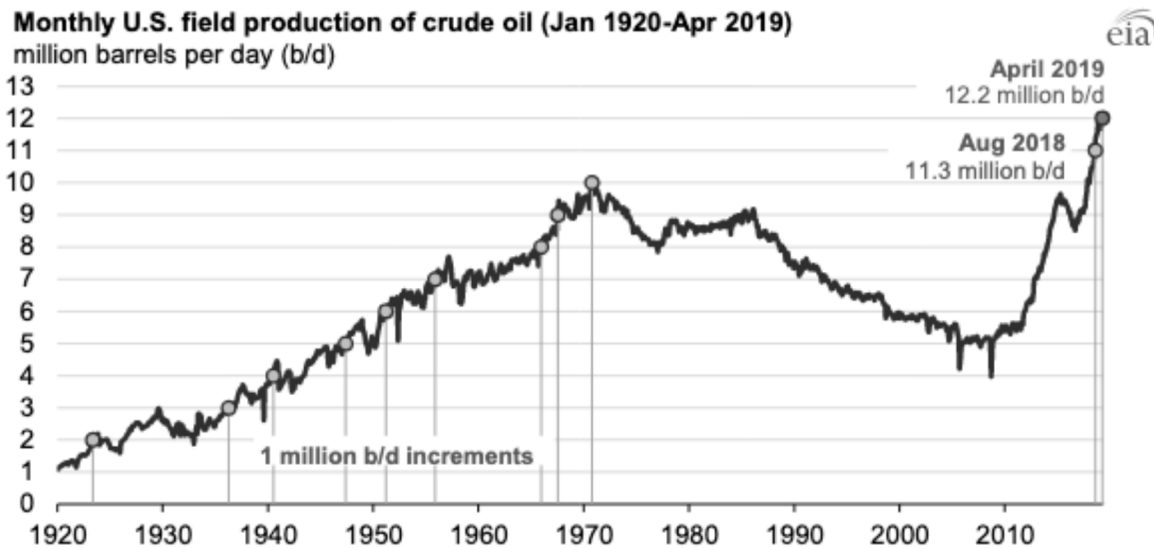


Figure 4.2 U.S. crude oil production surpassed 12 million barrels per day in April. U.S. Energy Information Administration (EIA).

The figure reveals how hydraulic fracturing and horizontal drilling techniques, implemented since the 1990s, have allowed both natural gas and oil reserves to increase. The increase is expected to continue as more fields are developed with the newly implemented technology. In late 2014, rapid increases in U.S. production led to oversupply in the global market, causing the price of oil to plummet.⁴⁰¹ This increase of supply is not limited to one

⁴⁰⁰ Geary, E. (2019, July 8). U.S. crude oil production surpassed 12 million barrels per day in April. U.S. Energy Information Administration (EIA). Retrieved February 23, 2022, from <https://www.eia.gov/todayinenergy/detail.php?id=40032>

⁴⁰¹United States Energy Information Association. (2020, January).

country. Oil reserves throughout the world have increased since 1980. Virtually every oil-producing country – both old and new – have had large increases. The greatest changes have occurred in Africa, with a total increase of 134% since 1980.⁴⁰² The importance of this cannot be overstated. The largest discoveries and expansions of carbon fuel are occurring in the developing world.

By 2018, the electrification rate in Africa was at 45%—81% of this electricity was provided by carbon fuel.⁴⁰³ With a fifth of the world's population and the lowest household electrification rate, Africa's energy consumption is in its infancy. The amount needed to develop countries in Africa will mean an incredible increase in carbon fuel usage and emissions. The increase will be facilitated by vast quantities of oil and natural gas discovered in places such as Angola and the Congo, which saw 466% and 309% increases in oil reserves, respectively. With reduced operating costs and increased efficiency in extraction across the board, developed and developing nations will have little incentive to move away from carbon-based fuels.⁴⁰⁴

The new carbon fuel rush represents a key challenge in the incentive base for moving away from carbon-based energy. Carbon, as it stands, is available in greater quantities every year. There must be an intentional effort to mitigate this fact.

Geopolitics of Non-Carbon Energy

Geopolitical context factors massively into the use of carbon fuels. It has the overall international affairs environment of the twenty-first century. Moving away from carbon fuels represents an opportunity to rewrite the geopolitics of energy. However, the transition is just that—a revision. Non-carbon fuel presents similar challenges and dependencies based not only on geography, but international affairs. Remediating the need for non-carbon fuel requires large amounts of land and investment, which is currently lacking. Sustainable non-carbon energy is still based on geography and requires large allocations of resources. From fields of wind turbines to deserts coated in solar panels, the cost is high. Every major non-carbon energy source requires its own rare resources. Lithium, nickel, and other rare-earth metals must be extracted in quantities larger than ever before. Additionally, the unreliable nature of such energy risks dependencies on the importation of energy – primarily carbon-based, – which will work to undo the transition away from fossil fuels. Potential supplemental energy sources such as nuclear have come under controversy in many countries where implementation may mean a successful energy independence. Counter to this, countries such as China seek to dominate these fields in investment and research development. Without independent domestic development, nations risk

⁴⁰² “Oil Reserves.” Our World in Data. Global Change Data Lab, 2021.

https://ourworldindata.org/grapher/oil-proved-reserves?country=~OWID_WRL.

⁴⁰³ Tekie, Bruk, Pedi Obani, Gerald Forkour, Ebenezar Amankwaa, Thelma Arko, Qondi Moyo, and Maria Ancilla Bomband. “Africa's Development - United Nations University.” United Nations: Institute for Natural Resources in Africa. United Nations, 2019.

https://i.unu.edu/media/inra.unu.edu/publication/5247/Discussion-paper-Africas-Development-in-the-age-of-stranded-Assets_INRARreport2019.pdf.

⁴⁰⁴ “Statistical Review of World Energy: Energy Economics: Home.” British Petroleum. The British Petroleum Company Ltd., 2021.

<https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html>.

future dependencies on foreign technology. The future requires the confrontation of these factors. It also requires the large mobilization of resources and international leadership on the methods of non-carbon development.

In 2014, China surpassed the United States in the production of low-carbon energy. At each country's current yearly rate of increase, China will more than double the United States' production by the end of the decade.⁴⁰⁵ This is possible due to massive government investment in large-scale, low-carbon energy projects. Projects such as the Three Gorges Dam, with a cost near \$30 billion, produced energy constituting 4% of China's total energy needs after the first three years of operation.⁴⁰⁶ This project and others have become a focal point of energy development in China. Comparative projects elsewhere in the world are hard to find, and reveal an emerging dominance in China for non-carbon fuel. These projects additionally represent a preview of the scale of mobilization needed to provide for a nation's energy needs without carbon.

Although the overall cost of non-carbon sources has decreased in recent years, the cost of transition away from fossil fuels will invariably be high.⁴⁰⁷ From 2010 to 2020, the United States saw a decrease in research and development of renewable sources of energy.⁴⁰⁸ The IEA estimates that by 2030, investment in non-carbon energy must reach \$1.3 trillion in order to meet the target of NZE 2050. This would mean surpassing the 2014 record-high \$1.2 trillion invested in carbon fuels.⁴⁰⁹ The simple reality is that the investment apparatus is not there. The largest amounts of research and development strictly favor carbon fuels. Without a marked change in this trend, the United States and others risk not only failing their emissions goals, but also being left dependent on foreign technology and development for future non-carbon energy.

The reality of constructing a non-carbon system is that it will be resource intensive. Most nations will have access to non-carbon sources of energy, but the distribution of suitable land and resource areas is uneven.⁴¹⁰ For example, areas such as the southwestern United States are suitable for the development of solar, while northern Europe possesses the potential for efficient wind power. Countries with high volcanic activity may make use of geothermal energy. Conclusively, the development of non-carbon energy requires consideration of the economic and security infrastructure connected to these regions.

Access to non-carbon energy will become a focus of domestic energy policy. However, beyond simple maintenance lies other issues as well. There exists a significant discrepancy of

⁴⁰⁵ "Electricity Generation from Low-Carbon Sources." Our World in Data. Global Change Data Lab, 2021. <https://ourworldindata.org/grapher/low-carbon-electricity?tab=chart>

⁴⁰⁶ Ponseti, Marta, and Jordi Lopez Pujol. "The Three Gorges Dam Project in China." Chinese Academy of Science, 2006. https://digital.csic.es/bitstream/10261/27902/1/Lopez-Pujol_01.pdf.

⁴⁰⁷ "U.S. Energy Information Administration - EIA - Independent Statistics and Analysis." Average U.S. construction costs for solar and wind generation continue to fall - Today in Energy - U.S. Energy Information Administration (EIA). U.S. Energy Information Administration, September 16, 2020. <https://www.eia.gov/todayinenergy/detail.php?id=45136>.

⁴⁰⁸ IEA. "Key World Energy Statistics 2021 - Analysis."

⁴⁰⁹ "Net Zero by 2050 - Analysis." IEA. International Energy Association, 2021. <https://www.iea.org/reports/net-zero-by-2050>.

⁴¹⁰ Timmons, David, Jonathon M Harris, and Brian Roach. "The Economics of Renewable Energy - Boston University." Boston University. Global Development and Environment Institute, 2014. <https://www.bu.edu/eci/files/2019/06/RenewableEnergyEcon.pdf>.

power produced versus power generated in non-carbon fuels. Where a traditional carbon-based energy plant may produce energy at about 90% of its capacity, a source such as wind may struggle to reach 30%.⁴¹¹ This will take comparatively more land and resources to produce a similar amount of energy. While in the future this technology is expected to improve, the reality is that development must occur now.

The need for large amounts of land and resources for non-carbon fuel cannot be understated. These resources will need to be procured on the international market and will create unique geopolitical challenges. For example, key in the production of electric vehicles, lithium represents a strategic resource poised to gain importance in the coming years. The worldwide production of lithium increased by 21% in 2021. Nearly all of the U.S. supply is imported, with 54% of these imports coming from Argentina. While discoveries of lithium in the United States account for nearly 10% of the world's reserves, the United States relies entirely on importation.⁴¹² The reality is that lithium represents only one of many precious metals which will be required in the development of non-carbon energy. If the United States is to undergo a transition, it will require secure methods of procurement of the materials required for development. The fact represents an undeniable geopolitical challenge in the future.

Carbon Hegemony

In 2020, the United States led the world in crude oil production, with a total of 706 mt (778.23 t) produced. During the same period, the United States was not even in the top ten of oil exporters.⁴¹³ At the same time, Russia was both number two in production and exportation. Producing 12.4% of the world supply of oil and exporting just over half that number, Russia represents a large player in the world market. It likewise leads the world in the export of natural gas. Looking at renewables, Russia has a starkly different outlook. It is fifth in hydroelectricity, fourth in nuclear energy, and most important of all, it produces comparatively miniscule amounts of wind and solar energy.⁴¹⁴ In the pursuit of non-carbon development, Russia has shown very little progress. Despite having a high potential for both hydroelectric and wind power development, the majority of their energy development is continually focused on carbon.⁴¹⁵ Russia occupies a powerful position in the carbon export market and has little incentive to jeopardize this position in favor of a transition away from fossil fuels.

This sentiment is not isolated to just Russia. OPEC, well known for its ability to dictate the global market, has also disagreed with the assessment of a reduction in carbon fuels. In 2016, its former secretary general Abd Salem Al-Badri stated that, "Fossil fuels will need to supply more than three-quarters of the energy mix by 2040," elaborating that "Fossil fuels remain

⁴¹¹ Timmons, David, Jonathon M Harris, and Brian Roach. "The Economics of Renewable Energy

⁴¹² Mineral Commodity Summaries. U.S. Geological Survey, 2022.

<https://www.usgs.gov/centers/national-minerals-information-center/mineral-commodity-summaries>.

⁴¹³ IEA. "Key World Energy Statistics 2021 – Analysis."

⁴¹⁴ IEA. "Key World Energy Statistics 2021 – Analysis."

⁴¹⁵ Iusubova, Narmina. University of Northern Iowa. UNI, July 2017.

<https://scholarworks.uni.edu/cgi/viewcontent.cgi?article=1425&context=etd>.

abundant and are necessary for our future, just as they have been an essential part of our past.”⁴¹⁶ While there is truth in the statement that carbon fuel will represent a key part of the future of energy, that outlook represents a significant market resistance to transition. While this represents a predictable attitude from one of the largest oil-producing organizations, OPEC can affect the ability for a country to progress in non-carbon development. Carbon fuels are key, and market manipulation of their supply can ensure dependency for the foreseeable future. This threat was articulated by the current OPEC secretary general Mohammed Barkindo, who warned that, “If the necessary investments [to fossil fuels] are not met, it could have not only implications as viewed in current gas developments in Europe and elsewhere around the world, [but] leave long-term scars, not only for producers but consumers as well”.⁴¹⁷ The statement is real for countries who have already been affected by a shortage of energy. Germany, relying on Nord Stream 2 for natural gas from Russia, broke from the rest of Europe on its outlook toward Russian aggression in Ukraine.⁴¹⁸ Despite eventually momentarily halting the opening of the pipeline,⁴¹⁹ the moves have shown the influence carbon fuel has on international politics. Carbon producers will not only disincentivize a transition through market power, but through hard power as well. The geopolitical reality of the future will be to mitigate this influence.

Mitigation is possible, but only through the fulfillment of need. The United States, as one of the largest producers of carbon fuel,⁴²⁰ could facilitate a movement away from countries like Russia, and likewise away from a carbon future. This involves not only energy sources, but material sources needed for non-carbon energy. The geopolitical reality of the future cannot rely on the goodwill of the market nor the actions of those incentivized to continue exporting carbon fuels. It requires a vanguard of policy which promotes the market viability of non-carbon energy.

Concluding Statement

Transition from carbon fuel creates geopolitical issues. New and robust sources of carbon fuel discovered within the past decades reveal that the initial conception of limited amounts of oil and natural gas is false. As a result, nation states will be continually incentivized to extract from these reserves. In addition, some of the largest of these reserves are geographically positioned in areas where countries are poised to enact the most economic development. Without mitigation of market incentive to continually invest in these new sources of carbon fuel, the reality of the future is an increase, not decrease, in use of carbon energy.

⁴¹⁶ “Fossil Fuels and the Future.” Organization of Petroleum Exporting Countries . OPEC, 2016. https://www.opec.org/opec_web/en/press_room/3467.htm.

⁴¹⁷ Suleymanova, Radmilla. “OPEC Says Oil Will Remain Number One, Despite Green Energy Push.” OPEC News | Al Jazeera. Al Jazeera, September 28, 2021. <https://www.aljazeera.com/economy/2021/9/28/opec-says-oil-will-remain-no-1-despite-green-energy-push>

⁴¹⁸ Eckert, Vera, and Kate Abnett. “How Much Does Germany Need Russian Gas?” Reuters. Reuters, January 20, 2022. <https://www.reuters.com/world/europe/how-much-does-germany-need-russian-gas-2022-01-20/>.

⁴¹⁹ Eddy, M. (2022, February 22). *Germany responds to Russia, halting Nord Stream 2 Pipeline*. The New York Times. Retrieved February 23, 2022, from <https://www.nytimes.com/2022/02/22/business/nord-stream-russia-putin-germany.html>

⁴²⁰ IEA. “Key World Energy Statistics 2021 – Analysis.”

In the scenario of transitioning into non-carbon sources of energy, there exists a similar litany of geopolitical complications. Non-carbon fuel is restricted to its viable geography, and the distribution of such fuel around the world is uneven. Each lacks the power generation capacity of carbon fuels, which necessitate more land and resources than would otherwise be required. Regardless of this technology progressing, the material cost of non-carbon energy will create similar trade dependencies that countries experience today. More rare-earth metals such as lithium will need to be extracted, traded, and processed, creating and expanding on commodity trade routes. The resulting increase and movement of trade will hold high strategic significance and represent potentials for conflict. Furthermore, the research and development of non-carbon energy is vital to the potential success of a non-carbon system. With research being concentrated in particular countries, there exists the possibility of the development of new dependencies and strategic vulnerabilities.

Finally, the existing carbon hegemony will not disappear overnight. Its players, the largest producers of carbon energy, are not currently incentivized to stop their exportation, and will actively pursue efforts to halt the transition away from carbon energy. They each represent a potential roadblock in the development of non-carbon energy. They threaten, both through market power and more literally in their rhetoric, to leverage their position to maintain the status quo. Without a reliable exporter of carbon energy who also seeks a transition to non-carbon energy, dependent national economies could remain tied to carbon.

In undertaking the effort to move away from carbon energy, one also accepts the geopolitical realities in the transition, implementation, and normalization of non-carbon energy. Without confronting these realities, their efforts will inevitably fail.

Chapter 5: Energy Security

Definition of Energy Security

Energy security is defined by the IEA as “the uninterrupted availability of energy sources at an affordable price.”⁴²¹ Theoretically, energy security for a country means access to energy regardless of events and circumstances in other states. In practical terms, this means each nation should have backup supplies or alternatives in case of serious interruptions to the supply of a critical source.

There are many potential energy security issues including, but not limited to, geopolitical conflict or political instability in energy-exporting countries, attacks on supply infrastructure, natural disasters, terrorism, and political manipulation by energy-rich countries. Energy security is important to every country, since it defines an issue of national security and economic stability. For governments, past energy crises have only highlighted the need for energy security.

Experience shows that the majority of nations follow the policy of developing to a high degree whatever energy sources exist within their borders. For a large number of emerging

⁴²¹ “Emergency Response Exercises – Energy Security.” IEA. IEA. Accessed February 14, 2022. <https://www.iea.org/areas-of-work/ensuring-energy-security/emergency-response-exercises>.

countries, this includes the use of coal—the most widespread fossil fuel—which often plays a central role in power generation and heating for both industry and residences.

Even as climate change becomes a more pressing problem, countries are still hesitant to take the necessary steps to reduce their carbon footprint. Such is the case where energy security, or the reliance on domestic resources, will contribute over time to forms of insecurity stemming from growing climate impacts.⁴²²

Past Instances of Energy Security Issues

Historically, energy security issues for the United States were generally tied to oil or other forms of carbon energy. In 2020, petroleum made up 32.2% of the United States' energy consumption by source.⁴²³ While still a significant percentage, oil's share of energy production within the United States has decreased over time, and since 2005, has also decreased in overall volume.⁴²⁴ The United States still does not produce all the oil it consumes. Though imports have fallen by more than a third, the country continues to import more than six million barrels per day of crude oil, rendering it dependent primarily on neighboring Canada and Mexico.⁴²⁵ This has drastically reduced the vulnerability to crises of the global market. In fact, rising oil production and decreasing consumption has made the United States several times—on the scale of a monthly basis—a net exporter of petroleum (crude oil and petroleum products) since 2019.⁴²⁶ Such is not the case for a majority of the country's allies, both in Europe and East Asia. The nations Japan and South Korea, as well as Europe, have endured energy security problems to present.

The primary reasons for energy crises relating to oil imports are interruptions in supply due to political instability in oil exporting countries, failures of infrastructure, lack of development of new reserves, and manipulation of the global market through the withholding of supply, among others. The most famous historical examples of such crises occurred in the 1970s, such as the 1973 Arab Oil Embargo. In 1973, Arab members of OPEC temporarily halted oil shipments to the United States, the Netherlands, Portugal, Rhodesia (modern-day Zimbabwe), and South Africa in response to their support of Israel during the Yom Kippur War.⁴²⁷ The embargo had dramatic effects on these countries, including the price of a barrel of oil

⁴²² IEA, "Emergency Response Exercises - Energy Security."

⁴²³ "U.S. Energy Information Administration - EIA - Independent Statistics and Analysis." U.S. Energy Information Administration (EIA). EIA. Accessed February 14, 2022. <https://www.eia.gov/outlooks/steo/report/electricity>.

⁴²⁴ "U.S. Energy Information Administration - EIA - Independent Statistics and Analysis." U.S. petroleum consumption decreased to a 25-year low in 2020 - Today in Energy - U.S. Energy Information Administration (EIA). EIA. Accessed February 20, 2022. <https://www.eia.gov/todayinenergy/detail.php?id=49016>.

⁴²⁵ "U.S. Energy Information Administration - EIA - Independent Statistics and Analysis." As total U.S. crude oil imports have fallen, imports from Canada have increased - Today in Energy - U.S. Energy Information Administration (EIA). EIA. Accessed February 20, 2022. <https://www.eia.gov/todayinenergy/detail.php?id=43196#:~:text=As%20a%20result%2C%20by%202019,and%20Venezuela%20have%20generally%20decreased.>

⁴²⁶ EIA, "U.S. petroleum consumption decreased to a 25-year low in 2020 - Today in Energy - U.S. Energy Information Administration (EIA)."

⁴²⁷ "Arab Oil Embargo." Encyclopædia Britannica. Encyclopædia Britannica, inc. Accessed February 14, 2022. <https://www.britannica.com/event/Arab-oil-embargo>.

quadrupling in the United States.⁴²⁸ In this situation, the dependence on the Middle East was leveraged by Arab nations both punishing supporters of Israel and elevating oil prices in order to capture more revenue. This prompted considerable changes in energy policy, including increased domestic oil production in the United States and a greater focus on energy efficiency.⁴²⁹

Cyber Attacks and Energy Security

The economy as a whole is transitioning to a more digital landscape. The energy sector is simply one part of this digitalization, albeit an important part. “Energy systems around the world are becoming more interconnected and intelligent.”⁴³⁰ There are many benefits to this shift, however, it does open up the possibility for new risks, notably cyberattacks. In 2021, there were many high profile cyber breaches “such as Solar Winds, Colonial Pipeline and dozens of others that had major economic and security related impact.”⁴³¹ Governments around the world are aware of this issue, yet it remains quite prominent. Studies show that “cybercriminals can penetrate 93 percent of company networks.”⁴³² This is quite a high degree of risk for the energy sector, especially as a transition away from carbon sources to more variable non-carbon sources necessitates further digitalization.

The U.S. government has taken steps to address the issue of cybersecurity. It organizes drills through its Office of Cybersecurity, Energy Security, and Emergency Response (CESER). CESER runs numerous cybersecurity exercises such as Liberty Eclipse, which is “the Department of Energy’s cybersecurity-focused exercise series.”⁴³³ It also runs CyberStrike, “CESER’s professional cybersecurity training for operational technology environments.”⁴³⁴ More money has been invested into developing tools to understand cyber risks and protecting against them, as well as building more critical infrastructure.⁴³⁵ These strides are a step in the right direction, and have already had an impact. On May 7, 2021, the Colonial Pipeline Company was able to “proactively [halt] pipeline operations in response to a ransomware attack.”⁴³⁶ They were then able to work in conjunction with the DOE, the FBI, the Cybersecurity and Infrastructure Security Agency (CISA), and the Federal Energy Regulatory Commission (FERC) “to mitigate gas shortages and resume operations as quickly, safely, and securely as possible.”⁴³⁷ This shows

⁴²⁸ Encyclopædia Britannica, “Arab Oil Embargo.”

⁴²⁹ Encyclopædia Britannica, “Arab Oil Embargo.”

⁴³⁰ IEA, “Energy Security - Areas of Work.”

⁴³¹ Brooks, Chuck. “Cybersecurity in 2022 – a Fresh Look at Some Very Alarming Stats.” Forbes. Forbes Magazine, January 24, 2022.

<https://www.forbes.com/sites/chuckbrooks/2022/01/21/cybersecurity-in-2022--a-fresh-look-at-some-very-alarming-stats/?sh=38497a256b61>.

⁴³² Brooks. ““Cybersecurity in 2022 – a Fresh Look at Some Very Alarming Stats.”

⁴³³ Office of Cybersecurity, Energy Security, and Emergency Response, “Energy Security.”

⁴³⁴ Office of Cybersecurity, Energy Security, and Emergency Response, “Energy Security.”

⁴³⁵ “2021: Ceser Made Huge Strides to Secure U.S. Energy Sector from Evolving Threats.” Energy.gov. Office of Cybersecurity, Energy Security, and Emergency Response. Accessed February 14, 2022.

<https://www.energy.gov/ceser/articles/2021-ceser-made-huge-strides-secure-us-energy-sector-evolving-threats>.

⁴³⁶ Office of Cybersecurity, Energy Security, and Emergency Response, “2021: Ceser Made Huge Strides to Secure U.S. Energy Sector from Evolving Threats.”

⁴³⁷ Office of Cybersecurity, Energy Security, and Emergency Response, “2021: Ceser Made Huge Strides to Secure U.S. Energy Sector from Evolving Threats.”

potential. However, amid the multiple other cyber attacks in 2021 that were not effectively stopped, it is clear that what has been done to date is not enough. The shift to a more digital future is not likely to stop. The U.S. government needs to devote considerable resources to strengthening the energy sector's cybersecurity system. Vulnerability in this area is not recommended during a transition away from carbon sources.

The New Energy Security Issue: How Dependence on Renewables Impacts Energy Security

In the past, energy security was primarily related to oil embargoes or price manipulations, but contemporary energy security has a new issue: renewables. While renewables like solar and wind are non-carbon sources and thus help mitigate emissions, they are not constant sources of energy. They are intermittent, so they require backups to fill in gaps in generation and are highly dependent on weather conditions. The share of renewable generation in the United States is expected “to increase from 20% in 2021 to 22% in 2022 and 24% in 2023.”⁴³⁸ The share in other nations is much lower and will likely only increase as “countries that represent 70% of global emissions of carbon dioxide” put in place actual policies “to reach net-zero emissions by mid-century or soon after.”⁴³⁹ While this does not mean that 100% of energy will come from renewable sources, a large portion will. Thus, issues of energy reliability need to be considered.

Renewable energy has been considered an energy security solution for dependence on coal and oil. Its costs have fallen greatly since 2015, and it theoretically improves a country's self-reliance by replacing imports. However, even as it solves one problem, it introduces others. These problems have been highlighted with the recent energy crisis in Europe. The EU's “share of renewable energy in energy consumption increased continuously between 2004 and 2019, from 9.6% to 19.7%.”⁴⁴⁰ The energy shares of energy consumption between EU member states are as high as 56.4% in Sweden and 43.1% in Finland.⁴⁴¹ This increase is completed with an attempt to dramatically cut the use of fossil fuels as well as nuclear power. This leaves these nations highly vulnerable to environmental disasters. Dramatic weather changes coupled with a resurgence in energy use as the pandemic eases has forced Europe to rely on other countries for energy. The United States, for instance, has sent dozens of tankers carrying LNG to Europe.⁴⁴² The policy effects of this crisis are clear, as Europe has moved to include nuclear energy and natural gas as “green” in their new energy policies.

This crisis has illuminated the risks involved with renewable energy. The fear is that countries might see the recent European energy crisis as a warning and put more focus on energy

⁴³⁸ EIA, “U.S. Energy Information Administration - EIA - Independent Statistics and Analysis.” <https://www.eia.gov/outlooks/steo/report/electricity>.

⁴³⁹ “Security of Clean Energy Transitions – Analysis.” IEA. IEA. Accessed February 14, 2022. <https://www.iea.org/reports/security-of-clean-energy-transitions-2>.

⁴⁴⁰ “Shedding light on energy on the EU. EuroStat.” Accessed February 14, 2022. <https://ec.europa.eu/eurostat/cache/infographs/energy>.

⁴⁴¹ EuroStat, “Shedding light on energy on the EU.”

⁴⁴² Blackmon, David. “How Europe's Energy Crisis Could Force the EU to Adopt More Sensible Policies.” *Forbes*. *Forbes Magazine*, January 5, 2022.

<https://www.forbes.com/sites/davidblackmon/2022/01/03/how-europes-energy-crisis-could-force-the-eu-to-adopt-more-sensible-policies/?sh=18b589c73ed3>.

security as opposed to making dramatic shifts in their energy sources. At this moment in time, coal is the primary resource for countries to maintain energy security. Coal has very well established infrastructure, it is very widespread, and it is cheap. This makes it easy for both developed countries and developing nations to rely on. Another issue is the lack of trust in governments that this crisis has caused. The U.S. government acknowledged that public confidence is a key aspect of energy security.⁴⁴³ To mitigate any potential hesitations of the public about a shift to utilizing more renewable energy, the IEA recommended that governments “provide credible step-by-step plans to reach their net zero goals, building confidence among investors, industry, citizens and other countries.”⁴⁴⁴ This will be especially important following Europe's energy crisis. A shift to primarily renewable energy introduces new energy security risks, therefore a lack of understanding or even disagreement by the public should be mitigated to the highest degree possible.

The final energy security risk involved with a transition to primarily non-carbon energy sources is access to key minerals required for the production of those forms of energy. “Overall mineral requirements for clean energy technologies almost triple between today and 2050 in the STEPS, and up to sixfold in the NZE.”⁴⁴⁵ This is a significant amount, especially given that there are far fewer and smaller countries exporting these critical minerals. Increases in the price of minerals due to political unrest within these countries, or disruptions in the supply chain, “could make solar panels, wind turbines, EV batteries and grid lines 5-15% more expensive, with ripple effects on the costs of transitions.”⁴⁴⁶ This is concerning given the goal of providing energy at an affordable price. Solar and wind are currently very cheap energy sources, but this could change. This potential for disruption needs to be accounted for by policy makers. Similar mechanisms to the existing energy security solutions for potential oil supply chain disruptions might function in this case.

Climate Change and Energy Security

Excluding the looming transition to primarily renewable energy sources, climate change introduces new energy security issues. Climate change not only increases the average temperature, but increases the unpredictability of weather as well as the frequency of extreme weather events. It is estimated that “around a quarter of the world’s electricity networks face a high risk of destructive cyclone winds, while over 10% of dispatchable generation fleets and coastal refineries are prone to severe coastal flooding and a third of freshwater-cooled thermal power plants are located in high water stress areas.”⁴⁴⁷ This is quite a significant number. In the case of extreme weather events, many would be faced with blackouts for extended periods of time. In terms of energy security, this is one of the worst problems.

⁴⁴³ Office of Cybersecurity, Energy Security, and Emergency Response, “Energy Security.”

⁴⁴⁴ IEA, “Emergency Response Exercises – Energy Security.”

⁴⁴⁵ “Energy Security and the Risk of Disorderly Change – World Energy Outlook 2021 – Analysis.” IEA. IEA. Accessed February 14, 2022.

<https://www.iea.org/reports/world-energy-outlook-2021/energy-security-and-the-risk-of-disorderly-change>.

⁴⁴⁶ IEA, “Energy Security and the Risk of Disorderly Change – World Energy Outlook 2021 – Analysis.”

⁴⁴⁷ “Electric Vehicles – Analysis.” IEA. IEA, November 1, 2021. <https://www.iea.org/reports/electric-vehicles>.

The current state of electricity grids only compounds this problem. The current structure of the electricity grid is very lean. This means that utility companies try to keep costs down by having “few redundant power lines for critical nodes. Power lines also aren't buried in areas where they might pose a risk (like sparking wildfires). As a result, failures are more likely to create cascading outages or other problems.”⁴⁴⁸ The electricity grid has been streamlined, opening it up to more potential failures in the case of extreme weather events, which are increasing. In addition, as the world moves to mitigate climate change through clean energy transitions, it transitions to more renewable energy technologies, “which are often sensitive to a changing climate.”⁴⁴⁹ This problem was exemplified in the recent European energy crisis. The current energy structure is not set up to deal with climate change. The government needs to take action to ensure that energy structures can cope with the energy security risks that climate change brings.

There have been limited steps taken by governments and organizations to address these issues. Actions by the U.S. government primarily involve exercises to coordinate reactions within the energy sector to extreme weather events or other natural disasters.⁴⁵⁰ These exercises come in the form of the Clear Path series. This series helps address the possibility of damage or complete failure to multiple critical infrastructure sectors.⁴⁵¹ It does so by running exercises and building upon and validating “improvements made in response to lessons learned from previous exercises and real-world incidents.”⁴⁵² This is a step in a positive direction. However, the IEA stressed the need for even greater resilience to climate change impacts if the energy sector is to be able to “cost-effectively meet the rising energy demands driven by global economic and population growth.”⁴⁵³ While the United States' population is decreasing, the global population is not, and global economic growth continues to rise. As a world leader, the United States plays a critical role within this global economy. Therefore, increased resilience within the United States energy sector would benefit the economy as a whole.

Markets Impact on Energy Security

The market can also impact energy security. Altering demand is a powerful tool that can be used to help achieve goals. One specific area in which the market might address energy security concerns is in relation to the demand for oil. Particularly in the United States, the demand for oil in the transportation sector is quite high, as many people have personal cars. In addition, much of the United States' cross-country shipping is done by trucks, rather than potentially more fuel-efficient methods such as trains.⁴⁵⁴ However, the potential for reducing oil

⁴⁴⁸ Arciniegas Rueda, Ismael, and Aaron Clark-Ginsberg. “The Downside of a Lean Electric Grid.” RAND Corporation. RAND Corporation, October 13, 2020. <https://www.rand.org/blog/2020/10/the-downside-of-a-lean-electric-grid.html>.

⁴⁴⁹ IEA, “Electric Vehicles – Analysis.”

⁴⁵⁰ Office of Cybersecurity, Energy Security, and Emergency Response, “Energy Security.”

⁴⁵¹ Office of Cybersecurity, Energy Security, and Emergency Response, “Energy Security.”

⁴⁵² Office of Cybersecurity, Energy Security, and Emergency Response, “Energy Security.”

⁴⁵³ IEA, “Emergency Response Exercises – Energy Security.”

⁴⁵⁴ Kiersz, Andy. “Here's How Stuff Gets Shipped across America.” Business Insider. Business Insider, April 22, 2014. <https://www.businessinsider.com/how-freight-crosses-the-country-2014-4>.

demand in the transportation sector lies in the development and increased marketing of electric cars. “Electric car sales reached a record 3 million in 2020, up 40% from 2019. This strong growth was a stark contrast with general car market sluggishness globally, with overall car sales down 16% due to the Covid-19 crisis.”⁴⁵⁵ While still a small fraction of the overall market, this number is clearly increasing and has the potential to dramatically reduce fuel demand.

The EV sector is only going to increase, as “More than 20 economies have announced targets to phase out internal combustion vehicles over the next 10-30 years.”⁴⁵⁶ For the United States specifically, “the federal aim is for EVs to make up 50% of new passenger cars and light trucks sold by 2030. At the same time, a number of individual states have announced more ambitious targets.”⁴⁵⁷ This has potential in two areas: mitigating climate change and reducing traditional energy security risks. Currently, because of the transportation sector, the economy is reliant on oil. However, if internal combustion engines could be phased out—and it looks as though they will due to increasing amounts of EVs—this reliance will be reduced. This would further reduce the United States’ dependence on other oil producing countries. To address the energy security issue of oil in this way, incentives need to be implemented to bolster demand. Such incentives include “differentiated taxation of vehicle registration, depending on the vehicle tailpipe CO₂ and/or pollutant emissions, spurs market penetration of zero-emission vehicles. Fiscal incentives for vehicle purchases, as well as complementary measures that enhance the value proposition of driving electric (e.g. preferential parking rates, road toll rebates and low-emission zones).”⁴⁵⁸ The market will play a key role in mitigating climate change and addressing energy security issues. Nonetheless, there needs to be incentives so that the market reacts in the desired direction.

A switch to primarily EVs is not without risks. The two primary energy security issues it introduces are the potential for increased volatility within the oil market and the need to increase electricity production. In the former, the problem with oil is that it is not generally a variable source of energy. In fact, it can take “years to develop new supply sources or vary production [of oil], and it is very hard for consumers to switch to other fuels or increase fuel efficiency in the near—term when prices rise.”⁴⁵⁹ This is significant, as plans to increase the production of EVs calls for a dramatic decrease of oil production.

However, it is unclear if these goals will actually be met or if they will change. There are many potential changes in policy settings that could come to be. If there are “no further changes in today’s policy settings, as in the STEPS, oil demand in 2050 remains above 100 mb/d [millions of barrels per day]. By contrast, if the world single-mindedly pursues a 1.5 °C stabilization objective, then oil demand falls to 24 mb/d in the same year.”⁴⁶⁰ This is quite a

⁴⁵⁵ IEA, “Electric Vehicles – Analysis.”

⁴⁵⁶ IEA, “Electric Vehicles – Analysis.”

⁴⁵⁷ IEA, “Electric Vehicles – Analysis.”

⁴⁵⁸ IEA, “Electric Vehicles – Analysis.”

⁴⁵⁹ “U.S. Energy Information Administration - EIA - Independent Statistics and Analysis.” Energy & Financial Markets - Crudeoil - U.S. Energy Information Administration (EIA). EIA. Accessed February 14, 2022. https://www.eia.gov/finance/markets/crudeoil/spot_prices.php.

⁴⁶⁰ IEA, “Energy Security and the Risk of Disorderly Change – World Energy Outlook 2021 – Analysis.”

significant potential for variability. Because the United States is an oil producer as well, it needs to consider how this potential for variability might impact not only its consumers—who might find themselves without oil—but its producers of oil and all their employees. Misjudging necessary oil production could lead to significant issues for the U.S. economy. In addition, electricity production will need to be ramped up to compensate for the increase in electricity demand, as the transportation sector moves to electricity as its main fuel source.

Solutions to Energy Security Without Reliance on Carbon Energy Sources

Within the goal of mitigating climate change, the need for solutions to energy security issues without relying on carbon energy sources is clear. The IEA has pushed many potential solutions to these issues. Its current work has involved organizing “Emergency Response Exercises on a biannual basis since 2002.”⁴⁶¹ The U.S. government conducts similar exercises within its government.⁴⁶²

However, there needs to be more proactive work. One primary area is boosting the flexibility of power systems. This involves “increased investment in dispatchable generation,” the “cost-effective use of existing energy infrastructure by using low-carbon fuels,” and incorporating “mechanisms to reward flexibility in electricity systems, and to expand energy storage, demand response and digital solutions as well as regional integration of electricity markets.”⁴⁶³ Increased flexibility will address several new energy security issues. Primarily, it will help address issues caused by the variability of energy production of renewable energy sources like wind and solar. It will also help mitigate the effects of any interruptions caused by extreme weather events. Finally, it will help reduce stresses on the oil and electricity markets caused by a shift to EVs.

Two other areas that would dramatically help reduce energy security issues occurring because of a shift to renewable energy would be increased investment in development and the use of a wider variety of energy sources. To help mitigate the variability in wind and solar, sources like nuclear energy can be used. Nuclear is an essentially non-carbon energy source that produces energy more reliably than wind and solar, even if it is more expensive. Investment into diverse low-carbon technologies such as “various forms of storage and demand-side response technologies” would also greatly reduce the stress upon the electricity grid as more variable energy sources are employed.⁴⁶⁴ Overall, while energy security is a pressing issue, there are solutions already in place, as well as the potential for more solutions to be instituted. Ensuring that adequate weight is given to energy security will foster a more smooth and peaceful journey to mitigating climate change.

Chapter 6: The Growing Role of Emerging Economies in Global Emissions

Definition of Emerging Economies

⁴⁶¹ IEA, “Energy Security - Areas of Work.”

⁴⁶² Office of Cybersecurity, Energy Security, and Emergency Response, “Energy Security.”

⁴⁶³ IEA, “Energy Security - Areas of Work.”

⁴⁶⁴ IEA, “Energy Security - Areas of Work.”

While there is no standard definition of what makes a country an emerging economy, this chapter draws on several characteristics that are particularly relevant to energy production and consumption.

Various institutions and scholars have used different parameters in their definitions. Most sources agree that emerging economies are diverse and that the line between emerging and developing economies is fluid. The International Monetary Fund (IMF) has three criteria for an emerging economy: systemic presence, market access, and income level.⁴⁶⁵ Systemic presence includes the size of a population, its economy, and exports, while market access denotes the share of a country's external debts; income level is a country's GDP per capita. The Balance defines emerging economies as "nations investing in more productive capacity."⁴⁶⁶ These countries are moving away from traditional economies, meaning an economy based on agriculture and the export of raw goods. According to The Balance, emerging economies are in the process of becoming industrialized countries.⁴⁶⁷ For the purposes of this report, an emerging economy is a country that is increasing its GDP and production.

The IMF lists twenty countries as emerging economies that take up 34% of global GDP and 46% of the purchasing power parity. Those countries are Argentina, Brazil, Chile, China, Colombia, Egypt, Hungary, India, Indonesia, Iran, Malaysia, Mexico, the Philippines, Poland, Russia, Saudi Arabia, South Africa, Thailand, Turkey, and the UAE.⁴⁶⁸

⁴⁶⁵ "Miles to Go: The Future of Emerging Markets – IMF F&D." n.d. International Monetary Fund. Accessed February 14, 2022.

<https://www.imf.org/external/pubs/ft/fandd/2021/06/the-future-of-emerging-markets-dutttagupta-and-pazarbasioglu.htm>.

⁴⁶⁶ Kimberly Amadeo. "What Are Emerging Markets?" The Balance.

<https://www.thebalance.com/what-are-emerging-markets-3305927>.

⁴⁶⁷ Amadeo, "What Are Emerging Markets?"

⁴⁶⁸ "Miles to Go: The Future of Emerging Markets – IMF F&D." IMF



Figure 6.1: (Data from the IMF) Map of Emerging Economies—emerging economies are in dark gray.⁴⁶⁹
Increasing Energy Demand and Production

In the past 15 years, the center of global energy has shifted from wealthy developed nations, the OECD, to the emerging economies of Asia. This is a historic change with profound implications for energy supply and carbon emissions. By 2019, only two countries—China and India—were using more coal than the rest of the world combined and generating more emissions than all of the OECD nations, including North America, Europe, Japan, and South Korea. China and India, however, are the largest countries amid dozens of emerging economies whose energy consumption is rapidly growing and whose choice of sources has huge importance and implications for global decarbonization.

Figure 6.2 shows that OECD energy consumption has largely plateaued since about 2006 while China, Asia, South and Central America, and Africa are all growing. The OECD accounted for 61% of final world consumption in 1973, but by 2019 its share had fallen to 38%, and levels of consumption remained steady. China, on the other hand, grew from 7.9% to 21% over the same period. Non-OECD Asian countries have also seen a dramatic increase, from 5.8% to 13.6%.⁴⁷⁰ A major anomaly to these trends among emerging economies is Russia, which suffered a major collapse in economic and industrial activity with the collapse of the Soviet Union.

⁴⁶⁹ “Miles to Go: The Future of Emerging Markets – IMF F&D.” IMF

⁴⁷⁰ IEA, *Key World Energy Statistics 2021*: 37

World total energy supply by region, 1971-2019 (EJ)

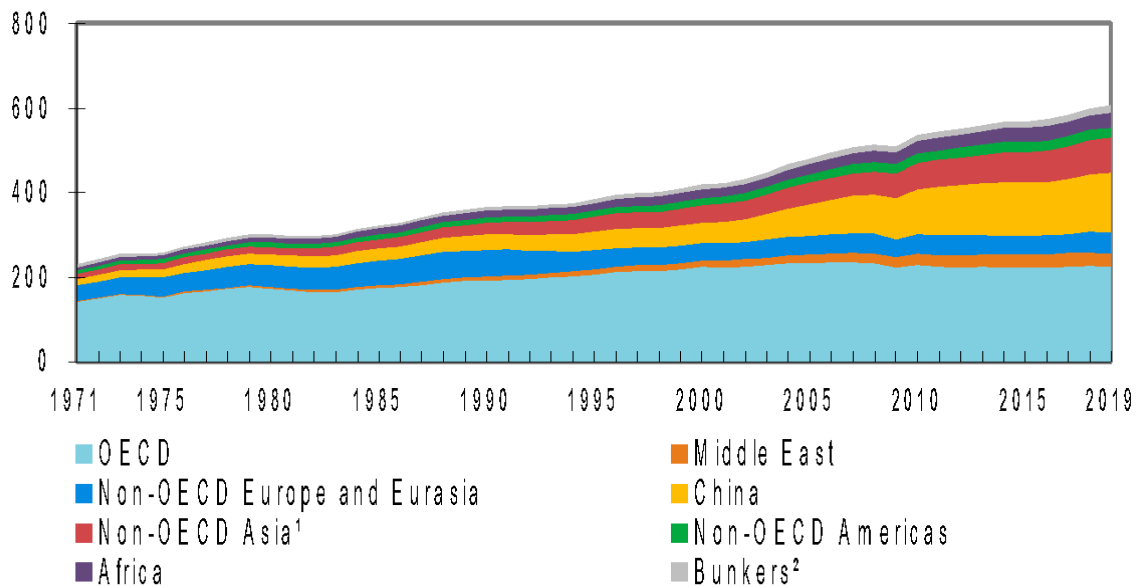


Figure 6.2: (Data from *Key World Energy Statistics*) Global energy consumption by region, 1971-2019.⁴⁷¹

This trend follows in the production of different energy sources like natural gas. OPEC took up 71.7% of natural gas production in 1973, but only 38.3% in 2019. The Middle East took up 2.1% of natural gas production in 1973 and 16.1% in 2019.⁴⁷² OECD decreased its overall coal production as well as its share of global production, while in 1973 they accounted for 55.7% and only 18.8% in 2019. China increased its share from 13.6% to 49.7%.⁴⁷³ Data shows that emerging economies like China are increasing their production and are becoming a greater share of the global use and production of energy. OECD countries no longer account for most of the energy use, which shows the increasing global importance of emerging economies.

Why Energy Demand Is Increasing

Data shows that energy demand and consumption are increasing most rapidly in emerging economies. Diverse factors contribute to rising energy demand. The primary factor is positive economic growth, a defining feature of emerging economies, which has typically seen annual increases in GDP and GDP per capita above 4% and as high as 10%.⁴⁷⁴

Economic growth drives energy use as more products are made, transported, and delivered, incomes rise and allow individuals to purchase more goods, including energy-consuming products, engage in new activities, and more.⁴⁷⁵ One-half of new consumption

⁴⁷¹ IEA, *Key World Energy Statistics 2021*:36

⁴⁷² IEA, *Key World Energy Statistics 2021*:15

⁴⁷³ IEA, *Key World Energy Statistics 2021* :17

⁴⁷⁴ “World Economic Outlook (October 2021) - Real GDP growth.” International Monetary Fund. Accessed February 23, 2022.

https://www.imf.org/external/datamapper/NGDP_RPCH@WEO/OEMDC/ADVEC/WEOWORLD.

⁴⁷⁵ Woetzel, “Outperformers: High-growth emerging economies and the companies that propel them.”

of goods occurs in emerging economies.⁴⁷⁶ India's number of "consuming class households" rose from 3.5 million in 1995 to over 35 million in 2016.⁴⁷⁷ This can cause a "pro-growth cycle," where rising production increases income, which then increases demand, which then circles back to increased production.⁴⁷⁸ Industrialization also means more production. In 1978, four out of five Chinese workers were employed in agriculture, but by 1994, only one out of two were agricultural workers.⁴⁷⁹ Increasing incomes leads to more consumption of goods; it also increases the number of people consuming energy. As of 2013, 1.2 billion people were experiencing complete energy poverty, as they had no access to electricity.⁴⁸⁰ Energy poverty is the lack of "adequate, affordable, reliable, quality, safe and environmentally sound energy services to support development."⁴⁸¹ Indonesia has made significant progress in reducing its energy poverty issues. In 2000, only 50% of Indonesians had access to electricity, but by 2018, 95% had access to electricity.⁴⁸² As countries expand their electrical grid to include more people, the energy demand increases.

Population changes influence energy demand as well. More people means more energy use. Consumption will also increase with population, as there are simply more people who need resources. Many emerging economies are also among the most populous countries, giving them a boost in energy demand. Brazil, China, Egypt, India, Indonesia, Mexico, the Philippines, and Russia all have populations well above 100 million people.

Increasing Emissions

Emerging economies tend to increase their carbon emissions over time. The main reason for this is that they rely strongly on domestic energy resources, which are often fossil fuels. China and India, for example, have large coal resources which produce the majority of the energy in both countries, including about 50% of all electricity.⁴⁸³ China's coal production—the largest in the world—went up 4.7% in 2021.⁴⁸⁴ The government had called for "miners to work at

⁴⁷⁶ Jonathan Woetzel, "Outperformers: High-growth emerging economies and the companies that propel them." McKinsey, 2018, <https://www.mckinsey.com/featured-insights/innovation-and-growth/outperformers-high-growth-emerging-economies-and-the-companies-that-propel-them>.

⁴⁷⁷ Woetzel, "Outperformers: High-growth emerging economies and the companies that propel them."

⁴⁷⁸ Woetzel, "Outperformers: High-growth emerging economies and the companies that propel them."

⁴⁷⁹ Zulie Hu and Mohsin S. Khan, "Economic Issues 8 -- Why Is China Growing So Fast?" International Monetary, 1997 Fund <https://www.imf.org/EXTERNAL/PUBS/FT/ISSUES8/INDEX.HTM>.

⁴⁸⁰ "What is energy poverty: definition, statistics & effects on society." Habitat for Humanity. Accessed February 14, 2022. <https://www.habitat.org/emea/about/what-we-do/residential-energy-efficiency-households/energy-poverty>.

⁴⁸¹ "What is energy poverty: definition, statistics & effects on society."

⁴⁸² "What is energy poverty: definition, statistics & effects on society."

⁴⁸³ Evelyn Cheng, "China has 'no other choice' but to rely on coal power for now, official says," CNBC, 2021, <https://www.cnbc.com/2021/04/29/climate-china-has-no-other-choice-but-to-rely-on-coal-power-for-now.html>.; Arshad R Zargar, "India making strides toward clean energy, but quitting coal isn't easy," CBS News, 2021, <https://www.cbsnews.com/news/india-coal-shortage-green-energy-renewables-transition/>.

⁴⁸⁴ Jillian Ambrose, "China's coal production hit record levels in 2021 | Coal," The Guardian, 2022 <https://www.theguardian.com/environment/2022/jan/17/chinas-coal-production-hit-record-levels-in-2021>.

maximum capacity to help fuel the country's economic growth."⁴⁸⁵ As many as 153 coal mines in China were approved for expansion in the second half of 2021.⁴⁸⁶

Many other emerging economies use coal as their primary energy source, such as Indonesia and India. In India, coal has the same success rates as in China. Coal production in 2021 was up 6.7% compared to 2019.⁴⁸⁷ According to the IEA, China is the world's biggest coal producer, followed by India.

Other countries have large oil reserves, such as Iran and Saudi Arabia. Saudi Arabia is the world's largest producer of crude oil.⁴⁸⁸ It also has at least 15% of the world's proven oil reserves, meaning it has the second-highest amount of reserves globally.⁴⁸⁹ Iran has the fourth-highest amount of oil reserves in the world.⁴⁹⁰ However, U.S. sanctions severely crippled its oil industry, which only began to recover in February 2022.⁴⁹¹ Many other emerging economies are among countries with large oil reserves. Listed by increasing rank, they are: Brazil, China, the UAE, and Russia.⁴⁹²

Natural gas is the most common fossil fuel in some countries as well. Russia is the second-largest producer of dry natural gas, and natural gas is its largest energy source.⁴⁹³ Most emerging economies have a lot of fossil fuel resources within their counties. For security and economic purposes, they focus on using those resources to fuel their growing energy demands. This leads to emissions growing with energy demand.

Fossil Fuel's Wealth

Many emerging economies have very large or growing fossil fuel industries. For many of these nations, oil and gas exports in particular are a key source of export revenue. Petroleum exports accounted for about one-half of the UAE's export revenue in 2017.⁴⁹⁴ Russia also received one-half of its export revenue from fossil fuels in 2017.⁴⁹⁵ Other nations with significant oil, gas, or coal exports included Indonesia, Malaysia, Vietnam, Brazil, and South Africa.

New fossil fuel reserves are also being discovered frequently. These can bring considerable wealth and energy security to countries that lacked such resources. One of the

⁴⁸⁵ Jillian Ambrose, "China's coal production hit record levels in 2021 | Coal,"

⁴⁸⁶ Muyu Xu and Shivani Singh, "China's monthly coal output rises to highest since March 2015," Reuters, 2021, <https://www.reuters.com/world/china/chinas-oct-coal-output-rises-highest-since-march-2015-2021-11-15/>.

⁴⁸⁷ "India's coal production stands at 74.8 million tonnes for December," The Hindu, 2022, <https://www.thehindu.com/business/Economy/indias-coal-production-stands-at-748-million-tonnes-for-december/article38131454.ece>.

⁴⁸⁸ "International," U.S. Energy Information Administration, <https://www.eia.gov/international/overview/country/SAU>.

⁴⁸⁹ Samuel Stebbins, "The largest oil reserves in the world are found in these 15 countries," USA Today, 2019, <https://www.usatoday.com/story/money/2019/05/22/largest-oil-reserves-in-world-15-countries-that-control-the-worlds-oil/39497945/>.

⁴⁹⁰ Samuel Stebbins, "The largest oil reserves in the world are found in these 15 countries."

⁴⁹¹ Alex Lawler, "As nuclear talks resume, Iran's oil exports increase," Reuters, 2022,

<https://www.reuters.com/business/energy/nuclear-talks-resume-irans-oil-exports-increase-2022-02-10/>.

⁴⁹² Samuel Stebbins, "The largest oil reserves in the world are found in these 15 countries."

⁴⁹³ "Russia - Countries & Regions - IEA," IEA, Accessed February 14, 2022, <https://www.iea.org/countries/russia>.

⁴⁹⁴ Samuel Stebbins, "The largest oil reserves in the world are found in these 15 countries."

⁴⁹⁵ Samuel Stebbins, "The largest oil reserves in the world are found in these 15 countries."

largest regional examples of this is sub-Saharan Africa, where many new offshore and onshore oil and gas fields have been discovered since 2010. Additionally, Turkey found new oil and natural gas fields in the Black Sea in 2021.⁴⁹⁶

Countries are also opening new coal plants and mines. Russia plans to open new mines in the Arctic, while India has been pushing for increasing coal production as well.⁴⁹⁷ These new fossil fuels could bring in billions of U.S. dollars in revenue to states and enhance their self-reliance in energy production. There is too much money in fossil fuels to expect emerging economies to abandon it.

Efforts by Advanced Economies

Advanced economies have pledged to help other countries make the transition into non-carbon sources. However, not all money pledged has been distributed. At the Copenhagen summit (COP15) in 2009, advanced economies pledged \$100 billion a year to less-developed nations with emerging economies, but that pledge was not met. Donor countries claim they sent \$78 billion in 2017 and \$80 billion in 2018, but estimates put the money at only about \$20 billion in 2017.⁴⁹⁸ A second estimate argues that some loans given were not useful due to repayment plans and that OECD countries were counting aid that did not go to relevant projects. Several countries have accused donor countries of over inflating their contributions. The United States has been giving far below what it should according to wealth-based estimates, while Japan donates more than its wealth-based share, though primarily in loans.⁴⁹⁹ However, even if the pledged amount was paid in full, developing countries claim that it would not be enough. At the most recent climate summit, COP26, China, India, and other developing nations requested \$1.3 trillion annually.⁵⁰⁰ The United States has pledged to double climate change aid by 2024.⁵⁰¹ Increased funding may not be enough, as climate mitigation and adaptation are expensive, and emissions continue to increase.

⁴⁹⁶ “Turkey discovered 60 mln barrels of oil equivalent reserves so far in 2021: Minister - Latest News,” Hürriyet Daily News, 2021, <https://www.hurriyetdailynews.com/turkey-discovered-60-mln-barrels-of-oil-equivalent-reserves-so-far-in-2021-minister-169059>; Ariel Cohen, “Turkey Finds Enormous Gas Field In The Black Sea — But Tricky Process Ahead,” Forbes, Sep 18, 2020, <https://www.forbes.com/sites/arielcohen/2020/09/18/turkeys-new-natural-gas-find-in-the-black-sea-exciting-but-tricky-process-ahead/?sh=240a84a75a86>.

⁴⁹⁷ Mike Eckel, “In Russia, Coal Is Still King. And The Government Wants Even More,” Radio Free Europe, 2021, <https://www.rferl.org/a/russia-coal-mining-environment-safety/31590889.html>; Leela, Jacinto “Behind a 'green façade', Modi expands coal mining on India's tribal lands,” France 24, 2021, <https://www.france24.com/en/asia-pacific/20211007-india-s-tribes-bear-the-brunt-of-modi-s-latest-push-for-coal-ahead-of-cop26>.

⁴⁹⁸ Jocelyn Timperley, “The broken \$100-billion promise of climate finance — and how to fix it.”

⁴⁹⁹ Jocelyn Timperley, “The broken \$100-billion promise of climate finance — and how to fix it.”

⁵⁰⁰ Matthew Dalton, “China, India and Other Developing Nations Seek \$1.3 Trillion a Year in Climate Finance,” Wall Street Journal, Nov. 4th, 2021, <https://www.wsj.com/articles/climate-finance-china-india-11636039142>.

⁵⁰¹ Valerie, Volcovici, “Biden pledges to double U.S. climate change aid; some activists unimpressed,” Reuters, Sept. 21st, 2021, <https://www.reuters.com/business/environment/us-seeks-double-climate-change-aid-developing-nations-biden-2021-09-21/>.

Chapter 8: Current United States Energy Situation

The United States' Reliance on Fossil Fuels

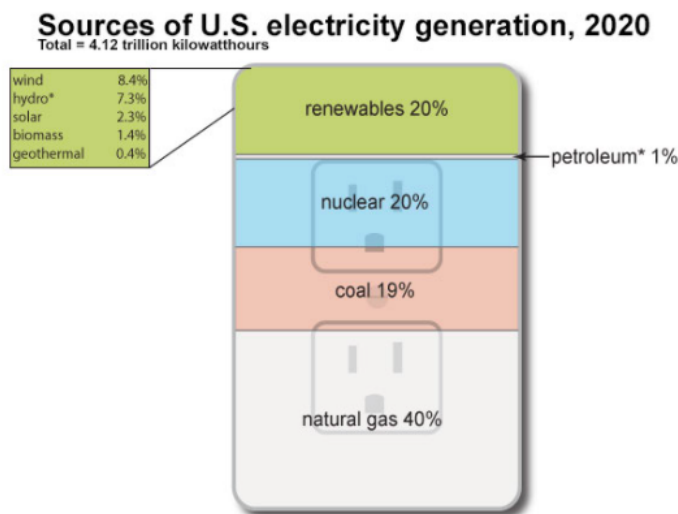
Approximately 60% of electricity in the United States comes from fossil fuels.⁵⁰² In 2020, as shown in Figure 1.1, natural gas made up 40% of the U.S. portfolio of power sources, making it the largest by a wide margin, with coal at 19%.⁵⁰³ Non-carbon sources, however, have grown considerably at 40%, divided evenly between renewables, including hydropower and nuclear. At present, natural gas and non-hydro renewables, especially solar and wind, are the fastest-growing sources of electricity.⁵⁰⁴

Figure 8.1

As pictured in the table to the right, natural gas made up the majority of U.S. electricity generation in 2020.⁵⁰⁵ (Graphic by the United States Energy Information Association).

Fossil fuel production in the United States increased from 73 quadrillion Btu in 2018 to 77.14 Btu in 2021, and is expected to rise.⁵⁰⁶ Based on the most recent Short-Term Energy Outlook (STEO), fossil fuel production is projected to continue rising, reaching a new record in 2023.⁵⁰⁷ Correlating with this increase in fossil fuel production, there has been a rise in CO₂ emissions as well. Global carbon dioxide emissions from natural gas increased 30% over the last decade. Natural gas now emits over 7.5 billion metric tons.⁵⁰⁸

Fossil fuels will not be going away any time soon. Even if the United States reaches NZE 2050, it would still be using approximately one-quarter to one-half as much oil and gas as it does today.⁵⁰⁹ Looking to the future, with rising climate change advocacy and public pressure, the United States could constrain its domestic output of fossil fuels. In April 2021, the U.S. Department of Treasury declared that the United States would no longer fund natural gas projects



⁵⁰²Jason Bordoff and Meghan O'Sullivan, "Green Upheaval: The New Geopolitics of Energy," January 2022.

⁵⁰³"U.S. Energy Information Administration - EIA - Independent Statistics and Analysis." Electricity in the U.S. - U.S. Energy Information Administration (EIA). Accessed February 14, 2022. <https://www.eia.gov/energyexplained/electricity/electricity-in-the-us.php>.

⁵⁰⁴ "U.S. Energy Information Administration - EIA - Independent Statistics and Analysis," Renewables became the second-most prevalent U.S. electricity source in 2020 - Today in Energy - U.S. Energy Information Administration (EIA), accessed February 24, 2022, <https://www.eia.gov/todayinenergy/detail.php?id=48896>.

⁵⁰⁵ U.S. Energy Information Administration, "Electricity in the U.S."

⁵⁰⁶U.S. Energy Information Administration "Independent Statistics and Analysis"

⁵⁰⁷U.S. Energy Information Administration, "Independent Statistics and Analysis"

⁵⁰⁸U.S. Energy Information Administration, "Independent Statistics and Analysis"

⁵⁰⁹Bordoff and O'Sullivan, "Green Upheaval"

abroad due to increasing climate concerns. However, they revealed that they will make exceptions and continue funding projects in Sierra Leone and several other developing nations to help their economies thrive.⁵¹⁰

Out of all fossil fuel sources, natural gas has become the most dominant. The United States consumed approximately 31.5 quadrillion Btu of natural gas in 2020.⁵¹¹ Natural gas is widely used and abundant. Gas now helps power the electric power sector, industrial sector, residential sector, commercial sector, and transportation sector. An increase in natural gas production in the United States has kept prices relatively low, though they have risen in 2022 due to large exports of LNG to Europe, decreasing the overall amount domestically. The increase in natural gas production can be attributed to more efficient drilling and production techniques associated with multistage hydraulic fracturing. Over the past decade, the increase in supply has led to a decline in prices, making the source more appealing.⁵¹² As a consequence of these low prices, natural gas has outcompeted both coal and nuclear energy in many parts of the United States. Coal and nuclear plants have shut down as a result, which has reduced emissions overall but has also decreased the total amount of non-carbon power generated. As many as 500 coal plants have closed over the past decade and a half.⁵¹³ In 2020, coal consumption in the United States was at the same level as in 1949. Coal production in 2020 was about 10.69 quads, the lowest amount since 1965.⁵¹⁴

The majority of energy lost by closing coal power plants has been replaced by natural gas. By partially substituting coal production, natural gas has decreased emissions—natural gas produces around 490 tonnes of greenhouse gas emissions annually compared to coal, which produces 820 tonnes annually.⁵¹⁵ Natural gas also causes fewer deaths per year as a result of air pollution in comparison to coal and oil. Furthermore, natural gas causes roughly 2.8 deaths per terawatt-hour of energy production, in comparison to 24.6 deaths caused by coal and 18.4 by oil.⁵¹⁶ As noted, however, natural gas has also been partially substituting nuclear power, meaning that emissions have increased relative to this non-carbon source. Nuclear energy produces only three tonnes of greenhouse gas emissions annually, and 0.07 deaths per

⁵¹⁰Bordoff and O'Sullivan, "Green Upheaval"

⁵¹¹"U.S. Energy Information Administration - EIA - Independent Statistics and Analysis," Use of natural gas - U.S. Energy Information Administration (EIA), accessed February 14, 2022, <https://www.eia.gov/energyexplained/natural-gas/use-of-natural-gas.php#:~:text=The%20United%20States%20used%20about,of%20U.S.%20total%20energy%20consumption.>

⁵¹²"U.S. Energy Information Administration - EIA - Independent Statistics and Analysis," U.S. energy facts explained - consumption and production - U.S. Energy Information Administration (EIA), accessed February 14, 2022, <https://www.eia.gov/energyexplained/us-energy-facts/>.

⁵¹³Rob Jackson, "Natural Gas Use Is Rising: Is That Good News or Bad News for the Climate?," Scientific American Blog Network (Scientific American, January 9, 2020), <https://blogs.scientificamerican.com/observations/natural-gas-use-is-rising-is-that-good-news-or-bad-news-for-the-climate/>.

⁵¹⁴U.S. Energy Information Administration, "U.S. energy facts explained"

⁵¹⁵U.S. Energy Information Administration, "Electricity in the U.S."

⁵¹⁶"Death Rates from Energy Production per Twh," Our World in Data, accessed February 24, 2022, <https://ourworldindata.org/grapher/death-rates-from-energy-production-per-twh.>

terawatt-hour—significantly less than natural gas.⁵¹⁷ It is fair to say that in the United States, gas is acting to slow carbon emissions, but that with continued increases, will reach a point where emissions will surpass those from the decreasing number of coal plants and total carbon from the power sector will rise once more.

The United States is in the precarious position of having enormous resources in every form of carbon energy (oil, gas, and coal), while also attempting to become a global leader in non-carbon energy production. Since 2015, the United States has become the world's largest producer of both oil and gas, and third in coal production. The United States is the largest crude oil producer in the world, making up 17% of total production at 706 megatonnes.⁵¹⁸ The United States is also the world's top natural gas producer, accounting for 23.6% of total production at 949 billion cubic meters.⁵¹⁹ For the first time since 1957, domestic energy production exceeded consumption in the United States in 2019.⁵²⁰ Energy consumption decreased by roughly 1%, while energy consumption increased by 6% in 2019.⁵²¹ Natural gas production equaled 95.75 quads, while consumption equaled 92.94 quads.⁵²² A majority of domestic energy production in 2020 was fossil fuels, specifically petroleum, natural gas, and coal. These three sources accounted for roughly 79% of total U.S. production in 2020.⁵²³

Energy and Emissions as a Political Issue

The topic of climate change has become politicized as disagreements arise regarding how to best handle the situation. The Democratic Party favors new federal legislation and policies that would rapidly lower emissions. Meanwhile, Republicans prefer to support fossil fuel industries and create policies that would help stimulate energy-related innovation by the private sector.

Unlike the Republican Party, Democrats reject the notion that combating climate change and maintaining a healthy economy are impossible to do simultaneously. The Democratic Party approves the goal of reaching net zero greenhouse gas emissions by 2050. The Democratic National Committee has also emphasized the need to eliminate carbon pollution from power plants by 2035.⁵²⁴ They support the development of technology for low and non-carbon energy sources and have proposed the installation of 500 million solar panels and 60,000 wind turbines within five years.⁵²⁵ They argue this would create domestic jobs. Democrats are in favor of instituting a clean-electricity standard. This would shift power providers to hydroelectric, nuclear, wind, solar, and other low-carbon forms of energy. The goal is to achieve 80%

⁵¹⁷U.S. Energy Information Administration, "Electricity in the U.S."

⁵¹⁸Hannah Ritchie and Max Roser, "Energy Mix," Our World in Data, November 28, 2020, <https://ourworldindata.org/energy-mix>.

⁵¹⁹Ritchie and Roser, "Energy Mix"

⁵²⁰U.S. Energy Information Administration, "U.S. energy facts explained"

⁵²¹U.S. Energy Information Administration, "U.S. energy facts explained"

⁵²²U.S. Energy Information Administration, "U.S. energy facts explained"

⁵²³U.S. Energy Information Administration, "U.S. energy facts explained"

⁵²⁴ "Combating the Climate Crisis and Pursuing Environmental Justice ," The Democratic Party, accessed February 14, 2022,

<https://democrats.org/where-we-stand/party-platform/combating-the-climate-crisis-and-pursuing-environmental-justice/>

⁵²⁵The Democratic Party, "Combating the Climate Crisis"

non-carbon electricity by the end of the decade.⁵²⁶ Meanwhile, the Republican Party is hesitant to shift away from fossil fuels.

The Republican Party is concerned about the potential loss of jobs and the economic toll that could occur with a shift away from fossil fuels. The United States is a major coal exporter, which supports many jobs. The United States' natural gas and oil industry provides 10.3 million domestic jobs and makes up roughly 8% of the nation's gross domestic product.⁵²⁷ Furthermore, it is estimated that a total transition to low and non-carbon energy could cost nearly \$100 trillion in additional capital spending over the next three decades.⁵²⁸ The majority of the Republican Party insists on continuing fossil fuel production. Over a dozen Republican state treasurers drafted a letter to John Kerry, President Joe Biden's climate envoy. The treasurers expressed frustration that banks were being pressured not to lend to oil, gas, and coal companies. They said the move would "eliminate the fossil fuel industry in our country."⁵²⁹ The letter highlighted the possibility that Republican states would pull assets from banks refusing to fund fossil fuel projects. Riley Moore, treasurer of West Virginia, said the end of financing fossil fuels would "devastate West Virginia and put thousands of families out of work."⁵³⁰ A recent Yale survey indicated that over the past 18 months, support among Republicans for non-carbon energy has dropped.⁵³¹ Rather than moving away from fossil fuels, Republican congressional leaders have supported other measures to address climate change. Specifically, measures focused on the private sector, such as planting about a trillion trees to help absorb carbon emissions and providing financial incentives to businesses to improve carbon capture technology.⁵³²

A lack of major movement addressing emissions problems on the federal level has shifted responsibility to the state level. All major U.S. cities and most states have now passed laws and launched programs to seriously reduce carbon emissions in the next few decades. California recently signed a COP26 commitment to have 100% zero-emission car sales by 2040.⁵³³ Hawaii became the first state to enact laws implementing the Paris Agreement. Virginia passed its Clean Economy Act, with ambitious goals for offshore wind energy and energy storage, as well as a

⁵²⁶Dino Grandoni, Brady Dennis, and Juliet Eilperin, "Democrats Push Sweeping Climate Legislation amid a Scorching Summer," *The Washington Post* (WP Company, July 16, 2021),

<https://www.washingtonpost.com/climate-environment/2021/07/16/climate-deal-democrats/>.

⁵²⁷"Oil & Natural Gas Contribution to U.S. Economy Fact Sheet," Energy API, accessed February 14, 2022, <https://www.api.org/news-policy-and-issues/taxes/oil-and-natural-gas-contribution-to-us-economy-fact-sheet>.

⁵²⁸Bordoff and O'Sullivan, "Green Upheaval"

⁵²⁹Oliver Milman, "Republicans Pledge Allegiance to Fossil Fuels like It's Still the 1950s," *the Guardian*, June 7, 2021, <https://linksinsight.co.uk/www.theguardian.com/us-news/2021/jun/07/republicans-fossil-fuels-coal>.

⁵³⁰Milman, "Republicans Pledge Allegiance"

⁵³¹Milman, "Republicans Pledge Allegiance"

⁵³²Alec Tyson, "On Climate Change, Republicans Are Open to Some Policy Approaches, Even as They Assign the Issue Low Priority," Pew Research Center (Pew Research Center, July 23, 2021),

<https://www.pewresearch.org/fact-tank/2021/07/23/on-climate-change-republicans-are-open-to-some-policy-approaches-even-as-they-assign-the-issue-low-priority/>.

⁵³³Elliot Davis, "Some States Are Taking Action against Climate Change, but Is It Enough?," *U.S. News*, January 2022,

<https://www.usnews.com/news/best-states/articles/2022-01-14/some-states-are-taking-action-against-climate-change-but-does-it-matter>.

commitment to greatly reduce greenhouse gas emissions in the power sector.⁵³⁴ Washington state passed a 100% clean energy law, which provides tax exemptions to promote clean energy projects.⁵³⁵ Even Indigenous tribes in the United States have enacted emission-reducing regulations. However, not all states are in agreement, as some continue to support oil and gas production.

In order for significant changes toward reducing emissions to occur, “There absolutely needs to be federal leadership on national and international goals and commitments,” according to Ben Grumbles, Maryland’s environment secretary.⁵³⁶ Federal emissions regulations assist in getting the country on the same page and working in unison toward making significant progress on limiting emissions.

The Potential of Low and Non-Carbon Energy in the United States

While still in competition with natural gas, low and non-carbon energy sources have vast potential in the United States. There has been an increase in national and state support for nuclear energy in recent years, including by the Biden administration. From 2014 to 2018, even though the number of operating nuclear reactors decreased, nuclear electricity generation increased.⁵³⁷ Upgrades to nuclear power plants have increased their capacity and helped nuclear plants consistently provide around 20% of total U.S. electricity generation from 1990 through 2019, even as total generation grew by more than 25%. Increased annual production is also due to the shortened length of time needed for reactors to be offline and refueling.⁵³⁸ Nuclear power generates over half of the country’s low-carbon electricity. This prevents over 470 million metric tons of carbon emissions from entering the atmosphere each year, equivalent to the pollution of 100 million cars.⁵³⁹ Currently, operating costs for nuclear power plants are relatively high. However, the DOE’s Light Water Reactor Sustainability (LWRS) program is working to modernize plant systems. This would reduce maintenance and operational costs and improve efficiency. The DOE is also working to develop accident tolerant fuels, which would have the potential to increase plant performance and produce less waste.⁵⁴⁰ With the modernization of nuclear power plants and improved efficiency, nuclear energy has great potential as a low-carbon source of electricity in the United States.

Wind is another low-carbon energy source with large potential in the United States, both onshore and offshore. Biden announced plans to develop new wind energy areas offshore the

⁵³⁴Julia Cusick, “States Are Laying a Road Map for Climate Leadership,” Center for American Progress, November 20, 2019, <https://www.americanprogress.org/article/states-laying-road-map-climate-leadership/>.

⁵³⁵Cusick, “States Are Laying”

⁵³⁶Davis, “Some States Are Taking”

⁵³⁷“U.S. Energy Information Administration - EIA - Independent Statistics and Analysis,” U.S. nuclear industry - U.S. Energy Information Administration (EIA), accessed February 15, 2022, <https://www.eia.gov/energyexplained/nuclear/us-nuclear-industry.php#:~:text=For%20cost%20and%20technical%20reasons,electricity%20generation%20was%20about%2020%25.>

⁵³⁸U.S. Energy Information Administration, “U.S. nuclear industry”

⁵³⁹“Advantages and Challenges of Nuclear Energy,” Energy.gov, 2021, <https://www.energy.gov/ne/articles/advantages-and-challenges-nuclear-energy.>

⁵⁴⁰Energy.gov, “Advantages and Challenges”

East Coast, including Empire Wind south of Long Island.⁵⁴¹ This would create 25,000 construction and development jobs between 2022 and 2030 and would support over 4,000 maintenance jobs thereafter. The DOE announced its goal of deploying 30 GW of wind power capacity by 2030. This would trigger over \$12 billion annually of capital investment in projects. It would also provide energy to 10 million homes per year and prevent 78 million metric tons of CO₂ emissions.⁵⁴² Efforts are underway to continually improve the potential of wind energy. The National Offshore Wind Research and Development Consortium (NOWRDC) awarded \$8 million to fifteen offshore wind research and development projects. This funding will “support structure innovation, supply chain development, electrical systems innovation, and mitigation of use of conflicts that will help reduce barriers and costs for offshore wind development.”⁵⁴³ Biden sees wind energy as having an “enormous opportunity” to “address the threats of climate change ... create millions of good-paying, union jobs ... [and] rebuild the middle class.”⁵⁴⁴

Solar energy, though less efficient in comparison to other low-carbon sources, also has untapped potential. Solar energy has gotten cheaper, dropping 70% in cost since 2014.⁵⁴⁵ Solar power capacity has grown from just 0.34 GW in 2008 to 97.2 GW today. Solar energy also provides new domestic jobs, currently employing over 250,000 solar workers.⁵⁴⁶ Biden has recognized that solar energy could potentially power 40% of U.S. electricity by 2035.⁵⁴⁷ However, grid integration challenges and “soft costs” (customer acquisition, permitting, and financing) prevent solar from really taking off. In order to increase efficiency and further drive down costs, technological advancements are needed.

Hydroelectric power also has potential in the United States. Hydropower takes up 37% of total U.S. renewable energy electricity generation.⁵⁴⁸ Hydropower facilities can immediately generate power to the grid, making it a good backup power source in the case of electricity disruptions.⁵⁴⁹ Hydropower provides clean drinking water, flood control, and irrigation support to communities. Construction costs remain relatively low when preexisting structures like dams,

⁵⁴¹“Biden Administration Jumpstarts Offshore Wind Energy Projects to Create Jobs,” The White House (The United States Government, March 29, 2021), <https://www.whitehouse.gov/briefing-room/statements-releases/2021/03/29/fact-sheet-biden-administration-jumpstarts-offshore-wind-energy-projects-to-create-jobs/>.

⁵⁴²The White House, “Biden Administration Jumpstarts”

⁵⁴³The White House, “Biden Administration Jumpstarts”

⁵⁴⁴The White House, “Biden Administration Jumpstarts”

⁵⁴⁵“Solar Energy in the United States,” Energy.gov, accessed February 15, 2022,

<https://www.energy.gov/eere/solar/solar-energy-united-states#:~:text=Solar%20power%20is%20more%20affordable,18%20million%20average%20American%20homes.>

⁵⁴⁶Energy.gov, “Solar Energy”

⁵⁴⁷Ella Nilsen, “Biden Administration Says Solar Energy Has the Potential to Power 40% of US Electricity by 2035,” CNN (Cable News Network, September 8, 2021),

<https://www.cnn.com/2021/09/08/politics/solar-energy-doe-report-climate/index.html>.

⁵⁴⁸“Hydropower Basics,” Energy.gov, accessed February 15, 2022,

<https://www.energy.gov/eere/water/hydropower-basics>.

⁵⁴⁹“Benefits of Hydropower,” Energy.gov, accessed February 15, 2022,

<https://www.energy.gov/eere/water/benefits-hydropower#:~:text=Hydroelectric%20power%20is%20a%20domestic,fishing%2C%20swimming%2C%20and%20boating.>

bridges, and tunnels can be utilized as a foundation.⁵⁵⁰ Approximately 74% of Washington state's electricity is generated by hydroelectric facilities.⁵⁵¹ Hydropower facilities generally have a longer lifespan than other energy sources. They often require fewer repairs and can operate for longer periods of time.⁵⁵² The DOE estimates that there is roughly 50 GW of untapped hydropower in the United States.⁵⁵³

Geothermal is another potential source with a small environmental footprint. Facilities consistently run twenty-four hours a day, seven days a week. The United States has the largest worldwide geothermal capacity at 3.8 GW. Geothermal facilities employ around 35,000 workers nationally.⁵⁵⁴ Geothermal energy could potentially supply energy to tens of millions of homes in the United States. The U.S. Geothermal Technologies Offices (GTO) is currently funding geothermal R&D to reduce costs and improve technology and efficiency.⁵⁵⁵ Geothermal electricity generation alone offsets the emissions of 4.1 million tons of CO₂, 110,000 tons of particulate matter, and 80,000 tons of nitrogen oxides per year.⁵⁵⁶

The transition to non-carbon energy in the United States is underway and needs the backing of state and federal governments. In 2019, non-carbon energy consumption surpassed coal for the first time in 130 years.⁵⁵⁷ The U.S. government predicts non-carbon sources will supply twice as much to the total energy consumption by the middle of the century. The only question that remains is “whether the completion of this switch will be delayed long enough to risk triggering the worst impacts of disastrous global heating.”⁵⁵⁸

Trends in U.S. Energy Since 2000

⁵⁵⁰Energy.gov, “Benefits of Hydropower”

⁵⁵¹Energy.gov, “Hydropower Basics”

⁵⁵²Energy.gov, “Hydropower Basics”

⁵⁵³“The USA Is the World's Third Largest Hydropower Producer by Capacity after China and Brazil,” International Association of the Year, accessed February 15, 2022, <https://www.hydropower.org/country-profiles/usa>.

⁵⁵⁴“Digging into Geothermal,” Energy.gov, accessed February 15, 2022, <https://www.energy.gov/downloads/infographic-digging-geothermal>.

⁵⁵⁵“Enhanced Geothermal Systems,” Energy.gov, accessed February 15, 2022, <https://www.energy.gov/eere/geothermal/enhanced-geothermal-systems-0>.

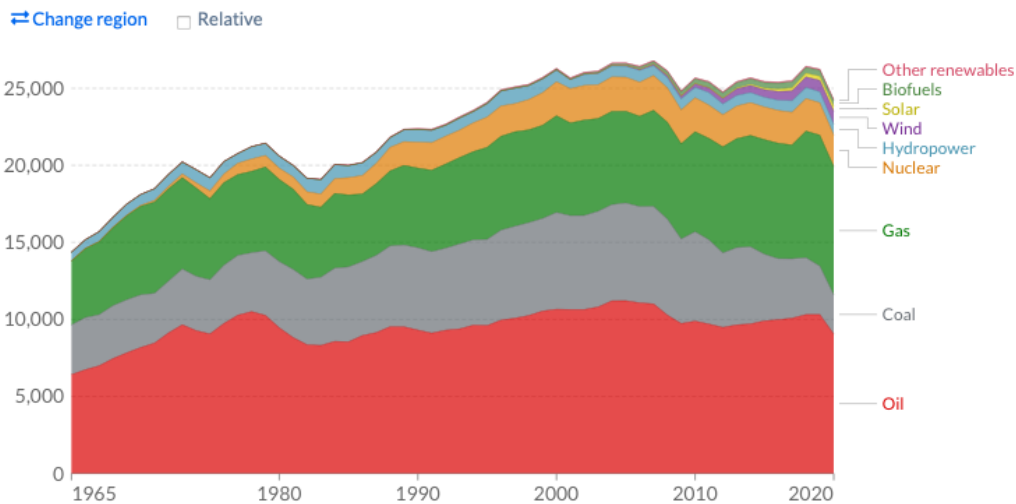
⁵⁵⁶“Geothermal Power Plants - Meeting Clean Air Standards,” Energy.gov, accessed February 15, 2022, <https://www.energy.gov/eere/geothermal/geothermal-power-plants-meeting-clean-air-standards>.

⁵⁵⁷“U.S. Energy Information Administration - EIA - Independent Statistics and Analysis,” U.S. renewable energy consumption surpasses coal for the first time in over 130 years - Today in Energy - U.S. Energy Information Administration (EIA), accessed February 15, 2022, <https://www.eia.gov/todayinenergy/detail.php?id=43895>.

⁵⁵⁸Oliver Milman, “Republicans New Favorite Study Trashes Biden's Climate Plans – but Who's behind It?,” The Guardian (Guardian News and Media, March 9, 2021), <https://www.theguardian.com/us-news/2021/mar/09/republican-study-wyoming-biden-climate-plans>.

Energy consumption by source, United States

Primary energy consumption is measured in terawatt-hours (TWh). Here an inefficiency factor (the 'substitution' method) has been applied for fossil fuels, meaning the shares by each energy source give a better approximation of final energy consumption.



Source: BP Statistical Review of World Energy

OurWorldInData.org/energy • CC BY

Figure 8.2. This graph illustrates the U.S. energy portfolio since 1965. (Graphic by Our World in Data).

It can be observed in Figure 2.1 that coal production has decreased significantly during the last decade, while there has been an increase from low-carbon sources. Emissions in the United States peaked around 2005 and have fallen since, largely due to the closure of coal plants. As can be observed in Figure 2.2, consumption of low-carbon energy sources surpassed coal in 2020. The United States consumed around 4,359 TWh of nuclear, hydroelectric, and other renewable sources combined in 2020, compared to just 2,556 TWh of coal consumed.⁵⁵⁹ The rapid decrease in coal consumption has had a major improvement regarding emissions. Natural gas has largely replaced coal, which has fewer greenhouse gas emissions but is not nearly as sustainable as non-carbon sources. The increase in production of solar and wind power has also substituted some of the decreases in coal consumption.

⁵⁵⁹Hannah Ritchie and Max Roser, "United States: Energy Country Profile," Our World in Data, November 28, 2020, <https://ourworldindata.org/energy/country/united-states>.

Energy production and consumption

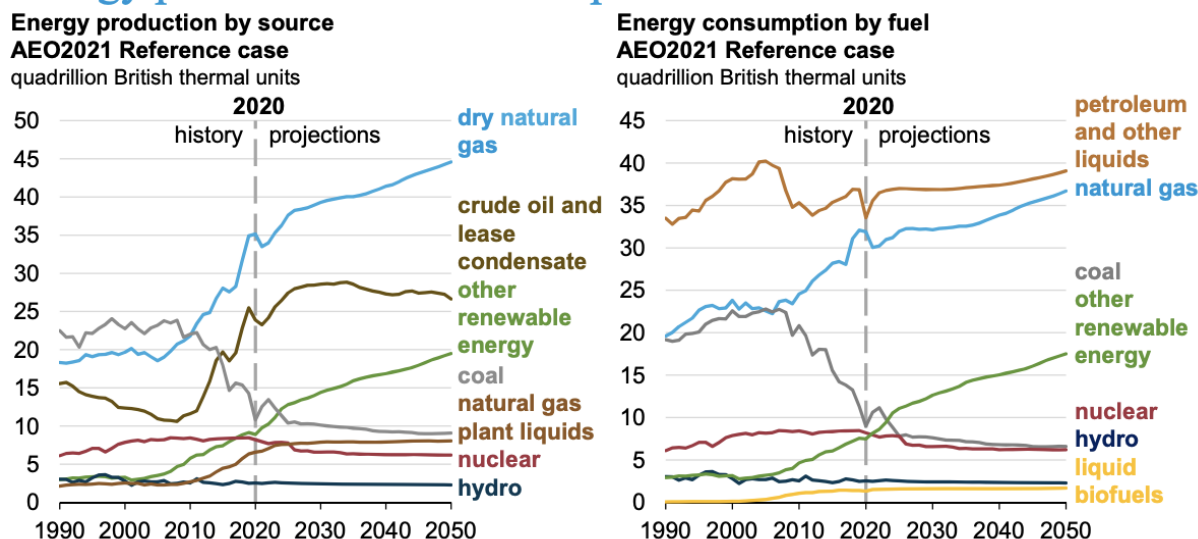


Figure 8.3. The chart on the left shows energy production by source in the United States from 1990 to 2020, with projections for the future. The figure to the right shows energy consumption by source in the United States from 1990 to 2020, with projections for the future. (Graphics by the United States Energy Information Administration).

The recent revolution in hydraulic fracturing, commonly known as “fracking,” has turned the United States into the main exporter of natural gas and, increasingly, crude oil and petroleum fuels. As Figure 2.1 illustrates, around the year 2010, the production of crude oil and natural gas skyrocketed. This is due primarily to advances in technology in the fracking process. Oil production in the United States reached an all-time high in 2018, surpassing Russia and Saudi Arabia to become the world’s largest oil producer.⁵⁶⁰ This has freed the United States from dependence on OPEC and has reduced the country’s dependency on its allies. According to the White House Council of Economic Advisers (CEA), “record U.S. petroleum production has helped stabilize the global price of oil and reduce the risk of huge price swings like the one that damaged the economy in 2007-2008.”⁵⁶¹ Crude oil is projected to level out as renewables become increasingly central to the U.S. energy profile.

Trends in U.S. Energy Moving Forward

Looking to the future, non-carbon energy (nuclear, hydro, and other renewables) can play an important role in improving U.S. energy security and reducing greenhouse gas emissions. Diversifying the energy supply will help diffuse reliance on any one energy source, reducing the likelihood of a major energy crisis. As the world moves toward a decarbonized energy system, many of the United States’ security risks will be significantly reduced. Some outcomes would include that “the influences of the petrostates and Russia’s leverage in Europe will be

⁵⁶⁰Jeffry Bartash, “Fracking Revolution That’s Made the U.S. the Top Global Oil Producer Is Boosting the Economy - and Keeping Emissions Down,” MarketWatch (MarketWatch, March 22, 2019), <https://www.marketwatch.com/story/fracking-revolution-thats-made-the-us-the-top-global-oil-producer-is-boosting-the-economy-and-curbing-emissions-too-2019-03-22>.

⁵⁶¹Bartash, “Fracking Revolution”

diminished, prices for electricity will be less volatile, and conflicts over natural resources will wane.”⁵⁶²

The largest source of emissions in the United States is currently transportation, specifically light-duty vehicles. The electrification of these vehicles will have a major impact, lowering U.S. emissions significantly. This change is already in motion, though it still has a long way to go. In 2021, hybrid, plug-in hybrid, and electric vehicles accounted for 11% of light-duty vehicle sales in the United States.⁵⁶³ Biden made an ambitious goal that by 2030, half of all new vehicles sold in the United States would be electric. Several big automakers have joined the revolution, including General Motors, Mercedes-Benz, Volvo, and Daimler, which have set goals of phasing out petroleum-powered vehicles by 2035.⁵⁶⁴

The Biden administration has made new promises to reduce emissions, starting by reentering the Paris Agreement. Furthermore, in February 2022, the Biden administration announced new support across agencies toward clean manufacturing, “including low-carbon production of the steel and aluminum we need for electric vehicles, wind turbines, and solar panels, and the clean concrete we need to upgrade our transportation infrastructure.”⁵⁶⁵ Since the industrial sector is responsible for nearly a third of the United States’ greenhouse gas emissions, targeting it will be significant.⁵⁶⁶ This can be done through efficiency upgrades and technological innovations. Looking to the future, it is clear that under the Biden administration, the long process of moving toward non-carbon energy is in motion.

Chapter 9: Realistic Opportunities for Reducing Carbon Emissions

Introduction

In the twenty-first century, it has become clear that the widespread use of fossil fuels is a primary cause of climate change and environmental degradation. Meanwhile, the current era is witness to increased technological development, which has begun to aid in initiatives to remediate the damage from energy consumption and expand the use of non-carbon sources. Consequently, this transition has resulted in fundamental changes in energy systems, from the generation of electricity and other services to the consumer market. To fully address climate change, the energy transition requires a comprehensive strategy addressing a number of dynamic elements, such as energy sources, technology, and markets, with special emphasis placed on the rise of non-carbon energy and its significant potential to reduce carbon emissions. The following

⁵⁶²Bordoff and O’Sullivan, “Green Upheaval”

⁵⁶³“U.S. Energy Information Administration - EIA - Independent Statistics and Analysis,” Electric vehicles and hybrids surpass 10% of U.S. light-duty vehicle sales - Today in Energy - U.S. Energy Information Administration (EIA), accessed February 16, 2022, <https://www.eia.gov/todayinenergy/detail.php?id=51218>.

⁵⁶⁴The Staff Of The Morning, “A Push for Electric Vehicles,” The New York Times (The New York Times, August 6, 2021), <https://www.nytimes.com/2021/08/06/briefing/electric-vehicles-president-biden-climate.html>.

⁵⁶⁵“Fact Sheet: Biden-Harris Administration Advances Cleaner Industrial Sector to Reduce Emissions and Reinvigorate American Manufacturing,” The White House (The United States Government, February 15, 2022), <https://www.whitehouse.gov/briefing-room/statements-releases/2022/02/15/fact-sheet-biden-harris-administration-advances-cleaner-industrial-sector-to-reduce-emissions-and-reinvigorate-american-manufacturing/>.

⁵⁶⁶The White House, “Fact Sheet: Biden-Harris”

will discuss some of the prospects in related technology, as well as its limitations and significance to the future in the United States.

Emerging Technology Landscape for Carbon Reduction

Overview of Non- and Low-Carbon Energy Technologies

Non-carbon and low-carbon energy sources, often known as "clean energy," enable countries to mitigate emissions and address climate change by advancing technology in energy production and use. These technologies help mitigate negative environmental impacts by greatly enhancing energy efficiency, resource sustainability, and environmental protection efforts. Among these technologies is the smart electrification process, which attempts to reduce emissions while improving consumer accessibility.

Smart Electrification

Smart electrification—an important component of non-carbon technology—enables major increases in renewable power generation, electrification, and digitization to leverage potential synergies. Furthermore, it provides the ability to make power systems more flexible and resilient, while also making the overall energy system more secure and less reliant on fossil fuels.⁵⁶⁷ Part of this is the electrification of energy services, including anything from transitioning fossil fuel to electric or fuel cell vehicles, to replacing oil and gas furnaces with electric boilers and heat pumps. Electrification is aided by increased investment in new and upgraded networks of infrastructure for transmission and distribution (T&D) of energy.

Electrification of Energy Services in the Infrastructure Sector

As smart electrification has evolved, various technologies have become well-established and highlight the benefits of this energy transformation. The infrastructure and building sectors are prime examples of how these technologies are being deployed. There is now an effort to enhance the use of renewable power to generate fuels such as hydrogen or e-fuels, which are then distributed via existing or new gas T&D networks.⁵⁶⁸ In order to achieve this transition, there are several relevant building, network, and end-use infrastructure upgrades that would have to take place. This transition would primarily require the update of end-use equipment such as gas boilers, the upgrade of natural gas T&D networks, the installation of smart gas meters to allow smart building services, and the general introduction of smart building services.⁵⁶⁹

T&D Network Upgrades

The energy T&D infrastructure in the United States is becoming a more complex and interdependent system. It consists of over 2.6 million miles of interstate and intrastate pipeline,

⁵⁶⁷ IRENA (2022), *Smart Electrification with Renewables: Driving the transformation of energy services*, International Renewable Energy Agency, Abu Dhabi, 11.

⁵⁶⁸ IRENA, 26.

⁵⁶⁹ IRENA, 29.

as well as 640,000² miles of transmission lines.⁵⁷⁰ Since energy demand has increased, the demands for this infrastructure have become more complicated, as it must support a diverse and changing mix of energy sources and services.⁵⁷¹ Aside from the overall rising demand for energy, the present T&D infrastructure faces a number of additional issues. The majority of T&D infrastructure is controlled by private sector actors, with certain infrastructure assets operated by the Federal Government, indicating that substantial cooperation between the private and public sectors are necessary.⁵⁷² Additionally, T&D infrastructure's multi-state or multinational reach adds another degree of complication. This multi-geographical aspect necessitates additional significant collaboration to achieve modernization, stability, resilience, and adaptation goals.⁵⁷³ Despite the numerous obstacles that T&D systems confront in the United States, the need for enhancements is more urgent than ever. Notably, about half of all gas transmission and pipelines in the United States were built in the 1950s and 1960s.⁵⁷⁴ As these systems were developed several decades ago, they have not kept up with the volume of oil and gas production or the increasing geographical demands for energy. In response to the changing global energy and technological environment, there is an urgent need to modify our infrastructure to meet current energy demands and improve distribution capacities.

Smart Digital Devices

Smart digital devices and associated operational systems have the potential to boost efficiency even further by allowing for more flexibility and the optimization of the demand, supply, and consumption of energy. Integration of these smart technologies into the energy transition is crucial for decreasing the risk of higher peak electricity loads while also maximizing new grid infrastructure investment.⁵⁷⁵ In the United States, electricity consumption is measured by the base load and peak load of electricity use. The base load defines the minimal amount of electrical demand required during a 24-hour period. Peak load, on the other hand, is a period of high demand for electrical power.⁵⁷⁶ In the current energy state, there is great risk of overloading our electrical grid by increasing the number of peak load times in a 24-hour period. This is where smart digital devices are crucial. These devices allow users to program when they would generally use power, allowing the market to capitalize on price signals and meet utility demand.⁵⁷⁷ Subsequently, this lowers overall electrical prices and helps avoid peak overloads by allowing this smart technology to determine energy consumption for consumers.

⁵⁷⁰ United States. Department of Energy, Issuing Body. Quadrennial Energy Review. Energy Transmission, Storage, and Distribution Infrastructure. Washington, D.C.: [U.S. Department of Energy], 2015, 2.

⁵⁷¹ U.S. Department of Energy, 2.

⁵⁷² U.S. Department of Energy, 3.

⁵⁷³ U.S. Department of Energy, 3.

⁵⁷⁴ U.S. Department of Energy, 5.

⁵⁷⁵ IRENA, 17.

⁵⁷⁶ "Peak Load & Base Electricity - Understand Differences." EnergyWatch, February 28, 2017.

<https://energywatch-inc.com/peak-load-base-load-electricity/#:~:text=Peak%20load%20is%20a%20period,electricity%20is%20in%20high%20demand.&text=The%20constant%20power%20needed%20by%20the%20electrical%20grid%20is%20the%20base%20load.>

⁵⁷⁷ IRENA, 17.

Key Trends Influencing Capacity for Adaptation to Carbon Reduction Strategies

Dimensions of Adaptation

In the context of climate change and mitigation initiatives, adaptation entails minimizing risks and vulnerabilities as well as strengthening the ability of governments, the private sector, communities, and natural systems. These parts of adaptation work together to help manage the effects of climate change, as well as render decisions and actions.⁵⁷⁸

Adaptation Needs

To address the fundamental adaptation concerns, it is necessary to incorporate people with diverse skills, experience, and backgrounds from the economic, private, public, and the climate sector to adequately address problems in adaptation. This includes addressing the gaps between what could happen as the climate changes and the direction which citizens would aspire climate change to go. Furthermore, proper risk and vulnerability information is essential for adaptation in order to identify requirements and appropriate adaptation choices to reduce risks and enhance capacity.

Although needs vary by group and location, they ultimately fall into several general categories that must be considered: biophysical and environmental demands, social needs, institutional needs, the need for private sector participation, and knowledge, capacity, and resource needs.⁵⁷⁹ When all of these sectoral needs are met, a shared approach to resolving these challenges becomes accessible, allowing for the greatest amount of adaptation to take place.

Adaptation Options and Actors

Identifying priorities resulting from climate risks and vulnerabilities lays the groundwork for choosing adaptation options. A variety of choice categories have been discovered over the years. These possibilities encompass a wide variety of structural/physical, social, and institutional acts. Adaptation choices are rarely developed to solely address climate threats or possibilities—rather, activities are frequently performed with other goals (such as profit or poverty reduction) in mind, while also achieving climate-related co-benefits.⁵⁸⁰ Because adaptation is inherently carried out in a single sectoral manner, focusing on how to handle climate change while avoiding the necessity for present adaptation options has become critical. Rather than focusing on adaptation solutions that address specific aspects of climate change, increasing emphasis is being placed on mainstreaming climate change into broader development policy and private sector operations.

⁵⁷⁸ Adaptation needs and options. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 839.

⁵⁷⁹ Adaptation needs and options, 844.

⁵⁸⁰ Adaptation needs and options, 849.

Maladaptation

Maladaptation, in general, refers to activities or omissions that may raise the likelihood of unfavorable climate-related consequences, such as susceptibility to climate change or negatively affected well-being, now or in the future. For example, the construction of well-engineered climate-resilient roads designed to withstand current and future climate extremes may encourage new settlement in areas highly vulnerable to the effects of future climates.⁵⁸¹ Maladaptation presents itself in a variety of ways, but many basic explanations may be recognized. Actions that may help a certain group or sector at a specific moment may be detrimental to those same groups or sectors in future climates, or to other groups or sectors in current climates. Another pattern of maladaptation is the failure to account for diverse interactions and behaviors across systems and sectors. As a result, information for establishing adaptive mechanisms is limited or inaccurate. For example, an adaptive technique that has been adopted and shows great economic advantage may fail to detect the environmental harm being done since the economic benefit is so significant, resulting in maladaptive methods to solve the issue.⁵⁸²

Opportunities and Limitations of Adaptation

Opportunities for and limitations of adaptation, while discussed as two distinct actors in adaptation, are complementary: adaptive capacity is influenced collectively by the extent to which actors take advantage of available opportunities, as well as the extent to which those actors or natural systems experience constraints.⁵⁸³ Furthermore, recognized limits may provide excellent possibilities for adaptation interventions to increase adaptive capacity.

Adaptation Opportunities

Adaptation opportunities are components that enable actors to plan and carry out activities to accomplish their adaptation objectives or to support natural systems' adaptive responses to climatic challenges.⁵⁸⁴ Consequently, an opportunity varies from an adaptation option, which is a specific method of achieving an adaptation aim or a conservation strategy. Adaptation opportunities range from increasing awareness of climate change, its consequences, and the potential costs and benefits of adaptation choices, to establishing specific adaptation-friendly policies.

An additional component to adaptation options comes from the opportunity for ancillary benefits (or co-benefits) to the implementation of adaptation strategies. Independent of direct

⁵⁸¹ Adaptation needs and options, 857.

⁵⁸² Adaptation needs and options, 858.

⁵⁸³ Adaptation opportunities, constraints, and limits. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 908.

⁵⁸⁴ Adaptation opportunities, constraints, and limits, 908-909.

benefits addressed in an adaptation project, co-benefits occur with respect to reducing vulnerability to climate change. The potential for these benefits provides two important implications for adaptation. The first being that consideration of co-benefits may result in a more favorable assessment of the cost-effectiveness of a specific adaptation option. Subsequently, this consideration may help in efficiently integrating adaptation into existing management and decision-making processes. Though ancillary benefits may occur in many ways, there are three central manners in which co-benefits occur out of adaptation options:⁵⁸⁵

1. Stimulating adaptation to current climate variability;
2. Generating climate adaptation goods and services;
3. And advancing sustainable development

Adaptation Limitations

A limit in adaptation is reached when efforts are unable to provide acceptable levels of security from risks to the existing objects and values, and are unable to prevent the loss of key attributes and components of ecosystems.⁵⁸⁶ In order to effectively avoid the limits of adaptation, it is crucial to address feedback that encompass social and environmental resilience. Eventually, limits will be exceeded through cascading feedbacks that are characterized by social polarization and conflict, ultimately resulting in social disruption.⁵⁸⁷

Major Perspectives in Technology and Adaptation

As the technology landscape emerges, there is great opportunity for innovation in the clean energy technology sector and multisectoral involvement in the implementation of strategies to mitigate carbon emission. National goals of climate mitigation can be achieved through a systemic approach with technological opportunities, such as an increase in deployment of EV technology and ICT controlled charging to mitigate power system overloads..

Chapter 10: Perception and Role of Consumer Choice in Carbon Emission Reduction

Introduction

The potential and limitations of innovation, improvement, and cost reduction are undeniable driving factors in the present energy transition. As previously mentioned, the world has reached the highest levels of greenhouse gas emissions in 800,000 years, and the opportunity afforded by non- and low-carbon technology, renewable energy sources, and a stronger emphasis on co-beneficial enterprises is inescapable. However, there is a disparity in this concept between the potential accessible to individuals and communities and the opportunity available to governments. Consumer participation in the energy market is critical, since human activity is the primary source of emissions to date. Although enormous advancements are being made in the many energy markets available to consumers, much attention must be paid to how we make these

⁵⁸⁵ Adaptation opportunities, constraints, and limits, 910-911.

⁵⁸⁶ Adaptation opportunities, constraints, and limits, 919.

⁵⁸⁷ Adaptation opportunities, constraints, and limits, 920.

items or technologies efficient, cost effective, and available for purchase and use by the individual consumer.

Consumer Behavior and Energy Choice

Lenses of Consumer Behavior

The question of whether consumers act logically or optimally when making energy use and efficiency decisions is widely contested in politics and academia, with two competing viewpoints on the subject. An economic viewpoint provides the initial perspective. Consumers, according to economists who attribute high levels of competence to them, make energy-related decisions rationally, weighing the costs-benefits of alternative schemes. As a result, effective analysis motivates consumers to invest in clean and efficient energy solutions. Consequently, the economic lens indicates that government interventions, such as performance standards and demand-side management programs, hinder economic efficiency and deny consumers preferred alternatives.⁵⁸⁸

The behavioral and technological perspectives are on the other side of the issue. Considering behavioral psychology and consumers' actual understanding of technology, behavioral psychologists and technology analysts claim that consumers' real-world decisions diverge from the ideals of preference maximization. If the perspective provided here is accurate, it would give justification for government involvement in the energy market to assist consumers in making the "correct" product choice.⁵⁸⁹

Types of Consumer Rationality

Rational Inattention

The concept behind rational inattention is that when information is costly to acquire, decision makers may choose to act on incomplete information rather than incur the cost to become adequately informed. Essentially, rational inattention becomes similar to a cost-benefit analysis, however, consumers are not weighing environmental implications of a product or long-term cost benefits, but rather circumventing that need and weighing the benefit of finding the information needed to make sound choices versus going to a store and purchasing a product labeled 'energy efficient.' Additionally, rational inattention can prevail in the case of a firm creating new technology that lowers long-term cost. To the consumer, the cost of adding new technology — which compensates the firm's loss on innovating this technology — will outweigh the long-term benefit, since the consumer does not understand the long-term benefit. Though rational inattention appears as a deficit in human behavior, it poses a strong incentive for consumers to continue to purchase inefficient products, as they have not weighed the benefits properly. Consequently, the concept of rational inattention poses several implications for policy and research interventions.

⁵⁸⁸ Howarth, Richard B. "Consumer rationality and energy efficiency." *1994 ACEEE Summer Study on Energy Efficiency in Buildings: Human dimensions of energy consumption* 1 (1994): 176-177

⁵⁸⁹ Howarth, 177.

In empirical research, a significant implication of rational inattention is that it is possible for consumers to accurately value energy-efficient products available on the market, however, driving a presence of inefficient provisions of energy efficiency. The concept of inefficient energy provision is that consumers who undervalue energy efficiency would underinvest in it, resulting in investment inefficiencies and interventions to direct investments to more efficient positions.⁵⁹⁰ In terms of policy design, rational inattention may lead to inefficient investment, but it is vital to note that it implies that there are actual economic consequences associated with paying attention. However, if making better choices requires exerted effort on the consumer's side, then policy that coerces or incentivizes attention would need to address the cost at which consumers feel would be worth trying to pay attention. Likewise, the apparent cost of effort perceived by consumers would divert the emphasis of such policies away from corrective taxes and toward an informational strategy of learning and knowledge sharing.⁵⁹¹

Bounded Rationality

Individuals consistently depart from logical decision-making, according to the study of bounded rationality.⁵⁹² This entails two major insights. To begin, humans do not make proper judgments because they are boundedly rational due to cognitive limitations, a lack of knowledge, and a lack of motivation. Second, humans have limited self-interest, which means that while making judgments, they are also motivated by other desires, such as fairness or reciprocity.⁵⁹³

There are two notions that extend from this type of cognitive constraint under the concept of bounded rationality. Consumer choice under risk and uncertainty compose the first branch of constrained rationality. This suggests that people frequently work under enormous uncertainty and are forced to make risky and rather misinformed decisions. Choice in this branch is reference-dependent, and probabilities are valued disproportionately. Intertemporal choice is the second branch of bounded rationality, which states that people value the present more than the future and make decisions accordingly.⁵⁹⁴

Managing Consumer Rationality in the Context of Carbon Reduction

As previously discussed, the variety of human rationality poses the problem of understanding whether or not there is a necessity for intervention, political or otherwise, to assist in the assurance of efficient investment in non-carbon technologies. As human behavior cannot always be accounted for, the energy product marketplace is stabilized by focusing on demand-side management programs and informational communication.

Demand-side Management Programs

⁵⁹⁰ Sallee, James M. "Rational Inattention and Energy Efficiency." *The Journal of Law & Economics* 57, no. 3 (2014): 811.

⁵⁹¹ Sallee, 813.

⁵⁹² Howarth, 178.

⁵⁹³ Gsottbauer, E., van den Bergh, J.C.J.M. Environmental Policy Theory Given Bounded Rationality and Other-regarding Preferences. *Environ Resource Econ* 49, 263–304 (2011).

<https://doi.org/10.1007/s10640-010-9433-y>

⁵⁹⁴ Gsottbauer, 263-304.

According to the U.S. Energy Information Administration, demand-side management (DSM) programs consist of the planning, implementation, and monitoring activities of energy use, designed to encourage consumers to modify their energy and electricity consumption and usage patterns.⁵⁹⁵ Traditionally, the balance of supply and demand in power systems has been served mainly through generating and network capacity planning. However, with growing flexibility needs as a result of the increasing prominence of renewable energy sources, there is a need to improve demand-side flexibility. Unlocking demand-side flexibility can provide system advantages that include peak load reduction, resulting in increased generating capacity and network upgrade postponement to reduced demand.⁵⁹⁶ More broadly, there are three categories of DSM. The first is demand response, which is an attempt to stimulate a change in the amount and pattern of energy use by consumers.⁵⁹⁷ The second category is concerned with energy efficiency; this can be accomplished through a number of means, such as behavioral changes and technological advancements.⁵⁹⁸ Finally, the third DSM category deals with distributed generation and storage. Demand-side distributed generation implies that the same concern about the environmental implications of energy that motivates energy efficiency may also inspire clean technology adoption and help reduce energy used from the grid. Furthermore, distributed storage produces an energy shift through similar price responsiveness characteristics when a consumer utilizes energy during an off-peak time.⁵⁹⁹

Satisficing Energy Choice

As previously stated, assuming that customers would make rational decisions about energy is naive. Because consumers rely on increasingly simple methodologies in the face of complexity and uncertainty, various simplification strategies — such as making a desired action easier, faster, and more convenient, minimizing the physical and psychological demands required to perform the action, and reducing perceived uncertainties — may help reduce cognitive overload and facilitate more effective decision-making in regard to energy consumption. By framing communications in a clear, simple, and accessible way, unnecessary complexity may be avoided. When it comes to reaching consumers, keeping things brief and simple is crucial for good communication. For example, instead of overwhelming consumers with too many energy-saving recommendations or too many options, offer them smaller quantities of the most

⁵⁹⁵ United States Agency for International Development & the National Renewable Energy Laboratory, *Preparing Distribution Utilities for the Future- Unlocking Demand-side Management Potential: A Novel Analytical Framework*, by Killian McKenna, Kapil Duwadi, Shibani Ghosh, and Adarsh Nagarajan, Contract No. DE-AC36-08GO28308: NREL, 2021. <https://www.nrel.gov/docs/fy21osti/79375.pdf>

⁵⁹⁶ McKenna, “Preparing Distribution Utilities for the Future- Unlocking Demand-side Management Potential: A Novel Analytical Framework.”

⁵⁹⁷ McKenna, “Preparing Distribution Utilities for the Future- Unlocking Demand-side Management Potential: A Novel Analytical Framework.”

⁵⁹⁸ McKenna, “Preparing Distribution Utilities for the Future- Unlocking Demand-side Management Potential: A Novel Analytical Framework.”

⁵⁹⁹ United States Agency for International Development & the National Renewable Energy Laboratory, *Preparing Distribution Utilities for the Future- Unlocking Demand-side Management Potential: A Novel Analytical Framework*, by Killian McKenna, Kapil Duwadi, Shibani Ghosh, and Adarsh Nagarajan, Contract No. DE-AC36-08GO28308: NREL, 2021. <https://www.nrel.gov/docs/fy21osti/79375.pdf>

critical information.⁶⁰⁰ Behavioral tactics should focus on transmitting basic ideas that the ordinary consumer can quickly and readily grasp, rather than offering information-intensive ads and sophisticated consumer education programs.

Major Perspectives in Energy Choice

If consumer rationality provided a holistic account of human behavior, our current understanding of economics would provide a unified approach to energy consumption analysis.⁶⁰¹ However, as previously indicated, consumers do not act rationally and thus require some form of intervention to appropriately make sustainable and efficient energy decisions. Moreover, an expanding field of research on consumer behavior and climate change has revealed a complicated relationship between consumer choice and energy use, demonstrating that individual consumers are incapable of recognizing truly beneficial environmental behavioral changes.⁶⁰² As a result, it is valid to suggest that governments and private entities should prioritize making environmentally responsible behavior the simple behavioral choice for consumers.⁶⁰³

Conclusion and Policy Recommendations

As both the United States and the world tackle the complexities of mitigating climate change while advancing global economic development, it is essential that governments thoughtfully transition toward carbon neutrality. Post-industrial nations have an immense role and responsibility in the coming decades to lead a transition away from high carbon producing energy sources and to build out low to no-carbon systems of energy production. The United States has an opportunity to position themselves as a leader in initiating revolutionary energy research and building the technology to help both the United States and other nations reduce carbon output. In the section below, this Task Force has developed fourteen policy recommendations with actions that the United States should take to lead the necessary global energy transformation in the coming decades.

Policies Related to Carbon Producing Energy Sources

Coal Mine Drainage Mediation | Meera Naomi Rynne

Coal mine drainage is water that is polluted from contact with past mining activity. Abandoned mines impact water quality in several ways, including acid mine drainage, alkaline

⁶⁰⁰ Elisha R. Frederiks, Karen Stenner, and Elizabeth V. Hobman, “Household Energy Use: Applying Behavioural Economics to Understand Consumer Decision-Making and Behaviour,” *Renewable and Sustainable Energy Reviews* 41 (January 2015): pp. 1385-1394, <https://doi.org/10.1016/j.rser.2014.09.026>.

⁶⁰¹ Howarth, 180.

⁶⁰² John Thøgersen, “Consumer Behavior and Climate Change: Consumers Need Considerable Assistance,” *Current Opinion in Behavioral Sciences* 42 (December 2021): pp. 9-14, <https://doi.org/10.1016/j.cobeha.2021.02.008>, 12.

⁶⁰³ Thøgersen, 12.

mine drainage, and metal mine drainage.⁶⁰⁴ This type of aftereffect pollution stems from production company malpractice. We recommend companies who participates in or have been involved in fossil fuel site production be required to invest in malpractice insurance to ensure the clean up of existing pollution or to prevent further pollution at mining sites. In West Virginia, the EPR coal company stopped running mines after declaring bankruptcy, abandoning pollution control measures. The remaining mess created a disaster, because “it costs nearly \$900,000 annually to pump and treat polluted water draining from the mine. ERP had only sporadically maintained it’s pumps. The deteriorating situation compelled West Virginia to step in and begin paying for pump maintenance on behalf of ERP, or else risk the system failing to contain the pollution.”⁶⁰⁵ Negligence from mining companies has resulted in contaminated water discharge in the drinking water for thousands of West Virginians. In all, required malpractice insurance will allow for more consistent protection against water pollution and waste from coal plants, and will prevent clean-up costs from falling on governmental bodies.

Market-Based Approaches to Reduce GHG Emissions | Meera Naomi Rynne

In recent years, it has been clear that connecting a personal buy-in for consumers helps reduce greenhouse gas emissions. “Research shows that putting a price on carbon-based fuels, in the form of a fee or tax, is an effective way of reducing GHG emissions and pollution levels across the globe.”⁶⁰⁶ The United States should implement federal action to implicate consumers in their daily GHG emissions. While some states have adopted market-based approaches, the United States will see greater outcomes by mandating national taxes on carbon-based fuels. Not only will this attach a personal stake in climate change, this tax would also produce a revenue that could be put into more specific R&D projects, such as alternative energy sources and CCUS.⁶⁰⁷ The United States needs to take a stronger stance on reducing carbon emissions and a carbon tax is a great place to start.

Continue Investment in Natural Gas | Emma Thuau

While the development of low and non-carbon energy sources increases, natural gas usage will continue to increase significantly to support energy demand. It is essential for the United States to further the transition away from oil and coal through increased investment in low-carbon energy alternatives like natural gas. Natural gas is a current, achievable, and realistic alternative to oil and coal. Despite an increase in the development and integration of renewable

⁶⁰⁴ “Abandoned Mine Drainage,” EPA (Environmental Protection Agency, July 8, 2021), <https://www.epa.gov/nps/abandoned-mine-drainage>.

⁶⁰⁵ Mark Olalde, “Exposed: West Virginia and Other States Relying on 'House of Cards' to Pay for Coal Mine Cleanup,” DeSmog (DeSmog, May 5, 2021), <https://www.desmog.com/2020/06/25/coal-surety-bond-pools-liabilities-mine-cleanup/>.

⁶⁰⁶ Aimée Dushime, “Addressing Climate Change through Carbon Taxes,” World Economic Forum (World Economic Forum, June 16, 2021), <https://www.weforum.org/agenda/2021/06/addressing-climate-change-through-carbon-taxes/#:~:text=Research%20shows%20that%20putting%20a,pollution%20levels%20across%20the%20globe.>

⁶⁰⁷ “Market-Based State Policy,” Center for Climate and Energy Solutions (Center for Climate and Energy Solutions, June 25, 2021), <https://www.c2es.org/content/market-based-state-policy/>.

energy sources around the world, Europe has demonstrated that solar and wind power cannot sufficiently sustain whole nations. Due to the extensive use of natural gas throughout energy markets in Europe, gas is in a remarkably strong position to lead the transition away from coal in power generation, thus significantly reducing CO₂ emissions. The United States is currently the largest producer of natural gas in the world and has a great opportunity to develop the energy sector and economy by exporting natural gas to Europe—and thus minimizing their reliance on Russian natural gas.

R&D incentives can promote additional efficiency in natural gas use, especially for transportation. According to the DOE, natural gas powered over 175,000 vehicles and roughly 23 million vehicles worldwide in 2021.⁶⁰⁸ Natural gas as a transportation fuel has many advantages, such as widespread distribution infrastructure, reduced gas emissions compared to gasoline and diesel, and the fact that it is domestically available.

Create Fossil Fuel Reserves and Design More Efficient Energy Markets | Emma Thuau

Given the uncertainty about future energy demand, policymakers should be prepared to keep legacy fossil fuel assets in reserve, in the case of a disconnect between energy supply and demand during a transition toward low carbon sources. According to the report *Crude Oil and Natural Gas Proved Reserves*, U.S. total natural gas proved reserves totaled about 473.3 trillion cubic feet in 2020 (Tcf).⁶⁰⁹ Recently, Europe has demonstrated the necessity for energy reserves, specifically when European countries had to revert to coal usage to maintain their energy demand. In addition, to incentivize the switch to renewable energy, regulators of utilities should adopt pricing structures that would compensate companies for providing energy reliability. For example, in order to prepare for peaks in demand, regulators should design markets that pay energy companies for maintaining capacity and supplies when reserves are not used. In order to reduce demand, policymakers must enact measures to increase efficiency of renewable energy sources, which will narrow supply and demand imbalances.

Phase Out Existing Coal Plants in Postindustrial Economies | John F. Reinhardt

The United States and other post-industrial economies should begin phasing out older, least-efficient and most-polluting coal plants while mandating and funding CCUS for coal-fired power stations globally. This will benefit the United States through amicable foreign policy and placement on the cutting edge of the energy transition. This policy should be enacted in the short to medium term (between 0 to 10 years), as time is of the essence in the climate and energy crisis. Coal plants should be phased out, as there is little irreplaceable about coal, unlike other carbon energy sources such as oil usage in jet fuel, plastics, and militaries. As the United States

⁶⁰⁸ Bordoff, Jason, and Meghan L. O'Sullivan. "Green Upheaval." *Foreign Affairs*, February 19, 2022. https://www.foreignaffairs.com/articles/world/2021-11-30/geopolitics-energy-green-upheaval?utm_medium=promo_email&utm_source=lo_flows&utm_campaign=registered_user_welcome&utm_term=email_1&utm_content=20220228.

⁶⁰⁹ "U.S. Energy Information Administration - EIA - Independent Statistics and Analysis." How much natural gas is left - U.S. Energy Information Administration (EIA). Accessed March 1, 2022. <https://www.eia.gov/energyexplained/natural-gas/how-much-gas-is-left.php>.

and other post-industrial states move into transitioning energy systems, all coal plants should be ultimately phased out. The United States and the West are uniquely poised, having the resources— material, financial, and human capital—to fund the infancy of the energy transformation by means of phasing out coal in the West and funding and mandating CCUS globally.

Policy Related to Non-Carbon Energy Sources

Nuclear Revamping and Increased Investment in Nuclear Reactors | Jangshik Hwangbo

Nuclear energy is the most efficient non-carbon energy source, however, it has been neglected due to the history of nuclear disasters. To work toward revamping nuclear energy, we recommend investment into a nuclear waste disposal facility. Yucca Mountain in Nevada was amended in 1987 as the sole initial repository for 70,000 tonnes of high-level waste. This location is beneficial because its tunnel is located about 305 meters below the top of a steady mountain, therefore, waste can be stored in a safer place than aboveground storage casks. Current delays exist due to underfunding and political opposition in Nevada.⁶¹⁰

Further, extending the lifetime of existing nuclear reactors and constructing new power plants must be included to achieve net-zero carbon emission. In 2020, eleven reactors were slated to receive an extension of an additional twenty years of life. This includes the replacement of steam generators and upgrades of instrument and control systems. Instead of constructing a conventional nuclear reactor, the United States should focus on building SMRs. It is much smaller, with less radiation, and is economically feasible compared to conventional power plants.

Lastly, public awareness of the safety of nuclear power should be promoted. In 2018, a collaboration between the American Nuclear Society (ANS) and Discovery Education helped to develop a nuclear science curriculum for high schools. The program provides lesson plans, career profiles, and a virtual field trip for students.⁶¹¹ Promoting public awareness on the safety and benefits of nuclear energy will help the public feel safe and confident in the expansion of nuclear energy systems.

Digitalization of All Current and New Hydropower Plants | Grace Chun

Despite being the oldest form of non-carbon energy and making up 37% of U.S. electricity consumption in 2020, hydropower is not in line with current technological trends.⁶¹² The United States should invest in the physical modernization of hydropower plants (i.e. advanced turbines) as well as implement digitization systems and advanced sensor suites to make better-informed decisions through real-time data.⁶¹³ The United States must take measures to

⁶¹⁰ “Nuclear Power in the USA.” World Nuclear Association. WNA, February 2022.

<https://world-nuclear.org/information-library/country-profiles/countries-t-z/usa-nuclear-power.aspx>.

⁶¹¹ “Stem Resources.” Energy.gov. Department of Energy. Accessed March 1, 2022.

<https://www.energy.gov/ne/stem-resources>.

⁶¹² Water Power Technologies Office, “Hydropower Program,” Energy.gov, accessed February 28, 2022,

<https://www.energy.gov/eere/water/hydropower-program>.

⁶¹³ Water Power Technologies Office, “Fleet Modernization, Maintenance, and Cybersecurity,” Energy.gov, accessed February 28, 2022, <https://www.energy.gov/eere/water/fleet-modernization-maintenance-and-cybersecurity>.

protect its digital assets during the digitalization of hydropower. This includes creating proper cybersecurity tools, investing in employee cyber education and training, and evaluating risk management practices that can best mitigate cyberattacks. Cybersecurity will help deflect nation-state actors who attack U.S. critical energy infrastructure with malicious intent and monetary motivations. Through digitalization, hydropower plants can increase and improve efficiency, essentialized by rapidly aging hydropower plants.

Increase Investment in R&D for Low-Carbon Technologies | Chihiro Kobayashi

Increasing investment in the R&D of energy, especially low-carbon energy, is essential to reduce dependence on high-carbon fuel and to accelerate the installment of low carbon power. The Advanced Manufacturing Office of the DOE has launched a variety of R&D projects that have made significant impacts on national innovation and quantifiable energy savings.⁶¹⁴

Policymakers should increase investment in R&D for new low-carbon technologies and end-of-life technology for renewable energy plants. Since the lifetime of renewable energy plants ranges from ten to forty years, it is important to be prepared for a wave of aging renewable energy systems with additional research and development to end-of-life management.⁶¹⁵ This may include lifetime extensions and the reuse, recycling, and disposal of materials. R&D is particularly needed in silicon purification processes for solar PV, recycling technologies for wind turbine blades, methods to avoid waste in manufacturing, and lowering the recycling costs of wastes.^{616 617}

Policy Related to DAC and CCS/CCUS

Increase Federal Funding to the R&D of New DAC Programs | Jacqueline Days

The rapidly worsening climate crisis, coupled with the improbability of completely eliminating energy-related carbon emissions in the near future makes it evident that carbon removal is an essential technology to utilize. The IPCC and the National Academies of Science claim that DAC is crucial and an optimal choice due to its potential for affordability and non-disruptive manner of carbon removal.⁶¹⁸ However, more investment in this technology is needed to fully optimize it and mitigate the existing drawbacks, such as large energy use, cost, and overall lack of deployment. Comparable to other nations such as Canada or Switzerland, the state of DAC in the United States is subpar and more R&D must be employed. The DOE has promised to allocate \$14.5 million to DAC research, which is increased from past amounts, but is

⁶¹⁴ Office of Energy Efficiency and Renewable Energy, “Research & Development,” accessed March 1, 2022, <https://www.energy.gov/eere/amo/research-development>

⁶¹⁵ NREL, “Useful Life,” accessed March 1, 2022, <https://www.nrel.gov/analysis/tech-footprint.html>

⁶¹⁶ Office of Energy Efficiency and Renewable Energy, “End-of-Life Management for Solar Photovoltaics,” accessed March 1, 2022, <https://www.energy.gov/eere/solar/end-life-management-solar-photovoltaics>

⁶¹⁷ American Clean Power Association, “Wind Turbine End-of-Life Strategies,” June 2020, <https://cleanpower.org/wp-content/uploads/2021/01/End-of-Life-Strategies.pdf>

⁶¹⁸ National Academies of Sciences, Engineering, and Medicine. 2019. Negative Emissions Technologies and Reliable Sequestration: A Research Agenda. Washington, DC: The National Academies Press. <https://doi.org/10.17226/25259>.

still a minuscule amount compared to other carbon-neutral technology investments. The recommended amount of funding per year is \$240 million.⁶¹⁹ Investment in DAC to this scale by the federal government would allow for the cost of DAC to break even, the neutralization of emissions, the creation of a plethora of jobs, and to make the United States a world leader in this technological field.

Expand the Marketplace and Demand for DAC and CO₂ | Jacqueline Days

Currently, the market and demand for CO₂ is low, which is a detriment to increasing DAC implementation, as there is little incentive for companies or industries to deploy DAC. Additional policy enacted to compel demand for CO₂ in the market would allow for DAC to create a successful self-sustaining system. First, we recommend the establishment of a federal mandate for fuels based on carbon captured from DAC.⁶²⁰ Considering fuel is still integral to the U.S. economy, this would provide solid procurement of fuel while ramping up DAC technologies that would mitigate carbon from the environment. Additionally, we recommend an additional regulatory policy that would require the development of new industries and factories emitting large quantities of CO₂ to build a small DAC plant, which would be subsidized. Next, the existing 45Q tax credit, which credits companies anywhere from \$12 to \$50 per ton of carbon captured, must be improved upon. Policies such as extending the commence construction period to 2030, extending the payout credit to thirty years, increasing the value of the credit for geologic storage to \$180 per ton, and lowering the minimum capture and use thresholds to 10,000 tons per year would make this tax credit even more valuable to companies.⁶²¹ This tax credit improvement would incentivize private companies to invest in DAC, thus opening up the market and increasing competition.

Increase Investment in CCS & CCUS Technology | Sydney Sherk and Yelyzaveta Ismaullayeva

Increasing investment in CCS and CCUS technologies will be essential for offsetting the effects of carbon output in the next decades. However, the benefits of CCUS and CCS are wholly dependent on their ability to thrive in the marketplace. We recommend that the United States increase investment in R&D for CCUS and CCS technology, as well as initiate public subsidies to bring CCS and CCUS technologies to a profitable level in the next five to ten years. These actions may be performed in conjunction with stricter enforcement of international climate agreements or with added carbon taxes, and may also require other methods of geoengineering. In the coming years the United States will act as a model for the success of CCS and CCUS at decreasing carbon emissions created as a result of energy production. In the next decade, the United States should also increase investment in CCUS and CCS technology for emerging

⁶¹⁹ John Larsen et al., “Capturing Leadership: Policies for the US to Advance Direct Air Capture Technology,” Rhodium Group (Rhodium Group, LLC, June 23, 2020), <https://rhg.com/research/capturing-leadership-policies-for-the-us-to-advance-direct-air-capture-technology/>.

⁶²⁰ John Larsen et al., “Capturing Leadership: Policies for the US to Advance Direct Air Capture Technology,” Rhodium Group

⁶²¹ John Larsen et al., “Capturing Leadership: Policies for the US to Advance Direct Air Capture Technology,” Rhodium Group

economies who need to develop with the usage of high-carbon energy sources. Financing of domestic and international CCS and CCUS technology is estimated to cost between \$655 billion and \$1,280 billion.⁶²² With CCS and CCUS technology implemented around the world, the global economy will have the space to allow for continued economic growth and increased quality of life while continuing to tackle carbon emissions.

Policy Related to Geopolitics and Political Interactions

Expand Local Production of Rare Earth-Materials | Emma Kamb

We recommend that the United States expand its local production of rare-earth materials such as lithium. Lithium and other critical minerals are paramount to the production of solar technologies such as solar panels, wind turbines, EV batteries, and grid lines.⁶²³ Currently, nearly all of the U.S supply is imported, with 54% of these imports coming from Argentina.⁶²⁴ This dependence on foreign countries presents an energy security issue. It leaves the United States open to dramatic price increases. Since discoveries of lithium in the United States account for nearly 10% of the world's reserves, opportunities for expansion of a rare-earth material industry is significant.⁶²⁵ This expansion would reduce energy security risks and benefit the U.S. economy through job creation.

Non-Antagonistic Foreign Policy | John F. Reinhardt

The United States must refocus foreign policy toward non-antagonistic and climate-forward ambitions by drastically increasing the funding and resources available at the Department of State and other non-military entities — effectively redesigning foreign policy to become diplomatically, scientifically, and policy focused. The United States' F-35 Lightning II jet program is comparable in costs to China's Belt and Road Initiative and employs more Americans than the State Department.^{626,627} It is not a radical conclusion to draw that the United States has willingly foregone staying competitive on the world stage in favor of a semi-operational jet. A state that spent about \$10 trillion between losing a war in Afghanistan and one jet program is near-definitionally unable or unwilling to lead or address the energy transformation in the face of climate change.⁶²⁸ This reality provides an irreconcilable tension

⁶²² Global CCS Institute, 2021. The Global Status of CCS: 2021. Australia. 12.

⁶²³ IEA, "Energy Security and the Risk of Disorderly Change – World Energy Outlook 2021 – Analysis."

⁶²⁴ Mineral Commodity Summaries. U.S. Geological Survey, 2022.

<https://www.usgs.gov/centers/national-minerals-information-center/mineral-commodity-summaries>.

⁶²⁵ Mineral Commodity Summaries. U.S. Geological Survey, 2022.

<https://www.usgs.gov/centers/national-minerals-information-center/mineral-commodity-summaries>.

⁶²⁶ Insinna, Valerie. "Watchdog Group Finds F-35 Sustainment Costs Could Be Headed off Affordability Cliff." Defense News (Washington, D.C., US), July 7, 2021.

⁶²⁷ Hillman, Jonathon E. "How Big Is China's Belt and Road?" Center for Strategic & International Studies. Last modified April 3, 2018. Accessed February 28, 2022. <https://www.csis.org/analysis/how-big-chinas-belt-and-road>.

⁶²⁸ Kimball, Jim. "Costs of the Twenty-year War on Terror: \$8 Trillion and 900,000 deaths". Brown University (Providence, RI), September 1, 2021.

<https://www.brown.edu/news/2021-09-01/costsofwar#:~:text=PROVIDENCE%2C%20R.I.%20%5BBrown%20University%5D,War%20project%20at%20Brown%20University>.

regarding addressing climate change, since the military is not equipped to lead this crisis. In terms of emissions and related international cooperation, this is the wrong approach. The United States should dedicate material and financial resources toward constructive measures such as aiding countries to develop sustainably.

Market Solutions to Incentivize Industry Change | Joseph Najmolhoda

It is imperative to the transition away from high-carbon emitting fuels that the market disincentivize continued development and usage of such fuels. Correspondingly, international climate agreements must have independent enforcement functions. In this case, the United States has a unique ability to leverage the market with its own resources to incentivize a transition. The process requires an initial increase of natural gas and oil production to establish foreign trade dependencies on American natural resources. This is followed by conditional allotment of investment to foreign nations on the basis of a reduction of carbon fuel usage and implementation of alternative energy forms. The investment can be constructed similarly to the ERP, also known as the Marshall Plan, wherein policy is generated by the foreign country⁶²⁹ and not IMF structural programs—which establishes a one-size-fits-all standard that ignores each nation’s individual needs.⁶³⁰ If done successfully, American industry can fund carbon-free transitions abroad, benefitting both economies. An increase of R&D, as well as the extraction of raw resources, is needed to accomplish this goal—specifically, more funding allocated to non-carbon sectors such as nuclear and the increased extraction of rare metals needed in non-carbon infrastructure such as lithium.⁶³¹ Recent events have shown that the United States and the international community can enact meaningful economic deterrence policies.⁶³² In fact, the Russian invasion of Ukraine has given the United States the ability to leverage a position on non-carbon energy. This position would prove integral in an international energy transition.

⁶²⁹ Tarnoff, Curt. “The Marshall Plan: Design, Accomplishments, and Significance .” Congressional Research Service, January 18, 2018.

https://digital.library.unt.edu/ark:/67531/metadc1156806/m2/1/high_res_d/R45079_2018Jan18.pdf.

⁶³⁰ Spraos, John. “IMF Conditionality: Ineffectual, Inefficient, Mismatched.” Princeton University , December 1986. <https://ies.princeton.edu/pdf/E166.pdf>.

⁶³¹ Mineral Commodity Summaries. U.S. Geological Survey, 2022.

<https://www.usgs.gov/centers/national-minerals-information-center/mineral-commodity-summaries>.

⁶³² “Russia's Economic Reality Has Changed, Kremlin Says.” Reuters. Thomson Corporation, February 28, 2022. <https://www.reuters.com/markets/asia/kremlin-says-russias-economic-reality-has-changed-stands-by-cbank-2022-02-28/>.

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