GRADING THE GRID

A National Energy Report Card

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A joint report from Northwood University's McNair Center for the Advancement of Free Enterprise and Entrepreneurship and the Mackinac Center for Public Policy

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Executive Summary

Report Card on U.S. energy production.

We ranked eight key energy industry sectors based on their ability to meet the growing demand for affordable, reliable, and clean electric generation.

Report Card						
Energy Source	Capacity Reliability	Environmental/ Human Impact	Cost	Technology/ Innovation	Market Feasibility	Final Grade
Natural gas	9	9	10	10	9	A
Coal	8	7	9	9	7	B-
Petroleum	6	7	8	8	6	C-
Nuclear	10	10	7	10	7	B+
Hydroelectric	10	8	8	8	6	B-
Wind	5	6	5	6	6	F
Solar	5	5	5	8	6	F
Geothermal	6	9	5	8	5	D+

Natural gas: 94 % (A)

Natural gas is at a unique position in our energy supply.

The nation has experienced rapid growth in energy demand for a range of activities: electricity generation, home heating, transportation, manufacturing, etc.

As governments around the nation attempt to impose a transition from traditional energy resources to energy sources often referred to as renewables, natural gas is the energy source that is best suited to integrate with the intermittency inherent in the use of wind and solar. Gas provides a reliable, affordable, and increasingly clean source of energy in both traditional and "carbon-constrained" applications.

Gas faces headwinds in the form of increasingly extreme net zero energy policies that will constrict supplies if implemented as proposed. Gas could also improve overall reliability if onsite storage was prioritized to help avoid supply disruptions that can occur in just-in-time pipeline deliveries during periods of extreme weather and demand.

Coal: 80% (B-)

Despite its low cost, abundant domestic supply, and reliability, Western nations—USA, Canada, UK, and across Europe—have targeted coal for closure largely due to climate change concerns. While most pollution concerns associated with coal use can be addressed with widely available emissions reduction technologies, coal does emit more pollutants and CO_2 than natural gas.

Due to growing regulatory pressure and effective competition from low-priced, domestic natural gas, coal use is declining in North America, as well as Europe. However, coal use worldwide—especially China and India—continues to grow rapidly. Across Asia, coal use is growing so rapidly that attempts to cease its use in the West as a climate change mitigation measure are being wholly eclipsed.[1]

The primary challenges faced by the coal industry are 1) a long-term campaign on the part of government and green special interests to stop its use, and 2) very effective competition from low-cost fracked natural gas, which is displacing coal as a primary baseload generation option.

Petroleum fuels: 70% (C-)

Petroleum products play a very small role in the production of U.S. electricity. They are almost a rounding error and are used primarily in older or geographically limited areas (like the Hawaiian Islands or Northeastern markets because of historical use).

Nuclear: 88% (B+)

Nuclear energy represents a best-of-all-worlds energy resource for the United States. Given its history as the nation's safest and most reliable electricity source and its ability to produce near-endless amounts of completely reliable and emission-free electricity, nuclear is an obvious choice, especially given the nation's current hyper-focus on net zero carbon dioxide emissions.

Nuclear's primary challenges lie in two areas: initial costs and concerns over safety related to fuel storage or the potential release of radioactive materials.

First, while initial costs to build can be high, they can be amortized over a 60- to 100-year expected life cycle. Additionally, costs can be addressed by reigning in the overactive nature of the Nuclear Regulatory Commission. Second, the industry's record demonstrates it is the nation's safest source of electricity.

Perhaps no better example of this technology's safety, reliability, and usefulness exists than the nation's fleet of nuclear-powered aircraft carriers, submarines, and cruisers. Building on Admiral Rickover's innovations, the U.S. Navy has reliably and safely powered a significant portion of its fleet with nuclear power for decades. As we have done in many other areas, it is possible to use the knowledge gained in this area in the civilian nuclear fleet.

Given the safety and reliability of both our military and civilian nuclear, concerns over meltdowns or having the fuel used to build nuclear weapons are more in the realm of science fiction than reality. The United States was once the world leader in developing safe, reliable nuclear technologies. We should focus on rebuilding that status.

Conventional hydroelectric: 80% (B-)

Hydroelectric is the one form of renewable generation that is completely dispatchable and has no emissions associated with its operations (compared with biomass).

While hydroelectric would seem to meet most of the tests of the environmental movement, it is often targeted for removal because it requires a great deal of bulk material in its construction and interrupts or changes natural river flows and floods riparian zones (displacing wildlife and human inhabitants). Given the expansive nature of large hydroelectric facilities, it is unlikely that any new developments could be permitted in North America.

Wind: 56% (F)

Wind is one of two so-called renewable energy generation sources widely promoted for its claimed ability to reduce the environmental impacts of electricity generation. Wind is marketed as being able to reduce carbon dioxide emissions, protect the environment, reduce electric rates, and improve grid reliability.

While it is true that wind does not produce carbon dioxide as it produces electricity, there are numerous other grid reliability, environmental, economic (or cost), and social issues associated with its use that are often overlooked.

Given that society increasingly relies on a steady and reliable supply of affordable energy, government policies that mandate and heavily subsidize a transition to wind generation represent a growing threat to human health and well-being.

Solar: 58% (F)

Solar is the second of two so-called renewable energy generation sources (wind is the first) widely promoted for its claimed ability to reduce the environmental impacts of electricity generation. Like wind, solar is marketed as being able to reduce carbon dioxide emissions, protect the environment, reduce electric rates, and improve grid reliability.

Like wind, solar does not produce carbon dioxide as it produces electricity. However, there are numerous other grid reliability, environmental, economic, social, and human rights issues associated with its use that are often overlooked.

Given that society increasingly relies on a steady and reliable supply of affordable energy, government policies that mandate and heavily subsidize a transition to solar generation also represent a growing threat to human health and well-being.

Geothermal: 66% (D+)

Geothermal plays a limited role in the production of U.S. electricity. Much like petroleum products, geothermal is almost a rounding error and is used primarily in geographically limited areas (like the Western states and the Hawaiian Islands)

Report Card on U.S. Energy Production

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Wind	5	6	5	6	6	F
Solar	5	5	5	8	6	F
Geothermal	6	9	5	8	5	D+

Methodology

Bottom Line Up Front: Each ranking area graded the energy resource on a scale of 1 to 10. If an energy source performed poorly, it received a 1, if it performed well, it received a 10.

The scores in each section were totaled and broken down from 1 to 50. The energy source was given a final letter grade of A to F based on its score out of 50. The grading system results in a comparative ranking that describes the energy resource as excellent (90-100 /A-range), very good (80-89/B-range), average (70-79/C-range), poor (60-69/D-range), and Failure (59 or below/F).[2]

Capacity and Reliability: We estimated the capability of this energy source to produce sufficient energy to meet demand. We also considered how plans to maintain existing (or build new) infrastructure and capacity will meet growing energy demand.

Environmental/Human Impact: We asked what are the environmental impacts, the human rights, or other labor issues associated with using this energy source.

Cost: We asked how the energy source competes with other energy sources in terms of pricing.

Technology and Innovation: We asked what technologies are used and what new technologies are being developed for this energy source.

Market feasibility: We considered whether the energy source relies on free-market forces to supply energy to the public. To what extent do subsidies and/or government mandates drive its adoption and use?

Recommendations: We considered policies that could be implemented to improve this sector's performance.

Introduction

> ***Electricity is to modern civilization what blood is to the human body.***
>
> -- Dr. Lars Schernikau, Prof. William Hayden Smith "The Unpopular Truth"

> ***The best way to protect people from heat or cold is access to plentiful, cheap energy, though that often means fossil fuels.***
>
> – Bjorn Lomborg in the Wall Street Journal (9/16/21)

We often hear that transitioning from fossil fuels and nuclear energy is essential. We are told we must transition to energy sources that are widely referred to as renewable, such as wind and solar. Fossil fuels, we are instructed, emit planet-warming greenhouse gases and other pollutants. Nuclear energy produces spent fuels that raise the long-term risks of radiation. The transition is painted as an essential energy policy, needed to protect humanity and the natural environment from the harm caused by traditional energy sources and to stave off the imminent and existential threat of climate change.

However, many details associated with this transition are brushed over or ignored. For example, before we commit to abandoning our foundational energy supplies, we should ask basic questions about the potential environmental harms associated with relying on wind and solar for much of our electricity. We should investigate what is involved with mining and refining the bulk and critical minerals and metals needed to manufacture wind turbines and solar panels and their components. We should ask very simple and straightforward questions to determine if wind and solar can even provide sufficient and consistent electricity to meet the needs of our energy-hungry society.

The details of this transition need to be more intently scrutinized.

Unlike conventional energy sources, wind turbines and solar panels are subject to the vagaries of weather patterns and diurnal cycles. On cloudy, windless days, electricity generation from this pair can drop to near zero (or zero), challenging grid reliability. The transition to wind and solar also entails significant infrastructure changes in a grid designed for the steady output of traditional, baseload power plants. But we are now assured that the grid that has provided safe and reliable electricity for decades must be substantially altered to address the variable nature of renewable generation. Instead, we should ask if the variable nature of wind and solar is well-suited to pair with our time-tested and reliable grid. We should ask if these intermittent resources are ready to meet our energy needs.

Integrating intermittent renewables into our electric grid requires that we also deploy backup mechanisms to forestall blackouts. However, the single most reliable and accessible backup option is natural gas, one of the fossil fuels that proponents of the transition tell us must be "left in the ground." Additionally, relying on renewable energy systems and the backup sources they require entails building duplicate infrastructure that operates alongside wind, solar, and batteries to provide power when wind and solar go to near-zero or zero. These backups and duplicative efforts all must be borne by ratepayers and taxpayers. The push for a rapid transition must be tempered by an understanding of the financial, environmental, and intermittency burdens imposed on electricity consumers.

In this paper, we review the arguments for and against eight major sources of electric power: natural gas, coal, petroleum fuels, nuclear, hydroelectric, wind, solar, and geothermal.

Fossil fuels emit carbon dioxide and other pollutants when combusted to generate electricity. But they have provided a reliable foundation for the advancements in technology, medicine, and transportation that have improved human lives and health over the past several decades. Coal is currently an important part of the nation's baseload electricity needs, but it suffers from a lack of political support due to the emissions associated with its use. Natural gas is a cleaner-burning option that has seen rapid growth and increased production because of the fracking (hydraulic fracturing) revolution. Petroleum fuels make up a relatively small, niche market that supplies an important, but shrinking customer base.

Nuclear power does produce spent fuels that must be stored or recycled, but it is an emissions-free resource, and its safety and reliability are unmatched.

Wind and solar are both emissions-free generation sources and are currently experiencing a great deal of policy and taxpayer support that is driving their expansion. However, they are beginning to impose unacceptable environmental and economic costs due to their low energy density and intermittent nature. Hydroelectric is an emissions-free, baseload energy option that provides reliable and affordable electricity. However, hydro is geographically limited, and it is often challenged for its impacts on rivers. Geothermal, is also geographically limited and, like petroleum fuels, supplies a small niche market.

While activists demand a transition away from fossil and nuclear fuels, these fuels still represent about 80% of our total electric demand. Grid managers are warning that the premature retirement of existing fossil fuel and nuclear assets represents a clear and present danger to overall grid reliability. Their warnings should be sufficient to give policymakers a moment's pause.

It's essential to remember that we produce electricity and power to maintain a higher standard of life for humanity. In his book Fossil Future, Alex Epstein correctly describes a basic truism in physics: energy is the capacity to do work. Epstein notes that we rely on energy as a type of "machine food" or "machine calories" to power machines.

"The essential value of energy and machines to human flourishing is that they amplify and expand our naturally meager productive ability—our ability to produce the material values we need to survive and flourish, from food to clothing to shelter to medical care to education."[3]

On the push to abandon fossil fuels, author and researcher Vaclav Smil explains, "The real wrench in the works: we are a fossil-fueled civilization whose technical and scientific advances, quality of life, and prosperity rest on the combustion of huge quantities of fossil carbon, and we cannot simply walk away from this critical determinant of our fortunes in a few decades, never mind years."

"Complete decarbonization of the global economy by 2050," continues Smil, "is now conceivable only at the cost of unthinkable global economic retreat, or as a result of extraordinarily rapid transformations relying on near-miraculous technical advances."[4]

The North American Electric Reliability Corporation (NERC) explains that "Environmental regulations and energy policies that are overly rigid and lack provisions for electric grid reliability have the potential to influence generators to seek deactivation despite a projected resource adequacy or operating reliability risk; this can potentially jeopardize the orderly transition of the resource mix.[5] For this reason, regulators and policymakers need to consider the effects on the electric grid in their rules and policies and design provisions that safeguard grid reliability."

The NERC Long-term Reliability Assessment also explains that there are high-risk areas running from the Midwestern states along the Canadian border south to Louisiana. These high-risk areas "do not meet resource adequacy criteria," and the electricity supply is "more than likely to be insufficient in the forecast period." The Assessment report warns that "more firm resources are needed."

NERC also points to elevated risk areas that "may not have sufficient availability and energy from resources during extreme and prolonged weather events and abnormal atmospheric conditions." These elevated risk areas make up a significant portion of the rest of North America.

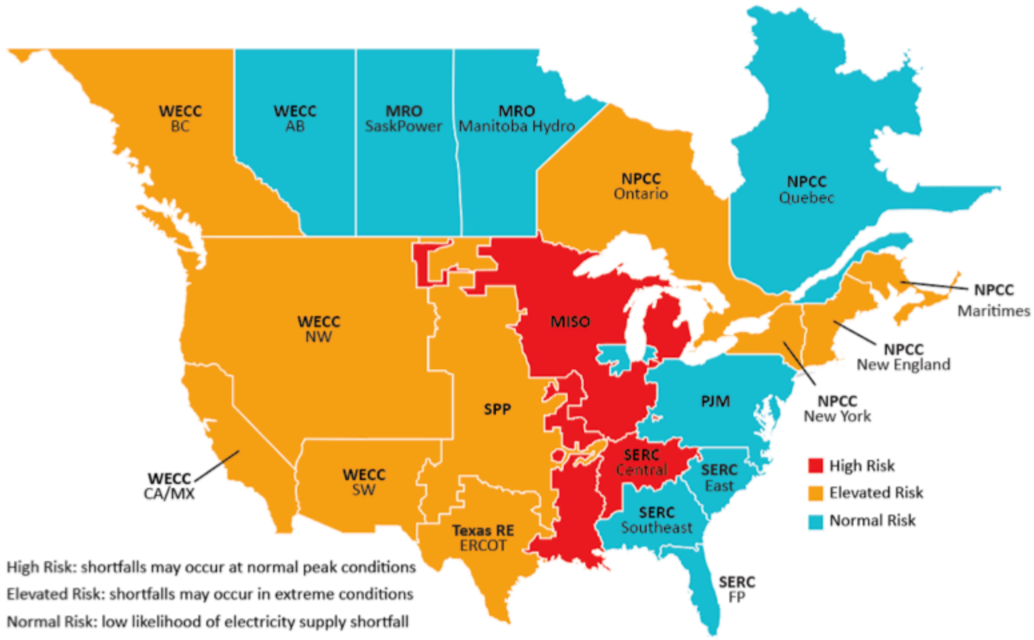


Figure 1: Risk Area Summary 2024–2028[8]

Figure 1: Map showing areas of risk in the North American grid 2024-2028 (Source: North American Electric Reliability Corporation)

Regional grid managers are sounding similar warning bells. In the "MISO's Response to the Reliability Imperative" report, the CEO of the Midcontinent Independent System Operator, John Bear warns that, "Studies conducted by MISO and other entities indicate it is possible to reliably operate an electric system that has far fewer conventional power plants and far more zero-carbon resources than we have today. However, **the transition that is underway to get to a decarbonized end state is posing material, adverse challenges to electric reliability.**" (emphasis in the original)[6]

We are told that the immediate transition to wind and solar is a laudable and worthwhile effort that will protect the natural environment and halt climate change. Our research demonstrates that the transition will impose a host of environmental and economic challenges and cause dangerous instability in the nation's electric grid.

Continued efforts to transition, therefore, require a far more measured and deliberate approach. The limitations of wind and solar power in providing consistent electricity service and the escalating costs associated with their integration into the grid underscore the need for prudence. The reliability of fossil and nuclear fuels must be recognized, and the ability to employ existing and new technologies to address the environmental impacts of these fuels should play a central role in addressing the need for a reliable, affordable, and clean energy supply.

Electricity Generation by Energy Source

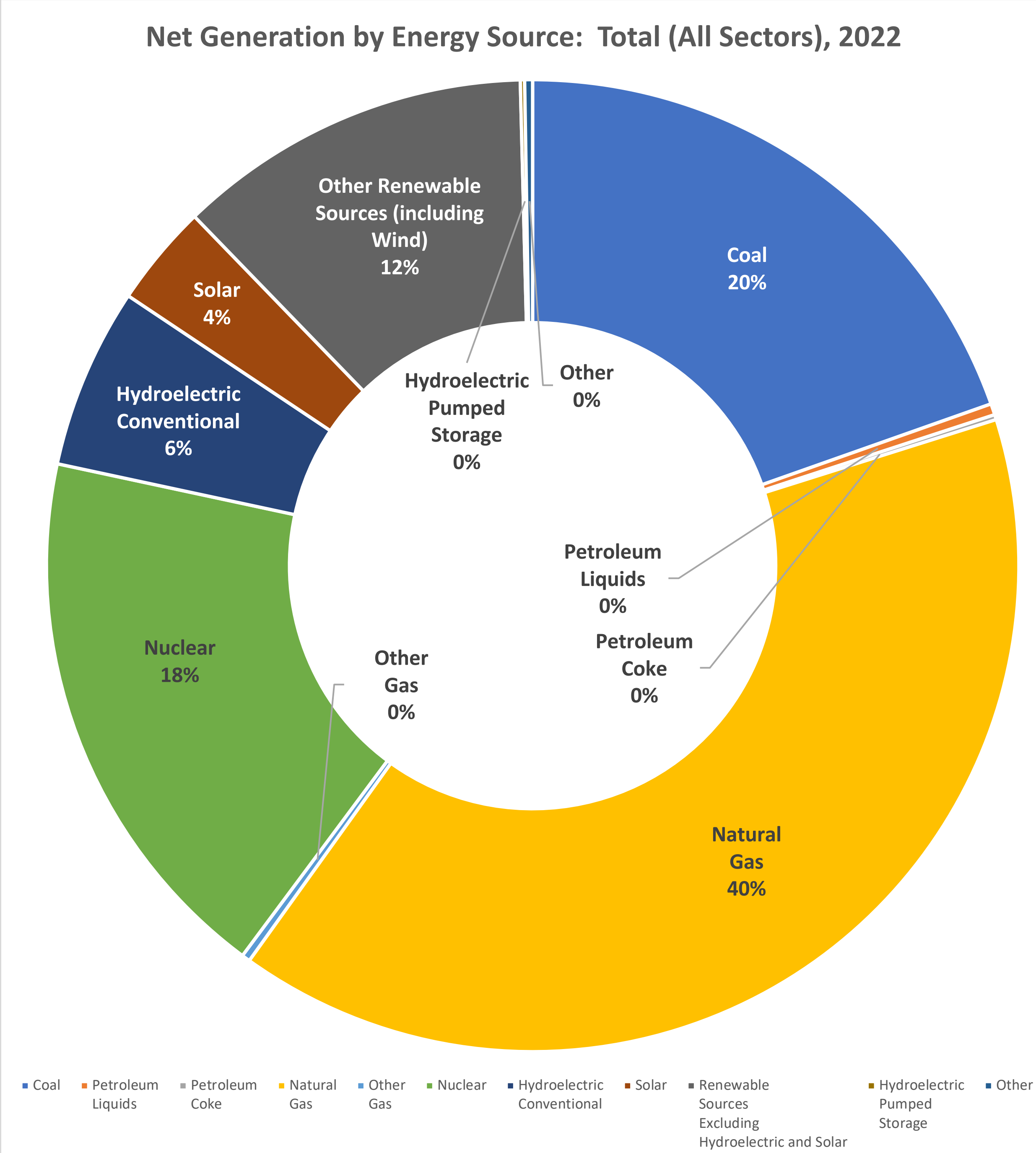


Figure 2: United States - Net Generation by Energy Source: Total (All Sectors), 2022 (Source: U.S. Energy Information Administration) [7]

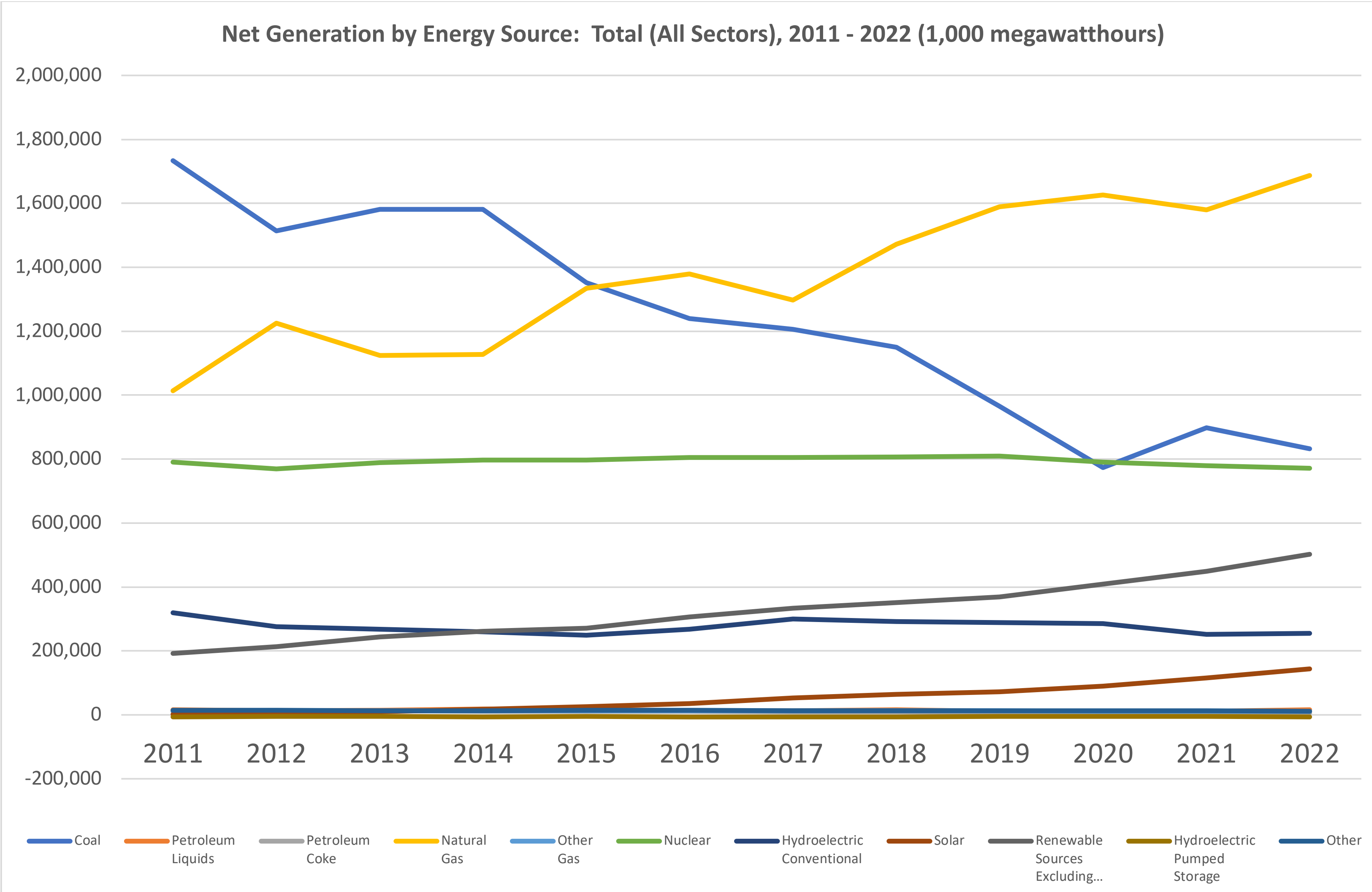


Figure 3: U.S. Net Generation by Energy Source – Total all sectors 2011-2021 (Source: U.S. Energy Information Administration)[8]

Table 1: U.S. Net Generation by Energy Source - Total (All Sectors) 2011-2021 (Source: Energy Information Administration)

	Net Generation by Energy Source: Total (All Sectors), 2011 – 2021 Generation at Utility Scale Facilities[9] (Thousand Megawatthours)											
Period	**Coal**	**Petroleum Liquids**	**Petroleum Coke**	**Natural Gas**	**Other Gas**	**Nuclear**	**Hydroelectric Conventional**	**Solar**	**Renewable Sources Excluding Hydroelectric and Solar**	**Hydroelectric Pumped Storage**	**Other**	**Total Generation at Utility Scale Facilities**
2011	1,733,430	16,086	14,096	1,013,689	11,566	790,204	319,355	1,818	192,163	-6,421	14,154	4,100,141
2012	1,514,043	13,403	9,787	1,225,894	11,898	769,331	276,240	4,327	214,006	-4,950	13,787	4,047,765
2013	1,581,115	13,820	13,344	1,124,836	12,853	789,016	268,565	9,036	244,472	-4,681	13,588	4,065,964
2014	1,581,710	18,276	11,955	1,126,635	12,022	797,166	259,367	17,691	261,522	-6,174	13,393	4,093,564
2015	1,352,398	17,372	10,877	1,334,668	13,117	797,178	249,080	24,893	270,268	-5,091	13,955	4,078,714
2016	1,239,149	13,008	11,197	1,379,271	12,807	805,694	267,812	36,054	305,579	-6,686	13,689	4,077,574
2017	1,205,835	12,414	8,976	1,297,703	12,469	804,950	300,333	53,287	332,963	-6,495	13,008	4,035,443
2018	1,149,487	16,245	8,981	1,471,843	13,463	807,084	292,524	63,825	350,467	-5,905	12,973	4,180,988
2019	964,957	11,522	6,819	1,588,533	12,591	809,409	287,874	71,937	368,862	-5,261	13,331	4,130,574
2020	773,393	9,662	7,679	1,626,790	11,818	789,879	285,274	89,199	408,539	-5,321	12,855	4,009,767
2021	897,999	11,663	7,511	1,579,190	11,397	779,645	251,585	115,258	448,424	-5,112	12,140	4,108,303
2022	831,512	15,805	7126	1,687,067	11,722	771,537	254,789	143,797	502,231	-6,028	11.114	4,230,672

Hydrocarbons/Fossil Fuels

Natural Gas

Grade: 94 % (A)

Bottom Line Up Front

Natural gas is at a unique position in our energy supply.

The nation has experienced rapid growth in energy demand for a range of activities: electricity generation, home heating, transportation, manufacturing, etc.[10]

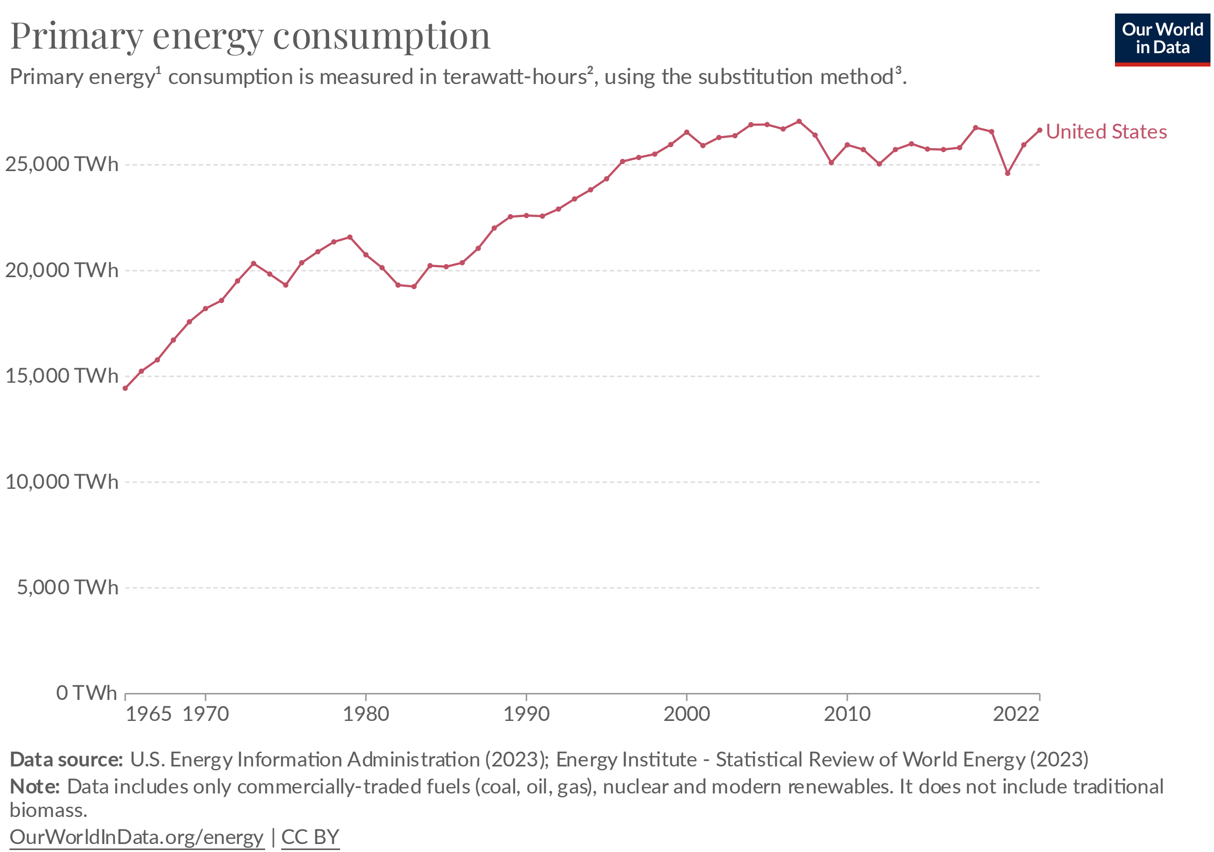


Figure 4: United States: Primary energy consumption (Source: Our World in Data)

As governments around the nation attempt to impose a transition from traditional energy resources to energy sources often referred to as renewables, natural gas is the energy source best suited to integrate with the intermittency inherent in the use of wind and solar. Gas provides a reliable, affordable, and increasingly clean energy source in both traditional and “carbon-constrained” applications.

Gas faces headwinds in the form of increasingly extreme net zero energy policies that will constrict supplies if implemented as proposed. Onsite storage could also improve overall reliability if prioritized to help avoid supply disruptions that can occur in just-in-time pipeline deliveries during periods of extreme weather and demand.

Capacity & Reliability: 9/10

Increased production due to the fracking revolution has made the United States a world leader in the production and export of natural gas. Natural gas is an essential fuel for the American utility industry to address and make up for the inherent unreliability of wind and solar.

As noted in the joint McNair, Mackinac Center report "The Truth About Natural Gas,"

> Natural gas has been a key driver in the developed world's rapidly improving standard of living and environmental conditions. The increased use of gas has reduced the overall cost of energy and increased energy reliability, both of which led to direct improvements in human health and well-being. Furthermore, as increasingly strict government regulation has targeted the use of coal for electricity generation, low-cost natural gas—a result of the Shale Revolution—has been available to pick up much of that lost energy production capacity.[11]

As gas picked up the electricity generation gauntlet, the nation consumed over 32.2 quadrillion Btu of natural gas in 2022.[12]

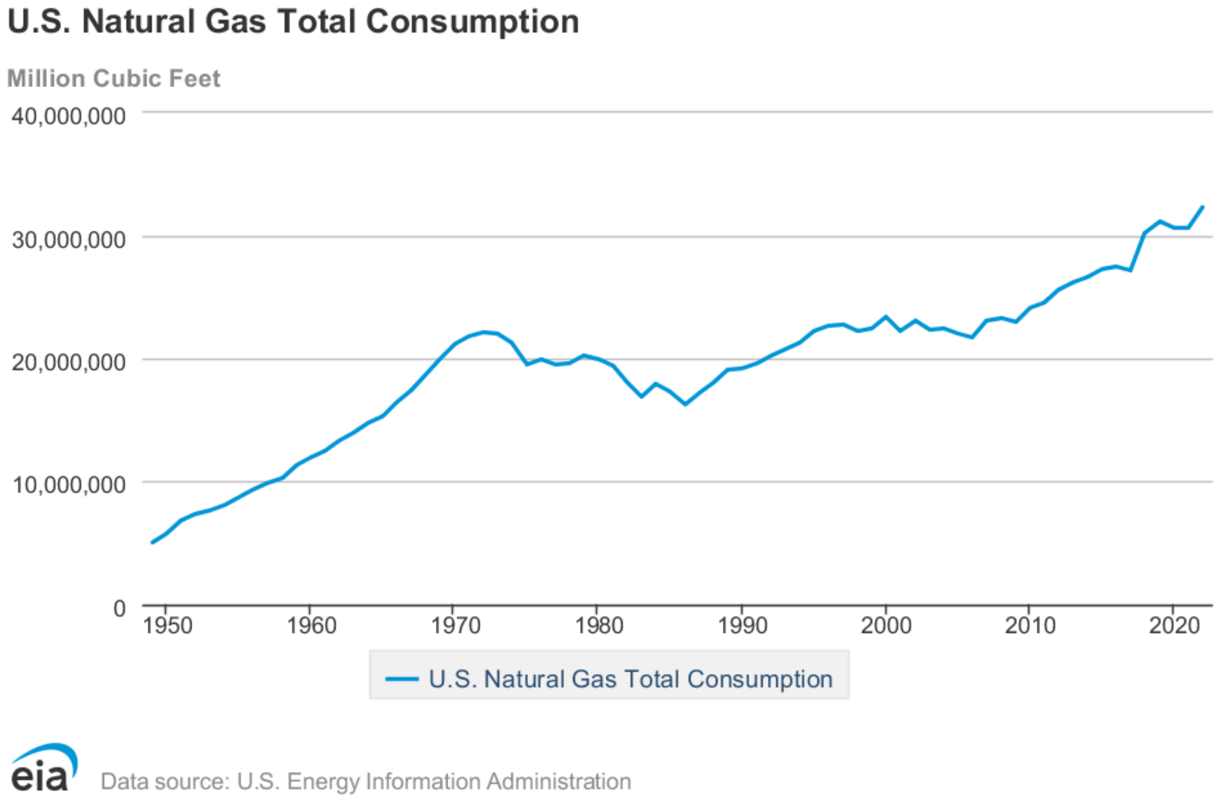


Figure 5: Natural Gas – primary energy consumption by source 1949 - 2022 in quadrillion Btu - excludes supplemental gaseous fuels (Source: U.S. Energy Information Administration)

That high level of use translates to natural gas making up 40% of the nation's electric generation mix in 2022 and 33% of primary energy consumption.[13, 14] The nation had not relied on natural gas for that significant percentage of total energy usage since 1971.[15]

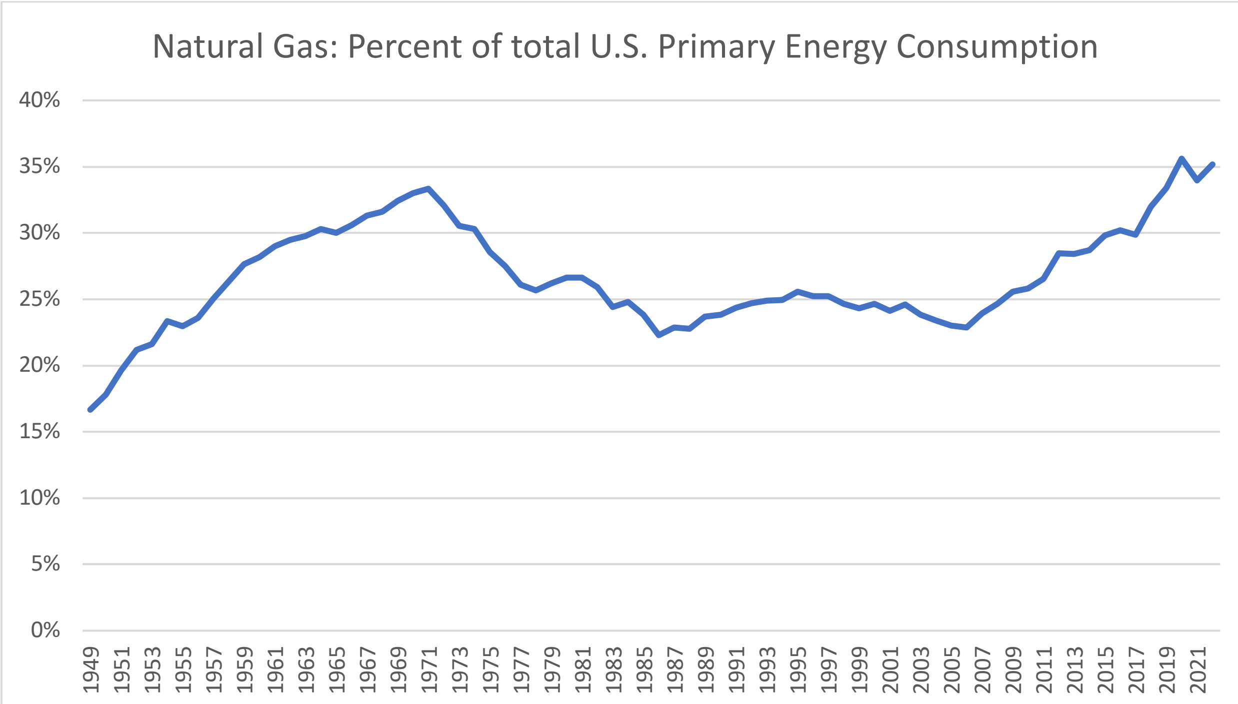


Figure 6: Natural Gas - Percent of U.S. Primary Energy Consumption by Year 1949 - 2022

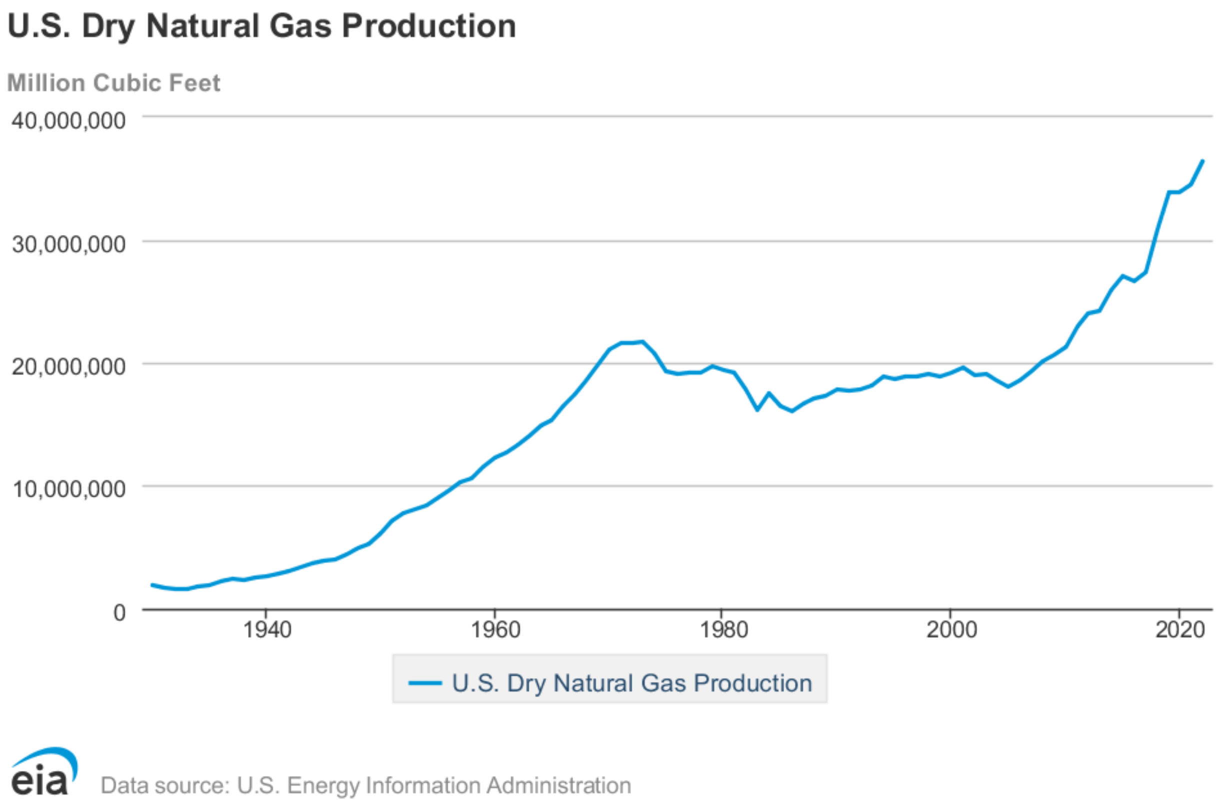


Figure 7: U.S. Natural Gas Dry Production - annual (Source: U.S. Energy Information Administration)[16] Dry natural gas is made up mostly of methane and has had any impurities or other liquid hydrocarbons removed.

Despite growing production levels, the fracking revolution has made overall gas resources far more abundant.

> "Longer-term, the Energy Information Administration reports that the expansion of horizontal drilling and hydraulic fracturing technology has allowed annual natural gas production in the U.S. to increase by more than 79% from 2007-2021."[17, 18]

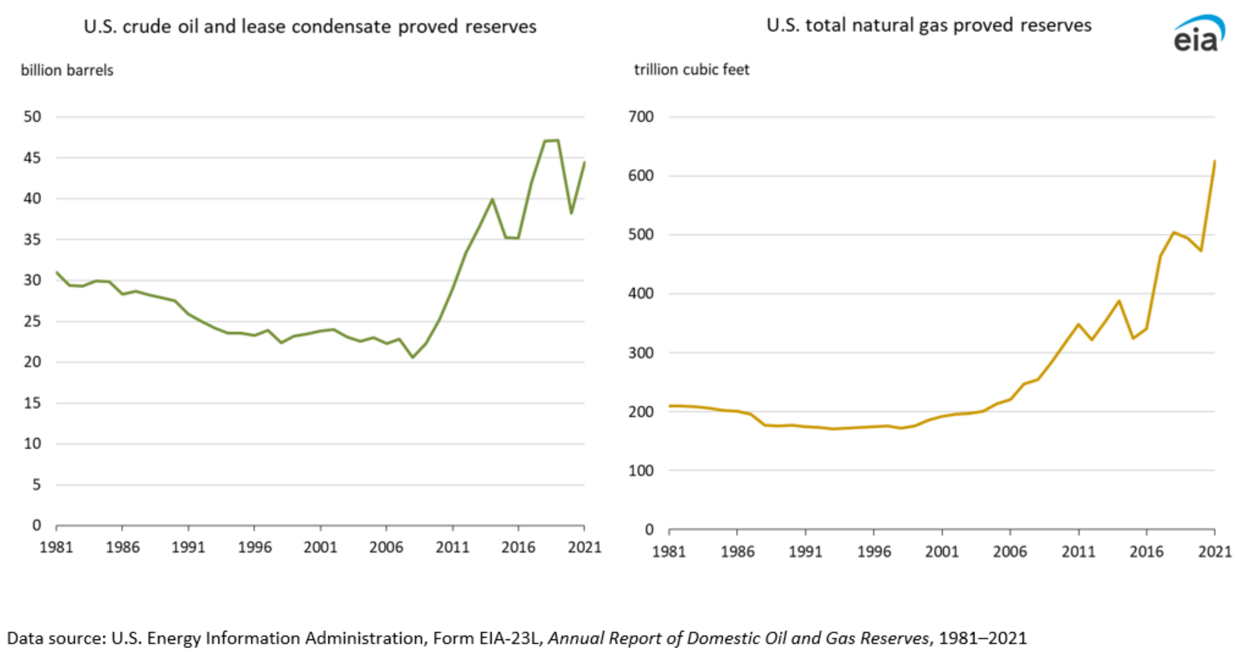


Figure 8: U.S. proved oil and natural gas reserves 1981-2021. (Source: U.S. Energy Information Administration)

As gas supplies become less constrained, “peak oil” and “peak gas” concerns have dwindled. This is a significant change as concerns about peaking reserves have existed since even before the State Geologist of Pennsylvania, John Archbold “warned in 1885 that ‘the amazing exhibition of oil’ was only a ‘temporary and vanishing phenomenon—one which young men will live to see come to its natural end.’”[19] However, Energy Information Administration data shows how the fracking revolution has effectively removed those concerns about limited natural gas supplies.[20]

Recent numbers, published by the U.S. Energy Information Administration indicate that “as of December 30, 2021, U.S. total natural gas reserves…totaled about 625.4 trillion cubic feet (Tcf).” EIA indicates that this represents a 32% increase from proved reserves of 473 Tcf estimated in 2020.[21]

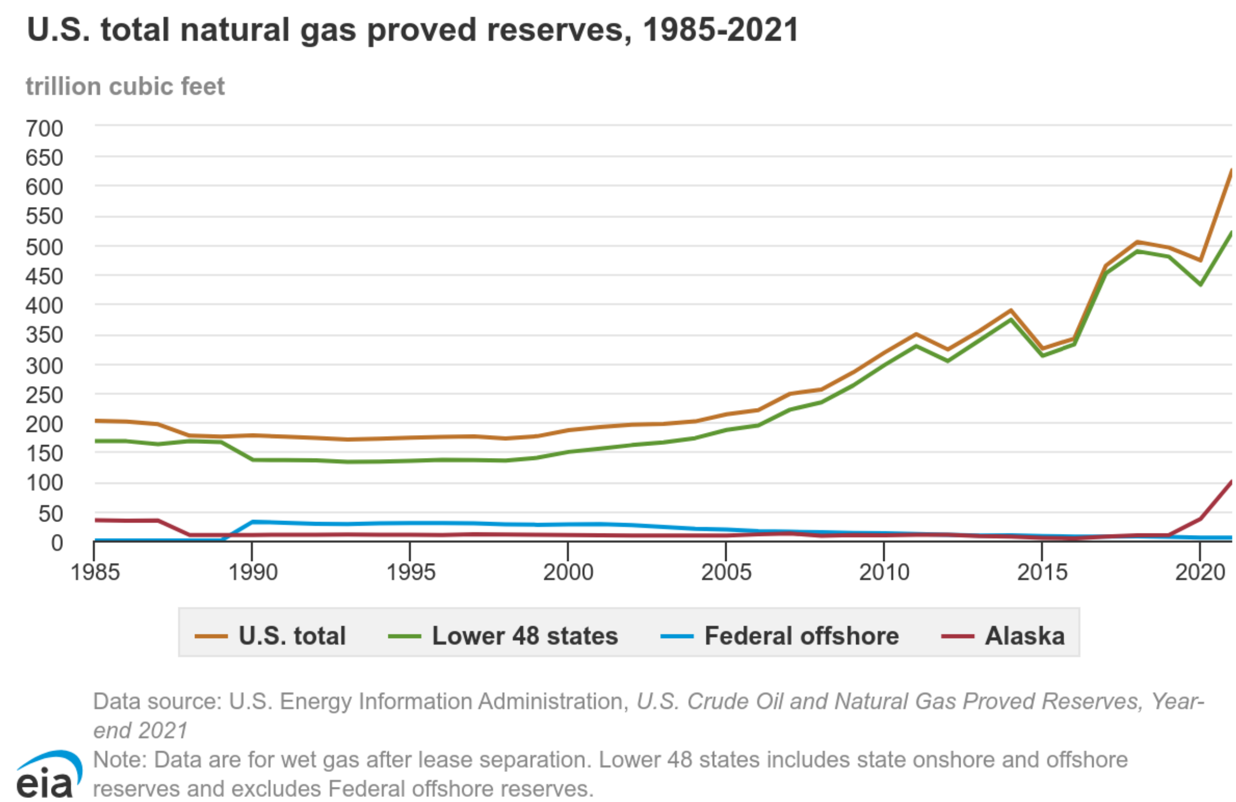


Figure 9: U.S. Total Natural Gas Proved Reserves, 1985-2021 (Source: U.S. Energy Information Administration)

As a result of growing reserves and domestic production in the United States, we have been able to reduce demand for international—mostly Canadian—supplies. Natural gas imports peaked in 2007 at 4.61 trillion cubic feet (Tcf), or 12.62 billion cubic feet per day (Bcf/d) and have "generally declined each year since then." [22] Total annual U.S. natural gas imports in 2022 were approximately 3.02 Tcf (8.28 Bcf/d).

As imports have decreased, rapid growth in domestic natural gas production has decreased prices (relative to international markets) and allowed U.S. exports to grow rapidly. Since 2016, the U.S. has been a net natural gas exporter; in 2022, annual exports reached an all-time high of 6.90 Tcf.

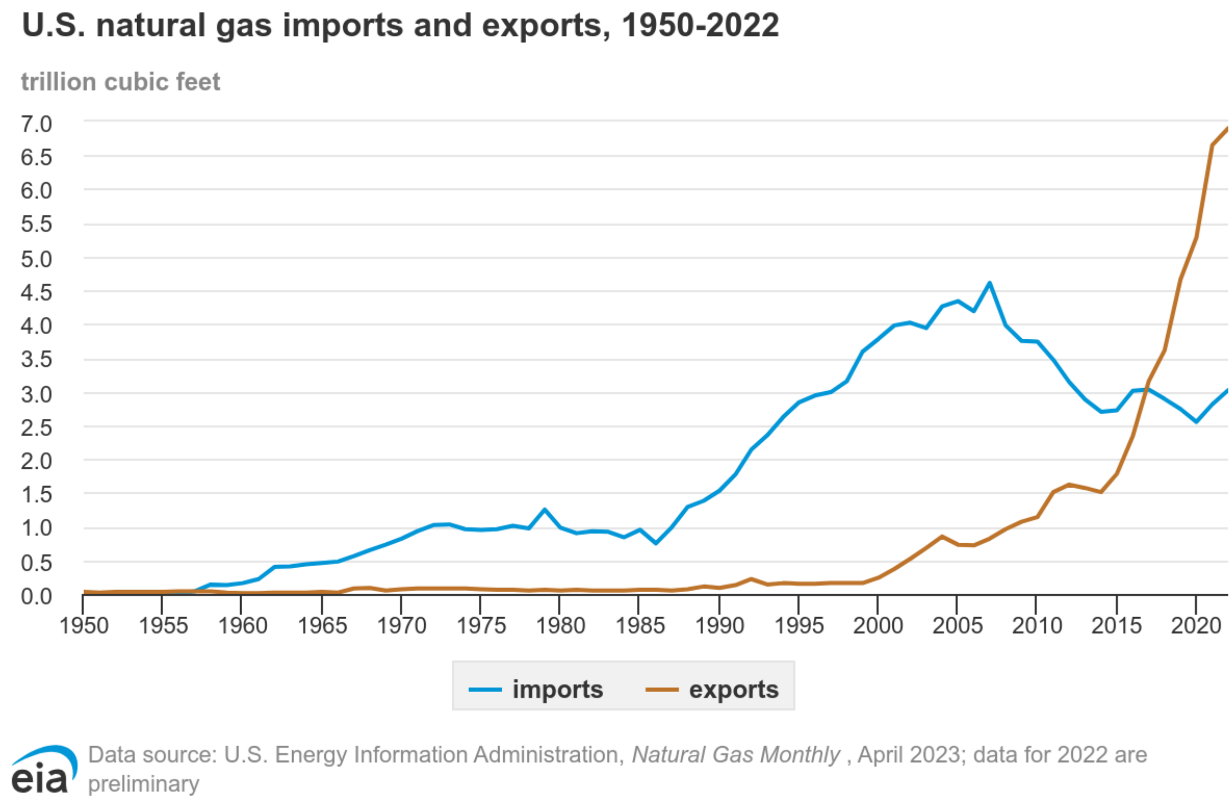


Figure 10: U.S. Natural Gas Imports and Exports, 1950-2022 (Source: U.S. Energy Information Administration)

A key factor in increased U.S. production, consumption, and exports has been increased pipeline capacity, which allows oil producers to increase the capture of "associated natural gas" coming from oil wells (especially in the Permian Basin in Texas and New Mexico). Liquid natural gas (LNG) exports have grown consistently since 2016 and now represent the majority of U.S. export volumes. Pipeline capacity represented about 44% of U.S. natural gas exports: 68% of pipeline volume was sent to Mexico, and 32% was sent to Canada.

Improving natural gas production has changed expectations and outlooks for the U.S. gas industry from concerns about shortages to the ability to export. "Several LNG import terminals were built in the 1970s, and a new wave of terminals was constructed in the mid-to late-2000s," reports the U.S. Energy Information Administration. "As domestic production increased, LNG imports declined, as many new terminals were barely used and the utilization rates of older terminals declined."[23] As of the end of 2023, "Five LNG export projects are currently under construction with a combined 9.7 Bcf/d of LNG export capacity," and North American LNG export capacity is expected to balloon to over 24.3 billion cubic feet per day (Bcf/d) by the end of 2027.[24]

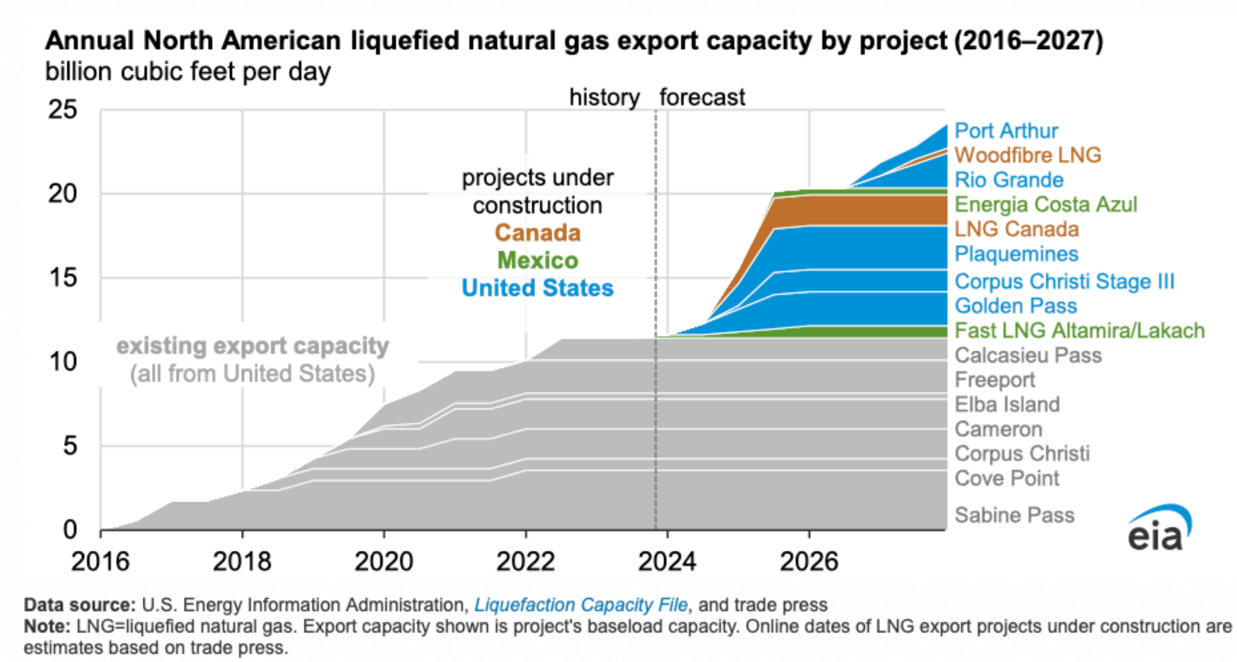


Figure 11: North American liquefied natural gas export facilities, existing, and under construction (2016-2027). Source: U.S. Energy Information Administration

Despite the obvious potential of this fuel, natural gas still faces headwinds. Fracking is allowing growing domestic production while net zero energy policies are pushing to reduce the use of gas. On numerous occasions, President Biden and other members of his administration have publicly promised to end the use of fossil fuels—coal and natural gas—and to restrict the construction and use of infrastructure used to transport those fuels. "I want you to look at my eyes. I guarantee you. I guarantee you," promised then-candidate Joe Biden to a member of the public at a campaign stop. "We're going to end fossil fuel."[25]

The Biden EPA has also proposed strict new methane regulations at the COP28 meeting in Dubai, United Arab Emirates on December 2, 2023. EPA claims the rule "leverages the latest cost-effective, innovative technologies and proven solutions to prevent an estimated 58 million tons of methane emissions from 2024 to 2038, the equivalent of 1.5 billion metric tons of carbon dioxide – nearly as much as all the carbon dioxide emitted by the power sector in 2021."[26] The American Petroleum Institute and the Energy Workforce and Technology Council critiqued the proposed rule. "While Energy Workforce shares the administration's goal of lowering methane emissions, we believe …[the] final rule will serve as a new tax on American energy production at a time when this industry could not be more vital."[27]

Adding to the restrictions being placed on gas development and use, the Biden Administration has also paused approvals of pending applications for U.S. liquid natural gas export terminals while it "update[s] the assessments used to inform whether additional liquefied natural gas (LNG) export authorization requests to non-Free Trade Agreement countries are in the public interest."[28] Official departmental writeups of this move highlight trade issues with non-free trade countries and energy security. However, a prepared White House statement does not discuss free trade. While it mentions energy costs and security, the statement clarifies that the decision to pause decisions on LNG exports was due to “the calls of young people and frontline communities who are using their voices to demand action.” The statement focuses almost completely on climate change and the Administration’s policy goals to cut greenhouse gases.

> “My Administration is announcing today a temporary pause on pending decisions of Liquefied Natural Gas exports – with the exception of unanticipated and immediate national security emergencies. During this period, we will take a hard look at the impacts of LNG exports on energy costs, America’s energy security, and our environment. This pause on new LNG approvals sees the climate crisis for what it is: the existential threat of our time.”[29]

Media outlets also tie the multiple-month-long, “open-ended analysis of the impacts of the [LNG] shipments” to demands from environmental groups that are arguing natural gas exports cause “significant methane emissions that warm the planet.”[30] After the Biden Administration’s announcement, the founder of the Vessel Project, publicly announced they had won and ordered a planned three-day sit-in at U.S. Department of Energy offices in Washington, DC to be canceled.[31]

Halting the approvals of new LNG export terminals was “just what the climate activists wanted” according to a New York Times article.

> “Ahead of the decision, White House climate advisers met with activists like Alex Haraus, a 25-year-old Colorado social media influencer who has led a TikTok and Instagram campaign aimed at urging young voters to demand that Mr. Biden reject the project. ‘And we absolutely will reward or punish him on this decision,’ Haraus told Coral, referring to Biden.”[32]

Industry representatives note the Administration’s timing is uniquely bad, given the important role that growing U.S. exports play in the world’s attempts to replace far less efficiently produced Russian natural gas. “The Truth About Natural Gas” report explained, “The International Energy Agency publishes a global methane tracker that demonstrates Russian natural gas production emits 30% more methane per unit of energy produced than American producers.”[33, 34]

The Empowerment Alliance also points out that restricting the flow of LNG in this fashion harms our allies.

> “Prior to its war against Ukraine, Russia supplied 40% of the natural gas imported by the European Union. Since then, it has been American LNG that has filled the gap and allowed us to support our allies during this crisis. If new U.S. LNG projects are blocked, Europe and Asia will have to import gas from elsewhere to meet their growing demand. Most won’t

> come from America's friends, and it will not be produced with the environmentally conscious methods that natural gas is produced within the U.S."[35]

At the same time, the ban harms American workers and businesses by restricting their ability to compete in valuable international energy markets.

While the federal government implements laws and regulations that will make it more difficult to produce, use, and export domestic natural gas, several state and local decisions that could have similar impacts are appearing.

In California, several cities have implemented bans on using natural gas in new construction: Berkeley, Oakland, San Francisco, Los Angeles, and San Jose. The California Restaurant Association sued in 2019 in response to the Berkeley ban, claiming the city had "overstepped its authority."[36] In 2021 a federal judge dismissed the lawsuit. However, a recent ruling from a three-judge panel on the Ninth Circuit Court of Appeals agreed with the Association that the city's ban was unlawful. In early January 2024, the full Ninth Circuit declined a new hearing, meaning the panel's ruling stands unless it is reviewed by the Supreme Court. If the ruling stands, bans being implemented by other cities are also likely to be unenforceable.

In New York, a provision in the state's 2023 budget effectively "ban[s] natural gas and other fossil fuels in most new buildings" due to what media outlets refer to as "mounting pressure from environmental advocates and climate-minded voters."[37] The new state law bans natural gas- and propane-fueled furnaces and stoves and requires transitioning to "climate-friendly" appliances like heat pumps and electric stoves.

This mix of bureaucracy and bad legislation across the Northeastern states has conspired to hurt American consumers and the environment. Residents of the Northeastern states are forced to use biomass and fuel oil, or (incredibly) Russian LNG, instead of cleaner and cheaper domestic natural gas.[38] New York state's 2014 ban on fracking, even though the state sits over the Marcellus shale, has limited residents' ability to access the clean and reliable energy provided by natural gas.[39, 40]

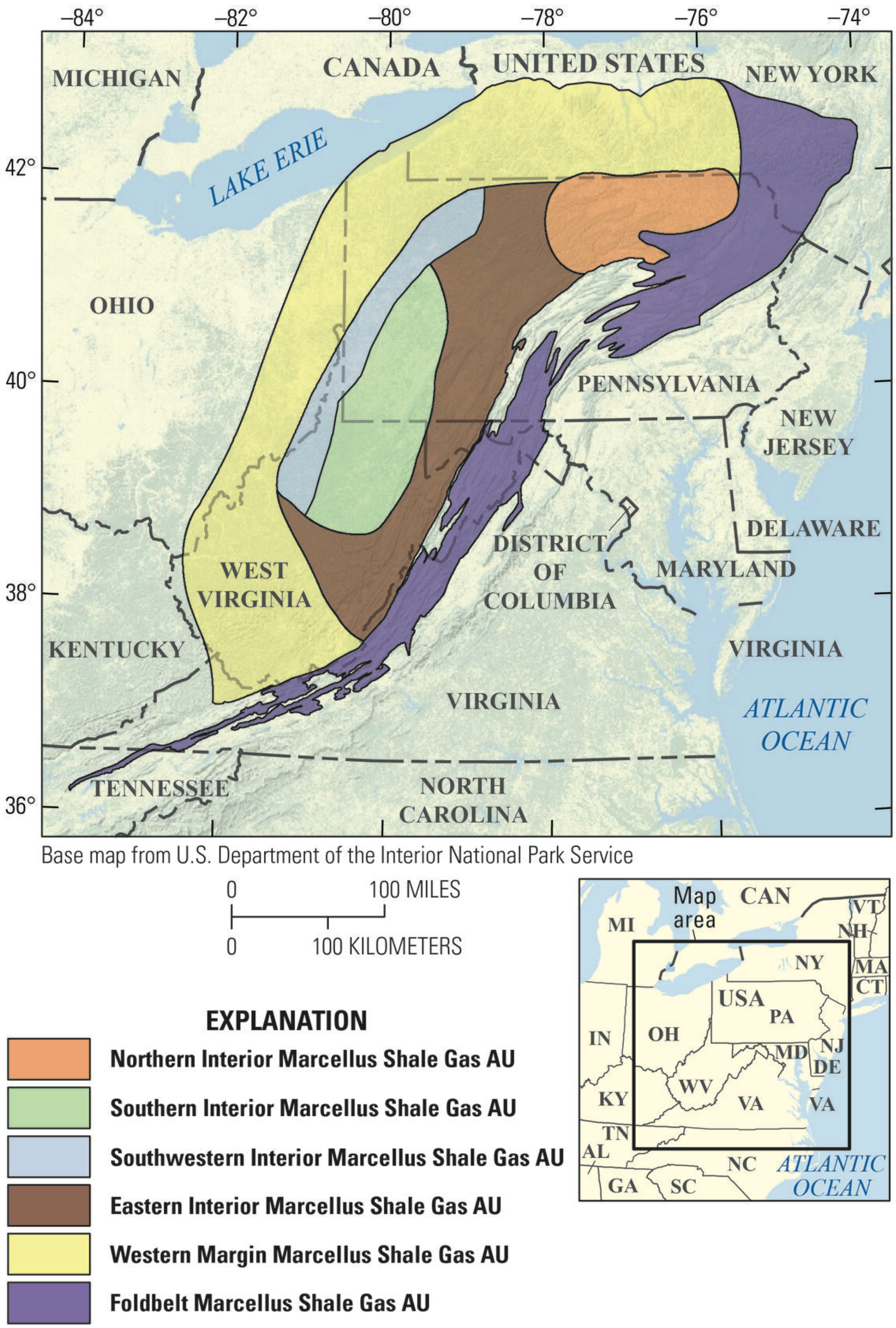


Figure 12: Marcellus Shale Assessment Map (Source: U.S. Geological Survey)

Environmental/Human Impact: 9/10

The fracking revolution has done more to reduce greenhouse gas emissions and other air pollutants than any other technology.

Descriptions that use terms like "climate-friendly" are instructive given that natural gas is the primary reason the United States has been able to reduce greenhouse gas emissions over the past few decades. More broadly, the discussion on the environmental benefits of using natural gas in "The Truth About Natural Gas: A Wellspring for the U.S. and Global Energy Future," describes how expanding the use of natural gas has improved environmental and human health.[41]

Human health and well-being

Since the beginning of the Industrial Revolution, "The Truth About Natural Gas" explains that "human life expectancy has doubled across the planet" because of improved medicines, health care, and food production. All these improvements are directly attributable to easier access to energy and the use of machines to reduce workloads or to improve agricultural productivity.

Air quality

At the same time as we have increased overall energy use (see Figure 4: United States: Primary energy consumption) at the start of the Natural Gas section, showing increasing primary energy use), we have rapidly reduced air pollutant concentrations. "EPA data demonstrates that, from 1970 to 2020, combined emissions of the six criteria air pollutants tracked by the federal agency — particulate matter (2.5 and 10 microns), oxides of sulfur, oxides of nitrogen, volatile organic compounds, carbon monoxide, and lead — had dropped by 78%."[42]

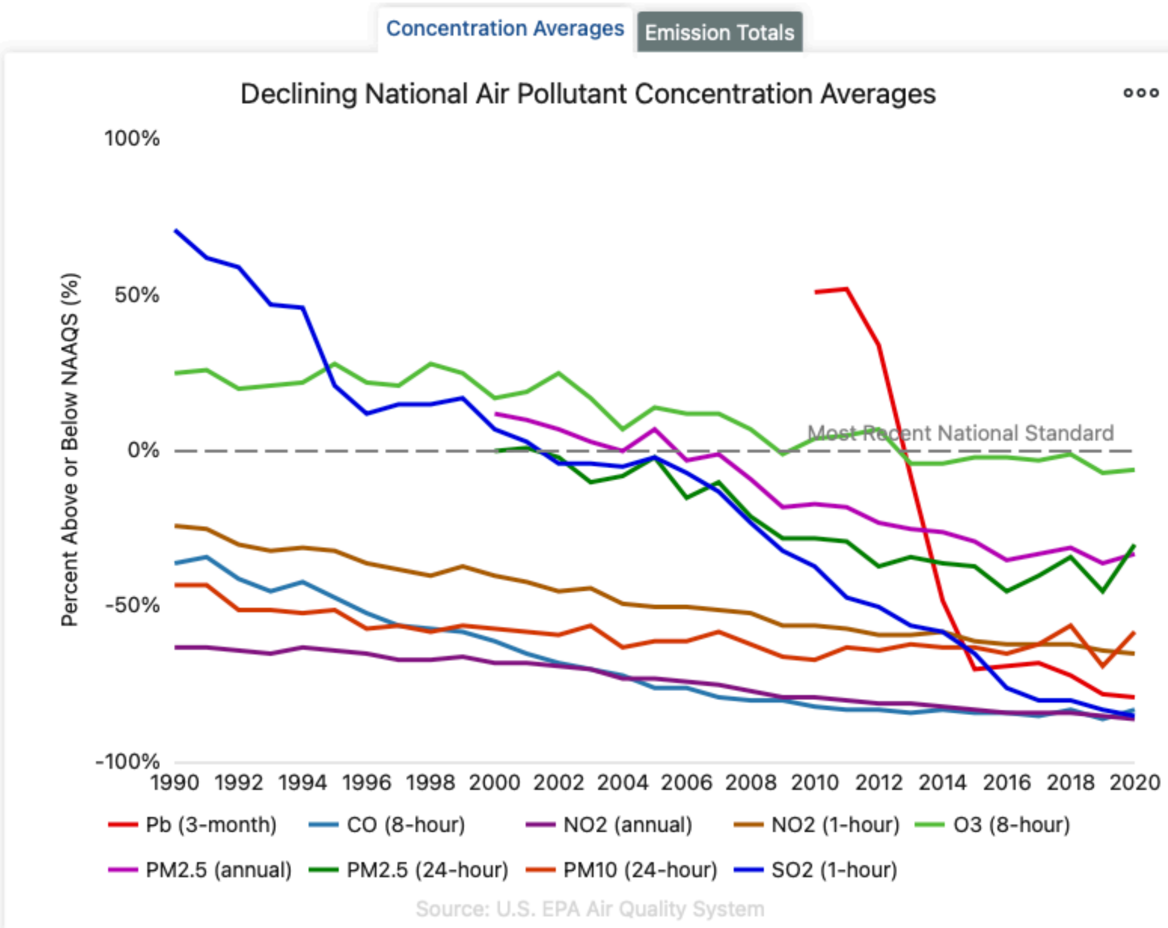


Figure 13: EPA Declining National Air Pollutant Concentration Averages

The presence of affordable, reliable, energy-dense, and increasingly clean energy sources allows human society to improve its economic well-being, which provides the freedom to focus on environmental mediation or improvements.

Greenhouse gas emissions

"The Truth About Natural Gas" report cites Environmental Protection Agency data to show how greenhouse gas emissions in 2020 were 21% below 2005. Updated information on the EPA website explains that rebounding economic activity after the COVID-19 pandemic and lockdowns led to a 6% increase in greenhouse gas emissions. "Greenhouse gas emissions in 2021 (after accounting for sequestration from the land sector)," reports the EPA, "were 17 percent below 2005 levels."[43]

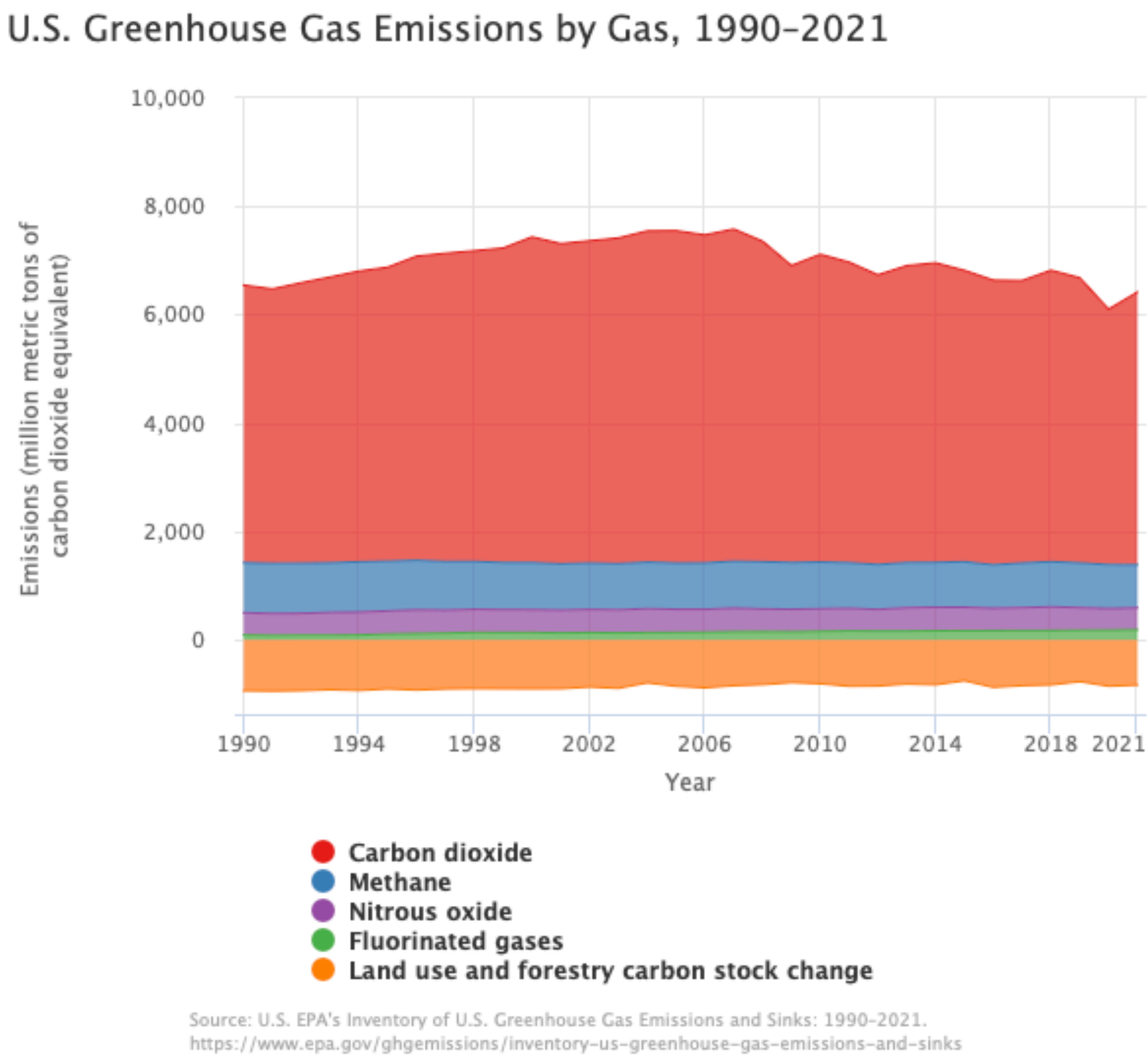


Figure 14: U.S. Greenhouse Gas Emissions by Gas, 1990-2021 (Source: U.S. Environmental Protection Agency)

Adding to the fact that greenhouse gas emissions have dropped 17% below 2005 levels, EIA data indicates that switching from coal to natural gas has been the primary driver of the nation's CO_2 reductions.[44]

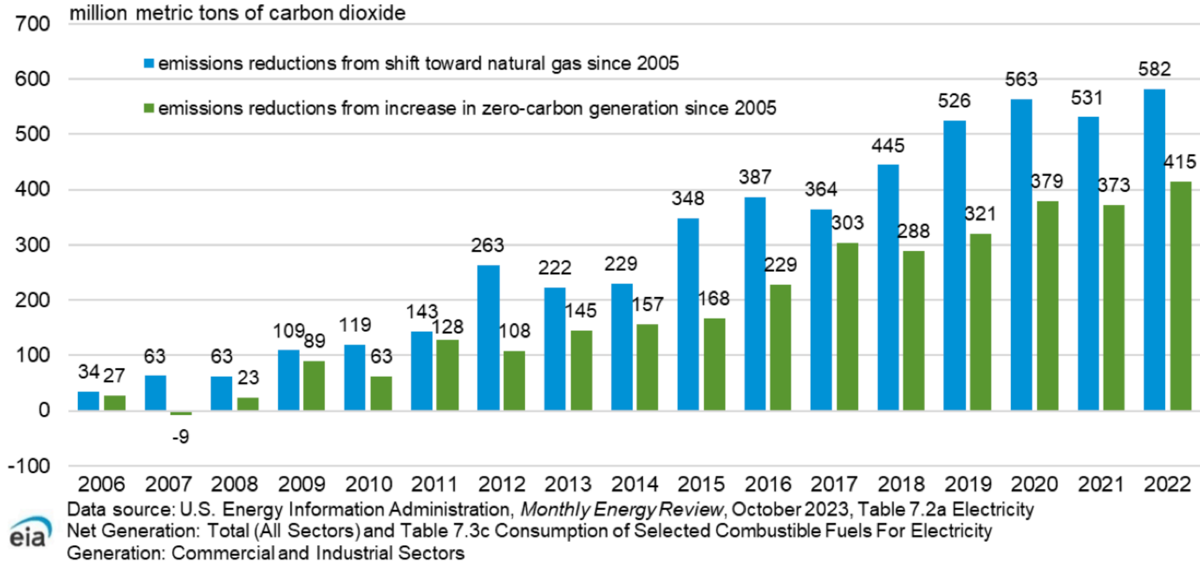


Figure 15: CO2 emissions reductions relative to 2005 caused by changes in the fuel mix of electricity generation 2005-2022 (Source: U.S. Energy Information Administration)

This reduction is because a relatively simple method of avoiding or reducing the emissions of pollutants and greenhouse gases is to use a different fuel. Different chemical characteristics of fuels allow for reduced emissions at the point of generation. For example, a very quick and rough look at the chemical makeup of dry natural gas (methane) and coal shows natural gas is CH_4 – one carbon atom for every four hydrogen atoms. Coal has a rough and approximate chemical makeup of $[CH]_N$ or one carbon atom for every hydrogen atom.[45] When these fuels are combusted, the hydrogen bonds with oxygen in the fuel to form water (H_2O), and the carbon bonds with oxygen to form carbon dioxide (CO_2). The increased ratio of carbon atoms to hydrogen atoms in coal produces more CO_2 molecules when coal is combusted than when natural gas is combusted.

Other molecules and elements in coal can also be released during combustion, such as nitrogen, sulfur, and heavy metals such as mercury. This makes natural gas relatively more attractive as an energy generation fuel source when one considers the cost of removing pollutants from the emissions of coal-fueled power plants.

Despite a brief respite in greenhouse gas emission reductions, U.S. emissions remain on a clear downward trend since the 2005 measuring point. While per capita emissions in the U.S. are still higher than the remainder of the world, total greenhouse gas emissions from the U.S. are now dwarfed by total greenhouse gas emissions from Asia.

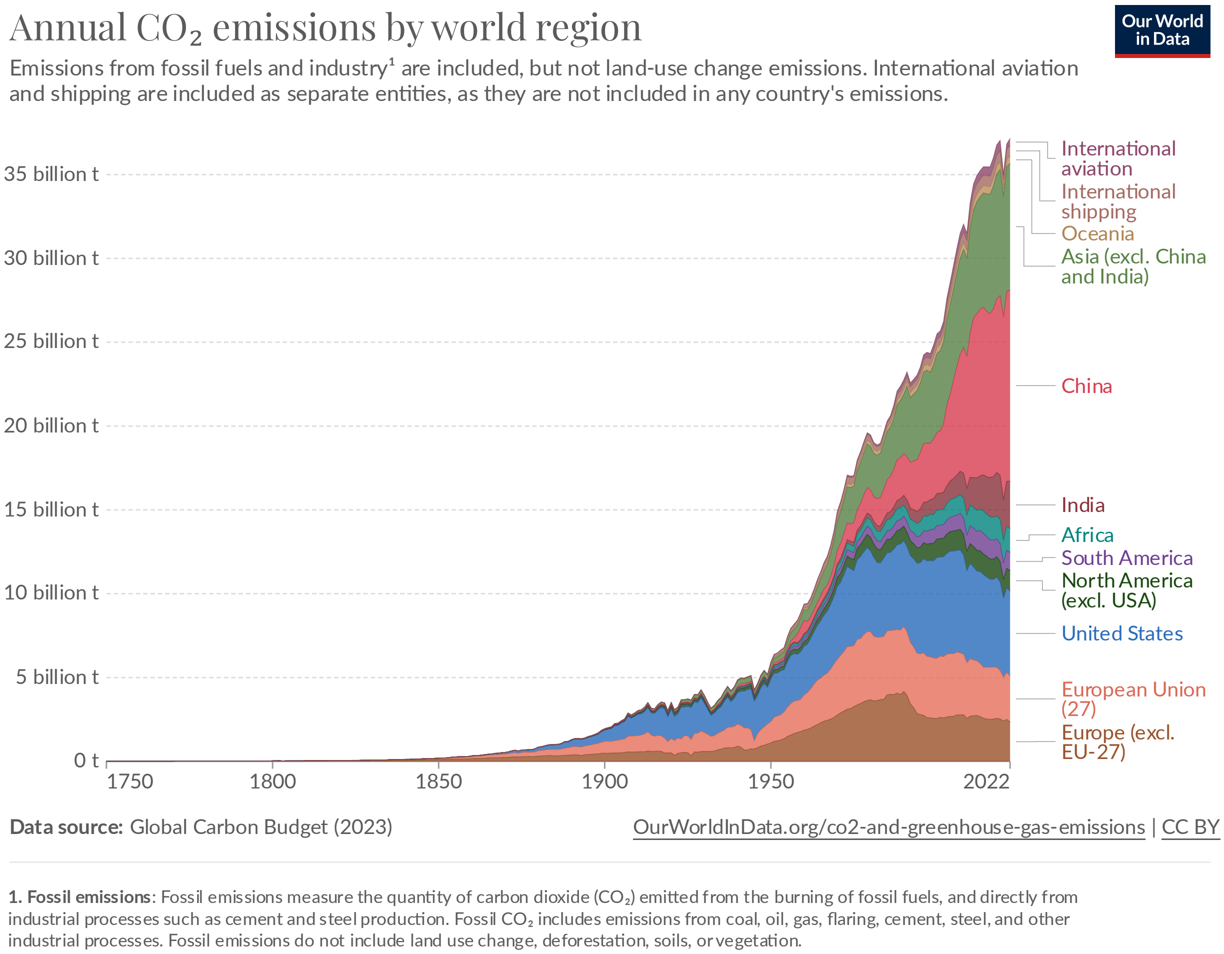


Figure 16: Annual CO_2 Emissions by World Region 1750-2022 (Source: Our World in Data)[46]

Fracking and groundwater

The release of films like Josh Fox's "Gasland," in 2010 highlighted concerns about the ability of fracking activities to harm or pollute groundwater. Fox continues to speak on this issue, arguing that political and industry interests have undertaken a campaign to debunk his work and harm his credibility.[47] While that characterization makes for frightening headlines on certain websites, the reality is that asking reasonable questions about the misrepresentations contained in Fox's work does not represent character assassination.

In the most notable example of this reasonable pushback against Fox's claims, documentarian Phelim McAleer demonstrated how a situation that would be frightening for many people was a well-known, historical idiosyncrasy of the geological conditions in Weld County, Colorado. In "Gasland," Fox filmed a resident of the area igniting the water coming from their kitchen tap with a lighter. Fox's documentary tied flammable chemicals in the water to drilling activities by natural gas producers. However, McAleer's film "FrackNation" demonstrated that people in that area had known since at least the 1930s that this was a natural phenomenon.[48] McAleer pushed back, claiming that Fox should have disclosed this fact in "Gasland."

Numerous other published reports, including reports from the U.S. Geological Survey, the U.S. Department of Energy, the U.S. Environmental Protection Agency, and the U.S. Government Accountability Office, as well as numerous state agencies and universities, have considered the claims that fracking harms groundwater and found them to be baseless.[49] The U.S. EPA reported that their research "did not find evidence that these mechanisms have led to widespread, systemic impacts on drinking water resources in the United States."[50]

Even a study funded by the environmental group Natural Resources Defense Council could not find a link between fracking and groundwater contamination. As described in an article on Energy in Depth, a project of the Independent Petroleum Association of America, the report noted that above-ground spills, not fracking, linked with oil and gas development could potentially cause contamination. "In North Dakota, the high occurrence of OGW spills is potentially threatening the quality of surface and drinking water sources."[51]

Energy density and land use

Natural gas also provides an energy-dense option for powering human lives and economies and fits well with Robert Bryce's "Iron Law of Power Density." Bryce notes "… the lower the power density, the greater the resource intensity."[52] In another study, Bradley Layton compared the energy densities of varying energy sources. "Gasoline is ten quadrillion times more energy-dense than solar radiation, one billion times more energy-dense than wind and water power, and ten million times more energy-dense than human power," explained Layton.[53] Using the numbers from Layton's work, gasoline is 1,000 times more energy-dense than natural gas. This means natural gas is 26 trillion times more energy-dense than solar and five million times more energy-dense than wind.

That energy density translates to far less land needed to produce and operate natural gas than either wind or solar.

Source	Joules per cubic meter
Solar	0.0000015
Geothermal	0.05
Wind at 10 mph (5m/s)	7
Tidal water	0.5–50
Human	1,000
Oil	45,000,000,000
Gasoline	10,000,000,000
Automobile occupied (5800 lbs)	40,000,000
Automobile unoccupied (5000 lbs)	40,000,000
Natural gas	40,000,000
Fat (food)	30,000,000

Figure 17: Energy Density of Various Energy Sources (Source: Layton, 2008)

Workforce

The North American natural gas industry produces a valuable product with a well-paid, highly skilled, and professional adult workforce. U.S. Bureau of Labor Statistics indicates the average hourly earnings for all Oil and Gas Extraction industry employees were $48.11/hr in November 2023 (or $100,069 annually, which is almost 57% higher than the national average for 2022 reported by the Social Security Administration).[54] These employees worked an average of 42.4 hours weekly.[55] BLS also notes that "Gas Plant Operators" have a mean annual wage of $78,430 and other workers in the natural gas sector are paid similar annual wages: natural gas distribution workers earn an average annual wage of $80,330, pipeline transportation of natural gas workers earn $80,460, oil and gas extraction workers $73,510.[56]

Cost: 10/10

Natural gas is our least expensive energy generation option when full costs are considered.

Gas competes very favorably with other energy sources. Many sources use the Levelized Cost of Energy (LCOE), popularized by organizations like the asset management firm Lazard, to provide a "Comparative LCOE analysis for various generation technologies on a $/MWh basis, including sensitivities for U.S. federal tax subsidies, fuel prices, carbon pricing and cost of capital."[57] The April 2023 Lazard's "Levelized Cost of Energy Comparison – Unsubsidized Analysis" lists natural gas peaking technologies at $115 - $221 per MWh and gas combined cycle technologies at $39 to $100 per MWh.

However, while LCOE does provide a useful metric for a rough comparison of energy options, it does not capture all the costs associated with various energy sources and, therefore, fails to provide a complete or accurate comparison.

"A November 2017 Berkeley Labs study on the 'Impacts of Variable Renewable Energy (VRE) on Bulk Power System Assets, Pricing, and Costs,' says that 'comparing the LCOE of different technologies that provide varying services is misleading.' For example, you can't use the same measure to weigh the value of a small natural gas turbine to a large nuclear facility, or renewable energy – a variable resource – to more reliable coal plants. Doing so gives the perception that they can provide the same service. The study explains that the more renewable generation facilities you build, the more it costs the system to make up for their variability, and the less value they provide to electricity markets."[58, 59] Given current energy policy targets of transitioning the nation's electric grid, a key value offered by natural gas is the ability to provide a fast and inexpensive means of addressing the variability and intermittency of wind and solar.

Other studies provide a more complete cost calculation than that offered by Lazard. "The Levelized Cost of Electricity from Existing Generation Resources," a report by the Institute for Energy Research and America's Power lists two key findings.[60] First, "on average, continuing to operate existing natural gas, coal, nuclear and hydroelectric resources is far less costly than building and operating new plants to replace them." Second, the report gives "a calculation of the costs that non-dispatchable wind and solar generation resources impose on the dispatchable generation resources which are required to remain in service but are forced to generate less in combination with them."[*]

The calculations in this report "estimate that the 'imposed cost' of wind generation is about $24 per MWh (of wind generation) when we model the cost against new [combined cycle] CC gas generation it might displace, and the imposed cost of solar generation is about $21 per MWh (of solar generation) when we model the CC and combustion turbine (CT) gas generation it might displace. The average LCOEs from existing coal ($41), CC gas ($36), nuclear ($33) and hydro ($38) resources are less than half the cost of new wind resources ($90) or new PV solar resources ($88.7) with imposed costs included." While the report is a few years old, it offers a useful metric and reminder of the need to account for the full costs of various energy options before making decisions to close existing or build new generation.

[*] The Palgrave Handbook of International Energy Economics defines "non-dispatchable" as those energy sources where "the operator cannot control the extent of their use." (See: https://link.springer.com/chapter/10.1007/978-3-030-86884-0_16 pg. 105)

LCOE-EXISTING vs LCOE-NEW (2018 $/MWh)[5]:	LCOE-Existing (FERC FORM 1 2008 - 2017)[1]	LCOE-New (EIA/AEO 2019)	LCOE New (adjusted by this report)
Capacity Factors (CFs):	FORM 1 Average CFs	EIA LCOE 2019 Best Case CFs	2014 - 2018 EIA fleet avg CFs[11]
Heat Rates:	EIA 2017 Heat Rates for Existing[13]	that EIA used in AEO 2019[7]	that EIA used in AEO 2019[7]
Fuel Prices:	2018 EIA Fuel Prices[10]	used in EIA LCOE 2019 [2, 8, 12]	2018 EIA Fuel Prices[10]
DISPATCHABLE FULL-TIME-RESOURCES			
Conventional Coal	40.9	[3] 58.6	[6] 70.9
CC Gas	35.9	46.3	50.0
Nuclear	33.3	77.5	75.2
Hydro (seasonal)	[14] 38.2	39.1	73.1
DISPATCHABLE PEAKING RESOURCE			
CT Gas	89.9	89.3	192.9
INTERMITTENT RESOURCES – AS USED IN PRACTICE			
EIA New Wind including cost imposed on CC gas	[4] (N/A)	55.9	90.0 + other costs[9]
EIA New PV Solar including cost imposed on CC and CT	[4] (N/A)	60.0	88.7 + other costs[9]

Figure 18: LCOE-Existing vs. LCOE-New in 2018 $/MWh (Source: Institute for Energy Research)

Newer reports completed in partnership with the Center of the American Experiment show similar cost comparisons between natural gas and other dispatchable fuels as compared to wind- and solar-based electric grids.

The modeling completed by the Center of the American Experiment recognizes total costs for energy sources including initial capital costs, taxes, storage, fuel, ramping, utility profits, transmission, operations, and maintenance, as well as costs for overbuilding and curtailment.

In modeling done for Michigan, the Center demonstrated that the average costs for existing resources versus building new wind, solar, and nuclear were far lower. Continuing to operate existing natural gas facilities in Michigan would impose an average cost (over the modeling period to 2050) of $22 per MWh, whereas building new solar installations as part of a push to meet net-zero by 2040 mandates with a wind-, solar, and battery-based electric grid would cost $278 per MWh. New wind would cost $180 per MWh. New natural gas combined cycle plants with carbon capture would cost an average of $64 per MWh.[61]

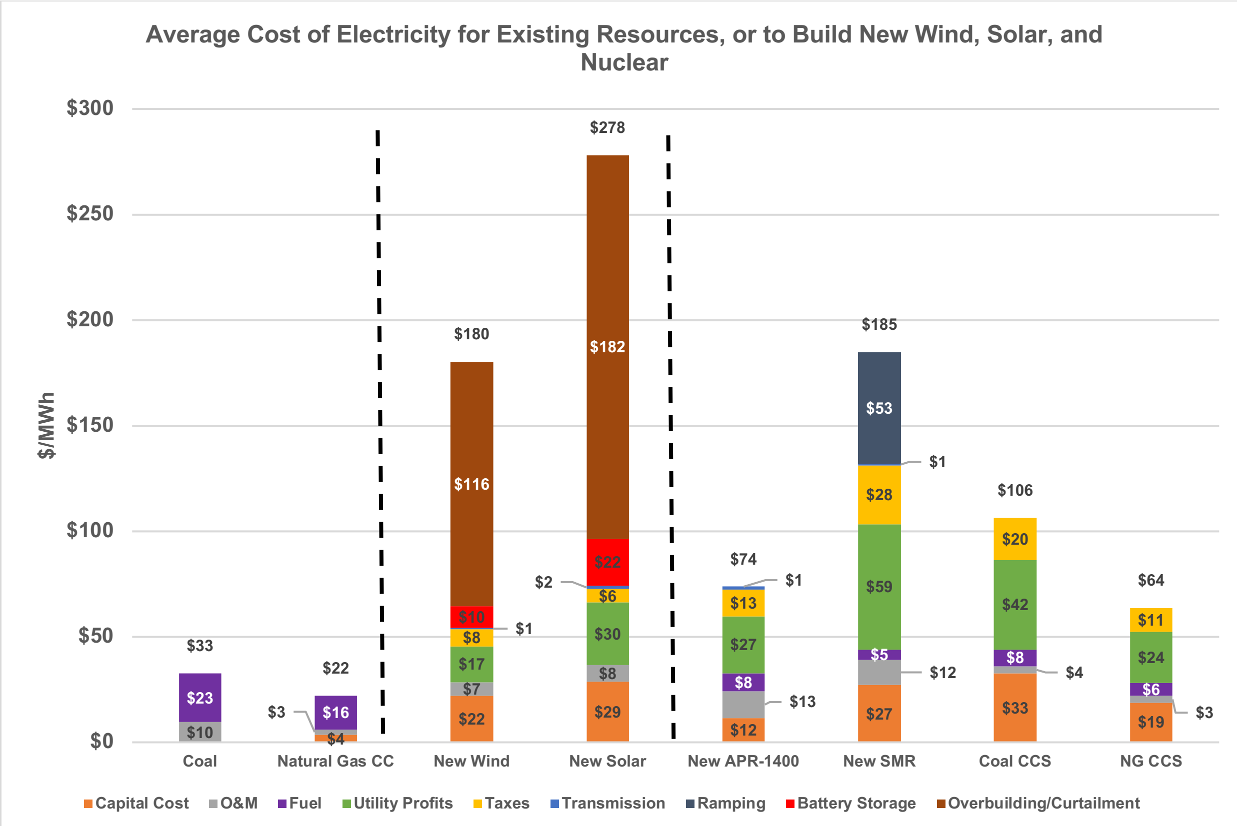


Figure 19: New solar facilities are the most expensive form of new electricity generation built under the modeling scenarios (Source: Mackinac Center and Center of the American Experiment)

Technology/Innovation: 10/10

The fracking revolution has released enormous amounts of clean, affordable energy, which has transformed the American electric industry and allowed it to drastically reduce emissions of pollutants and greenhouse gases.

Natural gas is used in a few key technologies to provide energy resources and electricity.

> Simple-cycle combustion turbines: "Functionally, these turbines are different than a steam turbine and are more like a jet engine. Combustion turbines combust compressed outside air with fuels, like natural gas, to directly drive a turbine that drives an electrical generator to produce electricity.
>
> Combustion turbines are typically used in a "peaking" capacity and provide a relatively fast ramping source of electricity to pair with the variable nature of renewable energy, or to effectively 'top up' the grid during times of peak demand. They are relatively inexpensive to build and rely on relatively inexpensive natural gas to produce electricity at an affordable price."[62]

Figure 20: The "vital numbers" for Siemens Energy's fast-ramping combustion turbine (Source: Siemens Energy)

New turbine technologies are also improving the economic and environmental performance of gas combustion turbines. The Siemens Energy HL-class gas turbine can fit on a small footprint (a 10-acre brownfield lot) instead of thousands of acres of farmland used by wind and solar options. The turbine can be powered with an essentially invisible underground natural gas pipeline and consistently produce 440MW. When used in a combined-cycle setup, this system can achieve capacity factors of more than 64% and can be paired with carbon capture technologies to address emission concerns.[63]

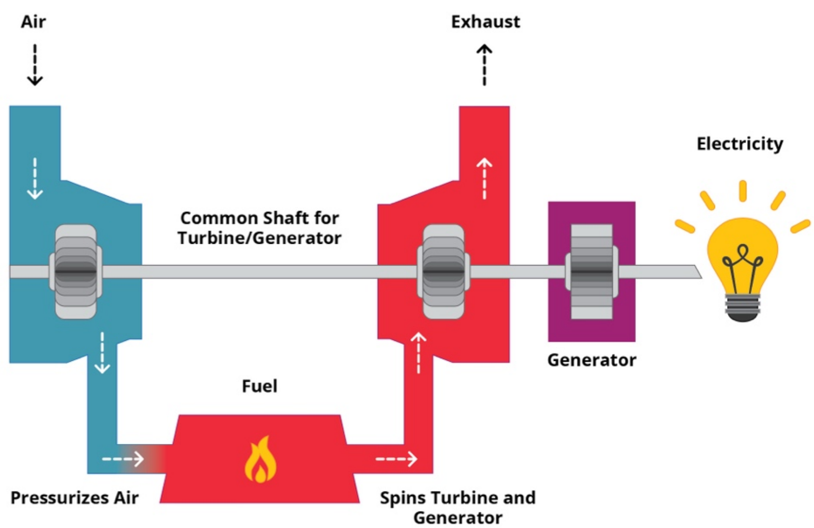


Figure 21: Simple-cycle combustion turbine (Source: Mackinac Center)

Combined-cycle gas turbines combine simple-cycle and steam turbine technologies to produce electricity. “They use the direct combustion of air and fuel — primarily natural gas — to drive a combustion turbine, as well as to produce pressurized steam. Water is heated by the exhaust, or waste heat, from the first turbine, to create the steam to drive a second steam turbine.”[64]

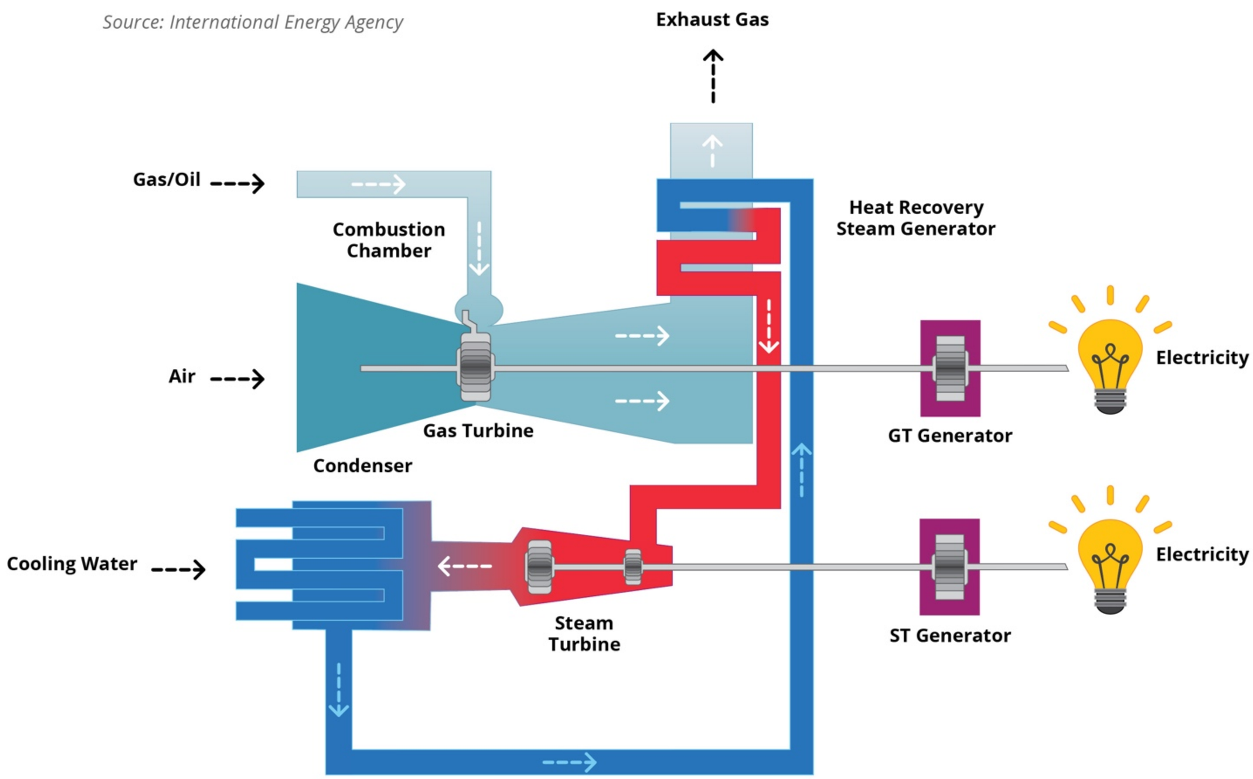


Figure 22: Simplified representation of a combined-cycle gas turbine (Source: Mackinac Center)

Combined-cycle technologies allow natural gas to operate as an effective baseload generation technology at competitive costs to coal and nuclear with approximately half of the greenhouse gas emissions of coal. “In 2019, coal-fired generation produced 2,257 pounds of CO_2 per megawatt-hour (MWh) of electricity. Natural gas-fired generation produced less than half that amount at 976 pounds of CO_2/MWh,” according to the U.S. Energy Information Administration.[65]

Market feasibility: 9/10

Despite efforts to restrict the use of this fuel via regulation, the American energy sector relies on the clean-burning and reliable supply of natural gas to power a significant portion of our electricity generation (as well as increased levels of home heating/cooking, transportation, and manufacturing). The markets need more natural gas, not less.

The discussion on costs and capacity above indicates natural gas has clear and convincing value to the nation in terms of providing clean, affordable, and reliable energy. The rapid growth of natural gas, as depicted in Figures 6 and 7 (U.S. Primary Energy Consumption—Natural Gas and U.S. Natural Gas Dry Production) demonstrates a clear market demand for this product.

Charges that fossil fuels are heavily subsidized must be addressed to determine if market demand is being driven by government policy, as opposed to market demand. Texas Public Policy Foundation detailed the relative amount of federal energy subsidies received from various energy sources in their report "The Siren Song that Never Ends." In this study, TPPF researchers recognized that from 2010 to 2019, oil and natural gas received $23.03 billion in federal "tax expenditures," $1.5 billion in "direct expenditures," and $0.4 billion in research and development for a total of $25.02 billion.[66]

Taken only at face value, these numbers indicate that the oil and natural gas sector would have received $25.02 billion or 19.6% of total federal energy subsidies from 2010 to 2019 to produce 40% of net electricity generation and 33% of total U.S. primary energy demand (see: Figure 2 - United States - Net Generation by Energy Source: Total (All Sectors), 2022).

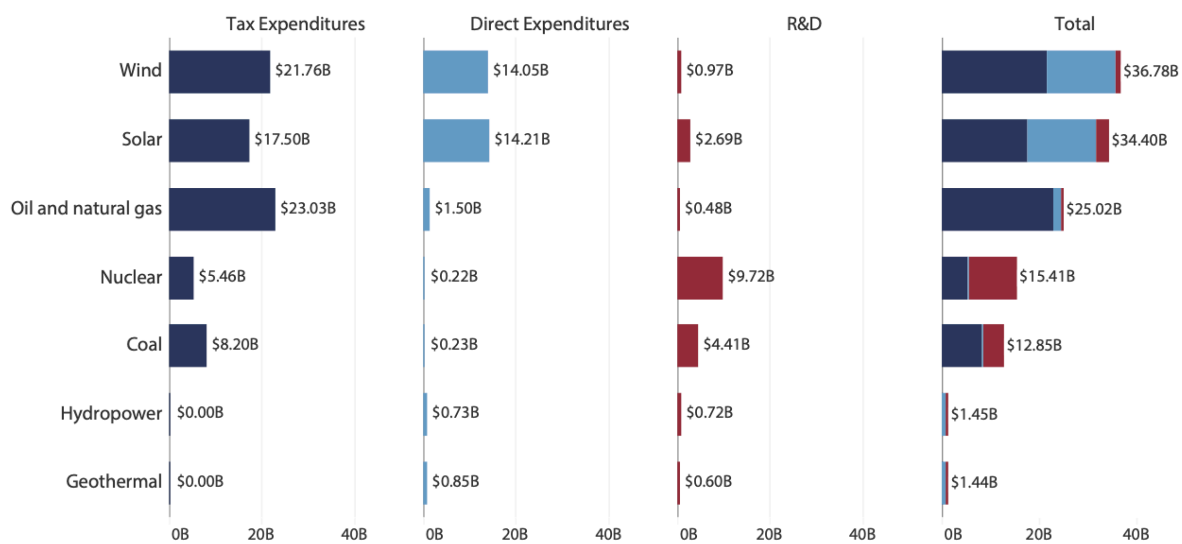


Figure 23: Total federal energy subsidies from 2010 to 2019 (billions of 2019 USD) - Source: Texas Public Policy

However, the TPPF study adds an important caveat that not all tax expenditures "are created equal." Says TPPF, "More than 90 percent of oil and gas subsidies quantified in this paper come from tax expenditures, and 76 percent comes from three specific tax expenditures: expensing of intangible drilling costs, excess of percentage cost over depletion, and master limited partnerships (MLPs)." They point out that describing these tax expenditures as subsidies is questionable and "often challenged" as "exploration and drilling are more comparable to research and development activities in other industries."

The TPPF study points to a statement before the House Committee on Energy and Commerce, given by Benjamin Zycher of the American Enterprise Institute.[67] In his testimony, Zycher explains, "The accelerated tax deduction for intangible drilling expenses allows expensing of labor and other drilling costs associated with exploration activities." He notes that costs are incurred in the development of capital assets for a business and should be depreciated. Doing this is not a "subsidy" as it resembles "the tax treatment of research and development costs in other industries." Zycher also explains that expensing for materials injected into existing wells to boost production is proper because they are a cost of business and "are consumed in the extraction process." Zycher describes how these are normal tax treatments that are allowed for any other business and cannot reasonably be considered a "'subsidy' specific to oil and gas production."

Therefore, working from the TPPF assertion that "more than 90% of oil and gas subsidies quantified" above can reasonably be described as costs of business or like research and development costs, oil and gas would more accurately have received approximately 4% of total federal expenditures to produce 40% of primary energy demand.

Whether readers choose to accept one or the other view of the total subsidies received by oil and gas does not impact the overall point being made in "The Siren Song that Never Ends," namely that "Every primary form of U.S. energy production has received substantial federal subsidies over the past two decades." Without substantial changes in energy policies, subsidies are likely to continue and grow, as we have seen in the passing of legislation like the Inflation Reduction Act.

Instead, they recommend that readers focus on the "nature of different energy subsidies and their effects on markets." While subsidies given to wind and solar are targeted toward promoting the construction of current generation technologies, tax treatments and payments to nuclear and fossil fuels encourage "research and specific aspects of exploration and development."

Recommendations

Demand for natural gas can fluctuate rapidly, depending on weather conditions and the ability of other sources, like wind and solar, to generate electricity. When weather conditions are favorable, utilities tend to rely on wind and solar to produce electricity to meet state-level renewable mandates and cut fuel costs.

However, variable, and intermittent wind and solar regularly underperform relative to their total capacity and often can go to zero generation when wind and sun resources don't cooperate. This reality forces utilities and regions to rely on the flexibility of natural gas generation (specifically simple-cycle turbines) for fast-ramping generation capacity.

Elected officials, federal and state agencies, and utilities are deliberately fixating on transitioning to an electric grid powered largely by wind and solar with natural gas backup. Therefore, a primary challenge for natural gas is its heavy dependence on just-in-time fuel deliveries by pipeline. As gas becomes more of a baseload energy resource, there is a significant potential for supply disruptions during periods of extreme weather or demand, or due to supply disruptions.

Rapid closures of other baseload resources—coal and nuclear—are exacerbating this situation and leaving gas exposed if there are restrictions in supply. This was the situation when Winter Storm Uri hit Texas in February 2021, causing a series of cascading failures that impacted supplies.

As one study explaining the cascading risks that drove the Texas blackouts noted, "About 40% of natural gas production was not available during the crisis. Texas' gas, electricity, and water systems are interlinked so failures in one of them can lead to cascading effects on the others. The natural gas system relies on electricity, and the electrical system relies on gas. Thus, constrained gas limits the ability to generate electricity and constrained electricity limits the ability to supply gas which in turn further limits the ability to generate power in a vicious circle."[68]

Several reports on the storm and blackouts attempted to paint the issue as a failure on the part of natural gas, including the above-noted study. However, data from the U.S. Energy Information Administration indicates that production from natural gas facilities across the state jumped by 450% in response to rapid growth in demand. Unfortunately, that rapid response was not enough as all other major energy sources across the state were also impacted by extreme demand and cold.[69, 70]

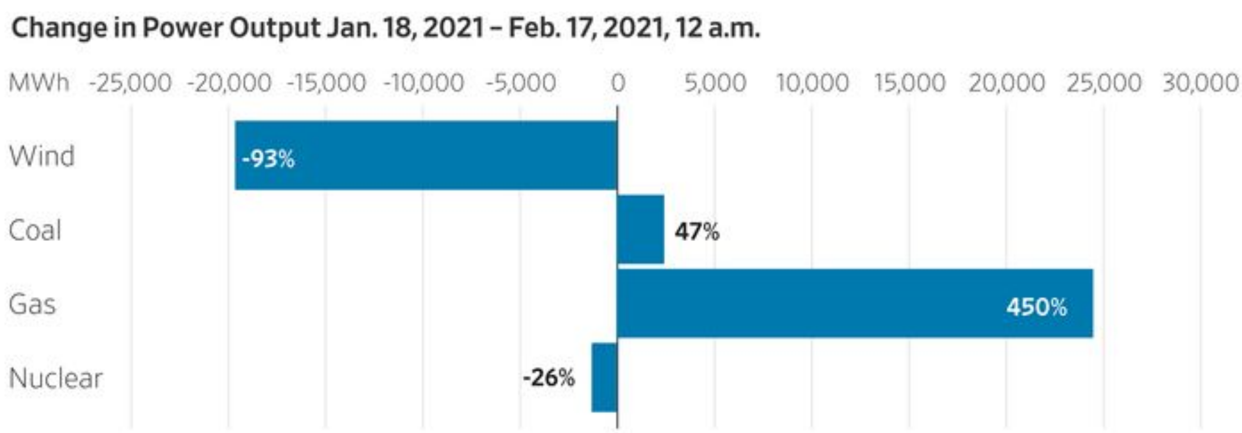


Figure 24: Change in power output by energy source during the February 2021 Texas blackouts (Source: Wall Street Journal and U.S. Energy Information Administration)

A similar issue occurred in Michigan during the January 2019 Polar Vortex event when natural gas supplies were restricted after a fire at the Ray Compressor Station.[71] At that time, wind and solar provided negligible amounts of electricity to the regional mix while natural gas—despite the shortages caused by the fire—coal, and nuclear provided approximately 90% of supply.

"Meredith Angwin has been highlighting the dangers of relying upon just-in-time delivery of natural gas for electricity generation for years," notes Isaac Orr and Mitch Rolling in a review of key energy issues from 2023. "This is why we have long argued that policymakers must consider requiring onsite fuel storage at natural gas plants to ensure that grid resiliency is not compromised during future cold snaps."[72]

Expanding on-site storage for gas facilities would address one key issue facing natural gas as it continues to supply most American electricity fuel needs and serve as an essential heating, cooking, and transportation fuel.

Coal

Grade: 80% (B-)

Bottom Line Up Front

Despite its low cost, abundant domestic supply, and reliability, Western nations—the USA, Canada, the UK, and across Europe—have targeted coal for closure largely due to climate change concerns. While most pollution concerns associated with coal use can be addressed with widely available emissions reduction technologies, coal does emit more pollutants and CO_2 than natural gas.

Due to growing regulatory pressure and effective competition from low-priced, domestic natural gas, coal use is declining in North America, as well as Europe. However, coal use worldwide—especially in China and India—continues to grow rapidly. Across Asia, coal use is growing so rapidly that attempts to cease its use in the West as a climate change mitigation measure are being wholly eclipsed.[73]

The primary challenges faced by the coal industry are 1) a long-term campaign by the government and green special interests to stop its use, and 2) very effective competition from low-cost fracked natural gas displacing coal as a primary baseload generation option.

Capacity & Reliability: 8/10

While domestic supplies and off-the-shelf coal technologies can easily provide ample, reliable, and affordable electricity, a long-term campaign by the government and special interests has driven America's coal industry to near (or actual) bankruptcy. Much of the nation's coal generation fleet is targeted for closure. As more of the fleet is closed, the fuel is less able to meet generation demands. However, the use of coal to provide reliable, affordable, (and even) clean electricity is growing rapidly in Asia.

At the core of coal's continued widespread use (worldwide) is the fuel's solid reliability, abundance, and low cost.

While coal use continues to grow rapidly around the world, in the USA, UK, Europe, and Canada, coal use is expected to continue to decline despite a short-lived bump in use after the end of COVID lockdowns in 2022. "U.S. coal-fired generation capacity will decline sharply by 2030," reports the U.S. Energy Information Administration, "to about 50% of current levels (about 200 GW) with a more gradual decline after that."[74]

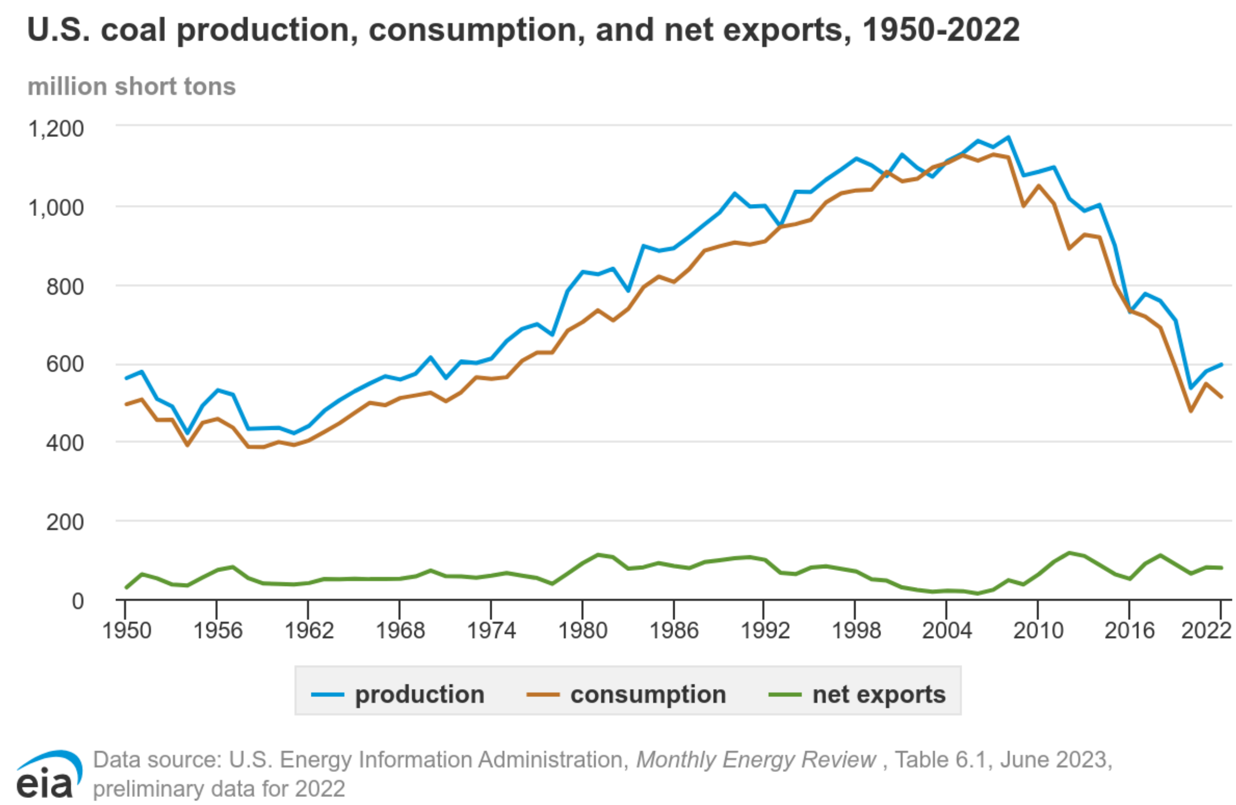


Figure 25: U.S. coal production, consumption, and net exports 1950-2022 (Source: U.S. Energy Information Administration)

Asian countries comprise the lion's share of coal use (especially new coal demand). "As of January 2023, China has 1,093 GW of coal power capacity in operation, accounting for 52% of the global total, 115 GW of new capacity under construction, and an additional 250 GW at various pre-construction stages."[75] Rapidly increasing Chinese, Indian, and Southeast Asian demand is expected to make up "3 out of every 4 tonnes of coal consumed worldwide in 2023," according to the International Energy Agency.[76]

In contrast, total operating coal generation in the U.S. was just over 200GW in 2023 and Energy Information Administration forecasts expect coal use to drop by 40% to 88% by 2050.[77]

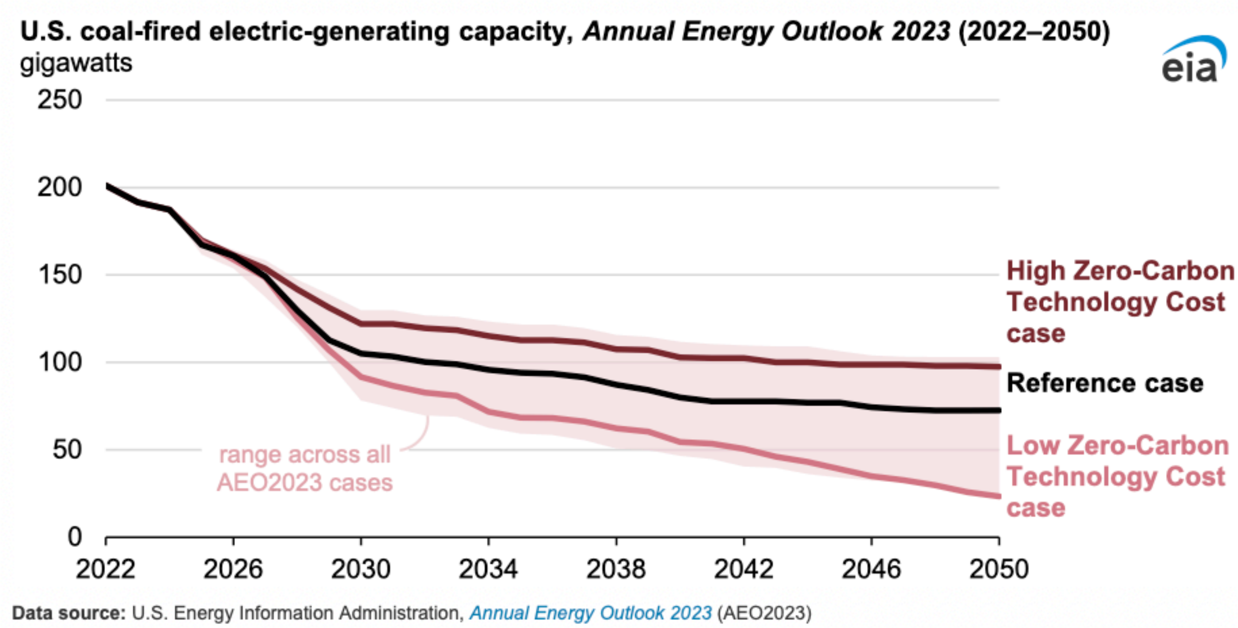


Figure 26: U.S. coal-fired electric generating capacity, 2022-2050 (Source: Annual Energy Outlook 2023 - U.S. Energy Information Administration)

IEA data predicts that, despite a short increase in 2022, coal use across Europe will continue to decline as wind, solar, nuclear, and hydroelectric expand. “In the United States,” notes IEA, “the move away from coal is also being accentuated by lower natural gas prices.” [78]

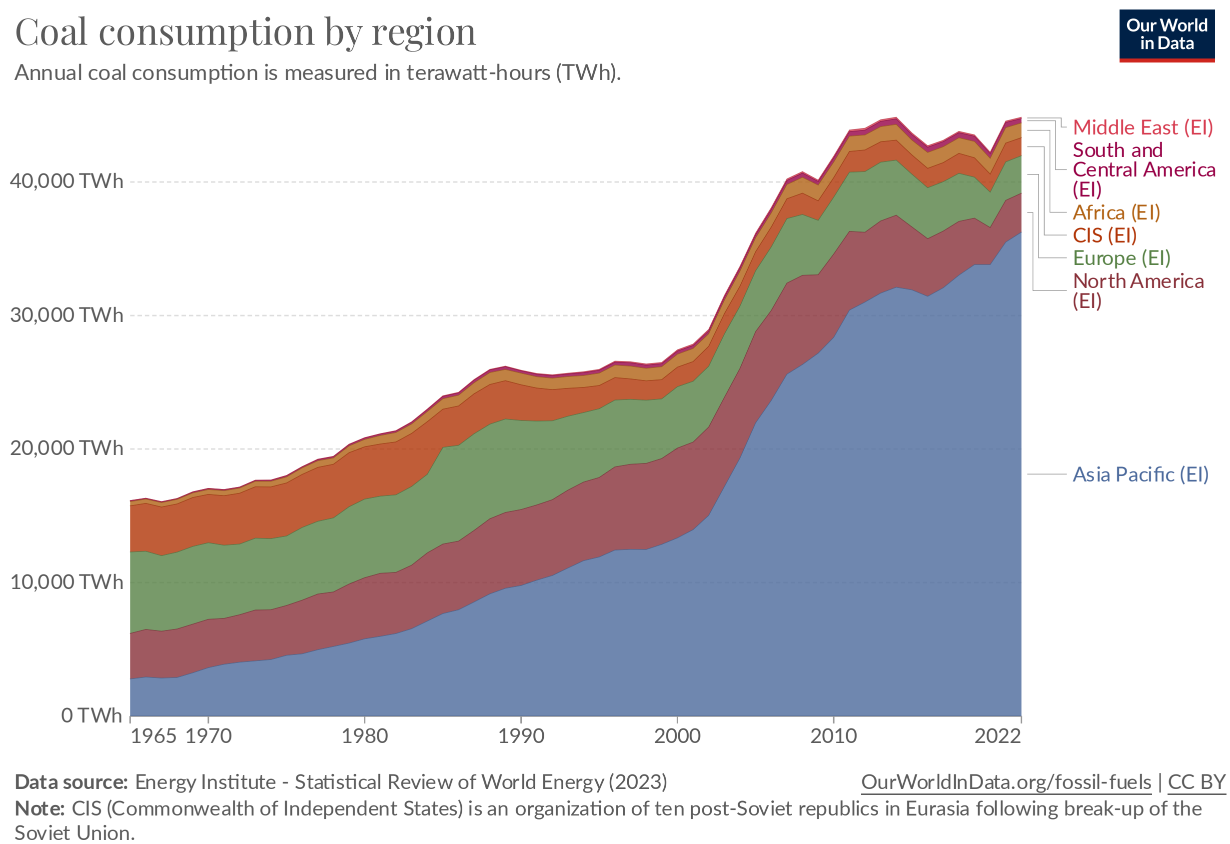


Figure 27: Coal Consumption by Region Source: Our World in Data[79]

Continuing government support for wind and solar through mandates and generous subsidies drives the new construction of these intermittent energy sources. As wind and solar achieve further market penetrations, coal facilities designed to operate as baseload—not cyclical or load-following—generation are less likely to be ramped up and down rapidly, than simple-cycle natural gas turbines. These coal plants, however, are experiencing declining efficiency as regional markets do not accurately value the reliability provided by baseload generation options. Instead, regional markets and pricing mechanisms are skewed by heavy federal subsidies, state net zero mandates, and low fuel costs associated with wind and solar.

> "Capacity factors for coal-fired [electric generation units] were at 67% on average in 2005 and have fallen to a low of 41% in 2020...[†] In 2021, there was a slight rebound in coal capacity factors, but overall coal capacity factors are expected to continue to decline. Looking at model projections of coal operation, by 2040, the Post-IRA 2022 Reference Case show coal capacity factors falling to an average of 10% across the remaining coal-fired EGU fleet."[80]

[†] U.S. Energy Information Administration defines "capacity factor" as "The ratio of the electrical energy produced by a generating unit for the period of time considered to the electrical energy that could have been produced at continuous full power operation during the same period." (See: https://www.eia.gov/tools/glossary/index.php?id=Capacity_factor)

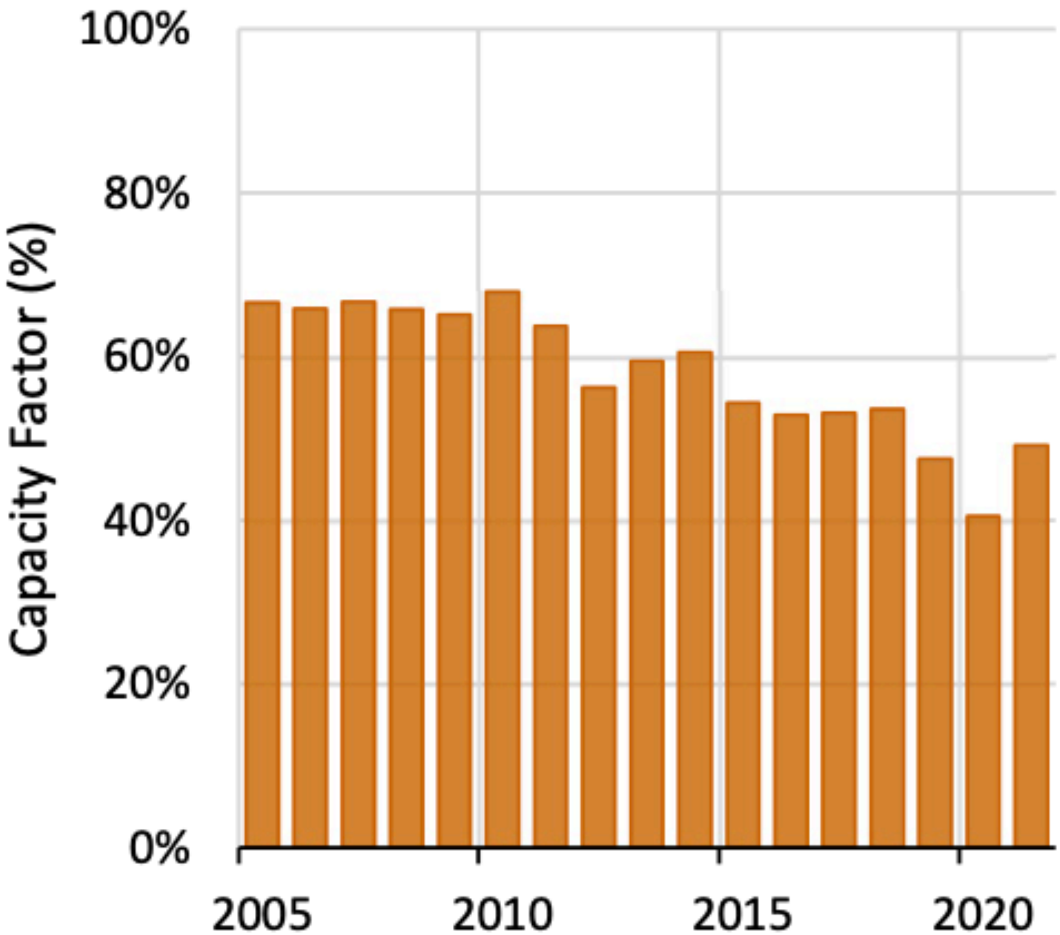


Figure 28: Coal average annual capacity factors, 2005-2021 (Source: U.S. Environmental Protection Agency)

> "[Coal] plants only operated at their highest efficiency capacity, 80%, 37% of the time in 2018, down from 55% in 2008, and plants spent more than 18% of the time operating below 60%, down from 12% ten years earlier. In response to changing conditions, coal plants are left with two main operating options: to shut down completely or change their electric output."[81]

Less efficient, cyclical operations can also lead to maintenance and repair issues—thermal fatigue and corrosion—further exacerbating costs and forcing these units to produce even more emissions per unit of electricity generated. In the same way that running an automobile at a consistent speed on the highway offers better overall gas mileage than driving in stop-start traffic, forcing generation sources to make up for the erratic generation from wind and solar causes increased inefficiencies.

Environmental/Human Impact: 7/10

While the world coal industry currently has off-the-shelf technology that allows "HELE" (high-efficiency, low emissions) coal plants to operate as cleanly and efficiently as natural gas generation, increasingly strict regulatory pressure has made it essentially impossible for these new technologies to be used in the United States. Regulators, elected officials, and utilities have chosen to simply close existing plants rather than upgrade or replace them with newer and more efficient technologies. Many of these closures are targeted well ahead of the expected lifespan of the plant. Instead, utilities and regulators are attempting to replace them with less reliable and more expensive wind and solar options.

Human health and well-being

"Fossil fuels, which provide 80 percent of the world's energy, have and will continue to have the unique benefit of providing low-cost, reliable energy to billions of people in thousands of places," explains Alex Epstein in the opening pages of his book, "Fossil Future." He notes that this is "a benefit that is desperately needed in a world where some 3 billion people still use less electricity than a typical American refrigerator."[82]

Since the Industrial Revolution, coal has been the energy source used to drive much of our development. We have used coal's reliable and predictable energy to adapt to an often dangerous and unpredictable natural world. As noted in the opening of the discussion on natural gas, "human life expectancy has doubled across the planet" because of improved medicines, health care, and food production. All these improvements are directly attributable to easier access to energy and the use of machines to reduce workloads or to improve agricultural productivity.

Air quality and Greenhouse gas emission

"Electricity in Michigan: A Primer" describes how coal combustion to generate electricity produces emissions, including various pollutants and greenhouse gases.[83]

- Sulfur and nitrogen oxides (NO_X and SO_X)
- Carbon monoxide (CO)
- Particulate matter (PM2.5 and PM10)
- Trace heavy metals, like mercury and selenium
- Carbon dioxide (CO_2)
- Water vapor (H_2O)
- Nitrous oxide (N_2O)[84]

Increasingly strict federal and state regulations are being passed in response to concerns about these emissions, especially emissions of greenhouse gases. These regulations represent a significant portion of the pressure to move the Western world away from coal combustion to produce electricity. However, the impacts of the rules will expose American residents to electric grid instability, leading to blackouts and significant cost increases.

In the United States, numerous federal regulations, too many to discuss fully in a single paper, target emissions from coal generation facilities. They include examples like the Clean Power

Plan, the Affordable Clean Energy Rule, the Mercury and Air Toxics Standard, and the Revised Cross-State Air Pollution Rule.[85, 86, 87, 88] Most recently, the federal government (via the Environmental Protection Agency) has proposed new standards governing the emissions of greenhouse gases from fossil-fueled power plants.[89]

EPA's proposed greenhouse gas rules for new and existing fossil-fueled electric generating units are based on the agency's argument that Section 111 of the Clean Air Act requires them to reduce greenhouse gas emissions using the "best system of emission reduction" (BSER), while also accounting for "costs, energy requirements, and other statutory factors." BSER, in this latest proposed rule, is based on load or capacity factor, meaning the amount a generating technology is used: low (or peaking units) with less than 20% capacity factor; intermediate where the capacity factor is 20% to an upper bound based on the design of the turbine being used; and baseload. Low load category emissions would be controlled with "lower emitting fuels." Intermediate and base load categories would use "highly efficient generation" technologies and either carbon capture and storage or "co-firing low-GHG hydrogen."

However, modeling by the Center of the American Experiment determined the proposed rule would cause resource adequacy issues, meaning electric grid reliability and electric utility services would be jeopardized with capacity shortfalls of as much as 26 gigawatts, or 19.5% of total regional demand in the Midwest.[90] "One in five homes would be subjected to rolling power outages," according to the Center's submitted comments on the rule. Furthermore, building additional generation capacity to forestall the rule's impacts would impose $246 billion in additional costs on utility customers across the Midcontinent Independent System Operator region.

Energy density and land use

The issue of shortfalls in electric service capacity is a growing concern as coal closures mount. This concern exists because, like natural gas, coal provides an energy-dense option for powering human lives and economies. Referring again to Layton's comparisons of density for varying energy sources, we see, Layton's estimate that "Coal, by comparison, has an energy density 50–75% that of oil."[91] Using a mid-range of 62.5% gives a rough estimate of 28,125,000,000 joules per cubic meter for coal, which is similar to the heat content found in a metric tonne of bituminous coal (approximately 27 to 30 GJ).[92] This means coal is roughly 700 times more energy-dense than natural gas, four billion times more energy-dense than wind, and 2 quadrillion times more energy-dense than solar radiation.

Like with natural gas, coal's energy density translates to far less land and resources needed to produce and operate coal than either wind or solar. As the World Nuclear Association explains, various generation technologies are referred to as "renewable" based on the idea that the fuel sources used to drive the generation process are naturally replenished over short periods. However, collecting diffuse sunbeams or gusts of wind entails mining, refining, and using significant amounts of mineral and metal resources. "The mineral demand intensity of a given generation technology is tightly linked to the energy density of the source of energy it uses. As such, the lower power density of intermittent renewable energies (i.e. solar and wind*) translates into substantially higher material demand as complex infrastructure must be distributed over large areas to gather diffuse energy."[93] World Nuclear Association numbers indicate that coal requires 7 metric tonnes of critical minerals per TWh of electricity produced. Natural gas requires 8 tonnes/TWh, nuclear requires 12 tonnes, solar requires 124 tonnes, onshore wind requires 130 tonnes, and offshore wind requires 200 tonnes.

	Plant t/MW	Indicative CF	TWh/yr	Operational lifetime (yrs)	Lifetime TWh	Plant t/TWh
Coal	2.5	85%	7.5	50	375	7
Nuclear	5.3	85%	7.5	60	450	12
Gas	1.2	60%	5.2	30	156	8
Solar	6.8	25%	2.2	25	55	124
Onshore wind	10.1	35%	3.1	25	78	130
Offshore wind	15.5	35%	3.1	25	78	200

Figure 29: Critical minerals, measured in metric tonnes per terawatt-hour, required per unit of electricity produced (Source: World Nuclear Association)

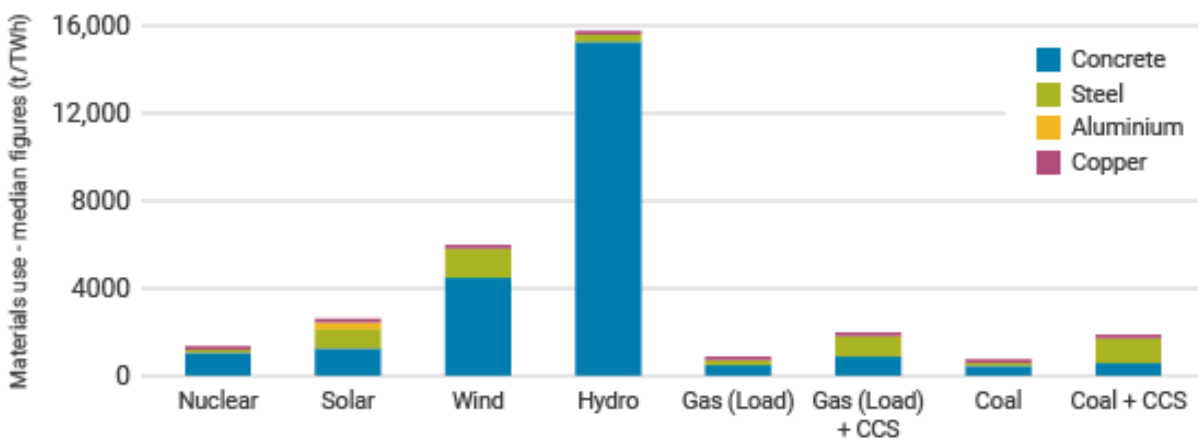


Figure 30: Key bulk materials, measured in metric tonnes per terawatt-hour, required per unit of electricity produced (Source: World Nuclear Association)

Workforce

Like natural gas, the North American coal industry produces a valuable product with a well-paid, adult workforce. U.S. Bureau of Labor Statistics indicates the average hourly earnings for all occupations in the mining industry (except oil and gas) were $36.86/hr (or $70,919 annually, over 11% higher than the national average) in October 2023 with an average of 44.3 hours worked weekly.[94, 95] BLS also notes that "Continuous mining machine operators" have a mean annual wage of $57,510, and other mining workers are paid similar annual wages.

BLS data indicates that power plant operators tend to earn more than miners. Median pay for power plant workers in 2022 was $46.91 per hour (or $97,570 annually, or 53% higher than the national average).[96]

Cost: 9/10

Existing coal plants are one of our least expensive energy generation options when full costs are considered.

Coal competes favorably with other energy sources. Referring to the same standards used in the discussion on natural gas, the April 2023 Lazard's "Levelized Cost of Energy Comparison – Unsubsidized Analysis" lists coal technologies at $52 per MWh for "the unsubsidized marginal cost of operating fully depreciated… coal… facilities." New coal construction costs between $68 and $166 per MWh.[97]

In this case, the Lazard metric does a better job as it recognizes the lower cost of retaining existing, fully depreciated facilities. The Institute for Energy Research study, "The Levelized Cost of Electricity from Existing Generation Resources," also captures this important difference. That study reports the LCOE of existing coal plants at $40.90 (2018 $/MWh) and new coal construction at $70.90 (2018 $/MWh). (See Figure 18: LCOE-Existing vs. LCOE-New in 2018 $/MWh.)

As described in the natural gas section, modeling completed by the Center of the American Experiment for the Mackinac Center recognized the total costs of energy sources operating in Michigan. This modeling demonstrated that the costs to retain existing coal resources would impose an average cost (over the modeling period to 2050) of $33 per MWh in Michigan.[98] (See: Figure 19: New solar facilities are the most expensive form of new electricity generation built under the modeling scenarios.)

Technology/Innovation: 9/10

Existing technologies can easily and cleanly supply the nation's electricity needs. It makes sense to continue to use coal, especially in areas where natural gas infrastructure limits its availability. However, regulatory pressures make it impossible to benefit from that reality.

The standard technology still used to power coal-fueled generation plants is a steam turbine, where coal is crushed into a fine powder and blown into a large boiler. The burning coal releases heat, which heats water in piping around the boiler. As the water heats, it expands and becomes pressurized. The pressurized steam is then released to drive a turbine, which generates electricity. After passing through the turbine, the water is cooled and recycled to be used again.[99]

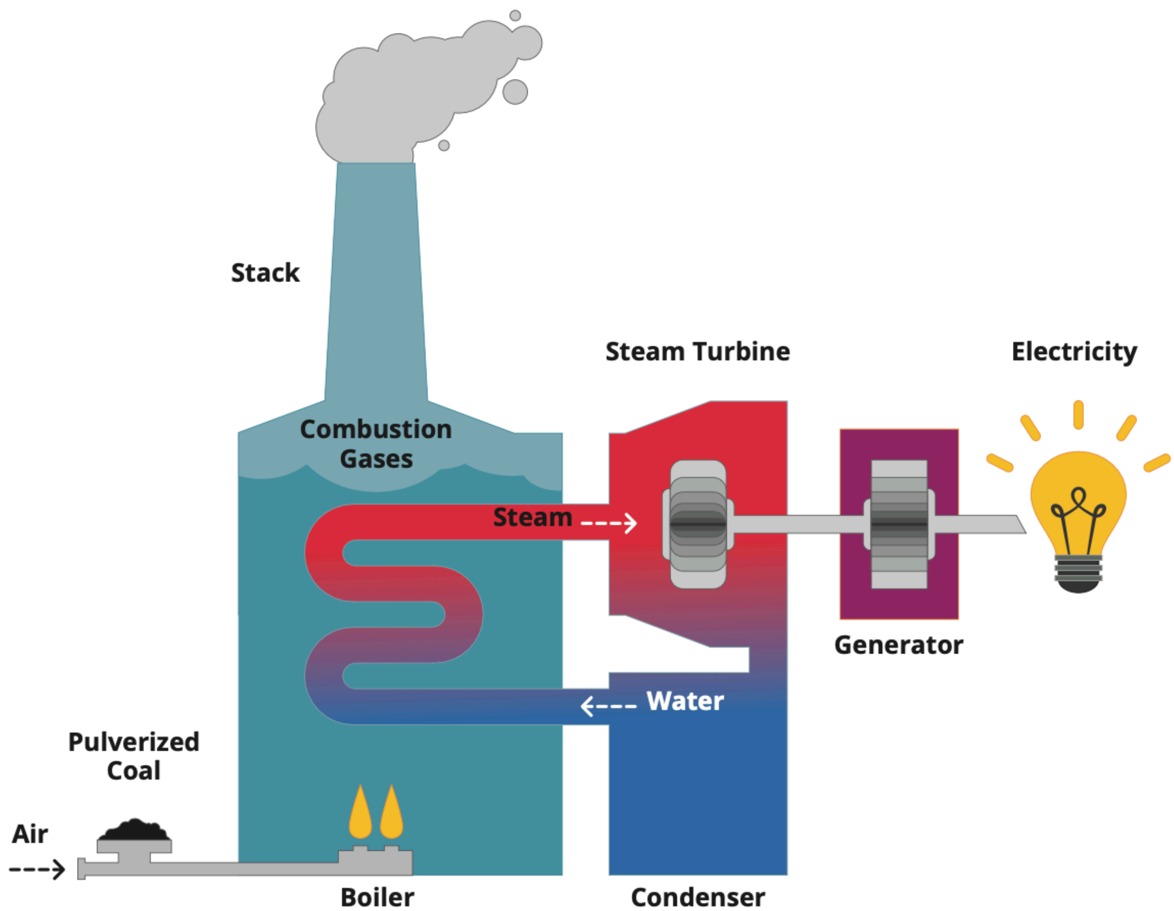


Figure 31: Simplified rendering of a coal-fired steam turbine generation facility (Source: Mackinac Center)

While the regulations targeting coal-fired generation are becoming increasingly unrealistic and costly, there are existing technologies that can reduce the emissions associated with the use of coal. They include, "carbon capture utilization and storage — also called CCUS, low NOX boilers, flue-gas desulfurization, selective catalytic reduction, chemical/gas/wet/dry scrubbers, gasification, and others."[100] High efficiency, low emissions (HELE) technologies, such as integrated gasification combined-cycle, (advanced) ultra-supercritical boilers, and combined heating and power, could currently allow new U.S.-based coal-fired generation stations to be built with efficiencies and emissions profiles similar to natural gas generation.[101] These technologies are currently being used worldwide in new Chinese, German, and Indian coal plants, but the weight of regulation has effectively made it impossible to build a new coal-fueled generation plant in the United States.[102, 103]

Market feasibility: 7/10

Regulators are ignoring coal's low-cost and reliable nature. Instead, they are focusing on an overly optimistic conception of environmental protection at the cost of reliability and *affordability. Given the extreme regulatory pressure facing the American coal industry, building new coal generation facilities is effectively impossible.*

Based on the clear economic value of coal in providing the nation with reliable electric power, the initial expectation would be more market demand for this fuel. However, a long-term anti-coal campaign carried out by government officials and well-funded environmental groups has compounded growing pressure from inexpensive fracked natural gas to put immense pressure on coal. As noted in Figure 25, U.S. production and consumption of coal have both declined rapidly from over 1,100 million short tons per year in 2008 to under 600 million tons in 2022.

Referring again to "The Siren Song that Never Ends" and Figures 2 and 23 in this report, TPPF researchers report that coal received $8.20 billion in federal "tax expenditures" from 2010 to 2019, $0.23 billion in "direct expenditures, and $4.41 billion in research and development for a total of $12.85 billion from 2010-2019.[104] Therefore, the coal sector would have received $12.85B or just over 10% of total federal expenditures during the study period to produce 20% of net electricity generation and 10% of total U.S. primary energy demand in 2022.

We reiterate that while subsidies given to wind and solar are targeted toward promoting the construction of current generation technologies, tax treatments and payments to nuclear and fossil fuels encourage "research and specific aspects of exploration and development."[105]

Furthermore, despite the growing pressure to close coal plants, there is an interesting real-life application of another of Robert Bryce's "Iron Laws." In the natural gas section, we explain Bryce's "Iron Law of Power Density," which states that "the lower the power density, the greater the resource intensity." Bryce's "Iron Law of Electricity" is instructive in this case. This "Law of Electricity" explains "that people, businesses, and governments will do whatever they have to do to get the electricity they need."[106]

A January 25, 2024 edition of the "Thoughtful Money" podcast with Adam Taggart discussed the issue of "Peak Cheap Oil." Energy experts Doomberg[‡] and Adam Rozencwajg debated whether the ability to continue supplying cheap oil had peaked, or if those concerns were overblown.[107] At about the 50-minute mark of the discussion, Doomberg's comments on the outcomes of the 2020-21 energy crisis in Europe highlighted the same concept as is contained in Bryce's "Iron Law of Electricity."

Doomberg described what Germany did when they lost easy access to relatively inexpensive Russian natural gas. "They suffered economically, and they still are, through their own — I think — idiotic policies," explained Doomberg. "But they immediately wiped away political constraints to getting their hands on any hydrocarbon that would work. And, as I think we both agree, it doesn't take but 2-3 million barrels, either way, to swing the market violently from -$27 per

[‡] "Doomberg" is a team of writers and energy experts that publishes articles on energy issues, tying those issues together with other world issues and events. Doomberg's writing is available online at https://doomberg.substack.com.

barrel to $130 per barrel, like you saw in the post-COVID … during the COVID emergency and the era that followed."

Much of the rest of Western Europe's experience is similar.

> "In the face of growing energy shortages and Russia's use of natural gas as a political weapon, several European countries are choosing to delay the increasingly dangerous rush to impose green energy. Germany, Austria, Netherlands, the Czech Republic, and the United Kingdom have (or are) reopening mothballed coal plants, at least temporarily. The Czech ambassador at large for energy security, Vaclav Bartuška, put it bluntly: 'If there is a gas cut out this winter, we will burn anything we can to keep our people warm and to make electricity.'" [108]

Recommendations

As noted in the recommendations for natural gas, weather is increasingly important in delivering reliable electricity supplies to North American utility customers. At the same time, we are rapidly expanding the supplies of weather-dependent generation options, like wind and solar. Wind and solar often go to near-zero generation during times referred to as "dunkelflaute" (or "dark doldrums" or "dark calm") in Germany, a regularly occurring winter event in which there can be extended periods of cloudy, windless days.[109] Once again, periods of extended inability to generate electricity demonstrate the value of reliable and affordable generation capacity.

Similar events were recently seen during a mid-January 2024 winter storm that swept across much of North America. Rolling blackouts, or threats of impending outages, were reported across the continent (and beyond) in Alberta, Texas, and the island of Oahu.[110] These energy shortfalls are all happening in areas that are targeting increased use of wind and solar while shuttering fossil and nuclear generation facilities.

We noted that heavy dependence on just-in-time fuel deliveries represents a challenge for natural gas. Coal does not suffer from this issue as, "Coal plants generally stockpile much more coal than they consume in a month."[111, 112] The following figure demonstrates this reality as non-lignite-burning coal plants in the U.S. have an average of more than 5 months of coal stored on-site and ready to be used.

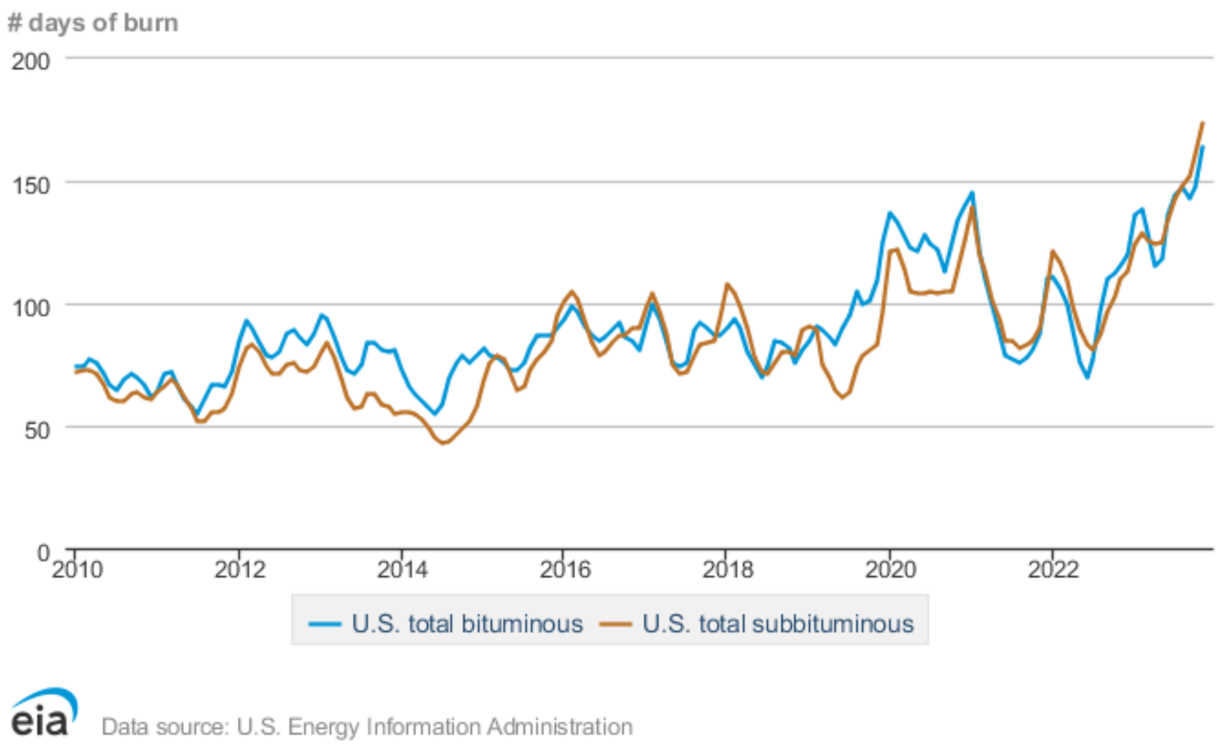


Figure 32: Days of burn by non-lignite coal rank, January 2010 to November 2023 (Source: U.S. Energy Information Administration)

As described in the recommendations for natural gas, coal supplied nearly half of the electricity used across the Midcontinent System Operator region during the January 2019 Polar Vortex event.[113] "Coal provided about half of our electricity, while natural gas provided 30 percent. Nuclear provided just over 14 percent, while wind was providing only about 4 percent and solar wasn't even listed; it was grouped in as one of the 'other' sources, at less than 2 percent."

Despite its low cost and reliability and the ready availability of emissions reduction technologies that can (and do) address many of the environmental concerns associated with coal use, regulatory agencies and special interests have targeted this fuel for closure. While many Eastern countries focus on its low cost and reliability, a key reason for coal's continued use in Western nations is its unflagging ability to rescue strained electric grids during periods of high demand.

To the extent that the government and utilities choose to ignore this fuel's ability to provide the reliable electricity needed by North American businesses and residents, we will continue to see increased grid instability.

Petroleum Fuels

Grade: 70% (C-)

Bottom Line Up Front

Petroleum products play a very small role in the production of U.S. electricity. They are almost a rounding error and are used primarily in older or geographically limited areas (like the Hawaiian Islands or Northeastern markets because of historical use).

Capacity & Reliability: 6/10

Petroleum fuels play a limited role in North American electricity generation. While they are important in the niche portions of the market that they fill, their limited level of use diminishes their overall contribution to capacity and reliability.

While petroleum fuels play a pivotal and currently irreplaceable role in transportation and manufacturing, they play a relatively minor role in electricity production. Energy Information Administration explains, "Petroleum products include transportation fuels, fuel oils for heating and electricity generation, asphalt and road oil, and feedstocks for making the chemicals, plastics, and synthetic materials that are in nearly everything we use."[114] EIA data also indicates all forms of petroleum products—petroleum liquids and petroleum coke—provide 0.5% of U.S. electricity by energy source in 2022.

Environmental/Human Impact: 7/10

As with coal units, technologies exist to use petroleum fuels efficiently. However, their limited market share also limits their overall impact.

Petroleum fuels emit approximately 3.5% more CO_2 per kWh than coal-fired units and 145% more than natural gas. EIA data indicates petroleum-based electricity generation emits 2.38 pounds of CO_2 per kWh generated. Coal emits 2.30 pounds and natural gas emits 0.97 pounds.[115]

Petroleum-based electricity generation faces critiques similar to those of coal-fired generation due to its perceived impacts on climate.

Workforce

As a part of the same industry as natural gas producers, the North American oil industry produces a valuable product with a well-paid, professional, adult workforce. U.S. Bureau of Labor Statistics indicates the average hourly earnings for all employees in the Oil and Gas Extraction industry were $48.11/hr in November 2023 (or $100,069 annually, which is almost 57% higher than the national average for 2022 reported by the Social Security Administration).[116] These employees worked an average of 42.4 hours weekly.[117] BLS also notes that "Gas Plant Operators" have a mean annual wage of $78,430 and other workers in the natural gas sector are paid similar annual wages: natural gas distribution workers earn an average annual wage of $80,330, pipeline transportation of natural gas workers earn $80,460, oil and gas extraction workers $73,510.[118]

Cost: 8/10

Petroleum fuels provide a valuable and affordable niche electricity generation application where they are used.

Given the limited use of petroleum fuels in generating electricity, the costs associated with this generation option are typically reported together with other generation sources. EIA data notes that pricing date for "gas turbine and small scale" generators "consists of gas turbine, internal combustion, photovoltaic, and wind plants." This generation category is described as having a total operating cost at investor-owned utilities equivalent to 4.3 cents per kWh[§], or $43 per MWh.[119, 120]

Technology/Innovation: 8/10

Existing technologies make it possible to use petroleum fuels relatively efficiently.

EIA data reports that "Petroleum was the source of less than 1% of U.S. electricity generation in 2022. Residual fuel oil and petroleum coke are used in steam turbines. Distillate—or diesel—fuel oil is used in diesel-engine generators. Residual fuel oil and distillates can also be burned in steam and gas turbines."[121] (See discussion of these technologies in the natural gas and coal sections—Figure 21-Simple-cycle combustion turbine and Figure 31: Steam turbine generator.)

Newer combustion turbine applications that do not use natural gas are also being planned. For example, Hawaiian Electric reports that it will upgrade and repower its Waiau Power Plant in Pearl City, Oahu with "more efficient, fuel-flexible units."

> "The six new units are combustion turbines or CTs, which are… intended to support generation resources, including variable renewable energy like wind, solar and battery storage, when they are unavailable or unable to meet system demand. At approximately 42 megawatts, each CT unit is smaller and more efficient than the oil-fired steam boiler it will replace, and each can respond quickly to fluctuations on the electric grid. Initially, the CTs will use biodiesel and can potentially use renewable gas or hydrogen when it becomes commercially available."[122]

While the utility intends to initially fire the turbines with biodiesel or renewable gas, they also recognize that the units "can run on biodiesel, diesel, and potentially hydrogen."[123, 124]

[§] EIA reports the cost as 43.28 Mills per kWh.

Market feasibility: 6/10

Petroleum fuels fill a niche market. There is little demand for them to expand beyond this use.

There is limited demand for expanding the use of petroleum liquids for electricity generation as they are a niche market in limited areas. Petroleum products are far more valuable for use in other areas such as transportation (gasoline and jet fuels), as lubricants, and feedstock for plastics, construction, and other manufactured goods.[125]

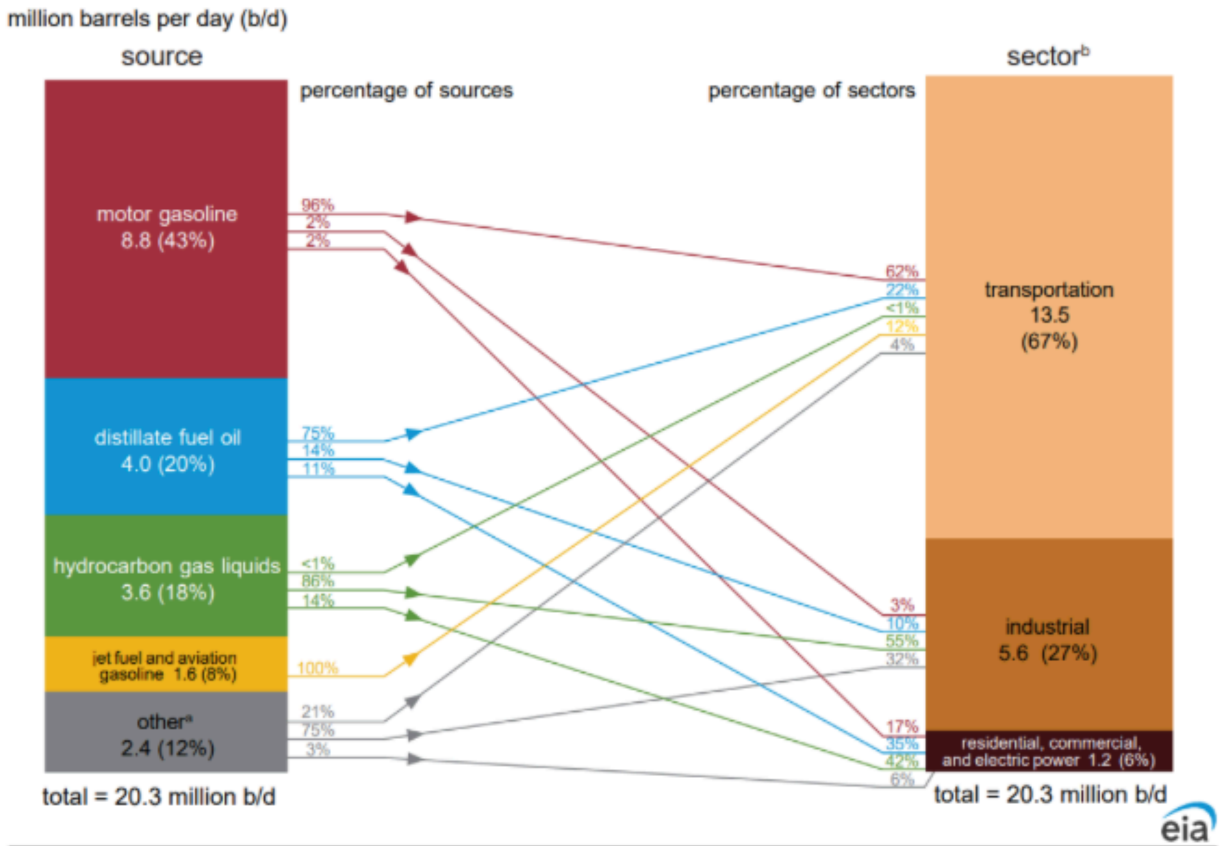


Figure 33: U.S. petroleum products consumption by source and sector, 2022 (Source: U.S. Energy Information Administration)

Recommendations

No recommendations are required in this sector as expectations are for the sector to remain a niche market and minor aspect of total electricity generation.

Nuclear

Grade: 88% (B+)

Bottom Line Up Front

Nuclear energy represents a best-of-all-worlds energy resource for the United States. Given its history as the nation's safest and most reliable electricity source, as well as its ability to produce near-endless amounts of completely reliable and emission-free electricity, nuclear is an obvious choice, especially given the nation's current hyper-focus on net zero carbon dioxide emissions.

Nuclear power's primary challenges lie in two areas: initial costs and safety concerns related to fuel storage or the potential to release radioactive materials.

First, while initial costs to build can be high, they can be amortized over a 60- to 100-year expected life cycle. Additionally, costs can be addressed by reigning in the overactive nature of the Nuclear Regulatory Commission. Second, the industry's record demonstrates it is the nation's safest source of electricity.

There is perhaps no better example of the industry's record of safety, reliability, and usefulness than the nation's fleet of nuclear-powered aircraft carriers, submarines, and cruisers. Building on Admiral Rickover's innovations, the U.S. Navy has reliably and safely powered a significant portion of its fleet with nuclear power for decades. As we have done in many other areas, it is possible to use the knowledge gained in this area in the civilian nuclear fleet.

Given the safety and reliability of both our military and civilian nuclear, concerns over meltdowns or having the fuel used to build nuclear weapons are more in the realm of science fiction than reality. The United States was once the world leader in developing safe, reliable nuclear technologies. We should focus on rebuilding that status.

Capacity & Reliability: 10/10

Nuclear power is the most reliable generation source today where it has been built. A recent push (perhaps a renaissance) in interest in nuclear power could further expand the market.

Nuclear energy in America has encountered resistance over the past few decades—largely due to misplaced concerns or misunderstandings about the risk of radiation and spent fuel storage and, more recently, due to growing costs associated with regulatory compliance. However, it still provides a significant portion of American electricity: 8% of primary energy demand and 18% of overall electricity generation in 2022.[126, 127]

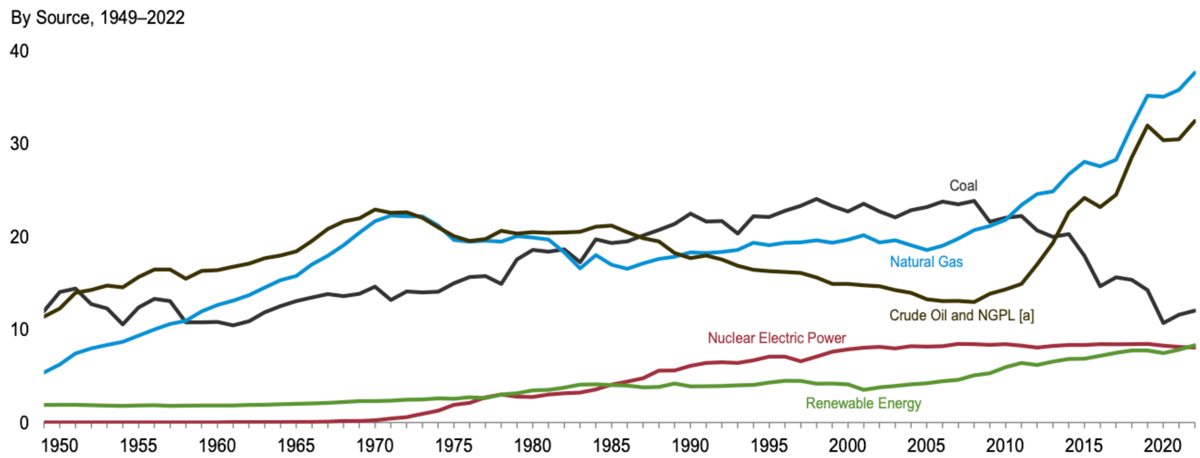


Figure 34: U.S. primary energy production, 1950-2022 (Source: U.S. Energy Information Administration)[128]

The stable nature of nuclear energy is not a surprise, given that a typical reactor can operate 24/7/365 until it is idled so "reactor operators [can] change out about one-third of the reactor core (40 to 90 fuel assemblies) every 12 to 24 months."[129]

The industry has recently experienced a spike in interest, given the nation's focus on climate concerns and the inability of wind and solar to provide reliable and affordable electricity. A great deal of attention was paid to the construction at the Alvin W. Vogtle Electric Generating Plant in Waynesboro, GA. Two new reactors at that plant are the first new utility nuclear generation built in the U.S. in over 3 decades. The plant saw substantial cost overruns and numerous extensions to the construction timeline. Unit 3 of the plant began commercial operation on July 31, 2023. Unit 4 is still under construction but began to load nuclear fuel into the reactor on August 17, 2023.[130] Cost overruns and delays at the V.C. Summer Nuclear Plant (units 2 and 3) in South Carolina caused the project's cancellation.[131]

Several other applications are in various stages of review. The Nuclear Regulatory Commission's page, which describes the locations of new applications, indicates the exhausting and expensive nature of the review process.[132] For example, getting approval to build the Fermi 3 plant in southeast Michigan took almost 7 years and cost the utility $100 million.[133] They applied to the NRC for the Fermi 3 permit in 2008 and received approval in 2015. The current costs do not support building the plant, but the utility's long-term plans will see its final coal generation plant closed by 2032.[134] This permit provides an option for new reliable and emissions-free capacity.[135, 136]

Environmental/Human Impact: 10/10

Nuclear energy is also the cleanest and most energy-dense generation source currently available. While some concerns exist about spent fuel management, they are largely based on misunderstandings and misrepresentations.

Human health and well-being
Referring again to "Fossil Future," Epstein rightly argues that "nuclear and hydro are the world's two largest sources of non-carbon energy. A pro-human approach to reducing or eliminating CO_2 emissions would eagerly embrace all forms of cost-effective non-carbon energy so as to produce as much non-carbon energy as possible."[137]

However, environmental challenges and safety concerns are associated with nuclear energy, such as the possibility of a meltdown. As described above, part of the process of fission of uranium and plutonium is that once started, it can continue and grow on its own.

A meltdown occurs when the fission processes inside the reactor are not sufficiently slowed by safety measures built into a reactor. If fission is allowed to grow, unrestricted, the heat and pressure can build to the point where the fuel and containment unit surrounding the reactor core and/or the fuel in the reactor could melt. This happened at the Three Mile Island nuclear facility in Pennsylvania and the Fukushima facility in Japan.[138, 139]

In a different, but still dangerous and dramatic situation, unrestricted growth in fission could produce a power surge and increased pressures in the reactor, leading to an explosion in the facility. This was the case in the 1986 Chernobyl facility incident in Ukraine.[140]

MIT's Nuclear Reactor Laboratory addresses those concerns, noting that "a nuclear explosion cannot occur because the fuel is not compact enough to allow an uncontrolled chain reaction."[141] The nuclear materials have not been sufficiently refined to allow them to explode in any way like a nuclear weapon. The explosion at Chernobyl was related to a poor design that lacked now-standard safety systems and containment features.

Despite confusion over the industry's safety record, and concerns about spent waste storage, nuclear energy has been a remarkably stable generation source. The World Nuclear Association reports that the worldwide nuclear industry has "over 18,500 cumulative reactor-years of commercial nuclear power operation in 36 countries."[142] They point out, "Apart from Chernobyl, no nuclear workers or members of the public have ever died as a result of exposure to radiation due to a commercial nuclear reactor incident."

Air quality/greenhouse gas emissions and spent fuel
As with all other energy sources, nuclear energy has benefits and costs associated with producing electricity. The benefits include an extensive supply of thermal and/or electric energy that does not produce the pollutants associated with other fuels. The products of combustion—NO_X, SO_X, particulate matter, carbon dioxide, etc.—are not associated with nuclear energy because nuclear fuels are not burned to produce heat.

The Nuclear Energy Institute reports that from 1995 to 2021, nuclear energy in the U.S. allowed for the avoidance of 60.28 million tons of sulfur dioxide emissions, 24.95 million tons of nitrogen oxide emissions, and over 16,726 million tons of carbon dioxide emissions[**].[143] These avoided carbon dioxide emissions are roughly equivalent to the carbon dioxide emissions from just over 10 years of gasoline and diesel travel in the U.S.[144]

The other primary concern and environmental hazard associated with nuclear energy is dealing with spent fuel and radioactive wastes. Nuclear isotopes such as iodine-129 must be addressed as part of a plan to deal with nuclear waste as they are "long-lived" fission products with a half-life of 15.7 million years. Iodine-129 does not pose as great a concern as other short-lived and highly radioactive isotopes like iodine-131, iodine-132, and iodine-133, which have half-lives of a few days to a few hours.[145]

After it is removed from the reactor, nuclear fuel is initially kept in large, water-filled steel and concrete ponds to reduce exposure to radioactive elements. The water in the pond helps cool the fuels and retain radiation. This type of storage helps to move used nuclear fuels past the half-lives of the highly radioactive isotopes, but storage facilities must still restrain radioactivity from longer-lived isotopes and must maintain security over these fuels to address international security concerns. However, the federal government has not yet established a national long-term storage plan. Therefore, nuclear plants store used fuel in large concrete and steel casks on the sites of nuclear plants once removed from the initial storage pools.[146]

The federal government has considered deep geologic disposal options, such as those found in the proposed Yucca Mountain repository in Nevada.[147] However, those considerations are stalled by an ongoing political battle over the advisability and safety of storing spent nuclear fuel in this location. Other options include reprocessing and refining used fuels, which can contain as much as 90% of the potential energy found in the unused fuel. Molten salt reactor designs can use waste from existing nuclear plants, but re-use and recycling of nuclear fuels has been discouraged—and prohibited since 1977—in the U.S.A. to allay nuclear proliferation concerns.[148], [149] Despite the hesitancy in the U.S., France and Canada are willing to recycle and use recycled nuclear fuels.[150] Currently, no long-term storage or reprocessing/recycling solution has been accepted or adopted in the U.S.

Energy density and land use

The extremely energy-dense nature of nuclear energy means that substantial amounts of energy can be produced with relatively little fuel and in relatively little space. Layton's discussion of the energy density of various fuels explains that if all the matter in Uranium-235 "were being converted to energy, the energy density would be about 10^{21} joules per cubic meter or over ten billion times more energy-dense than petroleum."[151] Of course, much of the potential energy in nuclear fuels is not converted into energy. As noted above, the Department of Energy explains, "More than 90% of [nuclear fuel's] potential energy remains in the fuel, even after five years of operating in a reactor."[152]

[**] NEI reports the totals in "short tons" or US tons, equivalent to 2,000 lbs. One US ton = 0.91 metric tonnes.

Making the math a little less complex, Robert Bryce explains that the energy return on energy invested or EROEI of nuclear vastly outdoes any of the other energy sources. Bryce notes that "we want maximum return on the cash we put in the bank or the stock market. We also want maximum return on the energy we spend. Just as it takes money to make money, producing energy always requires using energy."[153]

In his book, "Smaller Faster Lighter Denser Cheaper," Bryce explains how the energy-dense nature of nuclear fuels makes them an excellent choice for electricity generation. Nuclear energy "has 2,100 times as much power density as wind energy." So, replacing a single 2,000 MW nuclear plant would entail covering "three-quarters the size of the state of Rhode Island" with wind turbines.[154]

The same World Nuclear Association information described in the coal section reinforces that "the lower power density of intermittent renewable energies (i.e. solar and wind) translates into substantially higher material demand as complex infrastructure must be distributed over large areas to gather diffuse energy."[155] Where nuclear power uses 12 tonnes per terawatt-hour of electricity generated, both onshore wind and solar power use more than 10 times the critical minerals and far more (often by orders of magnitude) bulk materials like concrete, steel, aluminum, and copper.

	Nuclear PWR	Solar	Wind	Hydro	Gas (load following)	Gas (load following) + CCS	Coal	Coal + CCS
Concrete	1060	1220	4470	15,320	390	820	450	520
Steel	130	940	1450	330	320	970	160	1170
Aluminium	0.3	287.5	17.4	8.7	5.7	21.4	1.6	37.4
Copper	2.5	68.0	39.1	4.8	5.4	8.8	3.0	11.8
Capacity f.	85%	28%	35%	50%	30%	30%	85%	85%
Lifespan	60	30	30	100	60	60	60	60

Figure 35: Major materials for different generating technologies, tonnes per TWh (Source: World Nuclear Association/Bright New World)

Workforce

The North American nuclear industry produces a valuable product with a very well-paid adult workforce. U.S. Bureau of Labor Statistics indicates the average hourly earnings for "all occupations" in the Nuclear Electric Power Generation industry were $55.19/hr in April 2023 (or $114,800 annually, which is almost 80% higher than the national average for 2022 reported by the Social Security Administration).[156] BLS did not list an average hours worked per week, but based the salary on 2080 hours worked annually, or almost 40 hours weekly.

Cost: 7/10

While nuclear generation is currently expensive to build, much of that cost is based on an overzealous and litigious regulatory framework. Once nuclear plants are up and running, they provide some of the least expensive electricity we use.

Like coal and natural gas, nuclear competes favorably with other energy sources. Referring to the same weightings used in the discussion on both natural gas and coal, the April 2023 Lazard's "Levelized Cost of Energy Comparison – Unsubsidized Analysis" lists nuclear technologies at $31 per MWh for "the unsubsidized marginal cost of operating fully depreciated… nuclear… facilities." New nuclear construction is listed as costing between $141 and $221 per MWh.[157]

Again, the Lazard metric recognizes the far lower cost of retaining existing, fully depreciated facilities. Similarly, the Institute for Energy Research study, "The Levelized Cost of Electricity from Existing Generation Resources" captures the cost difference and reports the LCOE of existing nuclear plants at $33.30 (2018 $/MWh) and new nuclear construction at $75.20 (2018 $/MWh). (See Figure 19: LCOE-Existing vs. LCOE-New in 2018 $/MWh.)

Modeling completed by the Center of the American Experiment for the Mackinac Center demonstrated that the costs to build new baseload nuclear resources (APR-1400) in Michigan would impose an average cost (over the modeling period to 2050) of $74 per MWh.[158] (See: Figure 20: New solar facilities are the most expensive form of new electricity generation built under the modeling scenarios.)

Technology/Innovation: 10/10

The development of new, Gen IV nuclear plants represents a potential rush of emissions-free, affordable, and completely reliable electricity for North American markets. The potential for recycling and reusing spent nuclear fuel in modular reactors could provide centuries of new nuclear fuels that are already stored on-site at existing nuclear facilities.

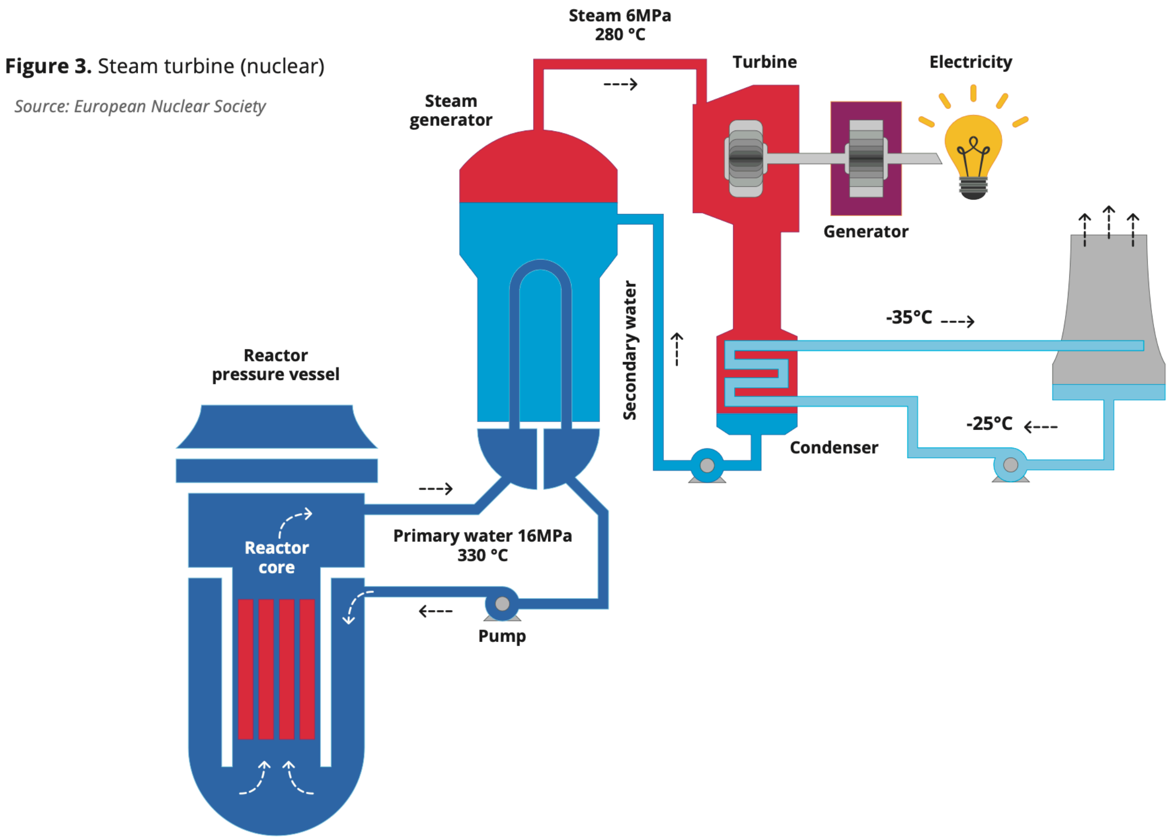


Figure 36: Steam turbine heated by a nuclear reactor (Source: Mackinac Center/European Nuclear Society)

Producing electricity with nuclear fuels is, in large part, very similar to the processes that are used to produce electricity with fossil fuels. The energy produced in a nuclear reactor is used to heat water and to produce pressurized steam that drives turbines and generators. In the case of fossil fuels, the heat is produced by combustion (burning) of the fuel to create heat. In a nuclear reactor, the heat is produced from the fission of nuclear elements—uranium, thorium, etc.[159]

In fission, uranium atoms are split apart when an "incident neutron" is released into an atom's fissionable (or easily split) nucleus. The energy released when these atomic bonds are broken is substantial. Therefore, it only takes a small amount of nuclear fuel to power many homes and businesses.

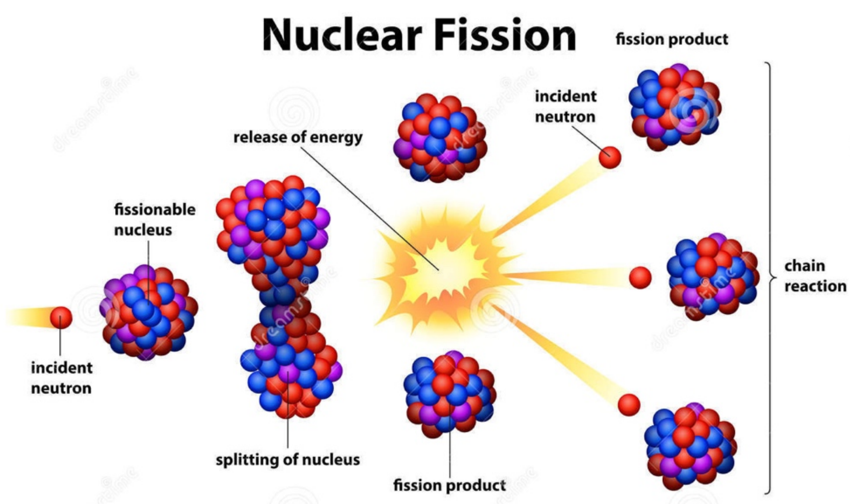


Figure 37: Nuclear fission explained (Source: iStock)

According to the Nuclear Energy Institute, a nuclear industry trade education and advocacy organization, the energy contained in a ¼" by ¼" pellet of uranium fuel—about the size of a pencil eraser—holds the same energy potential as 17,000 cubic feet of natural gas, 0.9 short tons of coal, or about 3.5 barrels of oil equivalent (BOE).[160] While the numbers will change markedly depending on the type or quality of coal or oil tested this equates to a very rough measure of 5,000 to 7,000 kWh, the same energy as would be used to power the average American home for about 6 months.[161]

Nuclear Technologies

One method for telling the main nuclear technologies apart is by referring to their "generation." Each generation relates to the time when they were developed and built and the general technologies and safety mechanisms that make up their designs.

Generation I: These nuclear designs were part of the initial forays into nuclear energy that began in the 1950s and were used into the 1960s. The last remaining Gen I nuclear reactor was the Wylfa Nuclear Power Station, in North Wales. This station began operation in 1971 and was decommissioned in 2015.[162]

Generation II: The next step in nuclear power, these reactors were primarily built for reliability and affordability. They are referred to as light water reactors (LWR) but use pressurized water reactor (PWR) and boiling water reactor (BWR) technologies.[163] Gen II reactors began to be commissioned in the late 1960s and were used until the 1990s. They make up most of the currently operating nuclear fleet worldwide.

Generation III: The bump up from Gen II to Gen III occurred in the 1990s and involves the addition of more advanced safety features such as passive vs. active safety systems. This means that, in an emergency, the reactor does not require powered (or active) measures by facility staff to cool down and contain the reactor. Additional improvements include increased modularization and increased reactor operational lives.[164]

Generation III+: The first Gen III+ reactors began operation in the 1990s and added improved passive safety features that rely on gravity or convection, rather than powered/pumped cooling. Gen III+ designs also have improved fuel management, allowing them to use fuels more efficiently.[165]

Generation IV: A key aspect of Gen IV technologies is a vast improvement in the use, recycling, or reprocessing of nuclear fuels.[166]

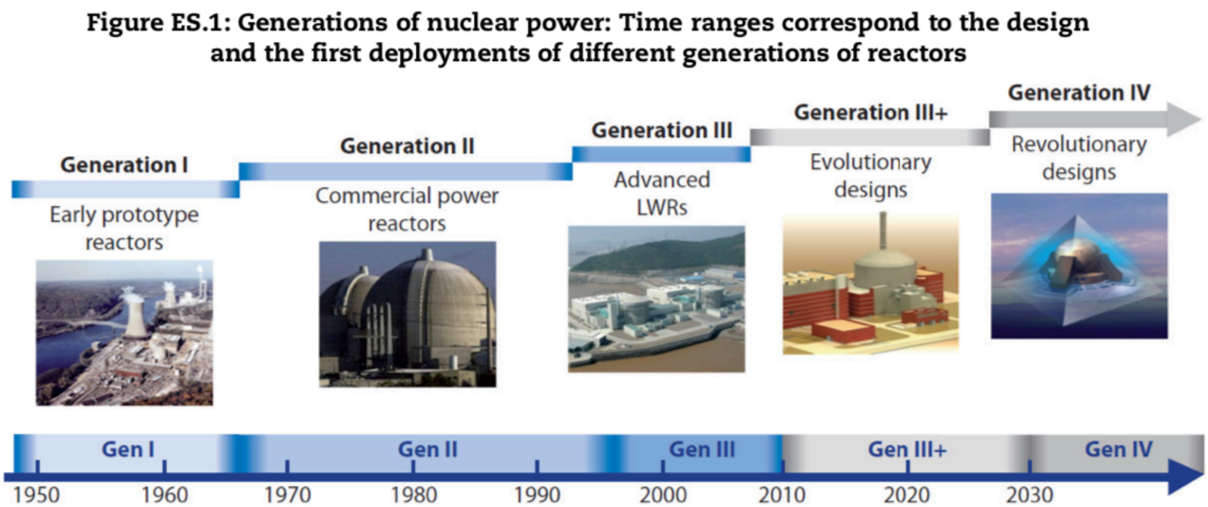


Figure 38: Generations of nuclear power: Time ranges correspond to the design and the first deployments of different generations of reactors (Source: Gen IV International Forum)

Gen IV, small modular, and thorium-fueled reactors: One potential answer to the safety and cost challenges leveled at Gen II plants and the extreme costs associated with Gen III and III+ reactors lies in developing Gen IV, or Generation 4, technologies. These newer nuclear technologies include options such as Small Modular Reactors (SMR), Molten Salt Reactors (MSR), or thorium-fueled reactors such as Liquid Fluoride Thorium Reactors (LFTR) and Thorium Molten Salt Reactors (TMSR).

SMRs generally refer to reactors with a nameplate capacity of less than 300 megawatts. They can include "micro modular reactors" (MMR) that are less than 10 MW and designed for extreme rough-duty situations, such as remote military bases.[167] SMRs are designed to be built and assembled in factories, shipped to the location where they will be used, and, depending on the amount of energy needed, connected incrementally, in series, to expand their overall generation capacity. Many proposed designs could also be installed below ground to ease security concerns and in existing brownfield (previously developed for industrial use) locations to replace decommissioned fossil fuel plants.[168]

The modular nature and transportability of SMRs would allow them to be built quickly and economically and used in various situations: for electricity generation, heat production, water desalination and water purification, hydrogen production, or other industrial uses. Research has also considered using nuclear technologies to replace natural gas in steam-assisted gravity drainage, also known as SAGD, processes in bitumen recovery from oil sands.[169] Using nuclear energy to develop these resources would greatly reduce the emissions associated with their production.

A key feature of SMRs is their smaller size and shorter construction times, compared with the multi-year and multi-billion dollar permitting and construction process associated with the much larger, contemporary Gen III(+) reactors. SMRs also benefit from being able to employ a variety of fuels and cooling technologies, including "water-, gas-, liquid metal-, and molten salt-[cooling]." [170] They also have as standard equipment many of the safety features designed into the newest and safest Gen III+ designs, including passive cooling that "requires no sustained operator action or electronic feedback to shut down the plant safely in the event of an emergency."[171] This means that events like the Three Mile Island, Chernobyl, or the Fukushima Daiichi accidents can't occur.

Furthermore, their use of relatively small amounts of nuclear fuels would allow them to be fueled during construction and put into use for years. Then, depending on their makeup, they could be returned to the manufacturer for refueling or decommissioning.

As an additional benefit, the much smaller footprint and faster construction timeline for SMRs would make private financing much easier. A key hold-up for the large, Gen III+ reactors is their massive size and requirements for billions of dollars of initial capital outlays for environmental impact studies, permitting, and construction.

<u>Timelines for Gen IV reactors:</u> Research and development of Gen IV technologies is being undertaken by the Generation IV International Forum (GIF), which "was initiated by the US Department of Energy in 2000." The group is made up of 13 countries with the stated purpose of "shar[ing] R&D rather than build[ing] reactors." The group has focused on six reactor designs that "were selected on the basis of being clean, safe and cost-effective means of meeting increased energy demands on a sustainable basis, while being resistant to diversion of materials for weapons proliferation and secure from terrorist attacks."[172] The reactors selected range in size from 150 to 1500 MWe and are targeted for development and operation after the 2020s.

Thorium

Discovered by the Swedish chemist Jons Jakob, thorium is a naturally occurring, mildly radioactive, and insoluble metal, which was named after the Norse god of thunder, Thor.[173] While thorium technologies have not received the same level of interest as other nuclear technologies, consistent support and work by proponents has helped to educate the public and policymakers about their potential. For example, advocates for thorium-fueled energy note that it could help address many of the economic, safety, and environmental concerns being raised over the use of the plutonium/uranium-fueled reactors that currently make up the American nuclear fleet.

Detractors of thorium technologies caution that existing infrastructure was designed to use uranium and plutonium fuels, that SMR and other Gen IV technologies can also use uranium, and that many of the concerns leveled at uranium can be just as easily leveled at thorium. In short, they argue that advocates should use caution when suggesting that thorium could serve as a silver bullet to solve our energy challenges. Despite those critiques, advocates point to several other areas where thorium stands out as a viable option for a vast supply of clean and affordable energy.

Past / Current Research

Interest in thorium as a potential nuclear fuel source is not a new idea. The Oakridge Labs operated a fully functional liquid fluoride thorium reactor for over 2.5 years in the 1960s.[174] The initial research into this fuel type was founded on the search for a nuclear-powered airplane during World War II. The U.S. Air Force attempted to develop this technology to power bombers that could stay in flight for extended periods to carry out long-range bombing runs. However, that project was dropped after the development of intercontinental ballistic missiles made the technology unnecessary.[175]

Those questioning thorium technologies concede the reactor research was carried out. However, they argue that the reactor was experimental and relatively small—only 7 MW—and produced heat that was dissipated into the air and never used to power electricity generation.

It is also worthwhile to point out that thorium-based fuels can be used in various reactor designs and do not necessarily need to be used (only) in molten salt reactors. Thorium fuels are currently being tested in existing light-water nuclear reactors in Norway. In this test, thorium was added to solid fuel rods in the Halden research reactor in two separate test runs. The first test ran from 2013 to 2015, and the second from 2015 to 2018. The results of both runs were used to improve the "fuel recipe and the skills to successfully produce [fuel] pellets." A third test is currently underway.[176]

Interest in developing a scalable, cost-efficient, low-emissions, low-waste, and safe energy source has encouraged renewed interest in the above-noted thorium molten salt reactor tests.[177] At the Netherlands-based research lab NRG (the Nuclear Research and Consultancy Group), "The first experiment in the series named SALIENT-01 (SALt Irradiation ExperimeNT) was irradiated in Petten's High Flux Reactor between August 2017 and August 2019.[178] This type of reactor uses thorium salt as a fuel source. Similar research is also ongoing in China and India.[179]

Concerns have been raised about the United States' lack of leadership in advancing this technology while other nations continue to develop it and perfect it for widespread use.

Thorium advocates, like the Thorium Energy Alliance, have repeatedly warned about the increased costs of allowing international interests to develop and trademark or patent thorium technologies. They point out that intellectual property challenges could drastically limit access to and increase the costs of these technologies if the United States cedes its rapidly diminishing lead in this area.[180] At the very least, currently operating test reactors demonstrate that thorium fuels are worthy of further research and consideration.

"Fail-safe"

A key driver supporting these technologies is that they are described as "fail-safe," meaning they cannot melt down. This is because thorium—in either liquid, solid or salt form—is not fissile. It is fertile, meaning it must be kick-started with neutrons from a "driver," or a fissile material.[181] As one source describes, thorium-232, the most abundant form of the element, must be "broken down through several stages of radioactive decay" by "bombarding it with neutrons."[182] That process forms uranium-233—the fission-ready element—and uranium 232—a highly radioactive isotope. Once the reaction is started, the reactor can "breed" or create uranium-233 in the reactor core, which can then maintain the fission reaction.

Critics say this proves the technology cannot be relied on because thorium is effectively inert without uranium-233 or some other means of starting the process. But advocates reply that the current stockpile of nuclear and spent fuels would be sufficient to ensure thorium reactors could remain operational for many decades.

Other safety features inherent to thorium molten salt reactors include molten salts having a "negative temperature coefficient of reactivity."[183] This means that, as it heats up, it expands. That expansion causes the fuel to become less reactive and, therefore, less likely to overheat. MSRs also have a plug in the bottom of the reactor that is designed to melt if there is a problem that causes temperatures to rise beyond safe limits. If this occurs, the heat will cause the plug in the reactor to melt, allowing gravity to pull the fuels from the reactor core, into tanks designed to cool and store the fuels.

Storage and use of spent nuclear fuels

U.S. nuclear plants store their spent fuel on-site in large steel and concrete "dry cask" storage facilities. Dry cask storage facilities are proven safe because "Dry storage has released no radiation that affected the public or contaminated the environment," according to the Nuclear Regulatory Commission.[184] "Dry cask storage has also been tested; a direct hit by a missile, traveling at 600 mph, could not breach the container."[185] Furthermore, when regulatory processes allow it, existing spent nuclear fuel represents a massive resource. As previously noted, the Department of Energy explains, "Spent nuclear fuel can be recycled to make new fuel and byproducts. More than 90% of its potential energy remains in the fuel, even after five years of operation in a reactor." DOE notes that France actively recycles its spent nuclear fuels to power its reactor fleet.[186, 187]

Radioactivity
On its own, thorium can be stored—inert—without going critical. This is not the case for enriched uranium, which would—if stored in stockpiles—begin the process of fission on its own. This aspect of current nuclear facilities requires extensive safety processes to be built into the reactors, to avoid a meltdown or explosive event.

Nuclear weapons proliferation
One of the key concerns expressed by anti-nuclear advocates is the idea that nuclear fuels could be misused by terrorists, or rogue nations to create nuclear weapons or dirty bombs.[188] However, thorium advocates claim that the dangers and complexities of extracting weapons-grade uranium from thorium make it too dangerous and difficult to do. They argue that rogue organizations would find it simpler and safer to just gain access to a source of plutonium. Thierry Dujardin, deputy director for science and development of the Organization for Economic Co-operation and Development's Nuclear Energy Agency says that thorium is no more dangerous or safer than other nuclear fuels regarding proliferation concerns.[189]

Other nuclear experts note that one benefit of switching to a thorium/uranium-based fuel (vs. the currently used uranium/plutonium-based fuels), is that this type of fuel allows recycling of existing nuclear wastes. This is because nuclear reactors currently only use a small portion of the total fuel, but proliferation concerns have restricted recycling efforts to stop the creation of plutonium as part of the recycling process. By mixing waste fuels with thorium for use in TMSR reactors, the creation of plutonium could be avoided, thereby reducing proliferation concerns and allowing far more efficient use of existing nuclear fuels, and increased recycling of nuclear waste stocks.[190]

Market feasibility: 7/10

The primary restrictions to the continued and expanded use of nuclear are regulatory pressures and electricity market-disrupting subsidies and mandates given to competing wind and solar. Given the nation’s insular focus on decarbonization, nuclear represents the primary means of achieving net zero mandates while still providing reliable and affordable electricity service.

There is clear economic value in the reliable electric service that nuclear energy provides. However, as with natural gas and coal, some groups have demonstrated a strong commitment to forcing nuclear energy closures. As noted in Figure 34 (U.S. primary energy production, 1950-2022), U.S. production of electricity with nuclear has been remarkably stable for the past 3 decades.

Referring again to “The Siren Song that Never Ends” and Figures 2 and 23 in this report, TPPF researchers report that nuclear received $5.46 billion in federal “tax expenditures,” $0.22 billion in “direct expenditures,” and $9.72 billion in “research and development” for a total of $15.41 billion from 2010-2019.[191] Therefore, the nuclear sector would have received just over 12% of total federal expenditures from 2010-2019 to produce 18% of net electricity generation and 8% of total U.S. primary energy demand in 2022.

Once again, we point out that subsidies going to wind and solar promote the construction of current generation technologies, while tax treatments and payments to nuclear and fossil fuels encourage “research and specific aspects of exploration and development.”

Recommendations

Nuclear energy presents an excellent opportunity for expansion to provide an essentially endless source of affordable, reliable, clean, and safe electricity. It can also be used for a rapidly growing list of industrial needs, including industrial heat, water purification, and hydrogen generation.

While nuclear energy has experienced some setbacks due to confusion over (or misrepresentation of) its safety record and cost increases caused by regulatory pressures, new Gen III+, Gen IV, and SMR technologies allow this energy source to provide both large baseload and smaller (or distributed) peaking options. Electricity produced by nuclear facilities is emissions-free and can meet state and federal net zero or carbon dioxide reduction mandates. Maintaining existing nuclear plants and building new plants would also help moderate the billions of dollars in planned expenditures for renewable (solar and wind) generation sources.

Renewable electricity generation

We open this section with the recognition that "renewable" is a misnomer that is applied to a group of electricity generation technologies because they have fuel sources that are renewed naturally, e.g. wind, sun, the water cycle, etc. However, as we describe in more detail in the following wind section, all of these energy sources require the development of mineral or metal resources, they use a great deal of fossil fuel energy (as well as bulk and critical minerals) in their development and manufacture, they must be regularly repowered (often on relatively short timelines), and they must be maintained (again, using fossil-fuel-powered equipment).

Although it is inaccurate, the term "renewable" is widely used. Recognizing that distinction, so-called renewable generation can be different than other generation technologies because hydroelectric, geothermal, wind, and solar do not require the combustion or fission of fuels to produce heat, which is then used to produce electricity. These technologies use water, the sun, or wind as their "fuel," or the means of driving generators that produce electricity.

Biomass options are the obvious exception to this rule. They are combusted in a boiler, or they can also be gasified or digested and the resulting methane gas is combusted in turbines or internal combustion engines in the same manner as fossil fuels.

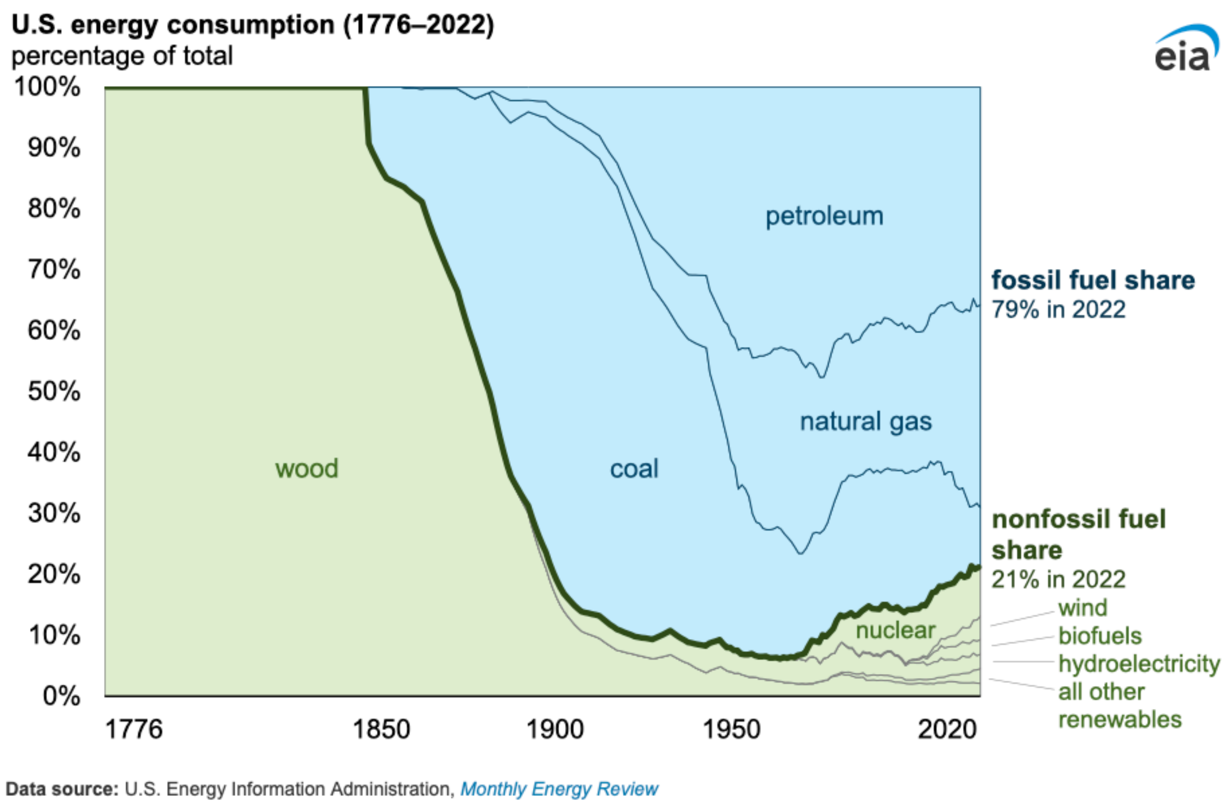


Figure 39: U.S. energy consumption, 1776-2022 (Source: U.S. Energy Information Administration)

Renewable energy sources made up 21% of total U.S. energy consumption in 2022.

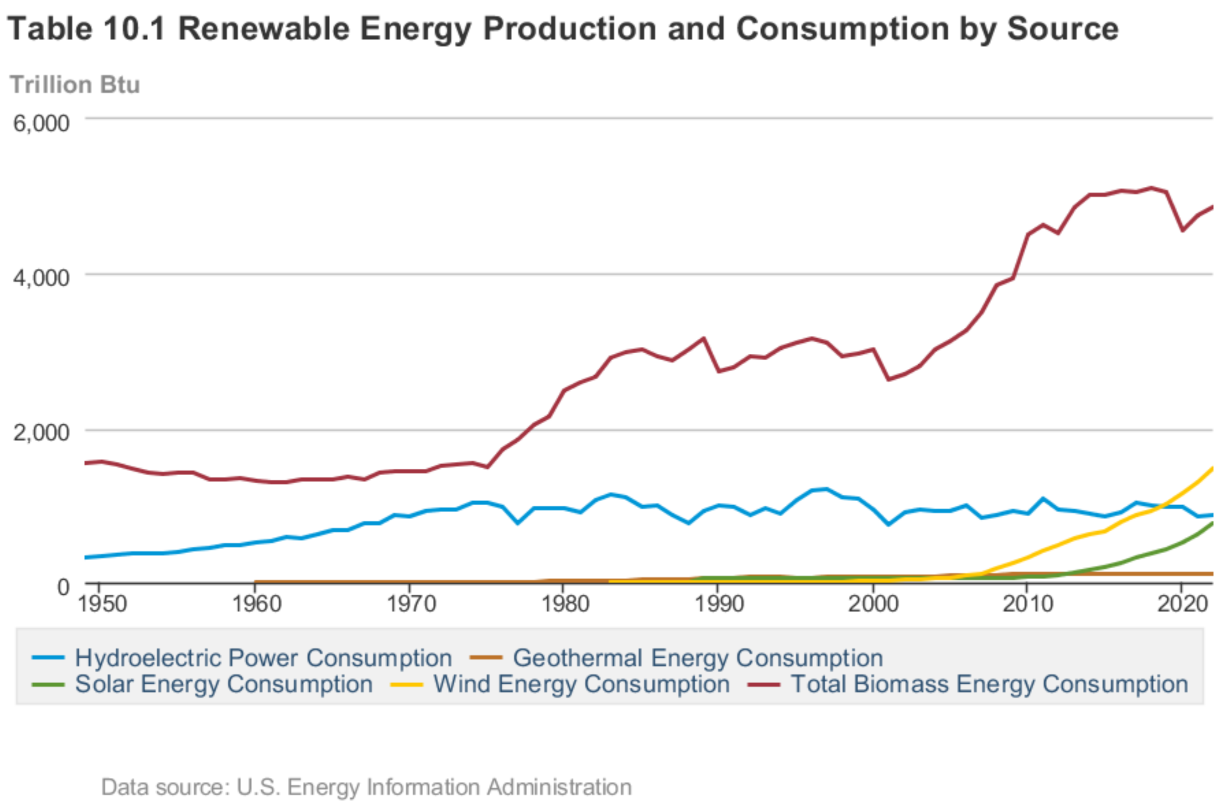


Figure 40: Renewable energy production and consumption by source (Source: U.S. Energy Information Administration)

Conventional hydroelectric

Grade: 80% (B-)

Bottom Line Up Front

Hydroelectric is the one form of renewable generation that is completely dispatchable and does not have any emissions associated with its operations (compared with biomass).

While hydroelectric would seem to meet most of the tests of the environmental movement, it is often targeted for removal because it requires a great deal of bulk material in its construction and interrupts or changes natural river flows and floods riparian zones (displacing wildlife and human inhabitants). Given the expansive nature of large hydroelectric facilities, it is unlikely that any new developments could be permitted in North America.

Capacity & Reliability: 10/10

Hydroelectric generation can provide completely reliable, dispatchable, and (near) emissions-free electric service in areas where dams and reservoirs can be constructed.

Hydroelectric represents approximately 6% of total U.S. electricity generation and about 29% of utility-scale renewable generation in 2022. (See Figure 2)

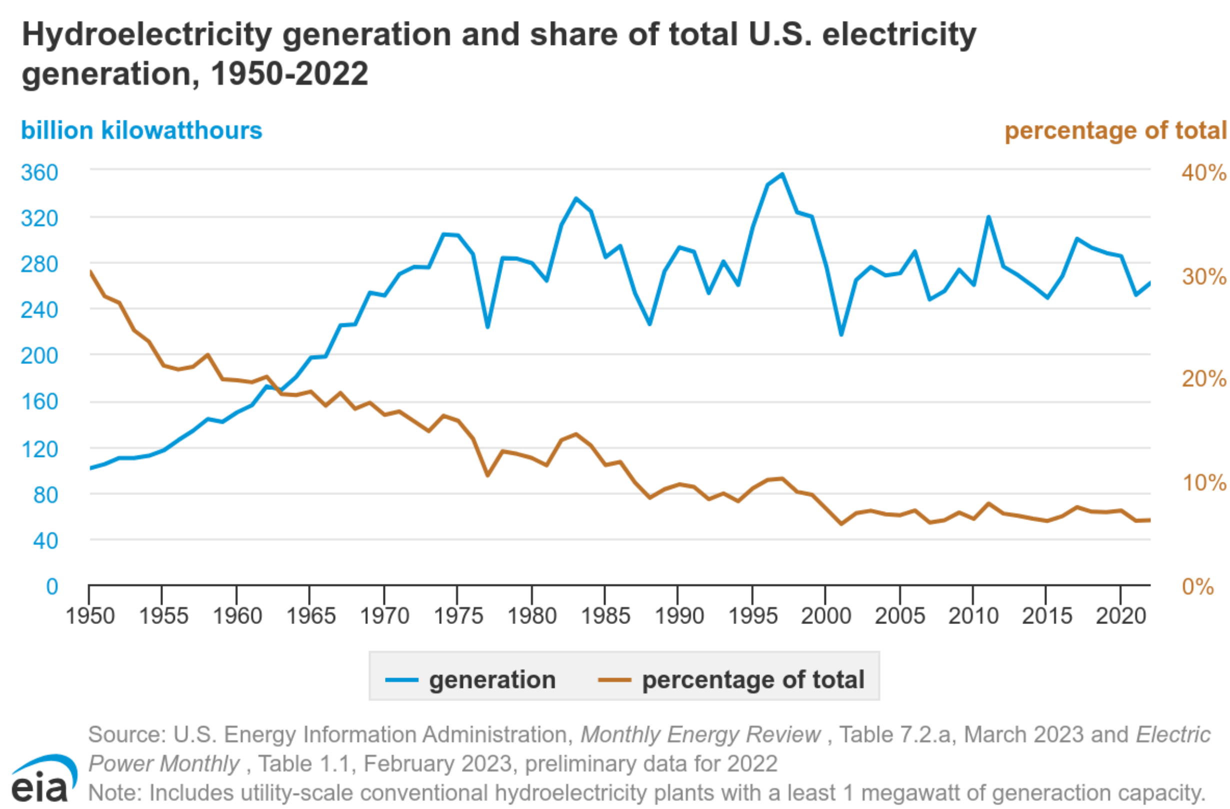


Figure 41: Hydroelectric generation and share of total U.S. electric generation, 1950-2022 (Source: U.S. Energy Information Administration)

Hydroelectric power is unique in that it is completely dispatchable, meaning it can be relied on to generate electricity when it is needed. Other renewable energy options, like wind and solar, do not have this ability. They are restricted to generating electricity when the weather allows.

Traditional hydroelectric facilities are, however, limited by geography. Over half of U.S. hydroelectric capacity is in Washington, California, and Oregon. These facilities must be located on or beside a water source and have a substantial dedicated area for a reservoir to retain the water behind a dam. The best locations in the nation for this type of facility are near the coasts or along major rivers in mountainous regions.[192] Despite geographical limitations, efforts to repower older facilities (with newer, larger, or more efficient turbines) or add turbines to dams previously used for flood control have added overall capacity.

Hydroelectric operators must also balance electricity generation needs with other water uses, like drinking water, irrigation, and wildlife habitat needs.

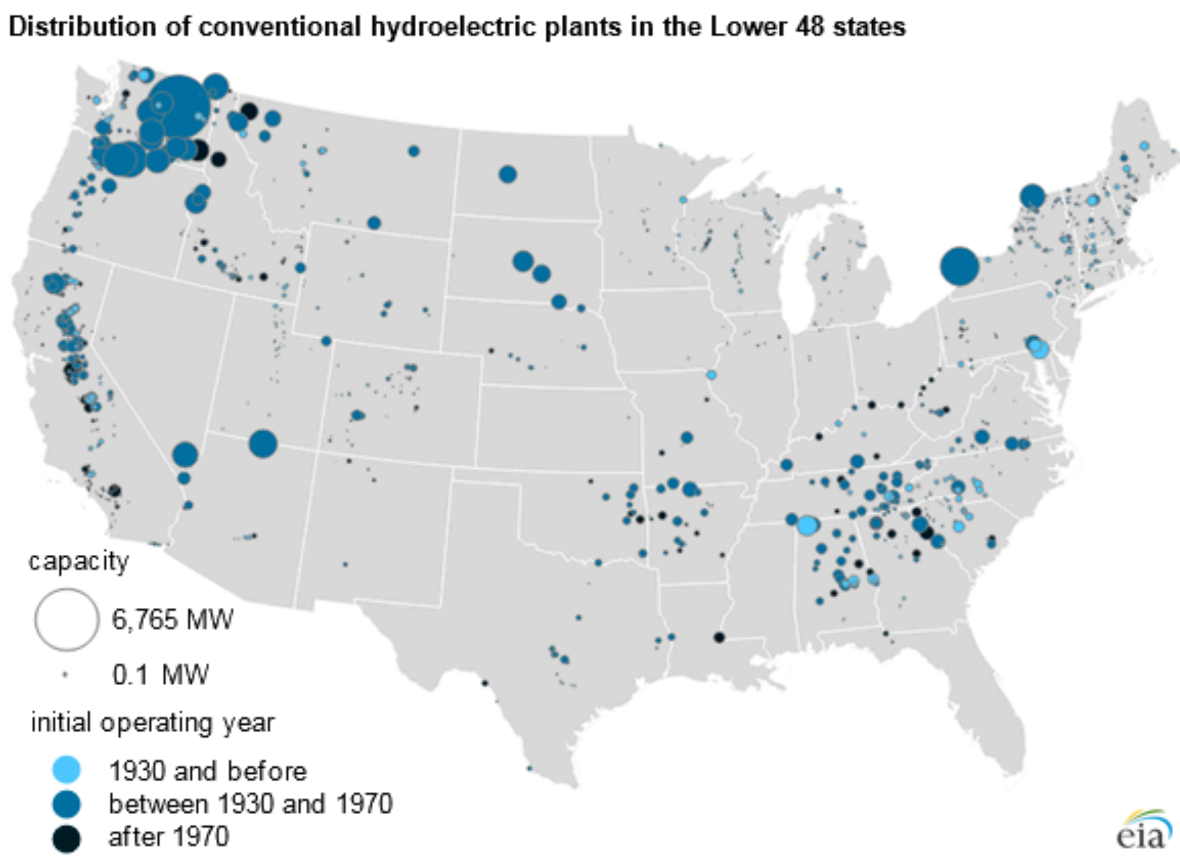


Figure 42: Distribution of conventional hydroelectric plants in the Lower 48 states (Source: U.S. Energy Information Administration)[193]

Pumped hydro represents one option for storing energy generated when overall demand is lower. The Ludington Pumped Storage facility in Michigan is one example. The facility has a capacity of 1,875 MW.[194] In the evening, when electricity prices are relatively low, this facility reverses its turbines to pump water from Lake Michigan, uphill and into a 1,000-acre reservoir. That water is held in the reservoir until electricity prices are higher, or there is a need for additional generation capacity. Then the water is released and run back through the generators to produce electricity that is fed into the state's grid. The water in the reservoir effectively acts like a battery that is recharged when electricity prices are low and used when they are higher. As pumped hydro facilities provide energy storage, they represent a net loss to the state's overall electricity generation. (It takes more electricity to push the water uphill into the reservoir than is generated by releasing it downhill.)

Environmental/Human Impact: 8/10

While hydroelectric power provides clean, dispatchable, and renewable electric service, it impedes the natural flow of rivers and impacts riparian areas. Reservoirs also impact human activities and wildlife habitat.

Hydroelectric generation is a renewable source of energy that emits no emissions while generating electricity. However, some challenges associated with hydroelectric generation are that it typically requires a dam that blocks river flows and can impede fish passage. The dams and the reservoirs they create use an immense amount of bulk materials in their construction (see Figure 35: Key bulk materials, measured in metric tonnes per terawatt-hour, required per unit of electricity produced). Dams and reservoirs also cause substantial changes in riparian ecosystems and can displace a mix of human and wildlife populations.

Additionally, although hydroelectric is a renewable energy resource, the creation of large reservoirs can cause the release of substantial amounts of methane gas.[195] This methane is generated by bacteria that digest and decompose organic waste, algae, and vegetation in the often cold, oxygen-depleted reservoir water. This process can be compounded by nitrogen-rich runoff from agricultural fields, which encourages algal growth in the reservoirs.[196]

Workforce

The North American hydroelectric industry produces a valuable product with a well-paid adult workforce. U.S. Bureau of Labor Statistics indicates the average hourly earnings for "all occupations" in the Hydroelectric Power Generation industry were $47.17/hr in April 2023 (or $98,110 annually, which is almost 54% higher than the national average for 2022 reported by the Social Security Administration).[197] BLS did not list average hours worked per week, but based the salary on 2080 hours worked each year, or almost 40 hours per week.

Cost: 8/10

Existing hydroelectric dams provide low-cost and reliable electricity.

Hydroelectric competes favorably with other energy sources. The April 2023 Lazard's "Levelized Cost of Energy Comparison – Unsubsidized Analysis" does not review the costs of hydroelectric. However, the Institute for Energy Research study, "The Levelized Cost of Electricity from Existing Generation Resources" does report the LCOE of existing hydroelectric facilities (seasonal) as

$38.20 (2018 $/MWh) and new hydroelectric construction at $73.10 (2018 $/MWh). (See Figure 18: LCOE-Existing vs. LCOE-New in 2018 $/MWh.)

Technology/Innovation: 8/10

The basic structure and framework of hydroelectric generation is straightforward. However, there are ways to add new, larger, newer, and more efficient turbines to existing dams.

Conventional hydroelectric plants rely on gravity and the potential energy in moving water descending from an elevated water source to force water past a turbine and generator.[198]

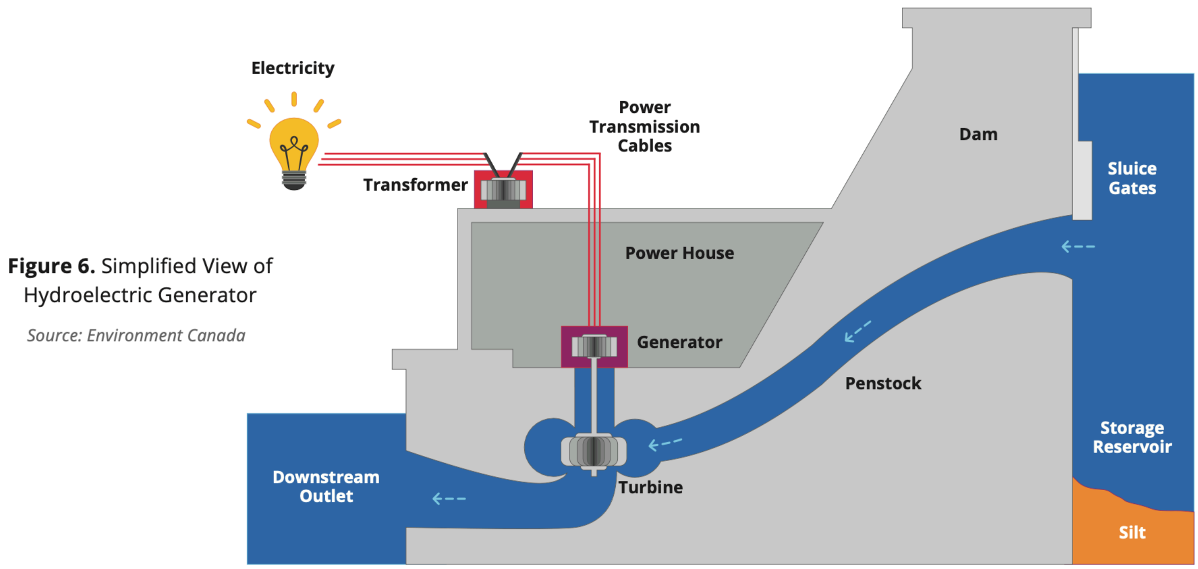


Figure 43: Simplified view of a hydroelectric generator (Source: Mackinac Center/Environment Canada)

The benefits associated with hydroelectric generation are that it is a relatively low-emissions form of renewable generation. It does not require the combustion or use of fuel to provide electricity. It has the additional benefit of being "dispatchable," which means the electricity it produces can be turned on or off in response to system demand. This makes hydroelectric more like baseload generation options such as coal, nuclear, natural gas, and biomass and separates it from other options like wind and solar, which can only produce electricity when the wind blows or the sun shines.

Market feasibility: 6/10

New hydroelectric construction is highly unlikely. Given the disruptions that would accompany any new large hydroelectric development, the ability to permit new dams and reservoirs is limited. However, there are opportunities to maintain and upgrade existing dams.

Most large hydroelectric facilities in the U.S. are situated on major rivers and were built by government agencies before the 1970s.[199] As the investments have already been made to establish these dams, it makes sense to continue using the 1,450 conventional and 40 pumped hydro facilities that already exist nationwide. Like other dispatchable energy sources—fossil fuels and nuclear—there is clear economic value in hydroelectric generation's reliable electric service. As demonstrated in Figure 34, U.S. production of electricity with hydroelectric has been relatively stable for the past 5 or more decades.

However, some groups, government agencies, and elected officials have demonstrated a strong commitment to forcing the removal of dams, given their influence on the natural flows of rivers and their impacts on riparian areas. NOAA Fisheries explains that "throughout the country, aging dams are being removed to improve public safety and restore river and coastal ecosystems."[200]

Referring again to "The Siren Song that Never Ends" and Figures 2 and 23 in this report, TPPF researchers report that hydroelectric received $0 in federal "tax expenditures," $0.37 billion in "direct expenditures," and $0.72 billion in "research and development" for a total of $1.45 billion from 2010-2019.[201] Therefore, the hydroelectric sector received just over 1% of total federal expenditures over that ten-year period to produce 6% of net electricity generation and 2.3% of total U.S. primary energy demand in 2022.

Given the high cost of new hydroelectric projects and the difficulty of getting permits to alter the flow of major rivers and flood new reservoirs, it is highly unlikely that a large new hydroelectric dam could be constructed in North America.

Recommendations

Hydroelectric energy provides a reliable, clean, and dispatchable source of electricity from long-lived renewable generation facilities. While geographical limitations restrict its use in some areas of the nation, and the areas that can be developed with hydro facilities likely already have been, hydroelectric offers an essentially endless source of electricity.

Despite the political pressures to remove dams, there are options and solutions to deal with the environmental concerns that hydro dams present. For example, systems (like fish ladders) can be built to address wildlife concerns and dredging can be employed to address siltation concerns.

Where possible, the nation's hydroelectric facilities should be preserved and repowered or upgraded to ensure these facilities can continue to provide relatively low-cost, clean, reliable electricity.

Wind

Grade: 56% (F)

Bottom Line Up Front

Wind is one of two so-called renewable energy generation sources widely promoted for its claimed ability to reduce the environmental impacts of electricity generation. Wind is marketed as able to reduce carbon dioxide emissions, while also protecting the environment, reducing electric rates, and improving reliability.

While it is true that wind does not produce carbon dioxide as it produces electricity, there are numerous other grid reliability, environmental, economic (or cost), and social issues associated with its use that are often overlooked.

Given that society increasingly relies on a steady and dependable supply of affordable energy, government policies that mandate and heavily subsidize a transition to wind generation represent a growing threat to human health and well-being.

Capacity & Reliability: 5/10

Wind provides an unreliable service that imposes a compounding level of grid instability as more of it is built.

A claimed benefit of wind power is that it provides an alternate form of electricity generation and helps to diversify the overall electrical grid. Working from that claim, wind generation has grown significantly over the past two decades. In 2000, wind generated 0.15% of the nation's electricity supply. In 2022, it generated 10.2%.[202] The U.S. Geological Survey's wind turbine database reports that as of, November 2023, 73,352 wind turbines were operating in 43 states (as well as Guam and Puerto Rico) with a total nameplate capacity of 144,950 MW.[203]

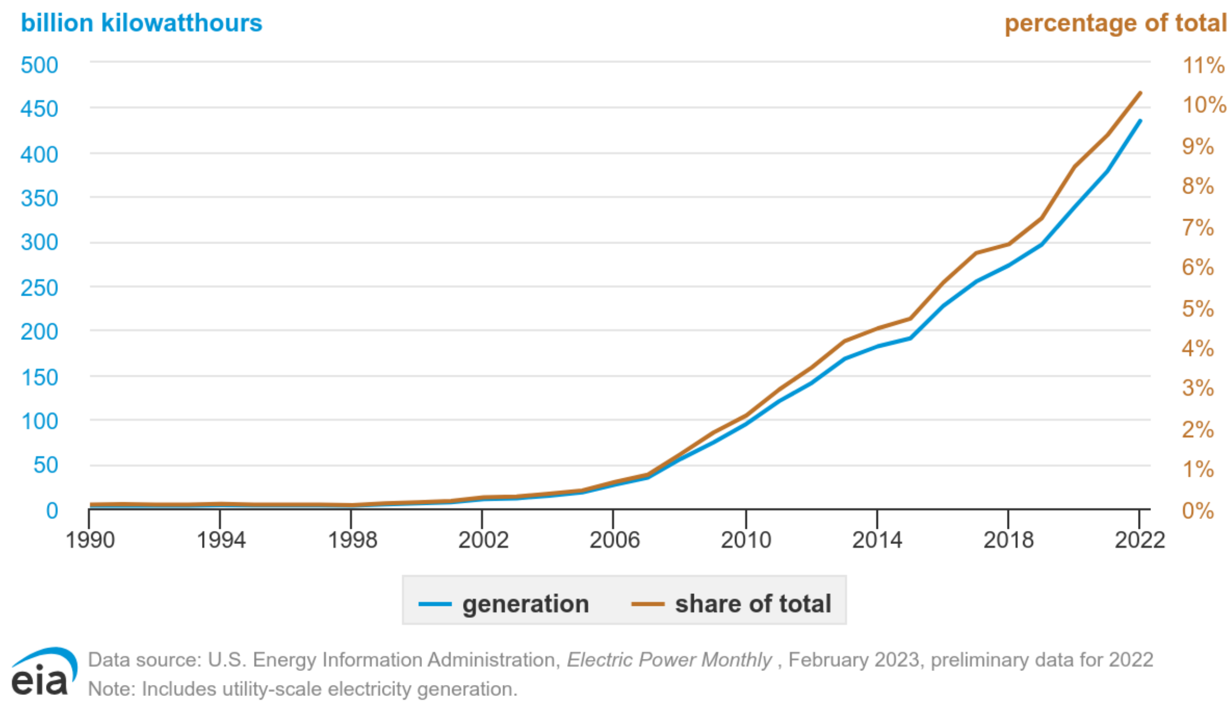


Figure 44: Wind electricity generation and share of total U.S. electricity generation, 1990-2022 (Source: U.S. Energy Information Administration)

Numerous state and federal programs require or mandate the increased use of wind as part of a decarbonization program. Across the U.S., 23 states, from California to Wisconsin (as well as the District of Columbia and Puerto Rico), have set “100% Clean Energy” or “carbon-free electricity” goals, requiring the widespread adoption of wind and solar.[204]

Far from diversifying the grid, these clean energy or carbon-free energy programs tend to force the grid to rely largely on wind and solar with natural gas backup and a stated plan to switch from gas to battery backup as quickly as possible. These transition plans at the state level, promoted by activist donors like the Bloomberg Foundation, push the closure of all remaining coal-fired generation assets and much of the nation’s natural gas as well.

In one piece describing a $500 million donation from the Bloomberg Foundation to the Beyond Carbon campaign, Robert Bryce describes “The goal of the effort is to shutter the bulk of our most important power plants—the ones that burn coal and natural gas and are therefore dispatchable and weather-resilient—and, in Bloomberg’s words, replace them with ‘renewable energy.’” Bryce argues that, since these plants provided 40% of the nation’s electricity in 2022, it would be difficult to “conjure” a more radical energy policy.[205]

Many of these efforts also target the closure of nuclear plants, as they did in Michigan with the 2022 closure of the Palisades Nuclear Plant. When that plant closed in May 2022, it removed 6.5% of the state’s electricity supply and 15% of its clean energy.[206]

The key challenge associated with transitioning the grid to intermittent resources like wind is the growing impact on reliability. As noted in the opening section, which discusses the condition of the electrical grid, America's grid is experiencing growing instability as wind achieves higher penetration levels.

The wind does not blow 24/7/365, and wind turbines can only produce electricity when the wind blows within a specific range of speeds; too fast or too slow, and the turbines stop producing.[††, 207] Wind is not a dispatchable resource because it cannot be controlled by an operator or turned on when needed. The U.S. Department of Energy reports that wind had a 34.6% percent capacity factor in 2021, which means that 65.4% of the installed capacity of wind sits unused on average.[‡‡, 208]

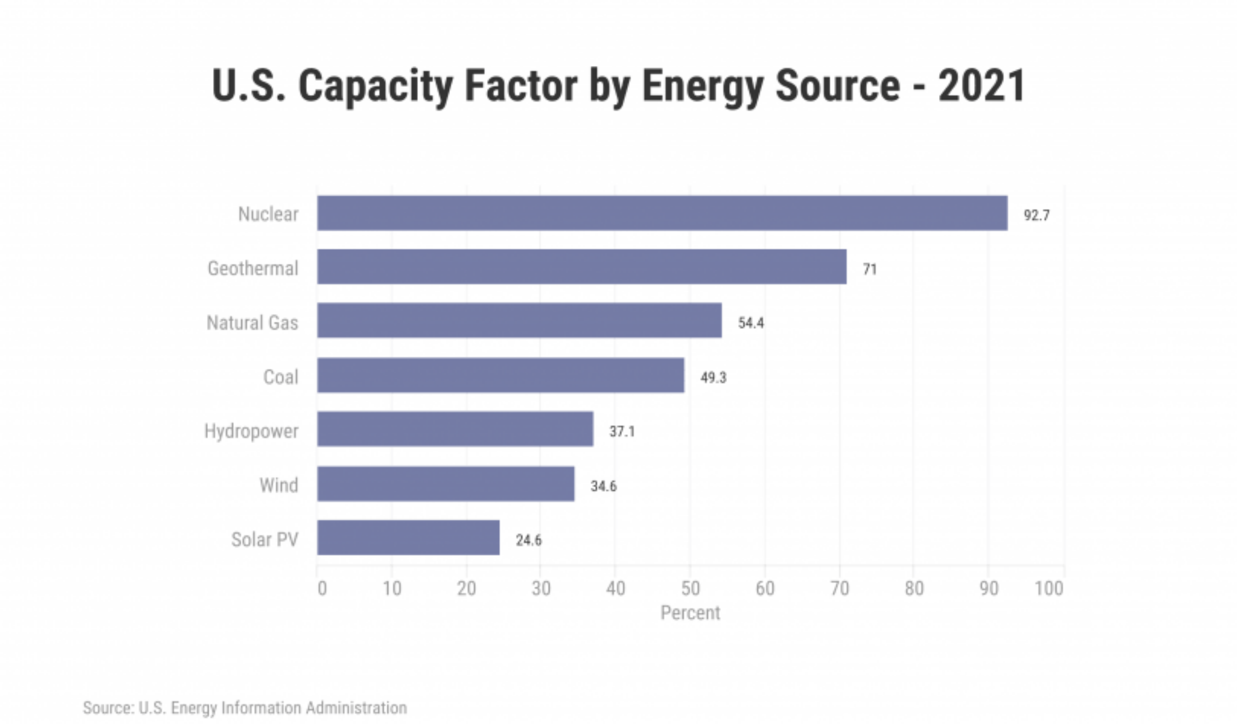


Figure 45: U.S. Capacity Factor by Energy Source - 2021 (Source: U.S. Energy Information Administration)

Jim Robb, CEO of the North American Electric Reliability Corporation, blamed growing grid instability on the rushed transition to wind and solar in an interview on Soledad O'Brien's "Matter of Fact" show. Robb explained that the "disorderly retirement of older" coal and

[††] Wind cut in speed is around 3-4 meters per second (~7-9 miles per hour). Cut out speed is around 25 meters per second (56 miles per hour). (See: https://researchhubs.com/post/engineering/wind-energy/power-output-variation-with-wind-speed.html)

[‡‡] As described in the coal section, U.S. Energy Information Administration defines "capacity factor" as "The ratio of the electrical energy produced by a generating unit for the time considered to the electrical energy that could have been produced at continuous full power operation during the same period." (See: https://www.eia.gov/tools/glossary/index.php?id=Capacity_factor)

nuclear generation facilities "is happening too quickly."[209] He warned that the electric sector must balance reliability, affordability, and environmental impact. He also assessed the industry's tendency to "overemphasize one of the three dimensions."

In this case, the industry has focused on the false hope that it can protect the environment by building wind and solar power. But Robb's warning reminds us that intermittent resources can't be expected to provide consistent power. Given our growing reliance on electrified transportation, heating, communications, medical care, etc., Robb noted that "Even a moment without power is a real problem for people."

Regional grid managers are sounding similar warning bells. In the "MISO's Response to the Reliability Imperative" report, the CEO of the Midcontinent Independent System Operator, John Bear warns that, "Studies conducted by MISO and other entities indicate it is possible to reliably operate an electric system that has far fewer conventional power plants and far more zero-carbon resources than we have today. However, **the transition that is underway to get to a decarbonized end state is posing material, adverse challenges to electric reliability.**" (emphasis in the original)[210]

And these warnings are ringing true. In the cold spell that spread across North America during mid-January 2024, several areas reported electricity shortfalls and warned customers they would need to reduce electricity use to avoid the need for rolling blackouts.

Areas where wind specifically failed to provide sufficient generation capacity included the state of Texas and the Canadian province of Alberta. In a January 13 post to the social media outlet "X" (formerly Twitter), Saskatchewan Premier Scott Moe explained that the major utility in his province "SaskPower is providing 153 MW of electricity to AB this evening to assist them through this shortage." Moe continued, noting "That power will be coming from natural gas and coal-fired plants, the ones the Trudeau government is telling us to shut down (which we won't)."[211]

Moe included a graphic of an earlier emergency warning sent out by the Alberta Emergency Management Agency, cautioning Albertans that "Extreme cold resulting in high power demand has placed the Alberta grid at a high risk of rotating power outages." The AEMA requested that Albertans "immediately limit their electricity use to essential needs only. Turn off unnecessary lights and electrical appliances. Minimize the use of space heaters. Delay use of major power appliances. Delay charging electrical vehicles and plugging in block heaters. Cook with microwave instead of stove."[212] At the time of the warning, temperatures across the province had dropped to as low as -45°C/-49°F. During the extreme cold, the Alberta Electric System Operator, the manager of the provincial grid, reported that wind was producing at only 2.9% of its installed capacity. While the province had 4,481 MW of wind capacity, wind turbines were producing a total net generation of 130 MW.

GENERATION			
GROUP	MC	TNG	DCR
GAS	11832	8976	204
HYDRO	894	158	157
ENERGY STORAGE	190	0	33
SOLAR	1650	0	0
WIND	4481	130	0
OTHER	444	336	0
DUAL FUEL	466	466	0
COAL	820	821	0
TOTAL	20777	10887	394

Figure 46: Alberta Electric System Operator "Current supply demand report" - January 13, 10:25 pm EST (MC-maximum capacity / TNG-total net generation)[213]

While the province of Alberta was experiencing shortfalls, the state of Texas was also concerned that cold weather would lead to shortfalls. The Electric Reliability Council of Texas, or ERCOT, the state grid manager, posted a "weather watch" to X. On January 14, ERCOT posted a warning that "extreme cold weather" would lead to "higher electrical demand and the potential for lower reserves."[214]

Environmental/Human Impact: 6/10

Wind energy has large environmental impacts from the need to rapidly expand mining to source critical or transition minerals, to its need for backup generation or battery sources, to its immense requirement for land, to visual impacts, to a growing list of impacts on wildlife.

We are told that we are implementing plans to transition to so-called renewable energy supplies to address climate change and "help the environment."[215]

The U.S. Energy Information Administration defines renewable energy as "energy from sources that are naturally replenishing but flow-limited; renewable resources are virtually inexhaustible in duration but limited in the amount of energy available per unit of time."[216] But the reality is that wind (and solar) does not meet the definition of renewable because, as Mark Mills from the Manhattan Institute explains.

> "Renewable plans proposed or underway will require from 400 percent to 8,000 percent more mining for dozens of minerals, from copper and nickel, to aluminum, graphite, and lithium… All machines wear out, and there is nothing inherently renewable about green machines, since one must engage in continual extraction of materials to build new ones and replace those that wear out. All this requires mining, processing, transportation, and, ultimately, the disposing of millions of tons of materials, much of it functionally or economically unrecyclable."[217]

Adding to this revelation is the reality that wind (and solar) generation options are wearing out and being repowered (or rebuilt with new equipment) much faster than taxpayers and ratepayers had been told, often in as little as half of their planned life cycle. "However, many of the turbines built to comply with the 25 percent mandate are already being refurbished or 'repowered,' long before the end of their supposed 25-year useful lives. One of these wind facilities, the Nobles wind farm, has already been repowered after just 12 years in service."[218] Apart from the obvious impacts this early repowering has on the pricing estimates used to promote wind and solar as affordable (like their LCOE cost estimates) it also radically increases the expected needs for metals, minerals, and other bulk manufacturing and construction materials.

Interestingly, these repowering plans also occur at, or soon after, the expiry of the generation source's eligibility for the tax credits that make their construction far more likely. "Prominent investor Warren Buffett clearly understood what it takes to ensure wind gets built when he bluntly stated that the subsidies and tax credits were 'the only reason to build them.' He continued, 'They don't make sense without the tax credit.'"[219] Information from the federal government bluntly confirms Buffett's assertion and recognizes subsidies as a key driver for the push to repower wind turbines. "Federal production tax credits provide an incentive to increase electricity generation from existing wind turbines. In December 2015, the production tax credit (PTC) was extended until the end of 2019. The four-year extension and legislated phase-out of the PTC is expected to encourage many asset owners to repower existing wind facilities to requalify them to receive another 10 years of tax credits."[220]

Another major claimed benefit of wind power is that it helps decarbonize the electrical grid, which will aid in addressing climate change concerns. "Wind power is crucial for combating climate change," the Global Wind Energy Council claims. "Under a new 2020 climate agreement, wind energy alone could contribute a very large portion of the emissions reductions under the pledges put forward so far. However, they are woefully inadequate to meeting the climate challenge."[221]

Estimates like this, however, require that we ignore wind's role as part of a larger, interconnected grid. Given its intermittency issues, wind alone cannot provide sufficient electric generation capacity. It must be backed up by a reliable source of energy, like natural gas. But, as noted earlier in this paper, forcing other energy sources to cycle, up and down, to cover for the intermittency imposed by wind and solar means less efficient operation and increased maintenance and repair issues, just as in-city, stop-and-start driving is harder on an automobile than traveling at consistent speeds on the highway. (Note: As solar panels also face the same intermittency issues as wind, the need for backup or battery support also applies to the solar industry.)

But battery technology is not currently capable, nor is it present in sufficient capacity or at an affordable cost to provide reliable grid-wide backup. "Battery storage not quite there yet," explained Bjorn Lomborg, president of Copenhagen Consensus in 2019. "Total energy storage for the US by end of 2018: 14 seconds of average US electricity demand."[222] By 2022, Lomborg cited data from the Wood Mackenzie Global Energy Storage Outlook to explain "We're told solar and wind [are the] future… But when wind is not blowing and sun not shining? Batteries! Yet The world uses 51GWh/minute and has 64GWh of battery storage: enough for 1m:15s. 2030: 10m:24s After that, need 100% backup, mostly fossil fuels."[223]

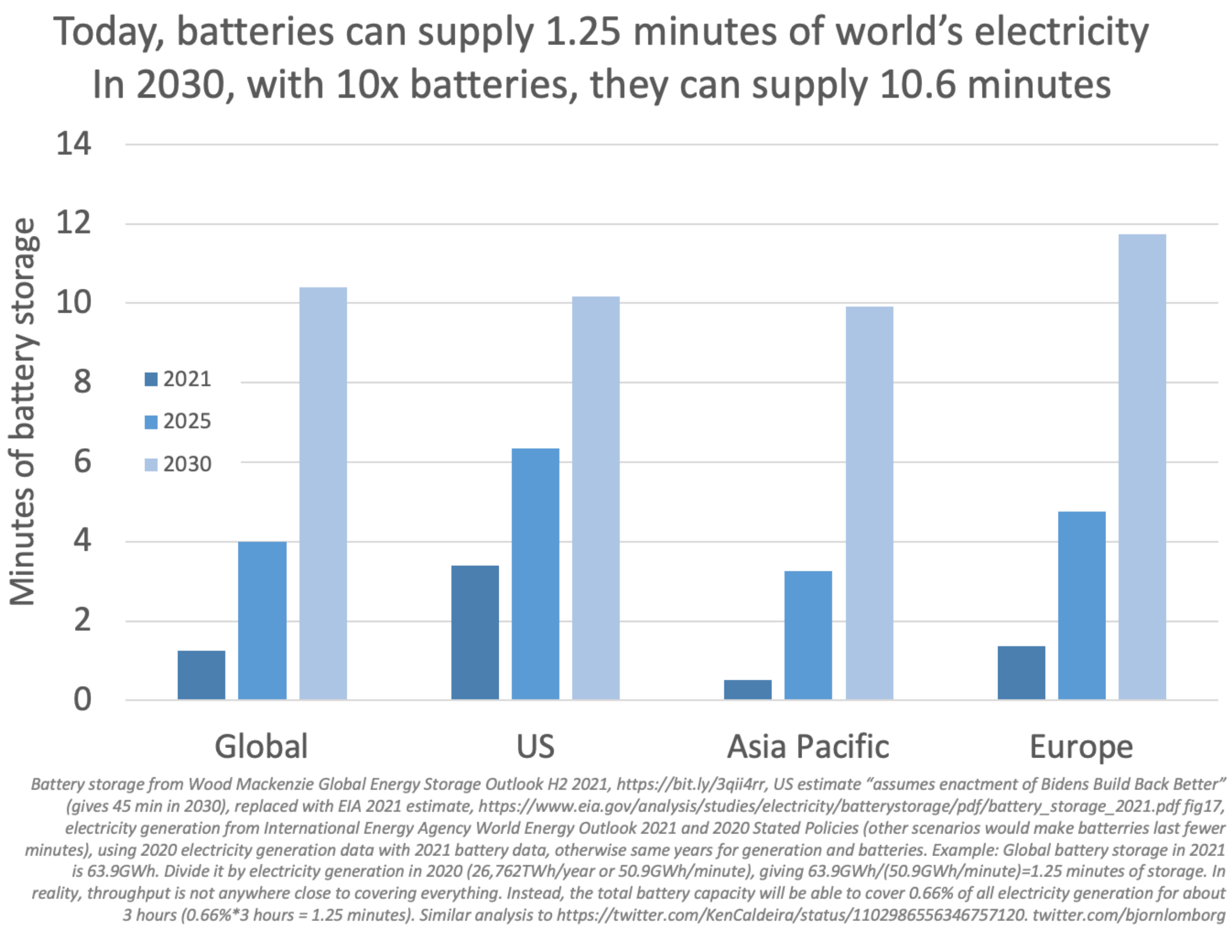


Figure 47: Global energy storage outlook: H2 2021 (Source: Bjorn Lomborg/Wood Mackenzie)

Furthermore, batteries (whether used to back up wind or solar) come with various environmental and human rights issues. Some of those issues are discussed in Siddharth Kara's book, "Cobalt Red," which describes the ongoing exploitation of workers and the natural environment in the Democratic Republic of the Congo. The DRC is the source of most of the world's supply of the mineral cobalt, which is used to manufacture lithium-ion batteries to improve energy density and charging speed.

Kara's book "describes the extreme human and environmental costs of the euphemistically named 'artisanal mining' occurring in the Democratic Republic of the Congo. Entire regions of the nation, including forests and water resources, have been ravaged and polluted to provide much of the world's cobalt supply."[224]

The supply chains involved with battery manufacturing have also been tied to the use of forced labor in the Xinjiang region of China (see the discussion on slave labor/forced labor in the solar section of this paper).

"China processes most of the world's iron into steel, bauxite into aluminum, and lithium and cobalt into battery-grade materials. A large and growing share of that very environmentally damaging and energy-intensive work is undertaken in the repressive environment of the Xinjiang Uyghur Autonomous Region (or XUAR or Uyghur Region) ... The PRC government has dedicated significant resources to moving the highly polluting and energy-intensive processing of… raw materials into the Uyghur Region, requesting and sometimes requiring public and private companies to incorporate state-sponsored forced-labor programs into their 'social responsibility' commitments."[225]

While much of the attention paid to these supply chains deals with the manufacture of electric vehicles, the overall supply chains for batteries, including utility-scale batteries, are murky and equally suspect. The technologies and companies involved in producing batteries are largely China-based. "China largely dominates the whole value EV battery value chain, from the processing of battery grade metals such as lithium and cobalt, to the battery components themselves, namely cathodes, anodes and partially separators too," explains a report by fDi Intelligence on battery supply chains.[226]

Furthermore, while wind developers are working to improve the outcomes of wind-wildlife interactions, wind turbines cause the death of millions of birds and bats every year.[227] "A 2013 Wildlife Society Bulletin study, using a total installed wind capacity of 51.6 GW, estimated 888,000 bat fatalities and 573,000 bird fatalities (including 83,000 raptors) annually."[228] A more recent report from the American Bird Conservancy estimated that "our projections leave little doubt that the annual toll in birds lost to U.S. wind turbines is at least more than half a million, and a similarly conservative estimate would put that number at nearly 700,000 birds. There is a case to be made that the number could exceed 1 million. And for multiple reasons stated above, these are all likely to be under-estimates."[229]

"The most significant threat is posed to species of large, threatened and high-conservation-value birds such as golden and bald eagles, burrowing owls, red-tailed and Swainson's hawks, peregrine and prairie falcons, American kestrels and white-tailed kites."[230] Larger bird species have lower reproductive rates, so it does not take as many deaths to significantly impact their populations. And the impacts on large raptors are significant.

ESI Energy, a subsidiary of NextEra Energy, "pled guilty to three counts of violating the [Migratory Bird Treaty Act], each based on the documented deaths of golden eagles due to blunt force trauma from being struck by a wind turbine blade at a particular facility in Wyoming or New Mexico, where ESI had not applied for the necessary permits. ESI further acknowledged that at least 150 bald and golden eagles have died in total since 2012, across 50 of its 154 wind energy facilities. 136 of those deaths have been affirmatively determined to be attributable to the eagle being struck by a wind turbine blade."[231]

Wind turbines are designed to collect a diffuse and ephemeral energy source and, referring again to Robert Bryce's Iron Law of Power Density—"the lower the power density, the greater the resource intensity"—explains why wind turbines take up so much space. The Mackinac Center "Electricity Primer" quoted a 2009 National Renewable Energy Laboratories study "that analyzed the land-use requirements of wind power plants and suggested large wind power installations (more than 20 MW) had a general density of 30-138 acres per MW."[232] The Primer further related how a 2017 research paper by Strata showed that "wind requires just over 70 acres per MW. In comparison, nuclear, natural gas, and coal generation each required just over 12 acres per MW. Solar required 43.5 acres per MW and hydroelectric required over 315 acres per MW."

Princeton University research bolsters the idea that wind (and solar) will require a great deal of land to drive the transition of the electric grid to net zero. In one scenario, researchers estimated that to meet federal net zero policies, a wind- and solar-based grid could take up to 425,000 square miles, or approximately 12% of the nation's land area.[233] The graphic included to demonstrate this wind- and solar-heavy energy plan showed that just the wind portion of the plan would need wind turbines and associated infrastructure covering a land area equivalent to Nebraska, Kansas, Oklahoma, Arkansas, Missouri, and Iowa.[234]

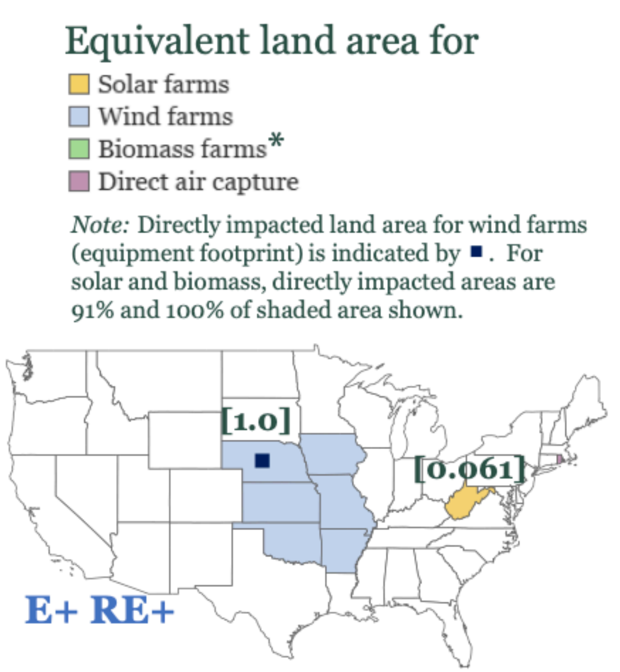


Figure 48: Princeton University study showing total land area/visual footprint in 2050 for solar, wind, and direct air capture facilities required to meet national net zero policies.

Workforce

To the extent that wind developers expand their reliance on battery backup to quell wind's intermittency problems, it behooves the industry, utilities, government, and consumers to demand that supply chains for wind and battery backups are free from materials or products produced by slave and child labor.

Apart from those obvious challenges, the North American wind industry employs a well-paid adult workforce. U.S. Bureau of Labor Statistics indicates the average hourly earnings for "all occupations" in the Wind Electric Power Generation industry were $40.55/hr in April 2023 (or $84,350 annually, which is 32% higher than the national average for 2022 reported by the Social

Security Administration).[235] BLS did not list an average hours worked per week, but based the salary on a total of 2080 hours worked annually, or almost 40 per week.

Cost: 5/10

As a full accounting for wind is completed, the costs it imposes on the grid and ratepayers quickly reveal that it is one of the most expensive forms of electricity generation today.

Government, media, and industry reports extol the drastic price decreases for wind installations over the past decade. "Experts anticipate cost reductions of 17%–35% by 2035 and 37%–49% by 2050 under a median or best-guess scenario, driven by bigger and more efficient wind turbines, lower capital and operating costs, and other advancements" according to Department of Energy projections.[236]

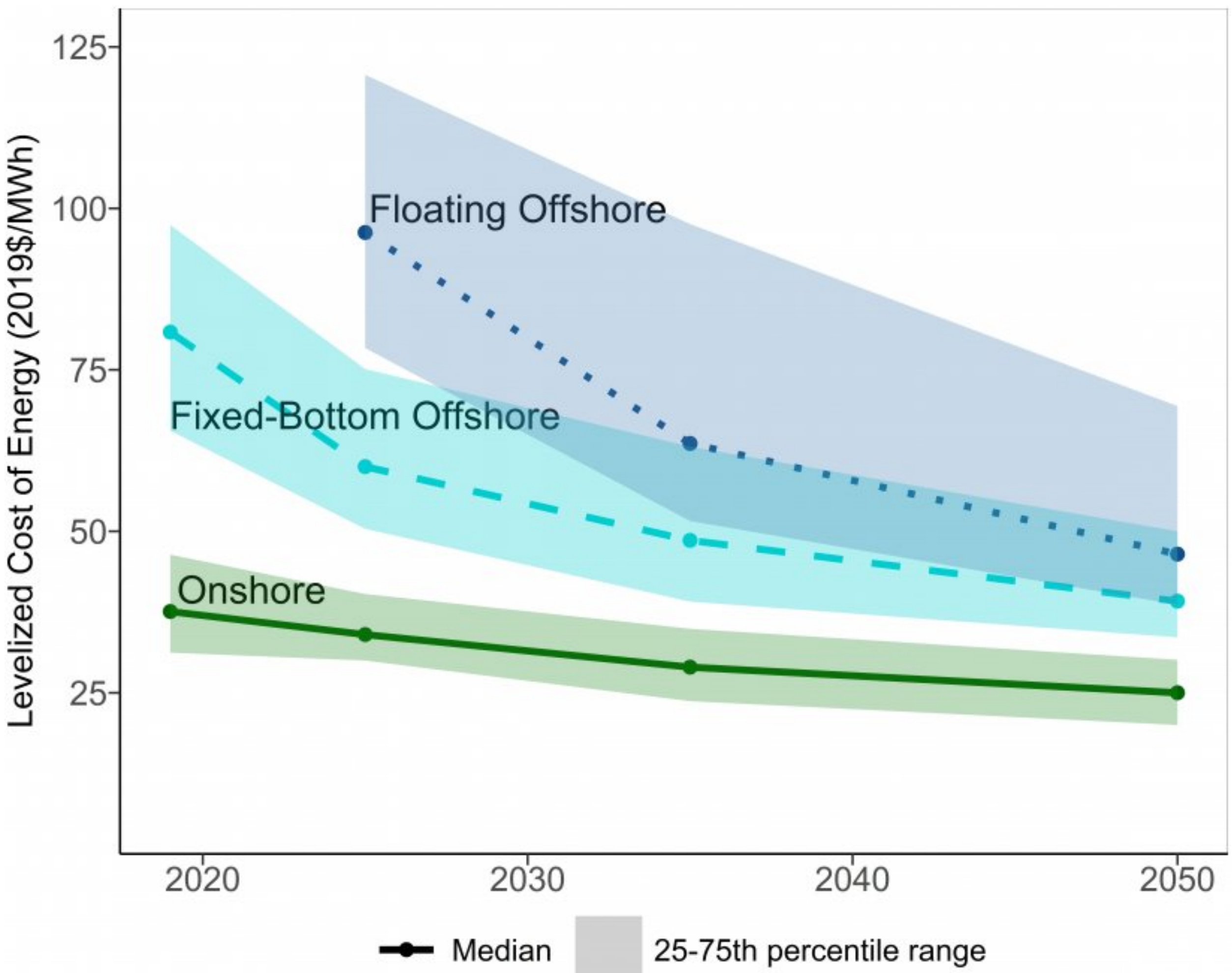


Figure 49: Estimates of future levelized costs for wind energy under the median scenario, based on responses to a global expert survey (MWh: megawatt-hour). (Source: Department of Energy/Berkeley Lab)

However, in the very recent past, since the COVID-19-induced disruptions to both the economy and energy use, prices for both wind and solar have spiked appreciably. "Soaring costs" according to World Economic Forum reports, "are forcing some wind power developers to delay or halt new projects."[237] These price increases are tied to a mix of factors including high interest rates, supply chain pressures, inflation, and long permitting and interconnection queues (where new generation projects are connected to the grid). "Swedish company Vattenfall estimates the costs of building an offshore wind farm have increased by up to 40% this year, making a planned 140-turbine offshore wind development in the North Sea unfeasible."

The price implications for offshore wind have been substantial, causing several wind developers to seek contract re-negotiations with coastal states. Several developers have pulled their support for offshore development projects, choosing to pay contract penalties rather than continuing with the development projects.

"While wind turbine prices have fallen steadily from $1,800 per kilowatt in 2008 to $770 to $850 per kilowatt in 2021, data from GlobalData shows that the average per-megawatt cost of a wind turbine has increased by 38 percent over the last two years. Turbines account for roughly half of the total cost of a wind project."[238]

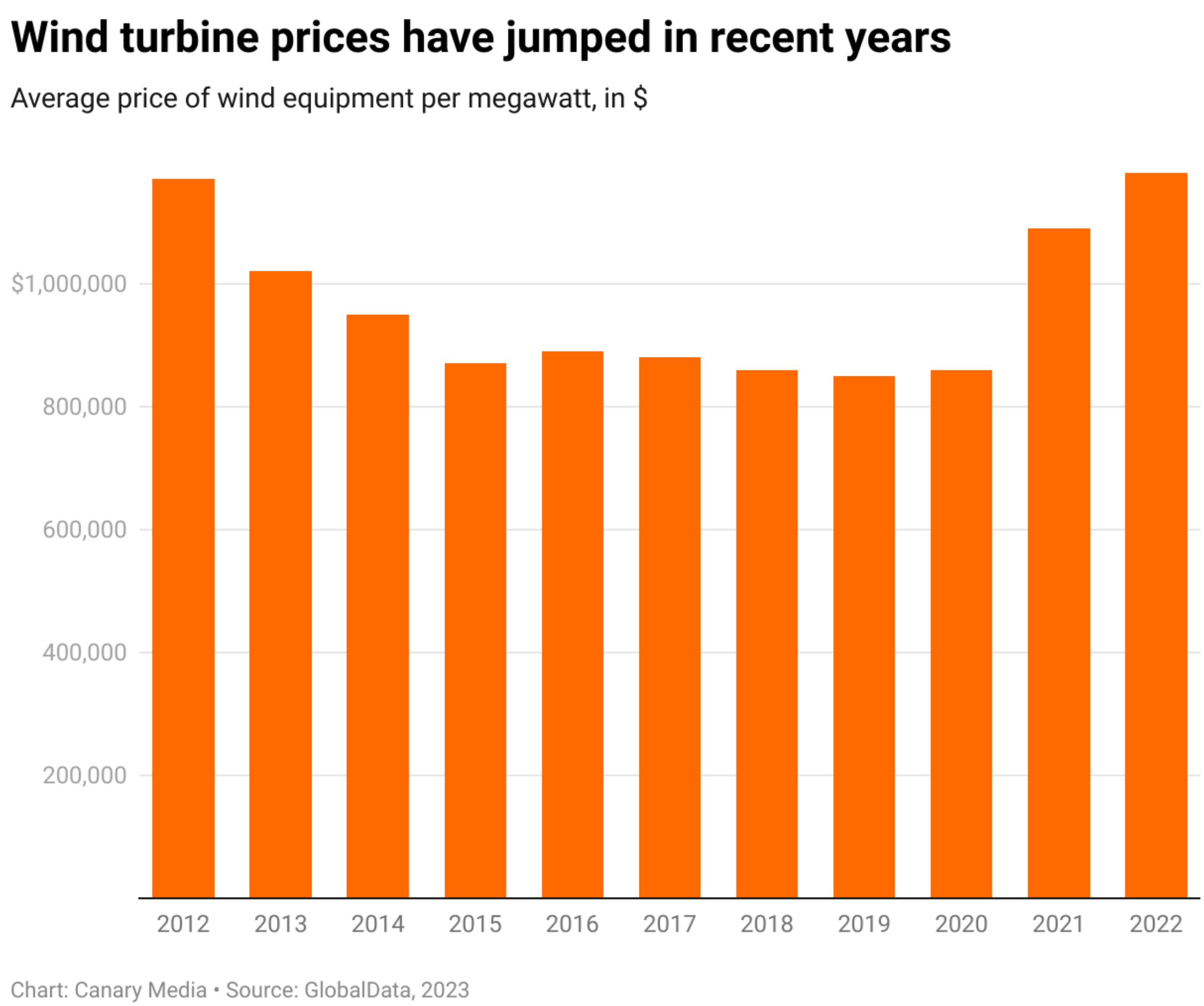


Figure 50: Wind turbine prices have jumped in recent years (Source: Canary Media)

Wind has consistently relied on government intervention and mandates to justify its development (see again Warren Buffett's explanation above). The April 2023 Lazard's "Levelized Cost of Energy Comparison – Unsubsidized Analysis" lists onshore wind technologies at between $24 - $75 per MWh, onshore wind + storage is not quite double the cost at $42 to $114. Offshore wind is listed at $72 to $140 per MWh.[239]

"The Levelized Cost of Electricity from Existing Generation Resources," by the Institute for Energy Research and America's Power reminds us that the 'imposed cost' of wind generation is about $24 per MWh, and the total cost for new wind resources is $90 (2018 $/MWh) with imposed costs included.

Modeling completed by the Center of the American Experiment for the Mackinac Center demonstrated that when designing a wind-, solar-, and battery-based grid to reach state net-zero mandates, costs for wind soar. The overall costs to build new wind resources in Michigan would impose an average cost (over the modeling period to 2050) of $180 per MWh when accounting for capital costs, imposed costs, overbuilding, curtailment, utility profits, taxes, and new transmission.[240] (See: Figure 19: New solar facilities are the most expensive form of new electricity generation built under the modeling scenarios.)

Technology/Innovation: 6/10

New, larger turbines are being developed to generate more electricity per turbine.

Apart from fire and water, wind is one of the oldest known sources of energy used by humans. From the early days of sailing vessels, wind has powered our activities and transportation. Wind turbines use the force of wind in the same way that hydroelectric uses the force of water. As wind passes by the blade of a turbine, the force it applies to the blade spins the generator inside the nacelle (or turbine housing) to produce electricity.[241]

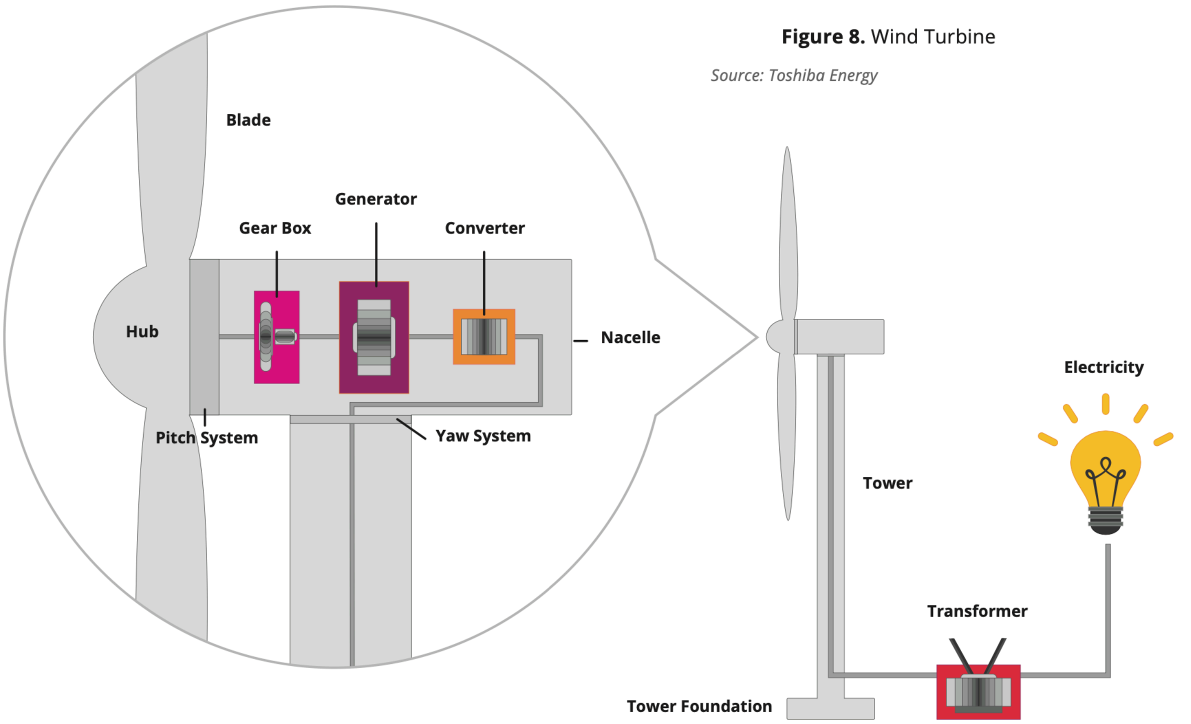


Figure 51: Wind turbine (Source: Mackinac Center/Toshiba Energy)

"A wind turbine's hub height is the distance from the ground to the middle of the turbine's rotor," according to the U.S. Department of Energy. "The hub height for utility-scale land-based wind turbines has increased 73% since 1998–1999, to about 98 meters (~322 feet) in 2022."[242] Higher turbines allow for a larger blade surface area to capture wind flows. They also get turbine blades higher up, into more consistent air flows, where wind speeds are less impacted by friction from trees, landforms, or human development.

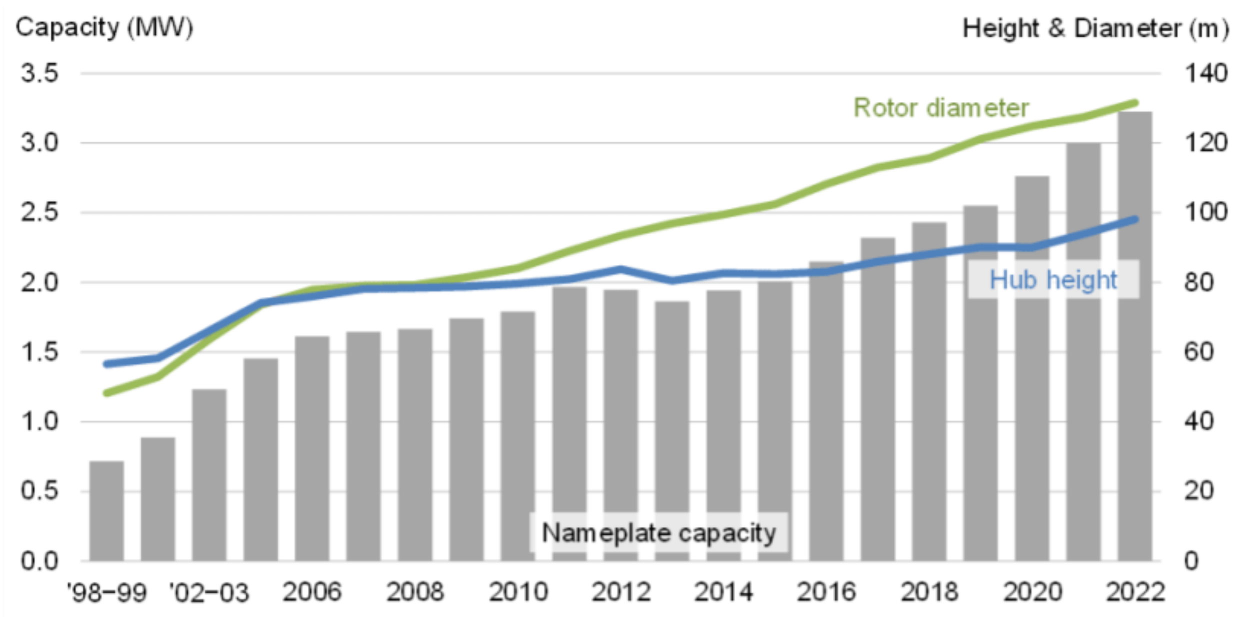


Figure 52: Graphic showing the increasing height and nameplate capacity of wind turbines, 1998 to 20222 (Source: U.S. Department of Energy Office of Energy Efficiency and Renewable Energy)

Market feasibility: 6/10

The primary argument in favor of building wind turbines is that they receive substantial federal government support in the form of tax credits and state-level government support in the form of mandates. Whenever subsidies and mandates for wind are threatened, wind development drops off rapidly.

While wind's growth is often presented as a market-driven phenomenon, even EIA information explicitly admits that government mandates and subsidies play a dominant role. "Government requirements and financial incentives for renewable energy in the United States and in other countries have contributed to growth in wind power."[243]

The commitment to rapidly expanding wind generation is clear in the many state and federal programs and regulations/pieces of legislation currently being implemented. As noted previously, 23 states have 100% clean energy or net zero goals that require much more wind to be built.[244]

However, the above information indicates that wind is a questionable investment given its high cost, lack of reliability, and impacts on the natural environment and wildlife. Referring again to "The Siren Song that Never Ends" and Figures 2 and 23 in this report, TPPF researchers report that wind received $21.76 in federal "tax expenditures," $14.05 billion in "direct expenditures," and $0.97 billion in "research and development" for a total of $36.78 billion from 2010-2019.[245] Therefore, after the wind sector received almost 29% of total federal energy subsidies, the industry produced only 10% of total U.S. electricity and 3.7% of total primary energy consumption by source in 2022. Once again, subsidies funneled to wind developments are primarily targeted toward encouraging the construction of more existing technology instead of encouraging the development of new technologies or resources.

Recommendations

As noted in the opening portion of this section, wind is a widely promoted and politically favored energy resource that is being developed rapidly. However, it is unlikely that this source would be developed if not for the generous federal support it receives from federal tax credits, (Production Tax Credit) or state-level mandates requiring its use as part of a net zero or clean energy program. While wind is widely believed to be an essential aspect of any decarbonization program, it has an abundance of negative costs and environmental impacts that are typically overlooked by regulators and utilities. The direct and imposed costs associated with wind entail that electric rates will continue to increase rapidly as more of it is built, while electric service reliability will wane.

Again, given that society increasingly relies on a steady and reliable supply of affordable energy, government policies that mandate and heavily subsidize a transition to wind generation represent a growing threat to human health and well-being.

Solar

Grade: 58% (F)

Bottom Line Up Front:

Solar is the second of two so-called renewable energy generation sources (wind is the first) being widely promoted for its claimed ability to reduce the environmental impacts of electricity generation. Like wind, solar is marketed as being able to reduce carbon dioxide emissions, while also protecting the environment, reducing electric rates, and improving reliability.

Like wind, solar does not produce carbon dioxide as it produces electricity. However, there are numerous other grid reliability, environmental, economic, social, and human rights issues associated with its use that are often overlooked.

Given that society is increasingly reliant on a steady and reliable supply of affordable energy, government policies that mandate and heavily subsidize a transition to solar generation also represent a growing threat to human health and well-being.

Capacity & Reliability: 5/10

Like wind, solar provides an unreliable service that imposes a compounding level of grid instability as more of it is built.

A claimed benefit of solar power is that it provides an alternate form of electricity generation and helps to diversify the overall electrical grid. Working from that claim, solar generation has grown from effectively nothing to just over 3% of total electricity generation in just over a decade. Solar is projected to grow rapidly to about 20% of supply over the next two decades.[246]

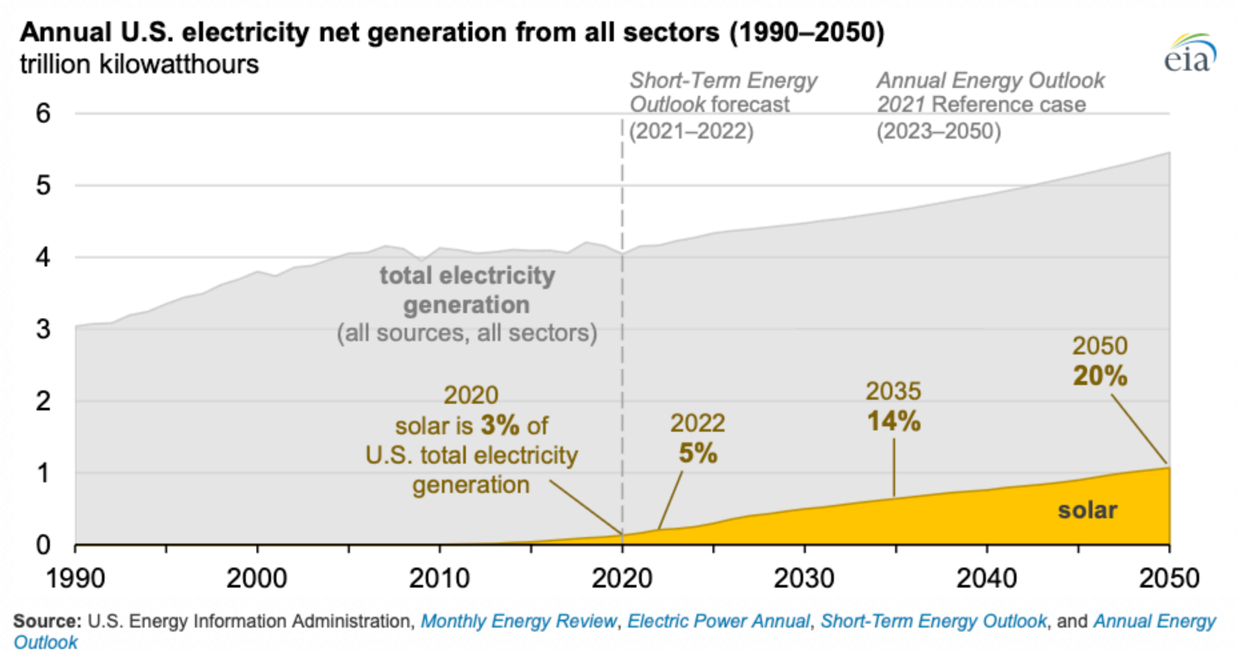


Figure 53: Solar Generation expected to grow to 20% of electric supply by 2050 (Source: U.S. Energy Information Administration)

Wind and solar generation are marketed together as green, efficient, inexpensive, and reliable forms of electricity generation. As with wind, solar is described as an essential component in diversifying and decarbonizing the North American electric grid. The Solar Energy Industries Association says the industry is “booming.” Industry data indicates that “solar has experienced an average annual growth rate of over 24%” over the last decade.”[247]

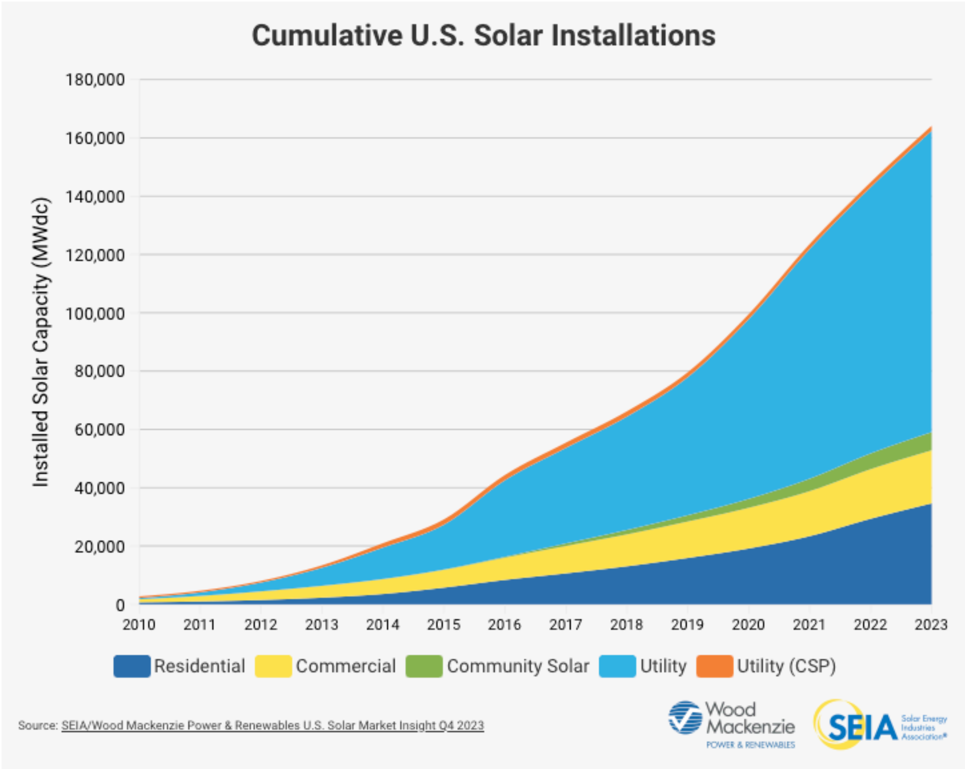


Figure 54: Cumulative U.S. solar installations (Source: Solar Energy Industries Association/Wood Mackenzie)

However, EIA again clearly states that solar (like wind) relies heavily on government support to become established and grow. "Utility-scale solar capacity didn't start ramping up in the United States until 2010. As the cost of solar panels dropped substantially and state and federal policies introduced generous tax incentives, solar capacity boomed."[248] In January 2023, 73.5 gigawatts of utility-scale solar capacity were installed across the country, but, before 2000," EIA explains, "U.S. wind capacity was negligible. Like solar power, tax incentives, lower turbine construction costs, and new renewable energy targets helped fuel the growth of U.S. wind capacity."

"Renewable energy targets" is a more pleasant way of admitting that wind and solar are being mandated by the 23 states (plus the District of Columbia and Puerto Rico) that have "100% Clean Energy" programs.[249] But, once again, these programs tend to kill off reliable energy sources, impacting grid stability. Just as the wind does not blow 24/7/365, the sun does not always shine and solar only produces electricity when sunlight strikes the solar panels. In many cases, it produces electricity at far lower levels when the sun is obscured by clouds or snow, or in more northern states, where the intensity of solar irradiance is reduced.

Like wind, solar is not a dispatchable resource because it cannot be controlled by an operator. As demonstrated in Figure 42, solar had an average capacity factor of 24.6% across the country in 2021, meaning that 75.4% of the installed wind capacity goes unused on average.[250] Again, that is an average rating. Northern states, like Michigan, have far lower capacity factors given the extremely low levels of solar irradiance that reach the state.[251]

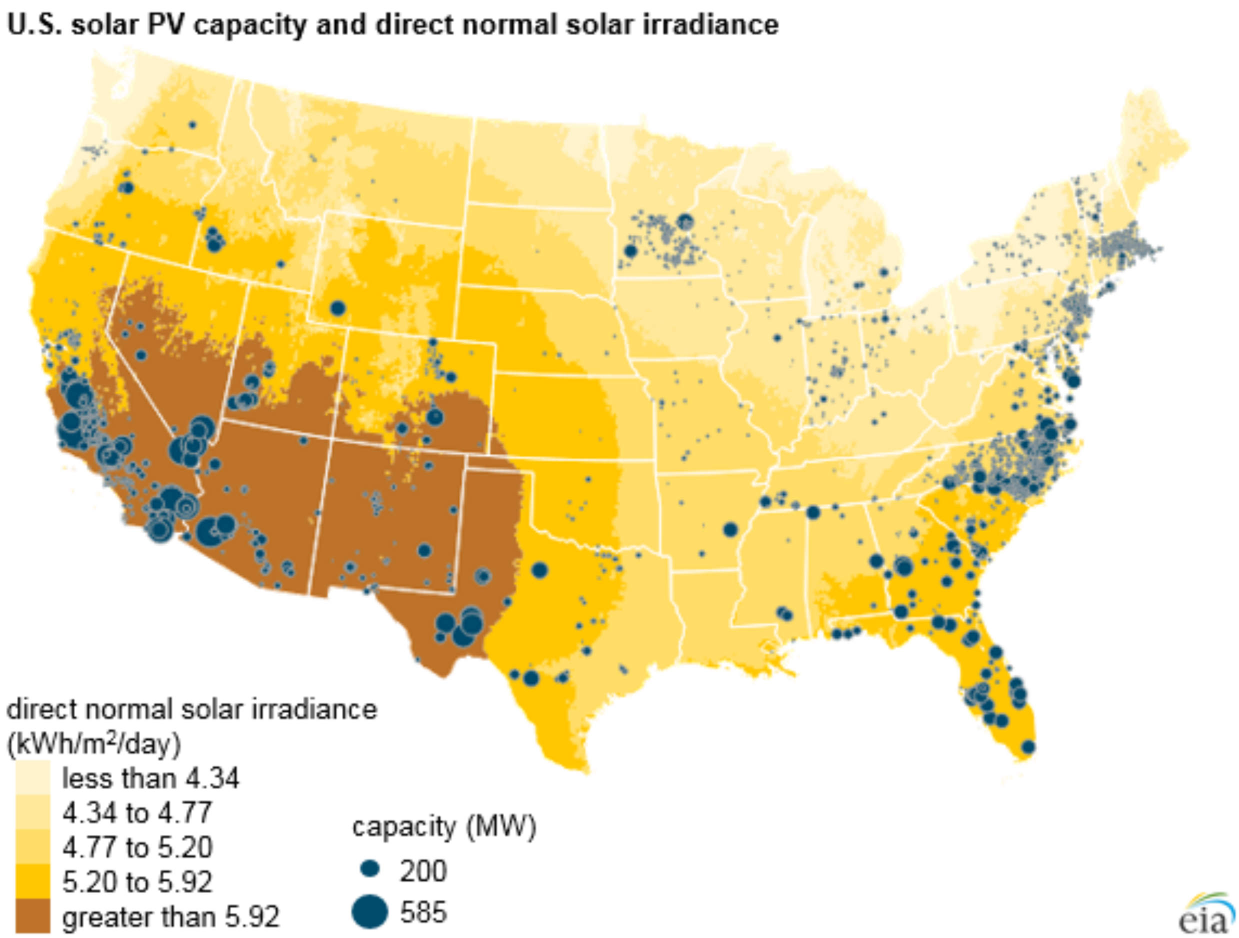


Figure 55: U.S. solar PV capacity and direct normal solar irradiance (Source: U.S. Energy Information Administration)

Once again, warnings from NERC and MISO apply here. Rushing the transition from reliable energy sources to ephemeral sun and wind exposes the nation to increasing reliability issues. Intermittent resources can't supply consistent power. Hawaii's experience builds on the descriptions of Alberta and Texas from the discussion in the wind section.

On January 8 and 9, during a heavy winter storm on the island of Oahu, heavy rains damaged two older oil-fired steam-generating facilities, taking them offline. At that time of year, it is normal for electricity demand to drop as the use of air conditioning decreases. Hawaiian Electric reports that this is the normal time to take dispatchable generation facilities offline for scheduled maintenance.

Hawaiian Electric officials noted that, under normal conditions, their wind and solar facilities could provide sufficient generation reserves to meet customer demand. In this case, wind speeds were low and cloud cover was heavy so, "Solar battery storage systems could not reach their capacity to compensate," meaning that the solar/battery mix failed to provide reliable energy for the island.[252]

> "Energy generation from wind facilities 'started to fall off significantly' and 'due to insufficient generation, earlier this evening Hawaiian Electric began 'load shedding.' Load shedding means systematically shutting off customers to, in the utility's words, 'avoid a more widespread outage or damage to the electric system from an imbalance of too much demand versus too little available generation.'"[253]

Hawaii is not alone in encountering difficulties when relying on solar generation. As discussed in "The Truth About Natural Gas," California is often considered the "nation's environmental conscience," but its heavy reliance on solar has exposed it to growing grid instability.

> "Overbuilding solar generation ensures that the state is oversupplied with electricity during the middle of the day, when the sun is shining. Then, as the sun begins to descend in the early afternoon, the state finds itself in need of an energy source that can rapidly ramp up to meet demand. At this time of day, people are returning home from work and turning on home appliances: stoves and ovens, air conditioners, etc. These rapid changes in demand, paired with the sudden daily drop off of solar generation, challenge California's utilities to meet net demand, causing a situation known as the duck curve."[254]

EIA explains that, as California's reliance on solar grows, the duck curve is getting deeper, presenting a challenge for grid operators."[255] Many in the energy industry now refer to it as the "Canyon Curve" because the ramping periods have become so steep.[256] EIA also notes that the challenges associated with adding large levels of solar to a grid are two-fold. First, the rapid ramping from solar to other sources and back means "conventional power plants…must quickly ramp up electricity production to meet consumer demand." When too much solar is added, it can produce more than the system can use and it must be sold or the solar must be "curtailed" (shut down to stop electricity production).

The second challenge is associated with the economics of the dispatchable plants that must be ramped up to address solar's intermittency. "The factors contributing to the curve reduce the time a conventional power plant operates, which results in reduced energy revenues. If the reduced revenues make the plants uneconomical to maintain, the plants may retire without a dispatchable replacement. Less dispatchable electricity makes it harder for grid managers to balance electricity supply and demand in a system with wide swings in net demand."

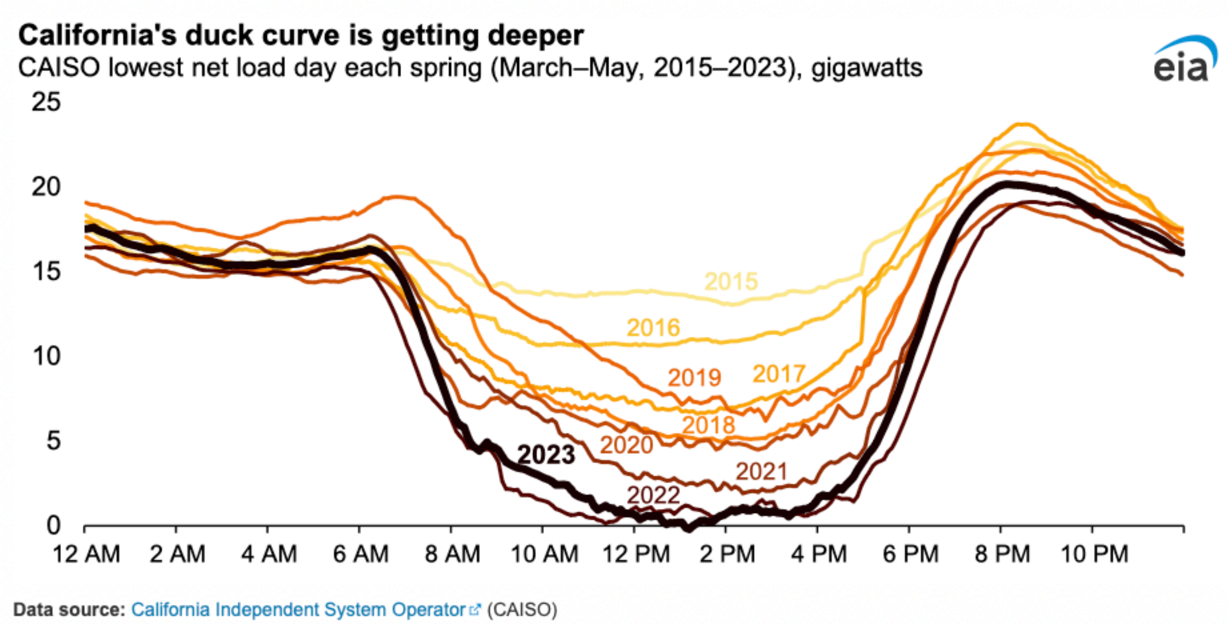


Figure 56: California net load curve - Duck curve is getting deeper (Source: U.S. Energy Information Administration/California Independent System Operator)

In a 2017 Department of Energy "Staff Report to the Secretary on Electricity Markets and Reliability," DOE staff explained that "the on-peak hourly capacity factor (similar in concept to capacity value) of [variable renewable energy] changes as a function of VRE penetration." The report demonstrated that as solar penetration went above 5% in the ERCOT region, the net on-peak capacity factor dropped to near zero.[257]

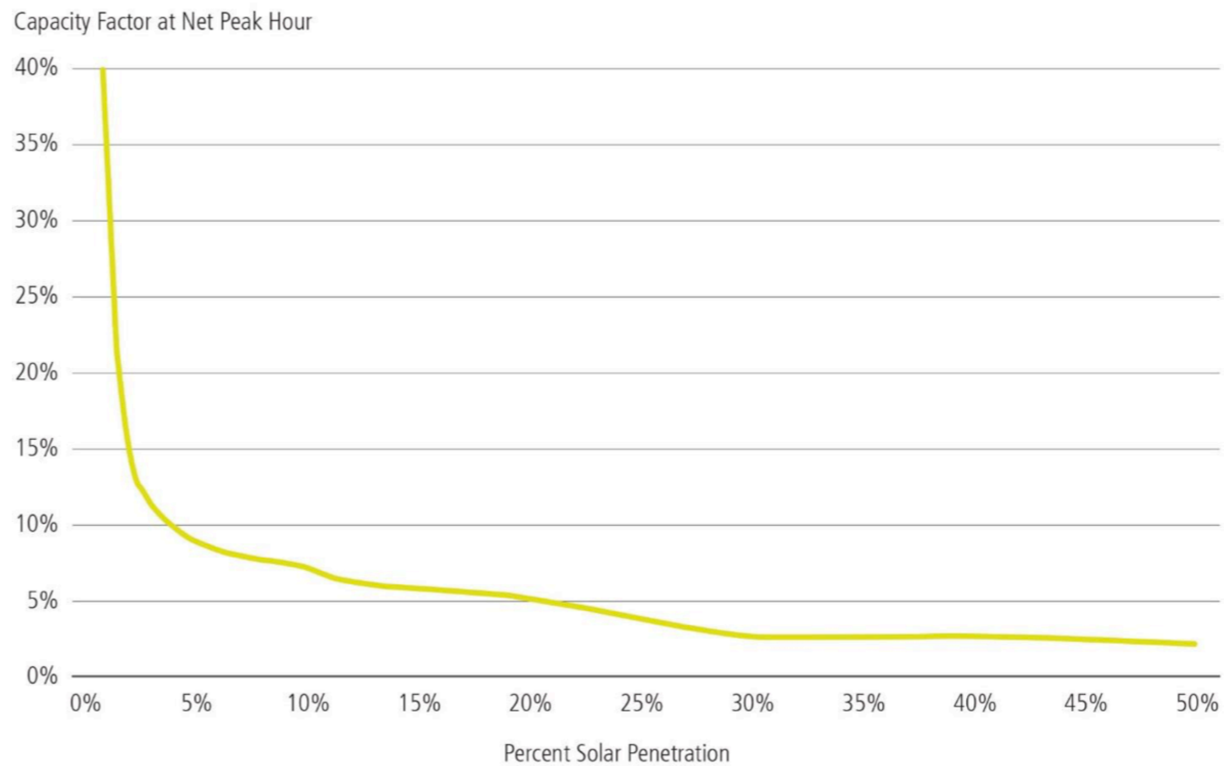


Figure 57: Historical solar on-peak capacity factors in ERCOT (Source: U.S. Department of Energy)

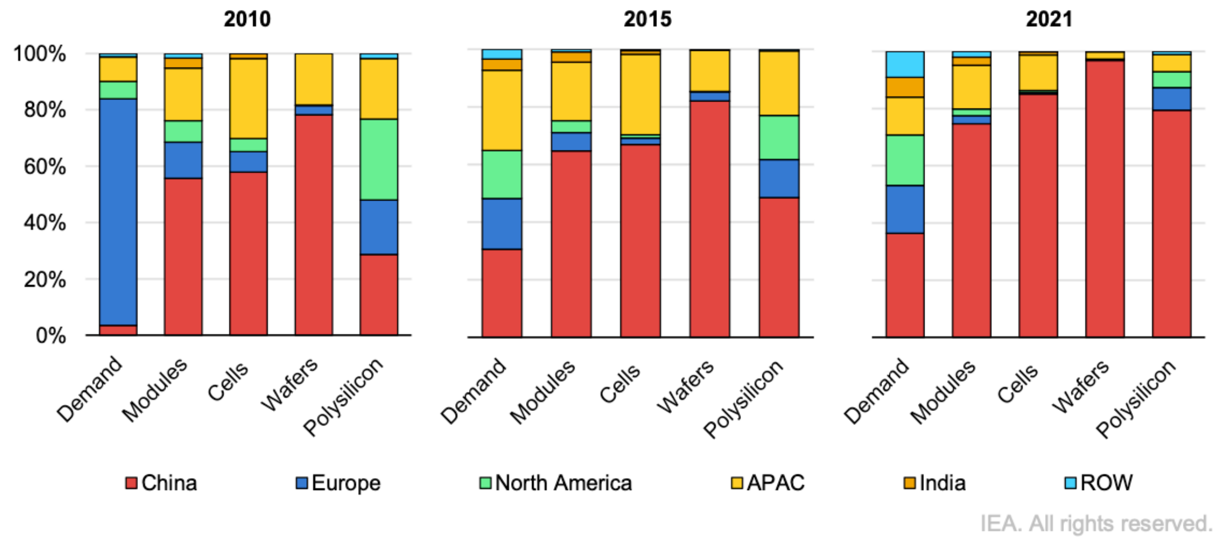
Environmental/Human Impact: 5/10

Like wind, solar energy has large environmental impacts from the need to rapidly expand mining to source critical or transition minerals, to its need for backup generation or battery source, to its immense requirement for land, to visual impacts, to a growing list of impacts on wildlife. Most importantly, solar manufacturing in China is stained by the use of "forced labor" (slavery).

Many justifications for the transition plans and switching to wind and solar generation include addressing climate change and "helping the environment."[258] Other justifications include ideas of social justice. The State of Wisconsin's "Clean Energy Plan" cites "the values of justice, equity, and collective action" as central to their work to "build a greener, cleaner future for Wisconsin."[259]

However, the International Energy Agency states, "China significantly dominates every single solar PV supply chain segment."[260] That reality creates a problem for anyone claiming the issues of "justice, equity, and collective action" are a reason to build more solar panels. The New York Times reports, "According to a report by the consultancy Horizon Advisory, Xinjiang's rising solar energy technology sector is connected to a broad program of assigned labor in China, including methods that fit well-documented patterns of forced labor."[261]

Solar PV manufacturing capacity by country and region, 2010-2021



Notes: APAC = Asia-Pacific region excluding India. ROW = rest of world.

Source: IEA analysis based on BNEF (2022a), IEA PVPS, SPV Market Research, RTS Corporation and PV InfoLink.

Figure 58: Solar PV manufacturing capacity by country and region, 2010-2021 (Source: International Energy Agency)

The U.S. Department of Labor reports that "95% of solar panels worldwide are made up of polysilicon. Nearly half of global production comes from Xinjiang, where polysilicon is produced by Uyghurs and other Muslim minorities under conditions of forced labor." The situation is so bad, according to the Department of Labor, that "China's system of forced labor threatens solar supply chains around the world."[262]

In a further ironic twist, Chinese polysilicon production is powered largely by cheap and reliable coal-fueled electricity. So, after they are installed in North America, Chinese solar panels may not produce carbon dioxide, but their manufacturers can't make that same claim. "Coal, the dirtiest fossil fuel," reports Time Magazine, "accounts for a majority of China's electricity generation. In Xinjiang Uyghur Autonomous Region, where the most energy-intensive step in the solar panel manufacturing process, polysilicon refining, is concentrated, coal accounts for 77% of power generation."[263] So, not only do a significant portion of Chinese solar panels have the stain of slavery, but they are also 30% more carbon-intensive than solar panels manufactured in the U.S.[264] Put "into simple terms, Chinese solar products have much lower prices due to the use of slavery, subsidies, IP theft, and lax environmental regulations. No serious review of these conditions can claim this either a moral or competitive option."[265]

The growing levels of solar development also lead to growing concerns about solar e-waste. The International Renewable Energy Agency report, "End-of-Life Management: Solar Photovoltaic Panels" states that, by 2050, global PV solar panel waste levels will be between 60-78 million metric tonnes, with another 6 million metric tonnes added each year.[266] A similar study by Environmental Progress, a pro-nuclear energy environmental group, argued that governments must devise a plan to deal with the "300 times more toxic waste per unit of energy" created by solar panels than is created by nuclear plants.[267]

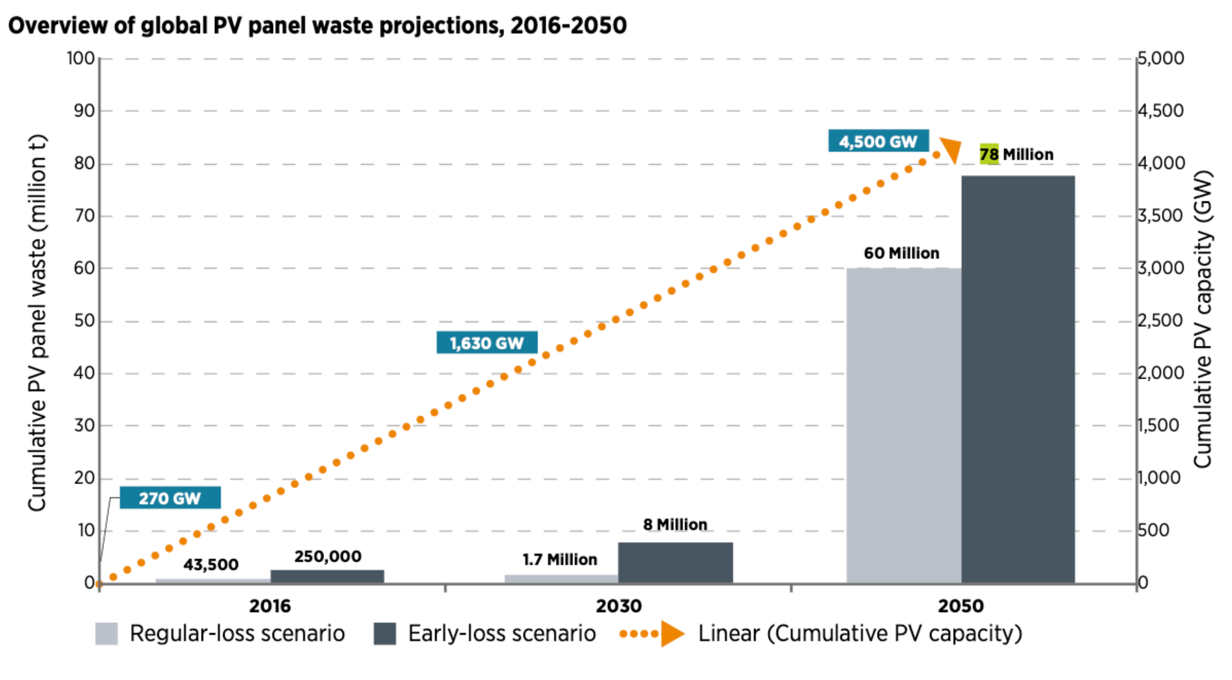


Figure 59: Overview of global PV panel, waste projections, 2016-2050 (Source: International Renewable Energy Agency)

Solar panels, like wind turbines, are designed to collect a diffuse and ephemeral energy source. Bryce's Iron Law of Power Density, "the lower the power density, the greater the resource intensity" entails that solar arrays will take up a lot of land. The Strata research paper described in the Wind section above highlighted that solar panels require 43.5 acres per MW. The Princeton University research agrees that the net zero transition, using a wind- and solar-based grid could take up to 425,000 square miles. Again, this equates to approximately 12% of the nation's land area.[268] While the wind portion would cover the land area of six states, the solar would take up an additional state's worth of land by covering an area the size of West Virginia.[269] (See Figure 48: Princeton University study showing total land area/visual footprint in 2050 for solar, wind, and direct air capture facilities that would be required to meet national net zero policies)

Workforce

The North American solar industry employs a well-paid, voluntarily employed, adult workforce. However, as described above, solar component and polysilicon manufacturing around the globe has been tied to the use of "forced labor," and a significant portion—nearly half of the world's supply of polysilicon comes from regions of China where slavery is a known problem.

Additionally, solar power suffers the same problems as wind power regarding battery backup for intermittent and unreliable generation sources. To the extent that solar developers expand their reliance on battery backup to quell intermittency problems, it behooves the industry, utilities, government, and consumers to demand that supply chains for solar and battery backups are free from materials or products produced by slave and child labor.

U.S. Bureau of Labor Statistics indicates the average hourly earnings for "all occupations" in the Solar Electric Power Generation industry were $46.61/hr in April 2023 (or $96,940 annually, which is 51% higher than the national average for 2022 reported by the Social Security Administration).[270] BLS did not list an average hours worked per week, but based the salary on a total of 2080 hours worked annually, or almost 40 hours per week.

Cost: 5/10

As a full accounting for solar is completed, the costs it imposes on the grid and ratepayers quickly reveal that it is (like wind) one of the most expensive forms of electricity generation in use today.

Replaying the same theme as wind, the government, media, and industry report a drastic decrease in the price of solar panels over the past several decades. Our World in Data indicates that prices for PV solar panels were $125 per watt in 1975 and have declined to $0.26 per watt by 2022[271]

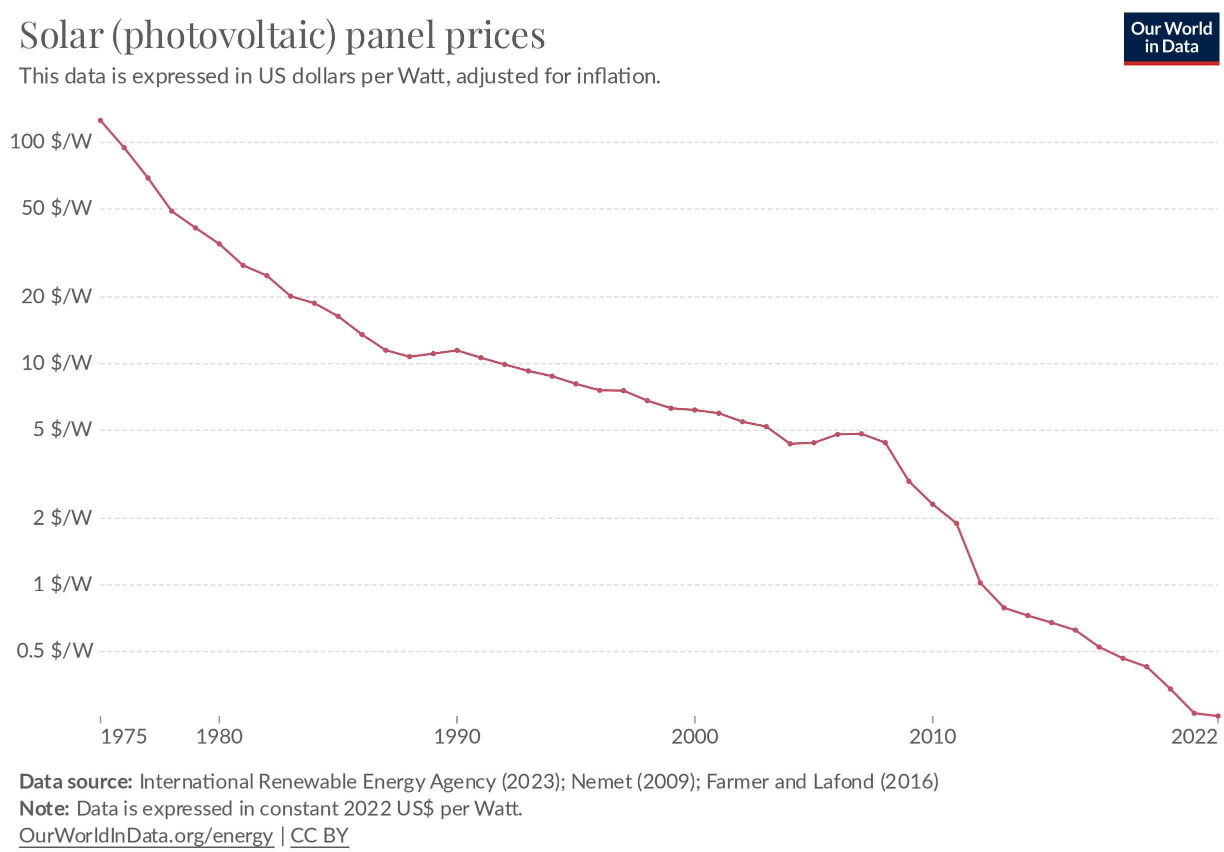


Figure 60: Solar PV panel prices, 1975-2022 (Source: Our World in Data)

As with wind, there was a spike in solar prices after the COVID-19 disruptions. That spike appears to have driven a short-lived production and buying spree. Chinese production flooded world markets, leading to reports that solar modules are "piling up in warehouses" and threatening a glut that could cut prices in half.[272] "At the end of last year," reports Markets Insider, "an estimated 45 gigawatts of modules in the US and 90 gigawatts in the EU had piled up, nearly twice the forecast installations for 2024…The glut sent prices down nearly 50% in 2023 as manufacturing levels stood three times above those seen in 2021, and the IEA said it saw the oversupply continuing."

Reports of dropping prices may initially fit with the narrative that solar has resumed its long-term trends for increased use due to dropping prices. However, despite dropping prices and a glut of backlogged panels stored worldwide, world solar markets are reportedly "slowing down" as the industry matures and moves past an "inflection point." Taiyang News quotes Wood Mackenzie research pointing to flat or dropping demand for solar out past 2030.[273] Despite its reported maturity and claims of dropping prices, the solar industry continues to rely on government intervention and mandates to expand its market share. Solar also appears to be experiencing the same push to repower as noted in the wind section. "But it's not the panels that are driving the trend — it's the inverters that convert energy from the panels into AC power for the grid."[274]

Industry reports about first and second-generation inverters, which were supposed to have 20-25-year lifespans, indicate that "inverters haven't lived up to their expected lifespans." They are failing only about halfway through their expected life cycle, and many companies established to maintain the panels are no longer in business. According to this report, as much as 23 GW of solar installations across the U.S. are expected to hit the 15-year point in the next five years. "Given the complexity of switching out inverters on some of these early solar installations, some solar equipment dealers recommend knocking out a host of potential upgrades all at once." This level of repowering due to shortened life cycles can't help but change price expectations for solar installations.

The April 2023 Lazard's "Levelized Cost of Energy Comparison – Unsubsidized Analysis" lists solar PV technologies at between $24 to $96 per MWh for utility-scale, $49 to $185 per MW for community/commercial and industrial, and $117 to $282 per MW for rooftop residential. Solar PV utility scale with storage is $46 to $102 per MW.[275]

"The Levelized Cost of Electricity from Existing Generation Resources," by the Institute for Energy Research and America's Power reminds us that the 'imposed cost' of solar generation is about $21 per MWh, and the total cost for new solar resources $88.70 (2018 $/MWh) with imposed costs included.

Modeling completed by the Center of the American Experiment for the Mackinac Center demonstrated that the overall costs to build new solar resources in Michigan as part of a plan to transition to a wind-, solar-, and battery-based grid would impose an average cost (over the modeling period to 2050) of $278 per MWh when accounting for capital costs, imposed costs, overbuilding, curtailment, utility profits, taxes, and new transmission.[276] (See Figure 19: New solar facilities are the most expensive form of new electricity generation built under the modeling scenarios.)

Technology/Innovation: 8/10

Innovations, such as thin-film technologies, are being developed to improve the ability of solar panels to generate electricity.

"Solar PV, or photovoltaic, electricity differs from other generation options in that it does not spin a turbine and generator to produce electricity; it produces electricity directly. As light strikes a solar cell, electrons within the cell are excited into movement. That movement creates a current within the crystalline semiconductor that makes up the bulk of the solar cell. That current is then collected and transmitted as electricity."[277]

Figure 8. Electricity generation within a photovoltaic solar cell

Source: UMR Geothermal

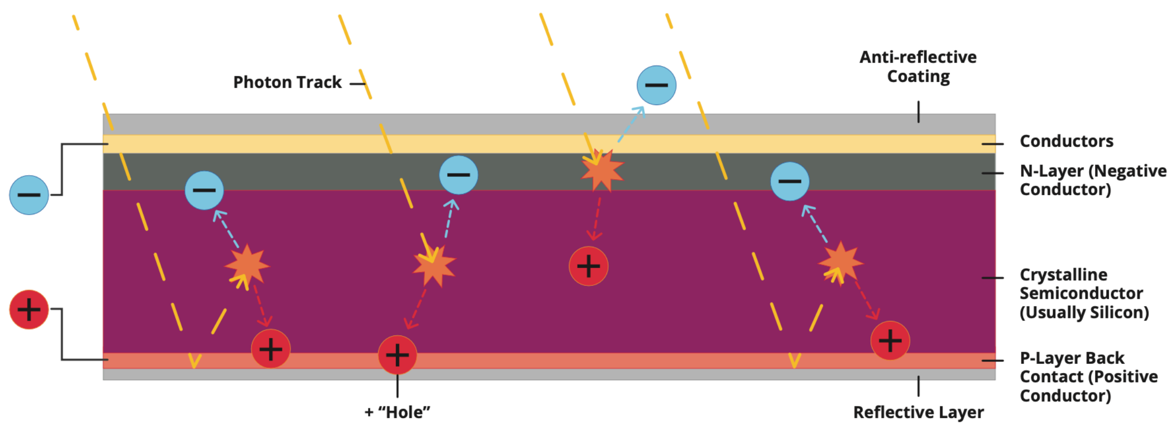


Figure 61: Electricity generation within a solar cell (Source: Mackinac Center/UMR Geothermal)

Solar installations pair many modules together into arrays. Smaller arrays are installed on homes, and medium-sized arrays are paired together for community solar and commercial and industrial installations. Very large groupings are used to form utility-scale installations.

Market feasibility: 6/10

Just like with wind turbines, the major 'market' argument in favor of building more solar comes from the substantial government support it receives in the form of federal tax credits and state-level mandates. Whenever subsidies and mandates for wind or solar are threatened, the development of both drops off rapidly.

Like the wind industry, solar's growth is often presented as a market-driven phenomenon. But even the solar industry publicly states that federal government tax credits have been the primary driver of the industry's growth. "The solar Investment Tax Credit (ITC)," notes the Solar Energy Industries Association, "is one of the most important federal policy mechanisms to support the growth of solar energy in the United States. Since the ITC was enacted in 2006, the U.S. solar industry has grown by more than 200x."[278]

The commitment to rapidly expanding solar generation is clear in the many state and federal programs and regulations/pieces of legislation currently being implemented. As noted previously, 23 states currently have 100% clean energy or net zero goals that mandate much more solar to be built.[279]

However, the above information indicates that solar energy is still a questionable investment given its high cost, lack of reliability, and impact on the natural environment and wildlife. Referring again to "The Siren Song that Never Ends" and Figures 2 and 23 in this report, TPPF researchers report that solar received $17.5 billion in federal "tax expenditures," $14.21 billion in "direct expenditures," and $2.69 billion in "research and development" for a total of $34.40 billion from 2010-2019.[280] After the solar sector received 27% of total federal energy subsidies, the industry produced only 4% of total U.S. electricity and 1.8% of total primary energy consumption by source in 2022.

Recommendations

As noted in the opening portion of this section, solar is a widely promoted and politically favored energy resource that is being developed rapidly. However, it is unlikely that this source would be developed if not for the generous federal support it receives from federal tax credits, (Production Tax Credit and Investment Tax Credit) or state-level mandates requiring its use as part of a net zero or clean energy program. While solar is widely believed to be an essential aspect of any decarbonization program, it has an abundance of negative costs, human rights, and environmental impacts that are often overlooked by regulators and utilities. The direct and imposed costs associated with solar entail that electric rates will continue to increase and electric service reliability will wane as more of it is built.

Geothermal

Grade: 68% (D+)

Bottom Line Up Front:

Geothermal plays a limited role in the production of U.S. electricity. Much like petroleum products, geothermal is almost a rounding error and is used primarily in geographically limited areas (like the Western states and the Hawaiian Islands).

Capacity & Reliability: 6/10

Geothermal plays a limited role in North American electricity generation. While the federal government states that the United States produces the most electricity with geothermal energy globally, it represents a minor portion of the country's overall electricity generation.

While the United States is the world's largest producer of electricity with geothermal energy, producing electricity in seven states, this energy source plays a minor role in the overall production of electricity in the U.S.[281] Energy Information Administration explains that "The United States leads the world in geothermal electricity generation. In 2022, the United States had geothermal power plants in seven states, which produced about 0.4% (17 billion kilowatthours) of total U.S. utility-scale electricity generation."

Environmental/Human Impact: 9/10

Geothermal energy can cause localized environmental concerns due to toxic gas releases or hazardous wastes. However, the limited market share of this source also limits its potential impacts.

Geothermal electricity generation emits minor amounts of CO_2 (about 1% of the CO_2 emitted by coal combustion), but using geothermal energy sources can have other impacts associated with drilling.[282] The U.S. Fish and Wildlife Service describes environmental impacts like air and water pollution, which can be caused by toxic gases like hydrogen sulfide and ammonia, or other gases like carbon dioxide and methane. Other environmental concerns associated with geothermal energy include the potential to trigger earthquakes or to cause land subsidence.[283] Hazardous waste disposal due to "dissolved solids discharged from geothermal systems include sulfur, chlorides, silica compounds, vanadium, arsenic, mercury, nickel, and other toxic heavy metals."[284]

Workforce

The North American geothermal industry employs a well-paid adult workforce. U.S. Bureau of Labor Statistics indicates the average hourly earnings for "all occupations" in the Geothermal Electric Power Generation industry were $41.61/hr in April 2023 (or $86,540 annually, which is almost 36% higher than the national average for 2022 reported by the Social Security

Administration).[285] BLS did not list an average hours worked per week, but based the salary on 2080 hours worked annually, or almost 40 hours per week.

Cost: 5/10

Geothermal energy can provide a useful niche generation application in select Western states where geological conditions allow reservoirs to be accessed affordably and other conditions limit access to less expensive options.

A "Geothermal Energy Factsheet," published by the University Center for Sustainable Systems states that "In 2016, geothermal electricity cost between 7.8-22.5¢ per kWh."[286]

Technology/Innovation: 8/10

Existing and developing technologies make it possible to use geothermal relatively efficiently.

Energy Information Administration explains that water/steam must be at 300°F to 700°F to allow geothermal-powered electricity generation. This is possible only in areas where geothermal reservoirs are located "within a mile or two of the earth's surface."[287] University of Michigan reports that enhanced geothermal systems that use a subsurface fracturing system "allow for the injection of a heat transfer fluid (typically water)" into rock may be able to expand geothermal generation to new areas.[288] Promising reports from a joint effort by Google and Fervo Energy indicate that using technologies developed for the fracking industry can speed up drilling times and reduce overall costs.[289]

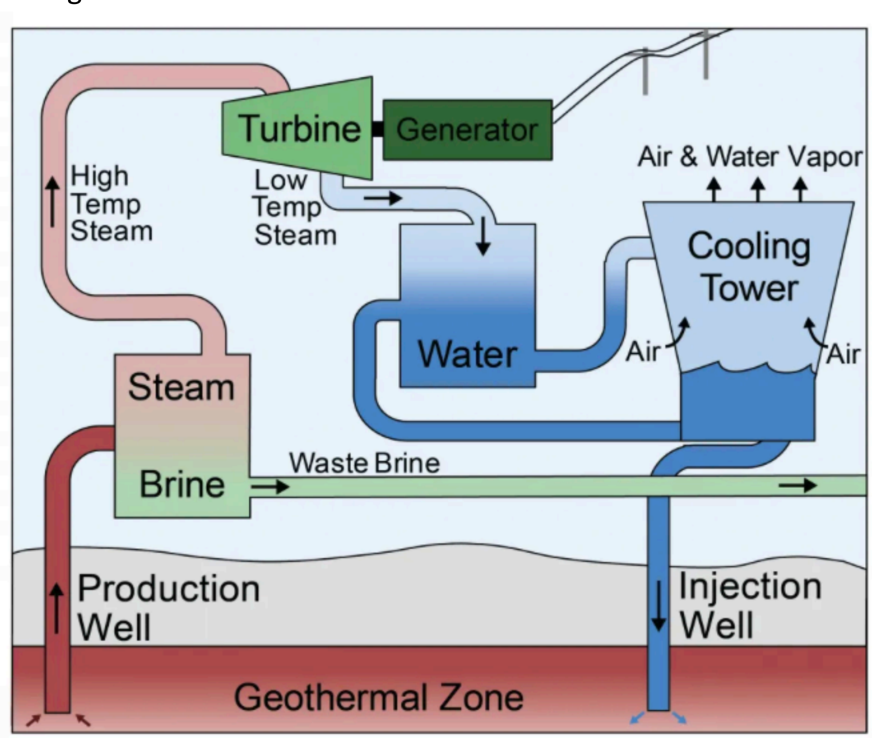


Figure 62: Flash steam geothermal plant (Source: University of Michigan)

Market feasibility 5/10

Geothermal systems currently fill a geographically limited niche market. While promising early reports on enhanced geothermal energy are available, there is little existing demand for geothermal to expand beyond its current limited use.

While the U.S. Department of Energy is studying the potential of expanding the use of enhanced geothermal systems, there is currently limited demand for expanding geothermal beyond its limited use in seven Western states.[290]

Recommendations

No recommendations are required in this sector as expectations are for the sector to remain a niche market and a minor aspect of total electricity generation in the foreseeable future.

Conclusion

Demands for a hurried transition from conventional, reliable energy sources to unreliable and expensive renewable alternatives are threatening the reliability of the North American electric grid. Pushing for increased efficiency and improved environmental performance is a laudable (and achievable) goal. However, we cannot allow misplaced environmental zeal to obscure electricity's pivotal role in promoting human health and well-being and powering our society.

Advocates for wind and solar hold them up as essential to environmental and climate health. However, rushing a systemwide transition to these untested and unreliable energy options puts human lives and the North American economy at risk. Their inherent intermittency will strain the ability of the grid to meet growing energy demands and the ability of ratepayers to cover the high costs they impose on the grid. In contrast, the reliability and affordability of fossil and nuclear fuels cannot be ignored. Admonitions from grid managers warning about the dangers of rushing to close reliable sources of electricity generation only serve to highlight the risks associated with the premature rush to transition to wind and solar.

This research demonstrates the high environmental and economic costs of hurrying the grid transition. While fossil and nuclear fuels do have environmental costs, we also have the technological capacity to address those costs as we continue to trust their unparalleled reliability for essential energy services.

Wind and solar energy have been marketed as a means of having our energy and environmental cake and eating it, too. We are told they are clean, cheap, and reliable. However, a closer look at their real costs, growing environmental impacts, and questionable human rights records leads to serious questions about their ability to serve as a realistic energy option.

Transitioning a service as important as the nation's electric grid cannot be rushed. It requires a far more careful and pragmatic approach than we see from elected officials and utilities nationwide. The rushed transition is neither reasonable nor prudent and must be reconsidered.

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