NATIONAL SECURITY
DATA AND POLICY
INSTITUTE

# U.S. Power Infrastructure: A Survey on Capabilities, Vulnerabilities, Innovation, Policy, and Investment

(U.S. Team) Eli Beaubien, Colin Heffern, Cole Leis, Robert James May

# Table of Contents

## List of Abbreviations

| | | | |
|---|---|---|---|
| **AI** | Artificial Intelligence | **ARDP** | Advanced Reactor Demonstration Program |
| **ASCE** | American Society of Civil Engineers | **BBB** | Big Beautiful Bill |
| **CCGT** | Combined Cycle Gas Turbine | **CCUS** | Carbon Capture, Utilization, and Storage |
| **CHIPS** | Creating Helpful Incentives to Produce Semiconductors and Science Act of 2022 | **COD** | Commercial Operations Contract |
| **DAC** | Direct Air Capture | **DOE** | Department of Energy |
| **EGS** | Enhanced Geothermal Systems | **EIA** | Energy Information Agency |
| **EO** | Executive Order | **EPA05** | Energy Policy Act of 2005 |
| **ERCOT** | Electric Reliability Council of Texas | **EV** | Electric Vehicle |
| **FERC** | Federal Energy Regulatory Commission | **FORGE** | Frontier Observatory for Research in Geothermal Energy |
| **GRIP** | Grid Resilience and Innovation Partnerships Program | **HVDC** | High Voltage Direct Current |
| **IAEA** | International Atomic Energy Association | **IEA** | International Energy Agency |
| **IIJA** | Infrastructure Investment and Jobs Act | **IR** | Interconnection Request |
| **IRA** | Inflation Reduction Act | **ISO** | Independent System Operator |
| **kWh** | Kilowatt-hours | **LNG** | Liquid Natural Gas |
| **LWR** | Light Water Reactor | **MSR** | Molten Salt Reactor |
| **MWh** | Megawatt-hours | **MOX** | Mixed Oxide Fuels |
| **NEDC** | National Energy Dominance Council | **NOX** | Nitrogen oxides (harmful fossil-fuel emissions) |
| **NRC** | Nuclear Regulatory Commission | **OCED** | Office of Clean Energy Demonstrations |
| **OPEC** | Organization of Petroleum Exporting Countries | **PPA** | Power Purchasing Agreement |
| **PMU** | Phasor Measurement Units | **PSH** | Pumped Storage Hydropower |
| **PV** | Photovoltaic | **R&D** | Research and Development |
| **RTO** | Regional Transmission Organization | **SBSP** | Space-Based Solar Power |
| **SCADA** | Supervisory Control and Data Acquisition | **SMR** | Small Modular Reactor |
| **UHV** | Ultra-High Voltage | **USC** | Ultra-Supercritical |
| **VHTR** | Very-High Temperature Gas-Cooled Reactor | **WAM** | Wide Area Monitoring |

## I. Executive Summary

Competition for technological dominance between the U.S. and China has transformed energy infrastructure into an instrument of national security. Artificial intelligence (AI) and quantum computing promise endless possibilities in their functions and capabilities to improve—or harm—society. Power infrastructure must be enhanced to innovate and employ novel technologies, or else the U.S. will find itself on the losing side of an unprecedented tech-war. This paper synthesizes the literature on emerging technology, power grid infrastructure, and energy policy and investment, offering a comprehensive analysis of past, present, and future power capabilities. Analysis is focused on a wide range of economic, political, and technological drivers of fortification of the power grid, the primary system for delivering electricity across the nation. It is evident that public and private priorities do not always align, leading to inefficient collaboration. Additionally, the current presidential administration's policies target increased generation for large tech companies, confounding modernization efforts intended to benefit typical consumers of power from electric utilities. It is difficult to find unified investment strategies for emerging technologies given the fragmented nature of the utility market and shifts in federal funding. As it stands, the U.S. is more energy independent than it was 15 years ago, but as climate change worsens and Chinese industry accelerates, unified national strategies are needed now more than ever.

## II. What is the Power Grid?

### Basic Structure

Traditionally, the power grid consists of three stages: generation, transmission, and distribution. Energy storage has become a vital fourth stage in the grid with the advent of advanced battery technology that increases total capacity. Each stage must work in tandem to maintain a constant flow of electricity. In other words, supply must constantly meet demand in real time.[i] The U.S. power grid powers over 160 million residences, businesses, and industrial bases across the country. Without electricity, crucial sectors cannot function, leading to widespread infrastructural failure. In Texas four years ago, this cost lives. Understanding these four phases of the power grid is crucial for handling future change.

*Generation* involves converting energy sources—be it fossil fuels or renewables—into electric power. Next, power lines *transmit* electricity at high voltages across long distances throughout the country. Transformers initially convert electricity into high voltage currents in the transmission phase to prevent unnecessary power loss. Finally, electricity is received by a substation that converts high voltage currents down to lower voltages with a transformer and then *distributes* electricity to end-users through feeder lines.[ii] *Storage* is an increasingly important component of the power grid as variable renewable energy sources and weather events strain the reliability of the power grid.

### Generation Energy Sources

Various energy sources are used to generate electricity in the U.S. The table below describes the generation share, generation output, capacity factor, and reliability of each major energy source. The share of the generation mix is "the share of different energy sources used to generate electricity."[iii] The generation output, measured in billion kilowatt-hours (kWh), refers to the amount of electricity generated from a given energy source annually. The capacity factor describes how frequently a power plant runs at full power. Reliability refers to the ability of an energy source to consistently provide electricity even when conditions vary and unexpected events occur.

| Energy Source | 2023 Share of the Generation Mix[iv] | 2023 Generation Output in Billion kWh[v] | 2024 Capacity Factor[vi] | Reliability |
|---|---|---|---|---|
| Natural Gas | 43% | 1,802 BkWh | 59.9% | Flexible baseload |
| Coal | 16% | 675 BkWh | 42.6% | Moderate |
| Nuclear | 18.6% | 775 BkWh | 92.3% | Very high |
| Wind | 10.2% | 425 BkWh | 34.3% | Variable |
| Hydropower | 5.9% | 240 BkWh | 35% | Variable |
| Solar | 3.9% | 165 BkWh | 23.4% | Low |
| Geothermal | 0.4% | 16 BkWh | 65% | High |

*Fossil Fuels*

Fossil fuels, specifically natural gas and coal, are the largest energy source for power generation (i.e., they continue to make up the largest share of the U.S. power generation mix), contributing 60% of total generation.[vii] Innovations in fracking and horizontal drilling led to the shale boom, causing natural gas to become the single largest source of U.S. electricity, while coal has steadily decreased from its peak in 2007. However, reserves are limited, with oil projected to last 49 years and coal 139 years, underscoring the need for more efficient use of the reserves.[viii] Fossil fuels play an important role in the clean energy transition, providing reliable baseload power (which is the minimum amount of electricity needed to be flowing on the grid). Innovations in fossil fuel technology can help to achieve decarbonization through improved efficiency and decreased emissions.

### *Nuclear Power*

Nuclear power is the second largest energy source, ranking second only to natural gas. However, nuclear generation has declined in recent years. Although three new reactors came online over the past decade, nine were retired, and three more are set to close in 2025.[ix] Nuclear power remains the only large-scale source of highly reliable, low-carbon electricity.[x] Major tech firms, including Google, Meta, Microsoft, and Amazon, are investing heavily in nuclear power to reliably increase their capacity. The globe's focus for nuclear advancements is currently on Generation IV Nuclear Power, which targets four pillars: sustainability, safety, economic competitiveness, and resistance to nuclear proliferation.[xi] Generation IV technological advances include advanced reactors that use passive safety features, alternative fuel and coolant types, or smaller reactor sizes to achieve those four aims.[xii] The U.S. has no operable advanced reactors, as all 94 reactors are light water reactors (LWRs) that use water as a coolant or moderator.[xiii]

### *Wind Power*

Wind is the largest U.S. renewable electricity generation source with over 73,000 turbines nationwide.[xiv] Turbines convert kinetic wind energy into electricity, primarily concentrated in regions with favorable wind conditions such as the Midwest and Texas.[xv] Wind generation is projected to rise 46.4% by 2030, with significant federal and private investment in new projects.[xvi] [xvii] Wind power's role in decarbonizing the U.S. grid is significant, but wind power must be paired with reliable baseload power.

### *Hydropower*

Hydropower is the oldest and second-largest renewable electricity generation source with over 2,200 facilities.[xviii] Hydropower facilities use flowing water to power a turbine, generating electricity.[xix] Hydropower is also more predictable and dependable than wind or solar energy. Under the Infrastructure Investment and Jobs Act (IIJA) and Inflation Reduction Act (IRA), the Department of Energy (DOE) allocated $430 million to upgrade 293 hydropower projects.[xx]

### *Solar Power*

Solar power has the least reliability out of all generation sources.[xxi] Solar's low reliability means that its successful expansion into the grid relies on improvements to transmission and storage.[xxii] Solar power works by using photovoltaic (PV) panels composed of semiconductors that absorb sunlight's energy and convert it to electricity. Advancements to PV panels can improve efficiency, helping add capacity to the grid with the assistance of baseload power. Solar power is growing in popularity, with capacity projected to increase by 37.5% from 2022 to 2030.[xxiii]

### *Geothermal Power*

Geothermal energy is the most reliable form of renewable energy and is theoretically available all over the world.[xxiv] Geothermal plants use heat from the Earth to turn water into steam, driving turbines that generate electricity. Conventional geothermal generation requires specific geological conditions; hydrothermal reservoirs (i.e., hot springs) must be drilled to release steam, powering turbines.[xxv] Current geothermal production is heavily concentrated in California and Nevada due to natural hydrothermal reservoirs. To support the modernization of the geothermal fleet, the DOE Geothermal Technologies Office has almost doubled its budget since 2023 to support upgrades and R&D.[xxvi]

## Transmission, Distribution, and Storage

### *Transmission*

Power lines transmit electricity at high voltages across long distances throughout the country. Transformers initially convert electricity into high voltage currents in the transmission phase to prevent unnecessary power loss. Transmission is growing in importance as renewable sources are integrated into the grid and electricity demand rises. Transmission is already at or near capacity in several states including Texas and Alaska, meaning more capacity cannot be added to the grid, and renewables cannot be incorporated.[xxvii] The White House claimed in 2023 that existing transmission capacity must be more than doubled to meet 2035 decarbonization targets.[xxviii] The U.S. government recently announced a $1.3 billion investment into building out U.S. transmission systems.

### *Distribution*

Feeder lines receive electricity from a substation that converts high voltage currents down to lower voltages with a transformer and then distributes electricity to end-users through feeder lines.[xxix] Distribution is vital to modernizing the power grid, ensuring reliable delivery to end-users, and enhancing the system's resilience. Increasing severe weather events and disasters highlight the need for advanced real-time information on the grid. This need has prompted significant DOE investments including the Grid Resilience and Innovation Partnerships (GRIP) Program, which allocated $10.5 billion in funding for projects across all 50 states to improve distribution.[xxx]

*Storage*

Storage of electricity is vital for grid stability, particularly as renewable energy generation increases variability in the grid.[xxxi] Grid-scale storage is the fastest-growing of all energy technologies due to four main reasons.[xxxii] First, storage is necessary to increase resilience in the face of inclement weather and compensate for variable renewable energies. Second, Chinese overcapacity in battery manufacturing means that the prices of grid-scale batteries are at an all-time low, making grid-scale storage more economically feasible. Third, the power consumption surge due to AI and EVs necessitates more storage. Finally, the rapid emergence of innovative energy storage provides alternatives to conventional lithium batteries.

## Private and Public Collaboration

Utility companies run the power grid. Most utilities are privately owned in the U.S., which can create barriers between adhering to government regulations and maximizing revenue. As of 2017, the share of investor-owned utility companies was 72%.[xxxiii] The largest utilities are local monopolies, but utility companies must cooperate with each other to ensure inter-state electricity transmission.[xxxiv] A heavily privatized system must work in accordance with regulations from the Federal Energy Regulatory Commission (FERC), DOE, and other authorities to guarantee that end-users have reliable and affordable electricity.[xxxv] Major U.S. investor-owned electric utilities alone generated over $378 billion in revenue in 2023, constituting roughly 76% of total revenue from end-users across the country's power grid operators.[xxxvi]

FERC established federally regulated entities called Independent System Operators (ISOs) and Regional Transmission Organizations (RTOs) under Order 888 to more stably manage bulk electricity transmission.[xxxvii] [xxxviii] Covering roughly two-thirds of the country, their purpose is to help facilitate unbiased and non-exploitative electricity prices and aid open-access electricity transmission across seven large regions. The Northwest, Southwest, and Southeast regions are not covered by either an RSO or ISO, only by individually owned utility companies.[xxxix] Before Order 888, utility companies had almost complete discretion over their own retail prices.[xl] RTOs and ISOs coordinate with independent power generators and integrated utility companies, but they do not own grid assets and cannot override private utilities' generation or transmission. FERC Order 888 ultimately deregulated the market by expanding access to a wider scope of consumers and producers, encouraging competition in the wholesale market for electricity even without control over assets themselves.[xli] On one hand, balancing authorities like RTOs and ISOs are a prime example of public and private collaboration, but given the wide spectrum of utility sizes, consumer needs, and fluctuating markets, optimal outcomes are not guaranteed.

## III. Why Should We Care?

Stable electrical infrastructure permits the critical functions of a nation, but as global tensions rise and a race for technological dominance ensues, modernizing the grid in response to China's acceleration of power generation and energy capabilities has turned into a chief national security imperative. Technologies like nuclear fusion reactors and perovskite solar cells are being researched and developed, and other existing tools like smart grids and microgrids are being increasingly implemented to boost grid efficiency. Demand for electricity generation will continue to grow as industry expands and technology like AI develops, but without substantial investment, the U.S. will fall behind, emboldening adversaries to exploit existing vulnerabilities within the nation's critical infrastructure.

There are several reasons to give the power grid urgent attention:

- **Major global and domestic events** like the war in Ukraine, the Iberian Peninsula blackout, and the blackouts in Texas and, at a smaller scale, California all highlight the consequences of a power grid crisis and the importance of grid resiliency and stability.
- **Growing demand for electricity to power data centers** is a central administrative focus given that AI and data centers are now deemed critical infrastructure by DOE.[xlii]
- **Transitioning away from non-renewable, environmentally harmful fuel sources** is crucial to mitigating climate change and bolstering America's energy independence.
- **Improving grid efficiency to decrease the number of outages** is necessary because of more frequent and severe inclement weather events.
- **Decreasing electricity costs for consumers** is important as increases in localized energy demand from data centers intersect with shifting energy export goals, leaving consumers to foot higher utility prices.
- **Improving grid cybersecurity** is essential to prevent large scale cyberattacks with the potential to wreak havoc on grid systems across the country.

Prioritizing the power grid both benefits American society and shields critical infrastructure from growing Chinese capabilities that threaten economic sovereignty and national security. It is easy to overlook the significance of the issue given the immediacy with which electricity is currently available to many Americans, but foresight is necessary to understand both the benefits that investment can bring to the grid and the consequences that will accompany pushing grid investment to the side.

## IV. Historical Overview

Power generation at a national scale requires reliable sources of energy in massive quantities. Fossil fuels are the industry standard, but their non-renewable nature leads to negative environmental impacts and reliance on imports. Renewable energy sources are being used more frequently because of their benefits, which include being more cost-effective, less harmful to the climate, and infinite in supply. Understanding trends in the nation's energy mix is crucial to assessing current trends and determining how to secure a future with energy self-sufficiency and stability.

### Non-Renewable Natural Resources

Petroleum overtook coal as the primary fuel for energy production around 1950. In 1973, the Arab Oil Embargo contributed to drastic increases in oil prices, harming the U.S. economy because of its reliance on oil imports from the Middle East.[xliii] As a result, President Nixon announced "Project Independence" that year to prioritize energy self-reliance, prompting large-scale construction projects to bolster power infrastructure and shift to resources like natural gas.[xliv] In 1975, President Ford championed the Energy Policy and Conservation Act, which gave price incentives meant to increase oil production and created the Strategic Petroleum Reserve.[xlv] [xlvi] Legislation like the Public Utility Regulatory Policies Act of 1978 (PURPA) continued to strengthen the effort for energy independence.[xlvii] Nuclear power production gained attention and increased considerably throughout the 1970s, but the 1979 Three Mile Island nuclear power plant accident resulted in slowed expansion along with a variety of safety-related changes in the nuclear industry.[xlviii] By 1982, the U.S. was importing only 28% of its oil as compared to more than 45% in 1977.[xlix] Throughout the 1980s and 1990s, GDP gained from oil and gas extraction began to decrease.[l] However, in that period, FERC helped expand interstate natural gas pipelines, setting the stage for the shale boom in the mid-to-late 2000s.[li] Between 2008 and 2015, the U.S. became the largest natural gas producer because of shale gas production, leading crude oil imports to drop from 12.5 million barrels per day in 2005 to 4.7 million in 2015.[lii]

### Trend Towards Renewables

Legislation in 1978 created an investment tax credit for solar applications and provided funding for solar production, intending to lower costs and incentivize purchases from the private sector. Even so, solar would contribute only marginally to the generation mix until the 2000s. The Energy Policy Act of 1992 furthered electricity market restructuring by promoting competition in generation, while transmission and distribution remained regulated.[liii] However, as economic deregulation occurred, environmental regulation became more prominent. The 1992 bill also called for greater energy efficiency and use of renewable energy, and it established a production tax credit for electricity generated from wind. Clean Air Act amendments in 1990 required alterations to fossil fuels throughout the decade to reduce pollution, and the amendments promoted and ultimately increased the use of natural gas for power generation.[liv] Transitioning to renewables like solar power as a viable source of energy has been a national policy goal since the Energy Policy Act of 2005 (EPA05) and its clean energy tax credits.[lv] Wind turbines and solar panels also became cheaper in the mid-2000s due to technological advancement and greater production worldwide.[lvi] In 2023, 58.1% of power generation for the power grid came from coal and natural gas, with solar, wind, and hydro energy making up 21.2%.[lvii] Statistics show an 18.8% decrease in coal use, a 7.1% increase in natural gas, and a 15.1% increase in solar energy from 2022 to 2023.[lviii] Use of solar and wind, the two renewable energy sources that are most prevalent in current policy and practice, has been steadily rising since 2013.[lix] [lx]

One benefit of renewable energy is that the costs of extracting and refining fossil fuels are avoided. The demand for imports would also decrease, strengthening the country's energy independence. Another hallmark of renewables like solar and hydropower is energy storage via battery technology, providing supplementary power when there are large spikes in electricity use or crises that impede generation. Solar power's largest benefit is its positive environmental impact, with solar contributing to the more than 25% decrease in carbon emissions between 2013 and 2023.[lxi] With maximal consumer involvement, solar energy systems may be able to provide up to 61% of a region's total energy needs according to a study by Rehman et al., decreasing electricity prices from $0.20 per kWh to $0.09 per kWh.[lxii]

## Previous and Current Administration Perceptions

Administrations throughout the 20th and 21st century have placed a premium on developing and strengthening the grid. From FDR's New Deal initiatives to provide poor and rural areas with electricity to Biden's allocation of over $65 billion to grid modernization via the IIJA in 2021, grid investment has remained a constant priority throughout the past century.[lxiii] Private companies fill in the gap where federal funding and planning fall short, especially with innovation. As the landscape of technology and the infrastructure needed to support it change, new demands and priorities arise.

While President Biden focused on diversification of the energy supply chain to support infrastructure via acts and programs like the IIJA, the Creating Helpful Incentives to Produce Semiconductors (CHIPS) and Science Act, and the GRIP Program, President

Trump has focused on a different bottom line–maximizing energy production by any means necessary.[lxiv] President Trump has endeavored to remove the U.S. from climate agreements across both his terms, hoping to establish trade leverage against fossil fuel exports from sources like OPEC. Additionally, his executive orders (EO) highlight the importance of energy independence and mineral refining, coal included, for the present standing of the U.S. in global energy markets and the future of his administration.[lxv] Exporting liquified natural gas (LNG) to Asia to disrupt China's energy market share is an example of an offensive maneuver the current administration has access to for combatting China's control of global supply chains. President Trump has placed a particular emphasis on expanding domestic energy capacity to meet the demands of data centers, which necessitate increased power production capabilities.[lxvi]

## V. Grid Vulnerabilities

The American Society of Civil Engineers (ASCE) decreased its rating of the energy sector from a C- to a D+ in the 2025 Report Card for America's Infrastructure.[lxvii] The authors of the ASCE report derive their grade based on criteria such as estimated investment costs, policy feasibility, economic or bureaucratic inefficiencies, solution implementation timeframes, and existing social and environmental deficits. The power grid faces mounting problems as developers plan to expand its capacity to make way for greater investment in AI. If not remedied, the U.S. will not be able to keep up with its own increasing demand for energy, let alone with China's.

### Aging Infrastructure & Supply Chain

Around 70% of nationwide grid assets are over 25 years old.[lxviii] Government agencies and industry professionals predict that modernizing the grid may take trillions of dollars.[lxix] This is particularly salient given that nuclear electricity generation continues to decline as 18 reactors have been retired since 2012.[lxx] The cost of transformers, which are vital in the transmission and distribution process, has risen by somewhere between 60% and 80% since 2020.[lxxi] To make matters more difficult, acquiring new transformers takes 120 weeks on average.[lxxii] Transformer capacity will need to rise by up to 250% by 2050 to meet electricity demand estimations, but given supply chain inefficiencies, supply may not be adequate.[lxxiii] Widespread transformer failure would have large repercussions on entire regions of the grid, and this possibility grows more likely as infrastructure continues to age.

In 2023, FERC authorized a collective request from electric utilities to raise their rates for a total of $13.51 billion in revenue to account for increased capital expenditure on maintenance and improvement.[lxxiv] Meanwhile, energy sector employment grew by 3% in 2023 (50% more than all U.S. employment growth) to match increasing demand for much-needed work.[lxxv] Department experts agree that maintenance is merely a short-term solution; repair costs and grid failures in an aging system will only rise absent long-term planning, especially given that the estimated investment gap will reach $578 billion by 2033.[lxxvi] [lxxvii] Events like the COVID-19 pandemic and Russia-Ukraine war have prompted inflation and supply chain issues globally, making fuel, shipping, labor, and materials more expensive for the electricity sector. Although wind and solar are among the cheapest energy sources, tariffs on imported solar panels and related components have increased costs associated with renewable energy and battery storage. Put together, high interest rates and regulatory bottlenecks are putting utilities under increasingly high debt, downgrading their credit ratings and contributing to their financial difficulties.[lxxviii] [lxxix]

## Inclement Weather Conditions

Weather events—such as flooding, hurricanes, thunderstorms and heat waves—account for 80% of electrical outages since 2000.[lxxx] Climate change is expected to worsen the frequency and intensity of weather events, with the number of weather disasters increasing 5x over the past 50 years.[lxxxi] Volatile weather is leading to increased costs for consumers as utilities spend more on power grid resilience, recovery, and insurance, which can lower their credit ratings. The Southwest region is particularly prone to harsh weather, making up 31% of the 1,542 major weather-related power outages (50,000 or more customers cut off from electricity) recorded between 2000 and 2021.[lxxxii] One of the primary reasons that the grid is so vulnerable to weather is that a vast majority of feeder lines and substations are above ground. From car crashes to falling trees or strong winds, there are many ways a feeder line or substation can be disrupted. High voltage power lines are much more resilient, as they are made of steel and aluminum, are higher off the ground, and are equipped with various measures to protect against lightning strikes or sagging lines due to heat waves.[lxxxiii] This is why 92% of disruptions come from the distribution stage.[lxxxiv] An alternate solution is to bury the lines, but this can be up to six times more expensive.[lxxxv] California's Pacific Gas & Electric Company (PG&E) has undertaken an extensive project of undergrounding 10,000 miles of power and feeder lines, which has the potential to reduce wildfire outage risks by 98%.[lxxxvi] Various European countries like the Netherlands and Germany have taken advantage of burying power and feeder lines, but America's size makes a nationwide effort to expand underground power lines infeasible, especially since the current administration is prioritizing investments in generation instead of distribution .[lxxxvii]

### *Texas Case Study & Lessons Learned*

The nation's largest grid failure occurred in Texas amidst an unprecedented winter storm in February 2021. The Electric Reliability Council of Texas (ERCOT), an RTO supplying 90% of the state's electricity, did not anticipate temperatures reaching 25 degrees Fahrenheit below the historic average.[lxxxviii] Given the improbability of such severe weather, most of the grid infrastructure was not hardened (i.e., protected against inclement weather). Natural gas pipelines and reservoirs for hydropower froze, wind turbines iced over, and solar panels did not capture sufficient energy, so the state could not provide enough power to meet surges in demand. At its worst point, 26% of ERCOT's total generation capacity was taken offline because there was not enough fuel to produce electricity.[lxxxix]

Biggar et al. affirm that weather was the dominant reason for the grid's failure. They posit that a more deregulated wholesale market could have provided the necessary flexibility to handle a weather crisis and encouraged more investment to proactively harden and improve grid infrastructure. The Public Utility Commission of Texas had already sanctioned a price cap for the wholesale price of electricity, which decreased the amount of potential investment in the state's infrastructure prior to the storm. Due to fuel loss for generation plants and a surge in demand, ERCOT had to load shed (i.e., shut down parts of the grid to avoid total failure) because the capped prices did not provide enough return to cover costs.[xc] Millions of Texans lost power to their homes for days at a time, and some utility companies went out of business with billions of dollars in debt.[xci]

Ultimately, the grid failed because it was not adequately hardened for such a severe storm. Policymakers and sector professionals believe possible solutions may lie in mandating hardening measures, like requiring a license to participate in the wholesale market based on meeting hardening criteria or only hardening the most critical grid assets, especially those in areas with the highest risk.[xcii] Other options include creating better quality retail contracts to insulate consumers from price variation or further deregulating the wholesale energy market.[xciii] Some parts of the literature suggest that a cost-benefit analysis does not recommend hardening infrastructure in certain states or regions given the rarity of such an extreme weather event; in other words, the costs of hardening outweigh the benefits.[xciv] One certainty is that future solutions will face difficulty in balancing economic and technological factors with the fundamental duty to provide electricity to homes that need it in a crisis.

### Innovations to Improve Resiliency and Modernize Transmission, Distribution, and Storage

Despite power grid vulnerabilities like aging infrastructure and inclement weather, the U.S. has been vigilant in researching and implementing innovative technologies to improve the efficiency, resiliency, and reliability of the power grid.

*Transmission Technology*

- *Ultra-High Voltage (UHV) Lines:* UHV lines transmit voltages of 1,000+ kV, offering low-loss transmission over long distances.[xcv] UHV lines could greatly enhance grid resiliency, enabling efficient cross-country electricity flow and integration of remote renewable generation facilities. There are no UHV lines in the U.S. due to cost and regulatory hurdles.[xcvi] Capital costs for UHV can exceed $3 million per mile, and some permitting timelines can stretch up to 5-10 years for new right-of-way acquisitions.[xcvii] [xcviii]

- *High Voltage Direct Current (HVDC):* HVDC reduces losses over long distances, enables undersea and underground links, and ties together asynchronously operated grids.[xcix] These are all improvements to HVAC, which is the primary transmission technology in the U.S.[c] The U.S. operates 4.56 GW of HVDC capacity across four major projects: Neptune Regional Transmission System in New York and Trans Bay Cable, Intermountain Power Project, and Pacific DC Intertie Projects in California. The Grain Belt Express is the largest ongoing transmission project in the U.S.; it uses HVDC across 800 miles and is set to cost $7 billion.[ci] To accelerate HVDC adoption, DOE awarded $11 million to four R&D efforts aimed at reducing HVDC costs.[cii] Expanded HVDC deployment would strengthen the grid against regional disruptions by balancing supply and demand across broader areas.

- *Superconducting Transmission Lines:* By using high-temperature superconductors, transmission lines can transport 5-10x the power of a conventional line with no electrical resistance.[ciii] The world's first superconducting line is the Holbrook Superconductor Project, which began in 2008 on Long Island.[civ] In 2021, American Superconductor's Resilient Electric Grid system, which uses superconducting lines to enhance reliability and capacity, was integrated into the Chicago grid.[cv] Further integration of superconducting lines could improve grid capacity and reliability, enhancing the grid's ability to quickly recover and maintain power, especially during extreme weather events.

*Distribution Technology*

- *Smart Grid:* A smart grid functions cooperatively, responsively, and organically to improve the reliability and efficiency of the grid.[cvi] Smart grids involve advances in grid automation, smart distribution automation, wide area monitoring, and AI grids. Smart meters transmit data from the consumer to the distributor and have been deployed at scale with penetration of over 70% of U.S. meters.[cvii] Under the GRIP Program, DOE started 16 smart grid projects expected to use $8 billion in private investment.[cviii] Additionally, DOE's smart grid grants have funded several distribution upgrades including $47.5 million for multi-state distribution improvements and $30 million for Snohomish County to deploy its SnoSMART wireless sensor and software network. [cix] Further smart grid deployment can significantly reduce outage times and enhance the grid's adaptive capacity.

- *Wide Area Monitoring (WAM):* Phasor Measurement Units (PMUs) provide time-synchronized data on current and voltage, giving operators a real-time picture of grid dynamics.[cx] By enabling quicker responses to disruptions and emergencies, WAM dramatically increases grid reliability. Over 1,700 PMUs are deployed across the U.S. feeding control centers, enabling fast detection of disturbances and quick responses.[cxi] DOE and various partners invested more than $347 million as a part of the Smart Grid Investment Grant to increase PMUs on the system.[cxii]

*Storage Technology*

- *Pumped Storage Hydropower (PSH):* PSH stores electricity by pumping water in two reservoirs at different elevations. It has high capacity and is relatively efficient, accounting for 96% of grid-scale storage in the U.S.[cxiii] PSH's capacity to deliver reliable electricity during peak loads or even blackouts enhances grid resiliency. The first new PSH plant in over 30 years is set to be built for $81 million at the Lewis Ridge Pumped Storage Project in Kentucky. [cxiv]

- *Flow Batteries*: Flow batteries store electricity in two separate liquid electrolyte tanks that can generate power when needed.[cxv] These batteries have longer lifespans and more flexible materials than traditional batteries.[cxvi] Their scalability and lifespans help ensure steady power during prolonged weather disruptions. In California alone, four demonstration projects are operable with a total of 31 MWh of storage.[cxvii] More pilot projects are underway as DOE announced $100 million in funding for pilot-scale long-duration energy storage batteries using non-lithium technologies.

- *Solid State Batteries:* Solid state batteries replace flammable and toxic liquid electrolytes with solids, increasing safety and energy density.[cxviii] While no commercial grid-scale solid state batteries exist, DOE is actively funding the space. This includes Solid Power, a company that received $50 million in funding, and Ion Storage Systems, which received $40 million to develop solid state grid-scale battery solutions.[cxix] [cxx]

- *Hydrogen Storage:* Hydrogen storage electrolysis converts renewable power into hydrogen, storing the electricity chemically and then converting it back later.[cxxi]

Hydrogen storage is still in development, as the conversion loses 60% of all incoming electricity.[cxxii] DOE's H2@Scale initiative awarded $104 million across 47 projects aiming to develop hydrogen storage.[cxxiii] [cxxiv] Its potential for long-term energy storage could provide critical support during extended energy disruptions.

- *Iron-Air Batteries:* Iron-Air batteries store energy via the reversible rusting of iron, creating a multi-day battery at low cost. This long duration and low cost storage solution can strengthen grid reliability at a fraction of the cost of lithium batteries.[cxxv] Form Energy is at the forefront of Iron-Air batteries, recently receiving $405 million in private funding and $30 million from DOE to accelerate manufacturing of a 100-hour Iron-Air battery.[cxxvi] Their main accomplishment is Form Factory 1, a $760 million facility with a capacity of 500 MW of Iron-Air storage, starting production in 2024.[cxxvii]

## Artificial Intelligence

AI provides unique opportunities and challenges to the power grid.[cxxviii] Integration of AI into smart grids has become a critical driver for improving the efficiency, reliability, and sustainability of the U.S. power grid. Simultaneously, AI is largely responsible for rapidly increasing electricity demand, increasing strain on an aging power grid. The question is whether the improvements that AI offers to the grid can sufficiently offset its immense energy demands.[cxxix]

### *AI Benefits to Power Grid*

AI technologies have the potential to improve energy operations across the power grid through decision support, predictions, and real-time operational efficiency.[cxxx] In the U.S., AI has been used to monitor transmission lines, isolate faults in the grid, and analyze huge amounts of data to better predict fluctuations in supply and demand.[cxxxi] Through these efficiency gains, AI could help mitigate 4% of global greenhouse gas emissions by 2030.[cxxxii]

One of the most prominent uses of AI in the power grid is predictive maintenance. AI in predictive maintenance could lead to a 20% increase in operational uptime and a decrease in maintenance costs.[cxxxiii] The DOE Grid Modernization Initiative is already using AI to improve load forecasting, helping to balance supply and demand.[cxxxiv] [cxxxv]AI can forecast energy production with remarkable accuracy, which can help integrate renewable energy into the grid while avoiding blackouts and inefficiencies in distribution.

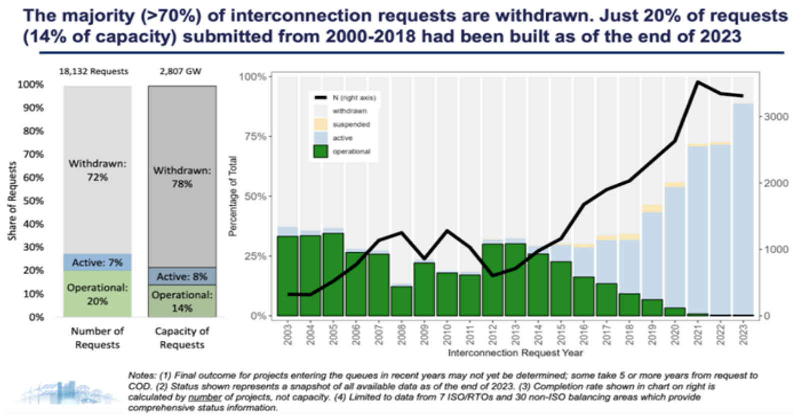
*AI Drawbacks to Power Grid*

After two decades of stable electricity demand, consumption is projected to grow 16% in the next five years.[cxxxvi] Demand growth is largely driven by energy-intensive technologies like AI, with AI data centers expected to account for 9% of total electricity demand by 2030.[cxxxvii] For perspective, a single ChatGPT query uses 10 times the electricity of a regular internet search, while a typical AI data center uses as much power as 100,000 households.[cxxxviii] Newer data centers currently under construction are projected to use 20 times this amount of electricity. This demand increase has strained the outdated U.S. power grid infrastructure, contributing to all-time high electricity prices that have been exacerbated by global disruptions and geopolitical tensions.[cxxxix]

Furthermore, integrating AI into the power grid has significant risks. Firstly, new AI integration into critical infrastructure such as the power grid opens new opportunities for cyberattacks.[cxl] Cyberattacks have already targeted critical infrastructure as seen through the ransomware attack on Colonial Pipeline, which shut down the nation's largest natural gas pipeline for five days.[cxli] AI models, which are reliant on extensive data to be successful (including personal identifiable information and private data), increase the risk of cyber breaches and data leaks. Additionally, AI autonomous decision-making could make confusing or harmful decisions on its own. For instance, an emergency could cut power to a hospital to keep the grid stable. Unforeseen events that AI systems were not trained for could result in erratic or harmful decisions, which necessitates human oversight and fail-safes when implementing AI into the power grid.[cxlii]

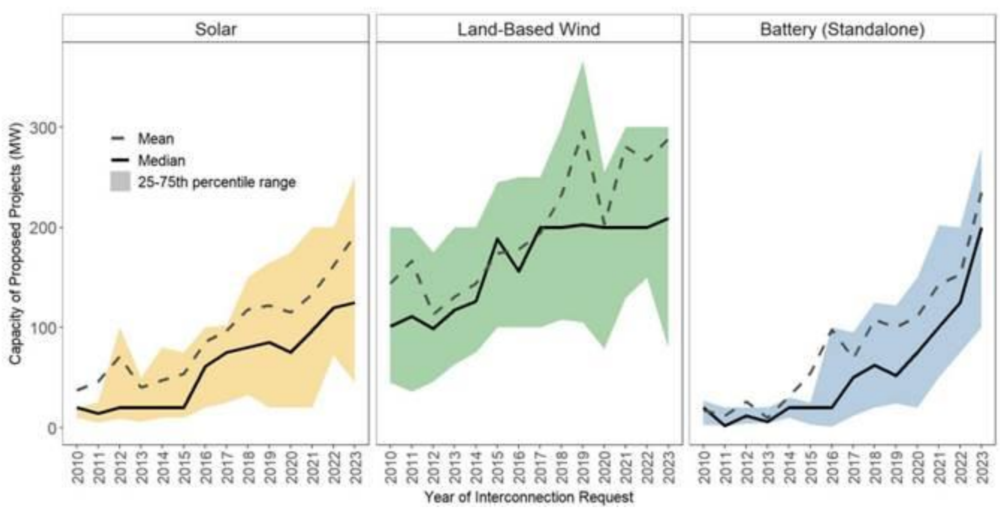
## Interconnection Requests

Given that electricity supply must constantly meet demand, as demand grows, so too must supply. An interconnection request (IR) is when a power plant submits a proposal to be attached to a part of the power grid to generate additional electricity.[cxliii] After approval, a power plant is granted a commercial operations contract (COD) to begin selling its electricity on the wholesale market. FERC is the deciding authority to grant any given IR the rights to commercial operation.[cxliv] The basic assumption is that if more IRs are approved, there will be more electricity generation capacity for the country, but the reality is more complicated. Generation requires equal improvement and expansion in transmission given that generation and transmission work in tandem; extra power without the ability to deliver it is ineffective. The number of active IRs has increased massively over the past decade. Currently, 2,600 GW worth of potential electric capacity is waiting on IR approval, more than twice the total installed capacity of active power plants in the U.S.[cxlv] In the graph below, blue bars represent the increasing number of active IRs, compared to the green bars that represent approved IRs for power plant operationalization.



cxlvi

Despite massive potential for expansion of the grid, IRs face two problems: 1) long wait times to achieve CODs and 2) rising costs. The average duration for an IR to be approved in 2023 is five years, a 70% increase from 2010.[cxlvii] Additionally, processing requests include upgrade and processing costs, which are 236% and 134% higher in 2023 than in 2014 for solar and wind plants, respectively.[cxlviii] In the early stages of a power plant's development, an IR can cost as much as 8% of total project capital expenses upon completion.[cxlix] Given that ~82% of the total capacity awaiting approval are either solar or wind-based power plants, many IRs have been withdrawn because of the inability to suffer waiting times and costs. Only 20% of proposed projects between 2000 and 2018 have achieved CODs and are connected to the grid.[cl]



cli

Synergy between generation and transmission expansion must be accomplished to grant more IRs approval. If every IR was approved instantaneously, there would be enough combined capacity to reach a zero-carbon electricity sector by 2035.[clii] That will not happen, but the total potential electric capacity in waiting demonstrates immense promise for advancement in national renewable energy goals. In 2023, FERC released an order aimed at improving the speed and viability of IRs by removing various financial barriers and placing penalties for potentially non-viable plants to deter entering the queue, thus reducing the total load of IRs to avoid slowdowns.[cliii] This FERC order will streamline the process and is predicted to reverse the current trend of decreasing IR approval rates, making way for greater power generation. Additionally, FERC Order 1920 compliments Order 2023 by improving short and long-term cost planning for the connection of new power plants to transmission infrastructure.[cliv]

## Cybersecurity

The grid relies on Supervisory Control and Data Acquisition (SCADA) systems, which is an umbrella term for the use of software and cloud networks to remotely (and automatically) control and monitor physical assets. SCADA is used to some degree in every infrastructure sector, and as reliance on cloud computing grows, so does the threat of malicious cyberattacks.[clv] SCADA was originally implemented without rigorous cybersecurity protocols, which creates a pressing vulnerability in the power grid.[clvi] Examples of cyberattacks on related critical infrastructure occurred abroad in Ukraine and even at home on the Colonial Pipeline, with each providing their own lessons for future actions in cybersecurity.

### *Ukraine Case Study & Lessons Learned*

In 2016, the first-ever wide scale grid blackout from a cyberattack occurred.[clvii] One-fifth of Kyiv lost power because of the Industroyer 1 malware developed by Russian hacker cells.[clviii] [clix] After the malware gained access into the grid's local cloud system, circuit breakers in substations attached to the Kyiv power grid were turned off remotely.[clx] Even when Ukraine tried accessing the system to respond, they were prevented from doing so. Six years later during the war, Industroyer 2 was employed against Ukraine in the same vein. The new and improved malware would have been able to take control and wipe the entire system to prevent a controlled restart, but Ukrainian response teams foiled the attack before it could cause irreversible damage.[clxi]

Cyberattacks like those toward Ukraine will continue to increase in frequency and severity. As AI becomes more powerful (and is used for hacking purposes) and as reliance on cloud computing increases, cybersecurity in grid infrastructure should be prioritized to prevent targeted wide scale blackouts. Ukrainian teams responded to Industroyer 2 with speed and efficiency because they were prepared for another attack. However, the U.S. has already been grappling with shortages in public sector cybersecurity and repeated cyberattacks in other sectors like healthcare and finance, so it is likely that a large-scale attack on the power grid will occur.[clxii] [clxiii]

*Colonial Pipeline Attack*

In May of 2021, a cyberattack occurred against the Colonial Pipeline, the longest pipeline for transporting refined petroleum products across the continental U.S.[clxiv] [clxv] A hacker group allegedly tied to Russia called DarkSide gained access into the central servers of the Colonial Pipeline, blocking certain functions and demanding a ransom in return for access back to the system.[clxvi] For five days, the pipeline was out of operation, leading to local gas shortages and panic-buying of gasoline across the Southeastern states who were most affected.[clxvii]

Though the pipeline did not have any direct impact on the power grid itself, it is nonetheless an important critical infrastructure asset. The worst consequences were avoided in this scenario, as the $4.4 million ransom price was paid (with more than half of it recovered by the federal government) and access was restored in a couple days.[clxviii] Regardless, this was another wakeup call for the U.S. to begin investing in cybersecurity both publicly and privately. Biden swiftly issued EO 14208 on "Improving the Nation's Cybersecurity" along with other policy implementations like the Cyber Incident Reporting for Critical Infrastructure Act of 2022 or the Department of Homeland Security Cybersecurity Directive.[clxix] [clxx] The Cybersecurity and Infrastructure Security Agency also rolled out the Joint Cyber Defense Collaborative in August of that year, a public-private partnership to bolster communication and collaboration for nationwide cybersecurity efforts.[clxxi]

As a result of the Colonial Pipeline attack, the government has pursued numerous pieces of legislation (46 separate pieces just in 2021) that aim to improve cybersecurity in the energy sector.[clxxii] The U.S. learned how susceptible it is to an attack and that its infrastructure is vulnerable even if it is thousands of miles away from their largest adversaries. There is nothing preventing a larger cyberattack on infrastructure from occurring other than implementing cybersecurity-strengthening measures at the public and private level, across states, immediately.

## VI. Policy & Investment Overview

### Critical Background

The shale boom in the mid-2000s sparked the EPA05—a landmark bill in developing American renewables. Specifically, the EPA05 established U.S. energy tax credits for solar and wind production and consumption. Subsequent administrations have built upon, renewed, and expanded these tax credits for electric vehicles, subsidizing critical mineral refinement, and battery production. Historically, the U.S. has connected an expansion in fossil fuels with a varying offset of renewable power generation, but this connection is beginning to strain.

The largest difference between the Biden and second Trump administration is the stress placed on energy grid diversity and clean energy investment. Whereas President Biden sought to increase solar, electric vehicle, wind, and other renewable source investment and infrastructure with the IIJA, IRA, and CHIPS and Science Act, President Trump did the opposite; a clear emphasis has been placed on expanding fossil fuels, especially coal and LNG. Coal is now defined as a mineral, and energy has been declared a national emergency, with direct calls to expand offshore mining and mining in Alaska and Midwestern states.[clxxiii]

In the current administration, few policy stances on the power grid have remained consistent. While differences in political rhetoric are often quite clear, following the paper trail of regulatory or investment changes can be difficult. This is because most of the Trump administration's stances on energy have been sent out by EO as President Trump has opted for moving with larger omnibus bills instead of working issue by issue. This is an effective way to pass legislation, but the method of crafting one huge bill while EOs fly off the desk prompts the need for additional clarity.

Notably, President Trump's EO "Unleashing American Energy" calls for the global effects of energy policy to be "reported separately from its domestic costs and benefits," virtually stating that externalities are not a concern when administering new policy for the Trump administration.[clxxiv] This theme is clear throughout Trump's EOs; climate and potential externalities are not costs to be considered in policymaking because they do not directly impact energy supply. The Trump administration's stated focus is to ensure "that an abundant supply of reliable energy is readily accessible," maximizing energy supply through rapid investment and deregulation of fossil fuels. In addition to these reliable fossil fuels, the Trump administration has stressed nuclear energy development in a slew of May 2025 EOs.[clxxv]

## Biden Administration

### *Policy Priorities*

The IRA and IIJA from the Biden administration built upon tax credits and loan guarantees for nuclear, clean, and green energy investment and development from the EPA05. The EPA05 introduced manufacturing, domestic home, and investment tax credits into clean energy alternatives and the development and use of variable renewable energy sources (solar and wind).

These tax credits have been crucial in expanding energy source diversity, a stressed issue constant throughout the Biden administration.[clxxvi] Seen in EO 14082, President Biden's goal with the IRA and IIJA was to expand energy generation through clean energy innovation and sustainable environmental justice.[clxxvii] This order expanded and solidified the goal of lowering consumer prices through long-term investments in emerging technology to benefit overall infrastructure, reiterating the intention of all three major energy-related bills passed under President Biden. With these trends in mind, three distinct categories of clean energy technology have emerged—wind, solar, and hydropower.

*Wind Power*

- *Offshore Wind Power:* Offshore wind captures electricity from wind blowing over water. Despite advantages (including stronger, more stable winds and easier installation for larger turbines), the U.S. has just 42 MW of offshore capacity, with a target of 30 GW by 2030.[clxxviii] In 2024, the Bureau of Ocean Energy Management approved the plan for Coastal Virginia Offshore Wind with a capacity of 2.6 GW.[clxxix] Additional projects include the 800 MW Vineyard Wind 1 which is under construction in Massachusetts.[clxxx]

- *Next Generation Turbines:* Next generation turbines are larger turbines exceeding 10 MW of capacity each, resulting in improved power generation and reduced costs per MWh.[clxxxi] Vineyard Wind I used General Electric's Haliade X 13 MW turbines, which reduced their costs by 20% compared to 6 MW turbines.[clxxxii] Additional advanced turbines include Siemens Gamesa SG 11 MW turbines, showing strong industry development in next generation turbines.[clxxxiii]

*Solar Power*

- *Bifacial Solar Panels:* Bifacial solar panels have PV cells on both sides to absorb sunlight reflected off the ground.[clxxxiv] This can increase energy yield by up to 30%, even more in highly reflective environments (snow or sand).[clxxxv] They account for 30-50% of all new PV installations in the U.S.[clxxxvi] In 2024, the U.S. Court of International Trade Commission put imported bifacial solar panels back under Sec. 201 tariffs after they enjoyed a two-year exemption from extra tariffs.[clxxxvii] This was done to strengthen domestic bifacial manufacturing capacity, especially after QCells (the largest solar manufacturer in the U.S.) announced it would invest more than $2.5 billion to expand U.S. operations.[clxxxviii]

- *Perovskite Solar Cells:* Perovskites are a family of materials offering higher performance and lower costs for solar cells.[clxxxix] They have a crystal structure enabling them to absorb certain colors of light more effectively, increasing efficiency by more than 26%. They can even be combined with traditional silicon solar cells, dubbed a tandem solar cell, which further increases efficiency to a record high.[cxc] No commercial U.S. installations exist due to durability and scaling difficulties. To combat this, DOE's Solar Energy Technologies Office awarded $44 million in R&D grants.[cxci]

- *Solar Tracking:* Trackers orient solar panels to follow the sun's trajectory, increasing the efficiency of PV panels by 10-30%.[cxcii] Up to 94% of new U.S. solar capacity used solar trackers, driven by Investment Tax Credit bonuses.[cxciii] [cxciv] The market leader for U.S. solar tracking is Nextracker, which raised $638 million in its IPO to expand U.S. manufacturing capacity and next generation curved module trackers.[cxcv]

- *Floating Solar Farms:* Solar panels installed on bodies of water reduce land use and increase efficiency by 10% from natural cooling.[cxcvi] The U.S. has 20 MW of floating capacity through four main projects: Canoe Brook Reservoir and Sayreville in New Jersey and Healdsburg and Windsor in California. The largest ongoing floating solar project is the Delta-Mendota Canal project in California, which received $15 million in funding from Investing in America.[cxcvii]

- *Space-Based Solar Power (SBSP):* SBSP collects solar power via satellite and then beams it back down to Earth.[cxcviii] The advantage of SBSP is that the Sun is 10x as intense at the top of the atmosphere and would be continuously available (independent of weather or time of day). Caltech's Space Solar Power Project, funded by $100 million from trustees, has proven pilot programs with a low-orbit experiment planned by 2027.[cxcix]

*Hydropower*

- *Tidal Power:* Tidal power uses predictable ocean tides to generate electricity.[cc] U.S. deployment is limited to pilot sites, with the DOE Water Power Technologies Office funding $6 million for two pilot sites in Cook Inlet and Rosario Strait.[cci] In 2024, the DOE Water Power Technologies Office released an additional $45 million for tidal power R&D.[ccii]

- *Hydrokinetic Power:* Hydrokinetic power captures electricity directly from flowing water without the need for dams, reducing ecological impact.[cciii] There are no commercial installations, with research concentrated in DOE pilot projects.[cciv] One project in Alaska has received $4 million in funding for the RivGen 2.0 and 2.1, which generate reliable electricity from river currents.

### *Investment Through Energy Policy*

While EOs played a role in implementing the following bills, the most significant legislation affecting power generation, transmission, distribution, and storage during President Biden's term included the IIJA, the CHIPS and Science Act, and the IRA.

Passed in late 2021, the IIJA was the most significant long-term investment in U.S. infrastructure in almost a century. It allocated over $65 billion (many sources say $73 billion)—more than any prior individual bill—to clean energy transmission and the power grid, providing funding for updates to electricity infrastructure—especially transmission lines. It also offered funding for research and development pertaining to transmission and distribution technologies as well as cutting-edge technologies including carbon capture, clean hydrogen, advanced nuclear reactors, and smart grid technologies. Finally, it designated $6 billion towards a production credit meant to keep existing nuclear plants online.[ccv]

The CHIPS and Science Act of 2022, meanwhile, provided $50 billion in funding and a 25% investment tax credit to boost semiconductor production and prompt additional investment from the private sector.[ccvi] Semiconductors are integral to nearly all parts of the power grid, making this bill highly beneficial to the electricity sector. The CHIPS and Science Act, while not energy generation, storage, or transmission related, does play a huge role in energy consumption. At just a high-level overview, the CHIPS and Science Act promotes the creation of high-tech domestic supply chains and creates outlets for American critical mineral processing. The semiconductors promoted by this Act are, at large, the brains behind the power grid.

Lastly, the IRA of 2022 constituted the biggest investment in energy and climate in U.S. history, providing $386 billion. Most of the bill's funding was dedicated to expansions of and modifications to tax credit incentives tied to clean power generation, electrification, green technology retrofits, increased clean fuel use, and electric vehicles. Additionally, the bill included $27 billion in grants meant to incentivize private investment in clean energy projects; gave rural electric cooperatives over $13 billion for clean energy generation and measures intended to support resilience, reliability, and affordability; and drastically increased the loan authority with which DOE could promote clean energy technologies. The bill allocated significant funding to domestic clean energy manufacturing.[ccvii] [ccviii]

Together, these Congressional Acts provided a large portion of the federal funding that flowed towards clean energy technologies and electricity infrastructure more broadly under the Biden administration.

*Biden-Era Investment Focus*

Between 2015 and 2024, total annual U.S. energy investment went from $79.54 billion for end use, $284.16 billion for fossil fuel supply, $1.52 billion for clean supply, $17.79 billion for fossil fuel power, $61.26 billion for grids and storage, and $70.42 billion for low-emissions electricity to $132.7 billion for end use, $206.13 billion for fossil fuel supply, $5.66 billion for clean supply, $10.57 billion for fossil fuel power, $125.14 billion for grids and storage, and $104.56 billion for low-emissions electricity.[ccix]

Measured in real 2023 dollars, major utilities' annual spending on the production and delivery of power rose from $287 billion in 2003 to $320 billion by 2023. For the most part, the increase came from capital investment in power infrastructure, which more than doubled during the period. Generation spending decreased by 24% over this period since fuel costs (which make up the majority of generation costs) fell and several old, costly fossil fuel plants were shuttered. Between 2022 and 2023, however, generation spending rose by 23% ($4.7 billion). Transmission spending almost tripled between 2003 and 2023, reaching $27.7 billion, and it rose by $2.7 billion (11%) between 2022 and 2023, with $1 billion going towards transmission station equipment, $1.1 billion going towards poles, and $0.4 billion going towards computer software. Distribution spending was the main driver of power spending increases between 2003 and 2023, increasing by $31.4 billion (160%). Over a fifth of this increase (at roughly $6.5 billion) came between 2022 and 2023, bringing the total for annual distribution spending to $50.9 billion. Investment in overhead lines, poles, and towers grew the most, with utilities spending $17.4 billion on overhead infrastructure during 2023—a 220% increase compared to 2003. Investment in underground infrastructure also more than doubled between 2003 and 2023. Additionally, considerable increases in distribution investment over this period were seen with line transformers, substation equipment, and infrastructure either on or near customers' property. Even though energy storage accounts for only a small portion of distribution spending, investment grew from $97 million in 2022 to $723 million by 2023—a massive increase.[ccx] [ccxi]

One key trend over the past decade and especially under the Biden administration was the shift in power generation investment away from fossil fuels and towards low-carbon energy sources like wind and solar due to government policies.[ccxii] From 2015 to 2024, the share of yearly investment in fossil fuel supply and fossil fuel-based power generation decreased from 60% to slightly below 40%. Fossil fuel supply costs fell during this period, but other investment sources, especially in low-emissions electricity, grids, and end use, grew swiftly. Together, competitively priced energy and policies promoting domestic competitiveness and foreign direct investment resulted in growing investment in manufacturing. Annual investment in the manufacturing of clean technologies rose from $2 billion in 2018 to $60 billion in 2024.[ccxiii]

## Second Trump Administration

### *Trump Energy Priorities*

The Trump administration's primary energy priority is maximizing domestic energy supply through an increase in fossil fuel production.[ccxiv] President Trump has established the National Energy Dominance Council (NEDC) to achieve this goal, a sort of “black box” when it comes to energy priorities and direction as there are no discernable public records for meetings. The goals of the NEDC are stated to be cutting red tape, spurring private investment, and action plans to expand pipelines, reopen plants, and approve nuclear development.[ccxv]

Energy efficiency is not a priority for the Trump administration, with the administration instead opting to rescind President Biden’s efficiency standards.[ccxvi] [ccxvii] In “Unleashing American Energy,” President Trump calls out lightbulbs, dishwashers, heaters, toilets, shower heads, and many more household appliances, arguing the need for more market competition and the need to “safeguard the American people’s freedom to choose.”[ccxviii] Efficiency standards created under the Biden administration were removed because of these justifications.

### *Shifting Policy Focus*

The switch from the Biden administration to the second Trump administration brought with it a range of disruptions to power sector funding. Among others, President Trump’s EO titled “Unleashing American Energy” redirected large amounts of federal funding away from renewables, halting disbursements of funding initially allocated through the IIJA and IRA.[ccxix] Moreover, federal aid and tax credits for a variety of renewable energy projects are at risk of being reduced or eliminated.[ccxx]

The fear surrounding investment in clean energy projects is sourced primarily from administrative actions. The first is President Trump’s initial IRA funding freeze following EO 14154, which has been attributed with companies cancelling, closing, or downsizing nearly $8 billion in projects in Q1.[ccxxi] [ccxxii] These projects range from solar cell factories to battery manufacturing plants—a decision which might prove counter towards the long-term goals of expanding American-made input goods towards critical infrastructure. Domestic energy storage, for example, needs heavy investment in emerging battery technologies in order to meet the 100% American-made goal.[ccxxiii] The second source of hesitation stems from the Trump-sponsored “One Big, Beautiful, Bill” (BBB), which puts onto paper the repeal of technology-neutral tax credits for clean electricity production and investment, the phaseout of most other energy credits, and limiting foreign entities of concern’s (FEOC) ability to claim energy credits.[ccxxiv]

### *Investment Sourcing*

As electricity demand rises, the U.S. power sector is experiencing unprecedented growth in capital investment. In 2024, the sector’s capital investment hit an all-time high at roughly $179 billion following five years of continuous growth with a compound annual growth rate exceeding 8.5%. This upward trend will likely continue in the immediate future, with the most major utilities' capital expenditure expected to hit $194 billion during 2025. Most of the funding for utilities' investments has historically come from filing rate cases and issuing debt or equity, and this has generally remained the case thus far. Rate increases prompted by utilities reached new heights between 2020 and 2024, largely because of increasing costs in the sector. From 2019 to 2024, customers' power bills consequently increased by 23%.[ccxxv]

*Trump-Era Investment Focus*

The U.S. invests heavily in all energy technologies and fuels. In June 2025, energy investment accounted for 2% of the U.S.'s GDP.[ccxxvi] Significant portions of U.S. investment in the power sector are concentrated in generation assets, including constructing new natural gas and nuclear power plants, along with renewable sources of energy; modernizing transmission and distribution systems; and employing novel technologies like battery storage, smart grid systems, cybersecurity measures, and smart meter use.[ccxxvii]

Before the switch in presidential administrations, the International Energy Agency (IEA) estimated that in 2025, energy investment would reach $140.3 billion for end use, $176.79 billion for fossil fuel supply, $8.73 billion for clean supply, $10.77 billion for fossil fuel power, $135.43 billion for grids and storage, and $116.44 billion for low-emissions electricity. In 2015, the shares of clean and fossil fuel investment were 41% and 59%, respectively, while in 2025, the shares of clean and fossil fuel investment are 68% and 32%, respectively.[ccxxviii]

The U.S. currently produces 8% of the world's lithium-ion batteries and possesses 42 GW of solar PV module manufacturing capacity, which is almost triple the capacity it had in early 2024.[ccxxix] At the end of April 2025, the American Clean Power Association committed an investment of $100 billion to manufacturing and purchasing American-made grid batteries, indicating confidence in the future of the domestic energy storage industry.[ccxxx] Along with manufacturing capacity, the U.S. is increasingly investing in generating capacity, much of which is from solar and battery storage facilities. This capacity is largely concentrated in California, Texas, the Northeast, and the upper Midwest.[ccxxxi]

## Near Future

*Investment and Policy Intentions*

The U.S.'s energy investment in the recent past indicates its consistent focus on energy security regardless of the present administration; over the last decade, the nation has made significant investments in energy to solidify itself as a key player in international markets and emerging value chains.[ccxxxii] Under the second Trump administration, the

U.S. will likely maintain the goal of energy security and continue to work towards an advantageous position in global markets and value chains.

The second Trump administration has signaled commitment to enacting policy supporting fossil fuel extraction in the years ahead, which will incentivize future investment.[ccxxxiii] [ccxxxiv] For instance, the administration is working to streamline permitting processes in the power sector, which may assist in updating the power grid and attracting greater investment into the sector in the near future since drawn-out permitting and interconnection requests are some of the main roadblocks.[ccxxxv] [ccxxxvi] The administration appears to have taken a special interest in coal; the interior secretary hopes to restart coal plants that previous Democratic administrations shuttered through regulations, and the energy secretary hopes to prevent further closures of coal plants. Some states have begun participating in this “coal renaissance,” with Arkansas, Wyoming, West Virginia, Kentucky, Nebraska, and Utah recently passing laws preventing premature coal plant closures.[ccxxxvii] Additionally, in Section 3 of EO 14261, the Chair of the NEDC is required to designate coal as a mineral, “entitling coal to all the benefits of a mineral.”[ccxxxviii] These benefits include expedited access towards federal lands designated for mining and greater support for public-private investment to be funneled towards coal generation.[ccxxxix] Previously inaccessible for fossil fuel production, a $10B+ National Critical Minerals Fund created by reallocating existing DPA funds now serves as a compass for a potential change of course in U.S. energy sourcing.

Though total annual investment projections suggest that investment in fossil fuels would continue to decline considerably over the next decade if policies were to remain constant, these shifts point towards a potential revival of fossil fuel investment over the next few years. In response to the current administration’s support for fossil fuel power generation, utilities nationwide are thinking about keeping existing coal plants online for longer than previously planned and constructing more gas-fired capacity to address electricity demand and reliability concerns.[ccxl]

The administration has also demonstrated an interest in increasing the U.S. supply of uranium, critical minerals, and hydropower, which may embolden investors focused on nuclear and even some forms of renewable energy.[ccxli] In general, the administration remains committed to the growth of domestic manufacturing, which includes critical mineral development and battery manufacturing.[ccxlii]

### *Investment Projections*

To meet the demands of consumers, ratings agencies, and regulators in the years to come, electric power companies in the U.S. aim to enhance the reliability, resiliency, and safety of the power grid, increase power output, and maintain affordability.[ccxliii] A great deal of future investment from the private and public sectors alike will no doubt come about as a result of increases in electricity demand induced by the growth of data centers and generative AI technologies. By 2030, data centers may account for 10% of U.S. power demand (compared to 4% now), which would require more than $16 billion in grid investment. More than 90% of data center operators consider power supply their biggest concern, and roughly half view upgrading grid infrastructure as the most significant mitigator.[ccxliv] A major goal of both private and public sector investment, then, will be to meet power demand in the face of major technology-driven increases.

According to the ASCE, the power sector will still need $578 billion more in investment by 2033 even if the IIJA and IRA get reauthorized in 2026, and this investment gap will grow to $702 billion by 2033 if IIJA and IRA funding is not replaced upon the bills' expiration.[ccxlv]

A wide range of sources attempt to estimate the amount of money that will flow into the power sector in the years ahead. One projection estimates that the U.S. will see $170–340 billion of additional investment in generation capacity, grids, and storage by 2030.[ccxlvi] Another projection indicates that over $700 billion will go towards grid and infrastructure investment by 2030.[ccxlvii] Yet another projection suggests that the U.S. power sector will need substantial, sustained investment over the next two or three decades to meet power demand, revitalize increasingly old infrastructure, incorporate renewables, and increase grid resilience, so industry-wide investments may total $1.4 trillion between 2025 and 2030, with comparable expenditures through 2050.[ccxlviii]

*Shifts in Investment Sourcing*

Total investment in energy and natural resources will continue to grow in the years ahead, but the growth rate for investment is currently only half that of the early 2020s, suggesting that caution about the speed of the low-carbon transition is stunting the sector's continued growth.[ccxlix] Although capital investment in the power sector is reaching new heights, experts argue that investment over the past decade has fallen short, creating opportunities across sectors for future investment.[ccl]

Although the most major utilities' capital expenditure is expected to continue to rise overall in the near future, costs are rising for the power sector and its consumers, which may disincentivize future investment and slow continued growth. Since utilities have already raised rates considerably and issued a great deal of debt, there may be less room for additional use of these traditional funding mechanisms going forward. Given the shifting landscape of the sector, the normal ways of securing funding may no longer be adequate on their own moving forward.[ccli]

To circumvent the challenges now associated with increasing rates for customers and raising debt, a number of utilities expect to issue a larger amount of equity in the near future so they can maintain a balance between debt and equity. Utility holding companies may receive nearly 14% of annual capital investment from equity in 2025. However, some power companies are also considering other sources of financing beyond the traditional avenues. These include private capital, cooperation with the technology sector, and government incentives and funds.[cclii]

Since 2016, private investors have become more involved in the power sector in the form of private equity and infrastructure funds. As power and renewables companies work to secure new types of investment, they have taken to selling off non-core businesses, project platforms, and unregulated assets to private investors to gain funding. Renewable energy developers have generally started drawing on private funding earlier in their project cycles. While many investors come directly from the sector, investors are increasingly seeking investments in assets with relevance to both the energy and technology sectors, including AI data centers and important pieces of supply chains. This means that more investors are coming into the power sector from outside sectors than before. Strategic partnerships are becoming more common between electric companies and private capital funds. These joint ventures allow firms to share risk and expertise, and they appear likely to become more common in the future.[ccliii]

The recent ballooning of data center investment will prompt increased investment in the power sector and its grid infrastructure over the next decade and beyond, largely in the form of strategic partnerships and Power Purchase Agreements (PPA). Total investment in data centers may exceed $2.1 trillion in the next half-decade, and firms are attempting to quickly secure clean power sources, resulting in the growth of the corporate PPA market. As technology and data center companies work to obtain renewable capacity for the future, investment in clean energy will inevitably rise drastically in the power sector. Notably, data centers are contributing to increases in demand for next-generation energy technologies through the creation of a market specifically for advanced geothermal plants and small modular reactors. By the end of 2024, 265 MW of advanced geothermal and 26 GW of nuclear deals had been reached. Such deals indicate that venture capital investors, technology companies, and developers will play an increasingly important role in energy and power grid investment going forward.[ccliv] The U.S. is investing in advanced geothermal technologies that are categorized as Enhanced Geothermal Systems (EGS).

EGS can create energy almost anywhere on Earth without the need for hydrothermal resources.[cclv] In EGS, fluid is injected into hot non-porous rock layers that are hydraulically fractured (fracked) and then heated water is transformed into steam, spinning turbines for electricity. EGS offers low operation costs, minimal surface impact, and oil and gas transferability. Oil and gas wells, industry, and workers are all very transferable to geothermal due to similar skillsets and equipment, allowing for smoother transitions. DOE's Frontier Observatory for Research in Geothermal Energy (FORGE) is the nation's leading geothermal research center, receiving $220 million in funding.[cclvi] FORGE is developing EGS technologies and aiming to drive down geothermal costs by 90% by 2035.[cclvii]

Provided below are advanced nuclear reactors technologies that the U.S. is investing in to achieve higher sustainability, safety, economic competitiveness, and resistance to nuclear proliferation:

- *Small Modular Reactors (SMRs):* SMRs use similar technology to LWRs but at a fraction of the size; SMRs are generally defined as generating 300 MW or less.[cclviii] They are factory-built and then field-assembled, offering lower capital costs and more flexible deployment. SMRs are not without fault as their variable costs are expected to be higher as well as potentially creating more radioactive waste.[cclix] In 2023, the Nuclear Regulatory Commission (NRC) approved the first SMR design: NuScale Power's 77 MW model, which received $400 million in DOE funding and is planned to be built by 2030.[cclx] [cclxi]

- *Fast Reactors (Sodium or Lead Cooled):* Fast reactors do not moderate the speed of neutrons, making them more efficient. Their main advantage is the use of mixed oxide fuels (MOX) that can recycle plutonium and depleted uranium, closing the fuel cycle to enhance fuel efficiency while decreasing radioactive waste.[cclxii] DOE's Advanced Reactor Demonstration Projects (ARDP) is funding a 50/50 cost share of up to $2 billion for TerraPower's Natrium sodium cooled fast reactor.[cclxiii] Construction started in 2024 in Wyoming and is set to be operational by 2028.[cclxiv]

- *Molten Salt Reactors (MSRs):* MSRs use molten salt as either the fuel and/or coolant. They operate at higher temperatures where molten salt can store large amounts of energy, improving efficiency.[cclxv] Additionally, MSRs can consume different nuclear fuel cycles, namely thorium, which is more abundant and cheaper than uranium. In 2023, NRC approved a test reactor for Kairos Power's Hermes salt-cooled reactor demonstration in Oak Ridge Tennessee.[cclxvi] Hermes received $303 million in funding from DOE's ARDP with operations to begin in late 2027.[cclxvii]

- *Very-High Temperature Gas-Cooled Reactors (VHTRs):* VHTRs use helium as a coolant and operate at extremely high temperatures, enabling higher efficiency and process heat for other industries.[cclxviii] Under the ARDP, X-energy's Xe-1000 VHTR won a $40 million grant and is undergoing NRC review, with commercialization expected by early 2030.[cclxix]

- *Nuclear Fusion:* Fusion is the final stage in advanced reactors. Fusion mimics the Sun's process by fusing two atomic nuclei to form a single heavier nucleus while releasing massive amounts of energy.[cclxx] If replicated at an industrial scale, it could provide limitless clean, safe, and affordable energy. DOE allocated a record $750 million for Fusion Energy Sciences in 2025, which is used to fund several pilot plant concepts.[cclxxi] One such pilot plant concept is Commonwealth Fusion Systems' SPARC tokamak, which aims for demonstration by 2027 and commercialization by 2050.[cclxxii] [cclxxiii]

*Future Investment Focus*

Based on present-day stated policies, IEA projects that by 2035, total annual U.S. energy investment will shift to $208.32 billion for end use, $124.42 billion for fossil fuel supply, $12.57 billion for clean supply, $3.08 billion for fossil fuel power, $177.24 billion for grids and storage, and $133.14 billion for low-emissions electricity. Based on current policy, IEA estimates that the shares of clean and fossil fuel investment in 2035 will be 81% and 19%, respectively.[cclxxiv] Looking forward, utility investment will largely be aimed at ensuring energy efficiency and reliability.[cclxxv] The following fossil fuel innovations are investment avenues for improving fuel efficiency and decreasing emissions:

- *Carbon Capture, Utilization, and Storage (CCUS):* CCUS captures up to 90% of $CO_2$ emissions from fossil fuel plants, aiding decarbonization.[cclxxvi] There are 15 large-scale CCUS facilities operating in the U.S. capturing 22 million metric tons of $CO_2$ per year, with an additional 121 facilities under construction.[cclxxvii] In 2023, the DOE Office of Clean Energy Demonstrations (OCED) selected two natural gas plants and one coal-fired plant to invest over $890 million in to increase national capturing capacity by over 30%.[cclxxviii] Federal support through the IIJA provided $8.2 billion in appropriations for CCUS projects over 2022-2026.[cclxxix] CCUS projects are also eligible for section 45Q federal tax credit, with the Treasury estimating $43.4 billion in credits from 2025-2034.

- *Direct Air Capture (DAC):* DAC extracts $CO_2$ directly from the air, unlike CCUS, which captures it at the point of emissions. Two large-scale DAC facilities are operational in Texas: Occidental Petroleum plant and Exxon Mobil's pilot unit.[cclxxx] The IIJA provided DOE's Regional DAC Hubs program $3.5 billion to create four DAC hubs, each capable of capturing at least 1 million metric tons of $CO_2$ per year.[cclxxxi] To combat high capture costs ($600-$1,000/ton $CO_2$), the DOE OCED announced $1.8 billion in new funding for DAC technologies in addition to the 45Q tax credits.[cclxxxii] [cclxxxiii]

- *Ultra-Supercritical (USC) Thermal Plants:* USC plants operate at temperatures and pressures above the critical point of water, where water becomes a supercritical fluid. Supercritical fluids require less energy to transition to steam, enabling higher thermal efficiencies.[cclxxxiv] The only USC facility in operation is the John W. Turk Coal Plant in Arkansas, which cost $1.8 billion to produce 650 MW at thermal efficiencies close to 50%.[cclxxxv] There are 159 supercritical units that operate at lower temperatures and pressures with thermal efficiencies of 42%.[cclxxxvi] In 2024, a U.S. consortium successfully completed the $27 million Advanced USC Component Test project funded by DOE.[cclxxxvii] This project validated advanced component designs, which will help bring advanced USC power plants to commercial development, although no new USC plants are under construction.

- *Oxy-Fuel Combustion:* Oxy-Fuel uses pure enriched oxygen instead of air for combustion. This can improve overall plant efficiency and reduce many pollutants including NOX.[cclxxxviii] No full-scale Oxy-Fuel plants operate yet, but several pilot projects are active. Southwest Research Institute received $3 million in DOE funding to design a large-scale Oxy-Fuel combustion plant.[cclxxxix]

- *Advanced Combined Cycle Gas Turbines (CCGTs):* CCGTs pair gas and steam turbines to achieve high efficiency. More than 500 CCGT plants operate in the U.S., accounting for 35% of the electricity produced annually.[ccxc] CCGTs' capacity factors rose from 40% in 2008 to 57% in 2022 driven by investments from the public and private spheres.[ccxci] GE Vernova is investing $160 million in its Greenville South Carolina gas turbine production facility to expand production capacity and further efficiency.[ccxcii] DOE is funding five projects worth $26 million to improve thermal efficiencies to their target of 65%.

Although spending on renewables and low-carbon fuels in the U.S. nearly doubled over the past decade, it now appears set to plateau as supportive policies are removed or weakened.[ccxciii] The share of investment directed towards low-carbon energy sources rose from 32% to 50% between 2015 and 2021, but growth has now stalled.[ccxciv] These trends suggest that utilities and the private sector may follow the current administration in turning away from investment in renewables and clean energy technologies.

**Cognitive Dissonance**

This section is predominantly speculation, as the BBB has yet to pass at the time of writing this paper. However, we can extrapolate President Trump's priorities and actions, applying them towards intended goals. These are simply concerns to be understood in the context of potential future policies.

- *Investment Regulation and the Invisible Hand*: As stated in "Unleashing American Energy," the Trump administration is leaving consumer choice and market competition as the main driver to lower consumer prices, opting to deregulate climate goals and efficiency standards. According to basic economic theory, if energy supply increases, energy prices decrease, *ceteris paribus*. However, the potential for concern increases when much of the present investment into current clean energy projects is frozen with the administration instead building new drills. The timetable on when market adjustments will occur, or if they will occur, will always be unclear. However, halting current development to start future development might delay promises of low energy prices during the current spike in energy demand.

- *Private Risk-Management and the Nuclear Shift*: The Trump administration has made expanding nuclear energy capabilities a clear priority as previously stated. However, and critically so, nuclear projects require heavy investment and are extremely expensive. EO 14302 calls for the expansion of nuclear material stockpiles to be used as energy along with locating strategic points for future generators.[ccxcv] However, this situation seems to be developing towards building SMRs adjacent to data centers. While this might meet the increase in energy demand for data centers, Americans with high utility bills might not experience a lower energy price, as these reactors are not producing energy for them. Since nuclear power generators are so costly, smaller projects intended to meet local data center energy demand could be the only projects started in the coming years. This means Americans foot the bill for electricity they cannot touch, impacting electricity prices in unpredictable ways.

- *Managing Externalities to Support the Aging Grid*: Since the Trump administration has done away with focusing on the climate, which was a focus from the Biden administration to counter inclement weather events, blackouts might become more common in areas with older grid assets. A proper plan must be created to either weatherize critical points on the grid or return to clean energy storage and production to combat these weather events from occurring.

- *Meeting Export Goals and Lowering Consumer Prices*: The Trump administration has strategically begun to export LNG towards areas to disrupt local supply chains abroad. This is a critical element of national and economic security, yet it leaves domestic energy prices high when exports are prioritized over American consumers. When global LNG prices are low, exports must increase to meet revenue goals. A balance must be struck between putting America first to lower energy prices and disrupting global economic chains for security purposes.

- *National Security Risks From Energy Source Concentration*: As seen in China in the 1990s, when heavy emphasis is placed on the production of fossil fuels and global prices for those resources are low, it is more economical to import energy or diversify the power grid.[ccxcvi] If the U.S. were to place heavy emphasis on LNG and coal exports, combined with poor global markets, the goal of energy independence pursued by the Trump administration might come at a financial cost rather than financial freedom.

## **VII. Conclusion**

The U.S. has much to gain from strengthening grid infrastructure—expansion of industry, bolstered cybersecurity, faster technological innovation, reduced electricity prices, and sustainable energy production to mitigate damage from climate change. If public and private players are not galvanized into collective action, if the current administration's priorities are not clearly stated or productively implemented, or if world events take focus away from long-run goals, the consequences of a weaker power grid than China will be apparent in the years to come.

President Trump issued EO 14154 "Unleashing American Energy," which prioritizes development absent externality concerns or efforts from President Biden's climate and efficiency standards.[ccxcvii] These points are reiterated in the president's "Big Beautiful Bill," also quoting stripped tax credits on renewables.[ccxcviii] Utility companies are hesitant of the administration's energy goals, which may lead to investor decisions independent of EOs. Although expanding renewable energy is not a central goal of the administration, it should be prioritized given its benefits. Solar, wind, and hydroelectric power well for lowering costs for end-users, increasing energy independence and helping grow energy storage capabilities.

Next generation power production, transmission, distribution, and storage make it possible to deliver electricity to consumers even when demand for power is at its peak. Fossil fuels contribute to baseload electricity production and can help bridge the gap as the U.S. works towards a more reliable grid. Investment in generation, transmission, distribution, and storage is critical for grid security and will enable emerging technologies to help lower electricity prices. Current policy focuses on increasing generation capacity in a time of high electricity demand, slowing investment into technologies that can improve the efficiency, reliability, and security of the power grid. Striking a balance between meeting energy demand and modernizing grid technology through investment is—and will remain for the foreseeable future—the leading challenge for the power grid.

## Appendix [A]

| Executive Order | Date | Deliverables | Summary |
|---|---|---|---|
| Unleashing American Energy (EO 14154) | January 20th, 2025 | Agencies must issue regulatory-review plans within 30 days. Revokes 12 existing climate/environment EOs. | EO 14154 declares that regulatory burdens have crippled U.S. energy production and sets a policy to "unleash" American energy. It orders all agencies to review and rescind rules impeding oil, gas, coal, hydropower, biofuel, nuclear, and critical mineral development, with 30-day agency plans to suspend or rescind burdensome regulations. It revokes a suite of prior climate/environmental EOs (12 Biden-era orders including EOs 13990, 14008, 14037, etc.) and terminates programs like the American Climate Corps. CEQ is directed to rewrite NEPA regulations within 30 days to fast-track energy projects. The outcome is a sweeping rollback of environmental regulations in favor of maximum energy development. |
| Establishing the National Energy Dominance Council (EO 14213) | February 14th, 2025 | Council membership: ~18 top officials (Energy, Defense, Agriculture, etc.). 100-day deadline for strategy/action-plan report. No discernable public records for meetings. | EO 14213 creates the National Energy Dominance Council, chaired by the Interior Secretary (and Vice-Chair by the Energy Secretary). The Council, comprising ~18 Cabinet and agency heads, advises the President on boosting all forms of energy production and streamlining related regulations. It must deliver within 100 days a National Energy Dominance Strategy with long-range goals (cutting red tape, spurring private investment) and action plans (e.g. new pipelines to underserved regions, reopening plants, approving small modular reactors). The order integrates this council into the National Security Council (Sec. 6) and requires agencies to cooperate, aiming to accelerate energy permits and production. |
| Zero-Based Regulatory Budgeting to Unleash American Energy (EO 14270) | April 9th, 2025 | Covered agencies include EPA, DOE, FERC, NRC, and Interior bureaus (BLM, BOEM, etc.); All covered energy regs get 1-year sunsets by Sep 30, 2025 (renewable up to 5 years). | EO 14270 mandates a "zero-based" approach to energy regulations. Covered agencies (EPA, DOE, FERC, NRC, Interior bureaus, Army Corps) must justify all existing rules and impose sunset dates on them. Each covered regulation receives an initial 1-year sunset (extensions by 1-year up to 5 years) unless agencies affirmatively reauthorize it. Agencies must propose rescissions of rules that lack current justification. The outcome is a massive rollback of outdated energy regs: agencies effectively rebuild their regulatory code from scratch under this budgeting system. |
| Protecting American Energy From State Overreach (EO 14260) | April 8th, 2025 | Cites "billions in fines" under state laws targeting fossil fuel companies; Targets state regulations/litigation in ~30 states. | EO 14260 directs the Attorney General and agencies to counter state/local measures that unfairly penalize U.S. energy producers. It cites examples of state "climate extortion" laws—such as New York and Vermont imposing retroactive "billions in fines" on past oil and gas production—and orders the DOJ to identify and challenge state taxes, fees, or lawsuits that unlawfully burden domestic energy industries. Outcomes include federal efforts to preempt or invalidate state climate taxes, stringent fines, or permitting bans that threaten national energy supply. |

| | | | |
|---|---|---|---|
| Reinvigorating America's Beautiful Clean Coal Industry and Amending Executive order 14241 (EO 14261) | April 8th, 2025 | "Hundreds of thousands" of American jobs in coal; reserves worth "trillions". Deadlines: 60-day coal resource report; 30–60-day rescind actions. | EO 14261 proclaims coal a vital and "beautiful" energy resource. It notes coal's importance (supporting "hundreds of thousands" of jobs and containing "trillions of dollars" in reserves). The EO directs Interior to assess federal coal deposits and leasing barriers (60-day report), rescinds the 2016 "Energy Pauses," resumes and expedites coal leasing and exports, and requires EPA and others to rescind rules that disadvantage coal (including tax credits and appliance bans). It also designates coal (incl. metallurgical) as a critical energy mineral. Outcome: reversal of coal restrictions and aggressive promotion of coal mining, power generation, and technology. |
| Strengthening the Reliability and Security of the U.S. Electric Grid (EO 14262) | April 8th, 2025 | 30-day deadline for DOE to set reserve margin standards (90-day report). 50 MW threshold: larger generators cannot leave low-capacity regions | EO 14262 uses emergency authority to bolster grid resilience amid rising demand. It directs DOE to invoke Federal Power Act §202(c) to order power deliveries when needed to prevent blackouts. Within 30 days DOE must develop a uniform regional reserve margin metric (with a 90-day analysis) to identify low-capacity areas. Crucially, the order bars generators over 50 MW from relocating out of regions with insufficient reserves, preventing loss of capacity. Outcome: strengthened DOE authority to manage energy supply and new rules to maintain adequate grid reserves in key regions. |
| Unleashing America's Offshore Critical Minerals and Resources (EO 14285) | April 24th, 2025 | 60-day Commerce report on industry interest and licenses. Target minerals: deep-sea "nodules" containing Ni, Co, Cu, Mn, REEs | EO 14285 promotes U.S. deep-sea mineral development. It highlights U.S. jurisdiction over abundant seabed nodules (rich in nickel, cobalt, copper, manganese, rare earths). Commerce (via NOAA) is ordered to expedite permits/licenses under the Deep Seabed Hard Mineral Resources Act and to report within 60 days on private-sector interest in deep-sea mining. The EO directs agencies (Defense, Energy, etc.) to use defense authorities (stockpiles, Defense Production Act) to finance and support deep-sea mining technology, and to engage allies on benefit-sharing. Outcome: streamlined federal support for offshore minerals exploration and reduced reliance on foreign suppliers. |
| Immediate Measures to Increase American Mineral Production (EO 14241) | March 20th, 2025 | Deadlines: 10-day list of key deposits; 30-day priority land designation. DPA Title III delegated for financing and stockpiling critical minerals. | EO 14241 orders rapid action to boost domestic mining of critical minerals. Agencies must inventory priority mineral projects (oil, gas, helium, REEs, battery materials) and expedite the top sites for permitting. The Defense Secretary is delegated DPA Title III authority to designate strategic mineral projects, and the International Development Finance Corporation is authorized to fund mining ventures. A $10B+ National Critical Minerals Fund is created by reallocating existing DPA funds. Outcome: accelerated permits, funding, and project planning to expand U.S. mineral output. |

| | | | |
|---|---|---|---|
| Ensuring National Security and Economic Resilience Through Section 232 Actions on Processed Critical Minerals and Derivative Products (EO 14272) | April 15th, 2025 | Section 232 timeline: 90-day interim report, 180-day final report. Focus on value-added imports for batteries, defense, tech industries. | EO 14272 directs Commerce to initiate a Section 232 investigation into imports of processed critical minerals (oxides, salts, metals) and derivative products (e.g. batteries, semiconductors, EVs) essential to security. Noting U.S. reliance on foreign sources, it sets a 90-day deadline for an interim report and 180 days for a final determination. Commerce is to consider tariffs, quotas, or incentives to strengthen domestic processing capacity. Outcome: potential trade actions (like tariffs or quotas) or incentives for reducing vulnerabilities. |
| Declaring a National Energy Emergency (EO 14156) | January 20th, 2025 | 30-day deadlines to report emergency CWA/ESA projects. 60-day DOD assessment of energy vulnerabilities (2808 authority invoked). | EO 14156 declares a national emergency due to inadequate U.S. energy supply and hostile foreign leverage. It orders agencies to use all emergency powers (including eminent domain and the Defense Production Act) to expedite energy projects, and EPA to consider fuel supply waivers. To fast-track infrastructure, it requires within 30 days the identification of projects eligible for emergency Clean Water Act and ESA permitting provisions, and to use those provisions to accelerate approvals. It tasks DOD with a 60-day assessment of military fuel/vulnerabilities and invokes 10 U.S.C. § 2808 for needed construction. Outcome: maximum federal action to remove delays on pipelines, drilling, and power projects under the emergency. |
| Deploying Advanced Nuclear Reactor Technologies for National Security (EO 14299) | May 23rd, 2025 | Army reactor deadline: by 9/30/2028<br>; 20 metric tons of HALEU committed to a fuel bank; Target 20 new nuclear cooperation agreements. | EO 14299 accelerates advanced nuclear (Gen III+, small modular, microreactors) for defense needs. It requires the Army to operate an on-base reactor by Sept 30, 2028, and designates the Army as DOD's nuclear energy executive agent. DOE must identify AI/data centers as critical infrastructure and select sites for advanced reactors (with the goal of first operation ~30 months out). The order establishes a fuel bank, releasing at least 20 metric tons of HALEU for authorized private reactor projects. It also directs the State Dept to pursue 20 new nuclear cooperation (Section 123) agreements globally, and DOE to approve reactor export licenses within 30 days. Outcome: catalyzes deployment of cutting-edge reactors in U.S. defense and expands U.S. nuclear exports. |
| Ordering the Reform of the Nuclear Regulatory Commission (EO 14300) | May 23rd, 2025 | Nuclear capacity target: ~100 GW today → 400 GW by 2050. License-review deadlines: 18 months for new reactors, 1 year for renewals. | EO 14300 overhauls the NRC to speed nuclear growth. It notes that between 1954–1978 the U.S. licensed 133 reactors, whereas only 2 have since become operational, and it sets a goal to expand U.S. nuclear capacity from ~100 GW to 400 GW by 2050. The NRC must reorganize (streamline staff, cut excess, reduce ACRS oversight and "wholesale" rewrite its regulations: proposed new rules are due in 9 months and final in 18 months. New NRC rules must impose strict timelines (≤18 months to approve a new reactor, ≤1 year for license renewal) with corresponding fee caps. It also orders NRC to replace linear no-threshold radiation standards with science-based limits and to create expedited pathways for vetted reactor designs. Outcome: dramatically faster licensing and reduced regulatory barriers. |

| | | | |
|---|---|---|---|
| Reforming Nuclear Reactor Testing at the Department of Energy (EO 14301) | May 23rd, 2025 | 60-day deadline to define “qualified test reactor,” 90-day to finalize DOE review rules. Approve ≥ 3 outside-lab test reactors (critical by 7/4/2026). | EO 14301 reforms DOE’s approach to testing advanced reactors. It defines “qualified test reactors” and orders DOE to revise regulations so such reactors can be built and operational within 2 years of a complete application. DOE must create interagency support teams to assist applicants and prioritize qualified test reactor projects. It establishes a pilot program outside national labs to approve ≥3 reactor designs, aiming for all to achieve criticality by July 4, 2026. It also directs DOE, with CEQ, to overhaul its NEPA compliance by June 30, 2025, creating categorical exclusions and expedited reviews for these projects. Outcome: DOE is enabled to rapidly prototype and test advanced nuclear designs. |
| Reinvigorating the Nuclear Industrial Base (EO 14302) | May 23rd, 2025 | Current U.S. nuclear capacity: ~100 GW; goal 400 GW by 2050. DOE to enable 5 GW uprates and 10 new reactors by 2030. Deadlines: 240-day fuel policy report; 120-day enrichment plan; 30-day DPA agreements. | EO 14302 directs broad measures to rebuild the U.S. nuclear supply chain and workforce. It tasks DOE (with DOD and OMB) with, within 240 days, a national policy/report on spent fuel management and advanced fuel cycle capability. Within 120 days, DOE and NRC must plan to expand domestic uranium conversion/enrichment to meet future LEU/HALEU needs. It halts the dilute-and-dispose plutonium program, instead directing surplus *Pu* to be processed into advanced reactor fuel. Using DPA authorities, DOE has 30 days to seek voluntary agreements with U.S. nuclear companies for cooperative LEU/HALEU procurement. DOE is also charged to prioritize 5 GW of uprates to existing reactors and 10 new reactors under construction by 2030 via loans/grants. Workforce initiatives include treating nuclear apprenticeships as a priority (per EO 14278) and directing Labor/Education within 120 days to expand nuclear vocational training. Outcome: stronger domestic fuel production (enrichment, recycling), industry-led investment, and skilled labor for a nuclear expansion. |

## Appendix [B]

| Technology | Stage of Development | Barriers to Large-scale Adoption | Expected Timeline for Commercialization |
|---|---|---|---|
| | *Fossil Fuel Power* | | |
| CCUS | Early Commercial | High initial investment | Rapid growth (current-2030) |
| DAC | Early Commercial | High operational costs | Rapid growth (current-2030) |
| USC Plants | Emerging Commercial | High capital costs | Near-term (~2030) |
| Oxy-Fuel | Experimental/Pilot | Technological complexity | Mid-term (2030-2040) |
| | *Nuclear Power* | | |
| SMRs | Early Commercial | Higher variable costs and nuclear waste | Near-term (~2030) |
| Fast Reactors | Emerging | Technological and regulatory complexity | Near-term (~2030) |
| MSRs | Experimental/Pilot | Material durability and lack of experience | Mid-term (2030-2050) |
| Fusion | Experimental | Major technical challenges | Rapid growth (current-2030) |
| | *Renewable Power* | | |
| Offshore Wind | Emerging Commercial | High infrastructure costs | Rapid growth (current-2030) |
| Next-Gen Turbines | Early Commercial | Manufacturing difficulty | Rapid growth (current-2030) |
| Tidal Power | Experimental/Pilot | Material durability and ecological damage | Mid-term (2030-2050) |
| Hydrokinetic | Experimental/Pilot | Limited suitable sites | Mid-term (2030-2040) |
| Bifacial Panels | Commercial | Tariffs on imports and supply chain constraints | Currently widespread |
| Solar Tracking | Commercial | Added costs and maintenance | Currently widespread |
| Floating solar | Early Commercial | Infrastructure complexity | Near-term (~2030) |
| SBSP | Experimental | Extremely high costs | Long-term (~2050) |
| EGS | Experimental/Pilot | Geological uncertainties | Mid-term (2030-2035) |
| | *Transmission* | | |
| UHV Lines | Experimental/Pilot | Infrastructure costs | Rapid growth (current-2030) |
| HVDC | Early Commercial | Infrastructure costs | Rapid growth (current-2030) |
| Superconducting Lines | Experimental/Pilot | High capital costs | Mid-term (2030-2040) |
| | *Distribution* | | |

| | | | |
|---|---|---|---|
| Smart Grid | Early Commercial | High levels of data complexity | Rapid growth (current-2030) |
| WAM | Early Commercial | Security concerns | Rapid growth (current-2030) |
| | *Storage* | | |
| PSH | Commercial | Environmental impacts | Currently widespread |
| Flow Batteries | Early Commercial | High initial costs | Near-term (~2030) |
| Solid-State Batteries | Experimental/Pilot | Limited Scale | Mid-term (2030-2035) |
| Hydrogen Storage | Experimental | High energy losses | Long term (2040-2050) |
| Iron-Air Batteries | Early Commercial | Scaling costs | Near-term (~2030) |

## Endnotes

[i] Siripurapu, James McBride, Anshu. n.d. "How Does the U.S. Power Grid Work? | Council on Foreign Relations." Accessed June 3, 2025. https://www.cfr.org/backgrounder/how-does-us-power-grid-work.

[ii] Siripurapu, James McBride, Anshu. n.d. "How Does the U.S. Power Grid Work? | Council on Foreign Relations." Accessed June 3, 2025. https://www.cfr.org/backgrounder/how-does-us-power-grid-work.

[iii] Lawson, Ashley J. "Electricity: Overview and Issues for Congress." Congress.gov, February 14, 2025. https://www.congress.gov/crs-product/R47521.

[iv] "Frequently Asked Questions (FAQs) - U.S. Energy Information Administration (EIA)." Accessed June 26, 2025. https://www.eia.gov/tools/faqs/faq.php?id=427&t=3.

[v] "Frequently Asked Questions (FAQs) - U.S. Energy Information Administration (EIA)." Accessed June 26, 2025. https://www.eia.gov/tools/faqs/faq.php?id=427&t=3.

[vi] "Frequently Asked Questions (FAQs) - U.S. Energy Information Administration (EIA)." Accessed June 26, 2025. https://www.eia.gov/tools/faqs/faq.php?id=427&t=3.

[vii] "Frequently Asked Questions (FAQs) - U.S. Energy Information Administration (EIA)." Accessed June 23, 2025. https://www.eia.gov/tools/faqs/faq.php?id=427&t=3.

[viii] Institute, Energy. "Home." Statistical review of world energy. Accessed June 25, 2025. https://www.energyinst.org/statistical-review/home.

[ix] Kennedy, Rebecca Leppert and Brian. "Growing Share of Americans Favor More Nuclear Power." *Pew Research Center* (blog), August 5, 2024. https://www.pewresearch.org/short-reads/2024/08/05/majority-of-americans-support-more-nuclear-power-in-the-country/.

[x] Rehm, Thomas E. "Advanced Nuclear Energy: The Safest and Most Renewable Clean Energy." *Current Opinion in Chemical Engineering* 39 (March 1, 2023): 100878. https://doi.org/10.1016/j.coche.2022.100878.

[xi] "Generation IV Goals, Technologies and GIF R&D Roadmap | GIF Portal." Accessed June 17, 2025. https://www.gen-4.org/generation-iv-criteria-and-technologies.

[xii] IAEA. "Nuclear Technology Review 2024." Nuclear Technology in Review. Accessed June 25, 2025. https://www.iaea.org/sites/default/files/gc/gc68-inf-4.pdf.

[xiii] "U.S. Nuclear Industry - U.S. Energy Information Administration (EIA)." Accessed June 17, 2025. https://www.eia.gov/energyexplained/nuclear/us-nuclear-industry.php.

[xiv] "Frequently Asked Questions (FAQs) - U.S. Energy Information Administration (EIA)." Accessed June 23, 2025. https://www.eia.gov/tools/faqs/faq.php?id=427&t=3.

[xv] "Where Wind Power Is Harnessed - U.S. Energy Information Administration (EIA)." Accessed June 18, 2025. https://www.eia.gov/energyexplained/wind/where-wind-power-is-harnessed.php.

[xvi] "Map: Projected Growth of the Wind Industry From Now Until 2050 | Department of Energy." Accessed June 27, 2025. https://www.energy.gov/map-projected-growth-wind-industry-now-until-2050.

[xvii] "Solar and Wind to Lead Growth of U.S. Power Generation for the next Two Years - U.S. Energy Information Administration (EIA)." Accessed June 26, 2025. https://www.eia.gov/todayinenergy/detail.php?id=61242.

[xviii] "Frequently Asked Questions (FAQs) - U.S. Energy Information Administration (EIA)." Accessed June 23, 2025. https://www.eia.gov/tools/faqs/faq.php?id=427&t=3.

[xix] Energy.gov. "Hydropower Basics." Accessed June 17, 2025. https://www.energy.gov/eere/water/hydropower-basics.

[xx] DOE Office of Energy Efficiency and Renewable Energy. "$400 Million To Support Rural and Remote Clean Energy Projects Coming Soon." Accessed June 20, 2025. https://content.govdelivery.com/accounts/USEERE/bulletins/3b4dff3.

[xxi] "Frequently Asked Questions (FAQs) - U.S. Energy Information Administration (EIA)." Accessed June 23, 2025. https://www.eia.gov/tools/faqs/faq.php?id=427&t=3.

[xxii] "Capacity Factors for Electrical Power Generation from Renewable and Nonrenewable Sources | PNAS." Accessed June 25, 2025. https://www.pnas.org/doi/10.1073/pnas.2205429119.

[xxiii] Kumba, Krishna, Patri Upender, Parusharamulu Buduma, Mithu Sarkar, Sishaj P. Simon, and Venkateswarlu Gundu. "Solar Tracking Systems: Advancements, Challenges, and Future Directions: A Review." *Energy Reports* 12 (December 1, 2024): 3566–83. https://doi.org/10.1016/j.egyr.2024.09.038.

[xxiv] Kulasekara, Hasal, and Vaithehi Seynulabdeen. "A Review of Geothermal Energy for Future Power Generation." In *2019 5th International Conference on Advances in Electrical Engineering (ICAEE)*, 223–28, 2019. https://doi.org/10.1109/ICAEE48663.2019.8975470.

[xxv] Olasolo, P., M. C. Juárez, M. P. Morales, Sebastiano D´Amico, and I. A. Liarte. "Enhanced Geothermal Systems (EGS): A Review." *Renewable and Sustainable Energy Reviews* 56 (April 1, 2016): 133–44. https://doi.org/10.1016/j.rser.2015.11.031.

[xxvi] AIP. "FY24 Budget Outlook: DOE Applied Energy R&D," September 22, 2023. https://www.aip.org/fyi/fy24-budget-outlook-doe-applied-energy-r-d.

[xxvii] Arciniegas Rueda, Ismael, Fiona Quimbre, Henri van Soest, and Avery Krovetz. "The U.S. Must Close the Long-Distance Power Transmission Gap with China," January 16, 2024. https://www.rand.org/pubs/commentary/2024/01/the-us-must-close-the-long-distance-power-transmission.html.

[xxviii] "National Transmission Needs Study | Department of Energy." Accessed June 25, 2025. https://www.energy.gov/gdo/national-transmission-needs-study.

[xxix] "eTool : Electric Power Generation, Transmission, and Distribution - Illustrated Glossary - Substations | Occupational Safety and Health Administration." Accessed June 25, 2025. https://www.osha.gov/etools/electric-power/illustrated-glossary/sub-station.

[xxx] Energy.gov. "Grid Resilience and Innovation Partnerships (GRIP) Program." Accessed June 23, 2025. https://www.energy.gov/gdo/grid-resilience-and-innovation-partnerships-grip-program.

[xxxi] IEA. "Energy Storage." Accessed June 18, 2025. https://www.iea.org/energy-system/electricity/grid-scale-storage.

[xxxii] "Grid-Scale Storage Is the Fastest-Growing Energy Technology." Accessed June 18, 2025. https://www.economist.com/the-world-ahead/2024/11/20/grid-scale-storage-is-the-fastest-growing-energy-technology.

[xxxiii] "Electric Power Annual - U.S. Energy Information Administration (EIA)." 2024. Accessed June 3, 2025. https://www.eia.gov/electricity/annual/table.php.

[xxxiv] "Electric Power Annual - U.S. Energy Information Administration (EIA)." 2024. Accessed June 3, 2025. https://www.eia.gov/electricity/annual/table.php.

[xxxv] Schittekatte, Tim, Dharik Mallapragada, Paul L. Joskow, and Richard Schmalensee. "Electricity Retail Rate Design in a Decarbonizing Economy: An Analysis of Time-of-Use and Critical Peak Pricing." *The Energy Journal* 45, no. 3 (May 1, 2024): 25–56. https://doi.org/10.5547/01956574.45.3.tsch.

[xxxvi] "Electric Power Annual - U.S. Energy Information Administration (EIA)." Accessed June 3, 2025. https://www.eia.gov/electricity/annual/table.php.

[xxxvii] White, Kit. "Energy Markets 101: Regional Transmission Organizations, Independent System Operators and Energy Efficiency | Midwest Energy Efficiency Alliance." Midwest Energy Efficiency Alliance (MEEA), September 9, 2024. https://www.mwalliance.org/blog/energy-markets-101-regional-transmission-organizations-independent-system-operators-and-energy.

[xxxviii] "RTOs: The 'air Traffic Controllers' of the U.S. Electric Grid | NMPP Energy - Reliable, Cost-Based Energy." Accessed June 5, 2025. https://www.nmppenergy.org/energy-education/rtos-air-traffic-controllers-us-electric-grid.

[xxxix] "RTOs: The 'air Traffic Controllers' of the U.S. Electric Grid | NMPP Energy - Reliable, Cost-Based Energy." Accessed June 5, 2025. https://www.nmppenergy.org/energy-education/rtos-air-traffic-controllers-us-electric-grid.

[xl] "RTOs: The 'air Traffic Controllers' of the U.S. Electric Grid | NMPP Energy - Reliable, Cost-Based Energy." Accessed June 5, 2025. https://www.nmppenergy.org/energy-education/rtos-air-traffic-controllers-us-electric-grid.

[xli] White, Kit. "Energy Markets 101: Regional Transmission Organizations, Independent System Operators and Energy Efficiency | Midwest Energy Efficiency Alliance." Midwest Energy Efficiency Alliance (MEEA), September 9, 2024. https://www.mwalliance.org/blog/energy-markets-101-regional-transmission-organizations-independent-system-operators-and-energy.

[xlii] The White House. "Executive Orders Archives," June 19, 2025. https://www.whitehouse.gov/presidential-actions/executive-orders/.

[xliii] Council on Foreign Relations. "Timeline: Oil Dependence and U.S. Foreign Policy." Council on Foreign Relations, 2023. https://www.cfr.org/timeline/oil-dependence-and-us-foreign-policy.

[xliv] DOS. "Foreign Relations of the United States, 1969–1976, Volume XXXVI, Energy Crisis, 1969–1974 - Office of the Historian." history.state.gov, n.d. https://history.state.gov/historicaldocuments/frus1969-76v36/d237.

[xlv] National Farmers Union. "A Selected Timeline of U.S. Energy," n.d. https://nfu.org/images/stories/education/Materials/Energy%20Curriculum/FINAL%20History%20of%20U.S.%20Energy.pdf.

[xlvi] Bracmort, Kelsi, Brown, Phillip, Clark, Corrie E., Holt, Mark, Lawson, Ashley J., Offutt, Martin C., Parfomak, Paul W., Ratner, Michael, Ryan, Lexie, and Yacobucci, Brent D. "U.S. Energy Supply and Use: Background and Policy Primer." Congress.gov, March 14, 2024. https://www.congress.gov/crs-product/R47980.

[xlvii] Tuttle, David , Gurcan Gulen, Robert Hebner, Carey King, David Spence, Juan Andrade, Jason Wible, Ross Baldick, and Roger Duncan. "The History and Evolution of the U.S. Electricity Industry." University of Texas at Austin Energy Institute, May 2, 2016. https://energy.utexas.edu/sites/default/files/UTAustin_FCe_History_2016.pdf.

[xlviii] National Farmers Union. "A Selected Timeline of U.S. Energy," n.d. https://nfu.org/images/stories/education/Materials/Energy%20Curriculum/FINAL%20History%20of%20U.S.%20Energy.pdf.

[xlix] Council on Foreign Relations. "Timeline: Oil Dependence and U.S. Foreign Policy." Council on Foreign Relations, 2023. https://www.cfr.org/timeline/oil-dependence-and-us-foreign-policy.

[l] Brown, Stephen, and Mine Yucel. "The Shale Gas and Tight Oil Boom." Council on Foreign Relations, 2013. https://www.cfr.org/report/shale-gas-and-tight-oil-boom.

[li] WANG, ZHONGMIN, and ALAN KRUPNICK. "What Led to the Boom?" *Economics of Energy & Environmental Policy* 4, no. 1 (2015): 5–18. https://doi.org/10.2307/26189470.

[lii] Rapier, Robert. "How the Shale Boom Turned the World Upside Down." Forbes, April 21, 2017. https://www.forbes.com/sites/rrapier/2017/04/21/how-the-shale-boom-turned-the-world-upside-down/.

[liii] Lawson, Ashley J. "Electricity: Overview and Issues for Congress." Congress.gov, February 14, 2025. https://www.congress.gov/crs-product/R47521.

[liv] National Farmers Union. "A Selected Timeline of U.S. Energy," n.d. https://nfu.org/images/stories/education/Materials/Energy%20Curriculum/FINAL%20History%20of%20U.S.%20Energy.pdf.

[lv] Siripurapu, James McBride, Anshu. "How Does the U.S. Power Grid Work? | Council on Foreign Relations." Accessed June 3, 2025. https://www.cfr.org/backgrounder/how-does-us-power-grid-work.

[lvi] Lawson, Ashley J. "Electricity: Overview and Issues for Congress." Congress.gov, February 14, 2025. https://www.congress.gov/crs-product/R47521.

[lvii] Siripurapu, James McBride, Anshu. "How Does the U.S. Power Grid Work? | Council on Foreign Relations." Accessed June 3, 2025. https://www.cfr.org/backgrounder/how-does-us-power-grid-work.

[lviii] "Electric Power Annual - U.S. Energy Information Administration (EIA)." 2024. Accessed June 3, 2025. https://www.eia.gov/electricity/annual/table.php.

[lix] "Electric Power Annual - U.S. Energy Information Administration (EIA)." Accessed June 3, 2025. https://www.eia.gov/electricity/annual/table.php.

[lx] Giacobone, Phoebe Skok, Bianca. "The US Interconnection Queue Is Twice Its Installed Capacity." *Latitude Media* (blog), April 11, 2024. https://www.latitudemedia.com/news/the-us-interconnection-queue-is-twice-its-installed-capacity/.

[lxi] "Electric Power Annual - U.S. Energy Information Administration (EIA)." Accessed June 3, 2025. https://www.eia.gov/electricity/annual/table.php.

[lxii] Hamdan, Ahmad, Cosmas Dominic Daudu, Adefunke Fabuyide, Emmanuel Augustine Etukudoh, and Sedat Sonko. "Next-Generation Batteries and U.S. Energy Storage: A Comprehensive Review: Scrutinizing Advancements in Battery Technology, Their Role in Renewable Energy, and Grid Stability." *World Journal of Advanced Research and Reviews* 21, no. 1 (2024): 1984–98. https://doi.org/10.30574/wjarr.2024.21.1.0256.

[lxiii] Council on Foreign Relations. "Timeline: Oil Dependence and U.S. Foreign Policy." Council on Foreign Relations, 2023. https://www.cfr.org/timeline/oil-dependence-and-us-foreign-policy.

[lxiv] The White House. "Executive Orders Archives," June 19, 2025. https://www.whitehouse.gov/presidential-actions/executive-orders/.

[lxv] The White House. "Executive Orders Archives," June 19, 2025. https://www.whitehouse.gov/presidential-actions/executive-orders/.

[lxvi] The White House. "Executive Orders Archives," June 19, 2025. https://www.whitehouse.gov/presidential-actions/executive-orders/.

[lxvii] "2025 Report Card for America's Infrastructure: Energy (D+)." American Society of Civil Engineers, January 17, 2017. https://infrastructurereportcard.org/cat-item/energy-infrastructure/.

[lxviii] Cochran, Courtney. "Fortifying the Grid in the Southeastern U.S. through Microgrids: Navigating an Uncertain Regulatory Environment." *Environmental Progress & Sustainable Energy* 43, no. 1 (2024): 1–16. https://doi.org/10.1002/ep.14337.

[lxix] Directors, Clarion Energy Content. "Going Underground: European Transmission Practices." *Factor This™* (blog), October 1, 2011. https://www.renewableenergyworld.com/power-grid/grid-modernization/going-underground-european-transmission-practices/.

[lxx] "Nuclear Power in the USA - World Nuclear Association." Accessed June 26, 2025. https://world-nuclear.org/information-library/country-profiles/countries-t-z/usa-nuclear-power.

[lxxi] "2025 Report Card for America's Infrastructure: Energy (D+)." American Society of Civil Engineers, January 17, 2017. https://infrastructurereportcard.org/cat-item/energy-infrastructure/.

[lxxii] "2025 Report Card for America's Infrastructure: Energy (D+)." American Society of Civil Engineers, January 17, 2017. https://infrastructurereportcard.org/cat-item/energy-infrastructure/.

[lxxiii] "2025 Report Card for America's Infrastructure: Energy (D+)." American Society of Civil Engineers, January 17, 2017. https://infrastructurereportcard.org/cat-item/energy-infrastructure/.

[lxxiv] "2025 Report Card for America's Infrastructure: Energy (D+)." American Society of Civil Engineers, January 17, 2017. https://infrastructurereportcard.org/cat-item/energy-infrastructure/.

[lxxv] "2025 Report Card for America's Infrastructure: Energy (D+)." American Society of Civil Engineers, January 17, 2017. https://infrastructurereportcard.org/cat-item/energy-infrastructure/.

[lxxvi] "2025 Report Card for America's Infrastructure: Energy (D+)." American Society of Civil Engineers, January 17, 2017. https://infrastructurereportcard.org/cat-item/energy-infrastructure/.

[lxxvii] Cochran, Courtney. "Fortifying the Grid in the Southeastern U.S. through Microgrids: Navigating an Uncertain Regulatory Environment." *Environmental Progress & Sustainable Energy* 43, no. 1 (2024): 1–16. https://doi.org/10.1002/ep.14337.

[lxxviii] Motyka, Marlene, Keith Adams, Micah Bible, Kate Hardin, Jaya Nagdeo, and Brian Boufarah. "Funding the Growth in the US Power Sector." *Deloitte Insights*, February 26, 2025. https://www2.deloitte.com/us/en/insights/industry/power-and-utilities/funding-growth-in-us-power-sector.html.

[lxxix] Institute for Energy Research. "U.S. Utility Industry Needs $1.4 Trillion Investment." *IER* (blog), May 1, 2025. https://www.instituteforenergyresearch.org/the-grid/u-s-utility-industry-needs-1-4-trillion-investment/.

[lxxx] "2025 Report Card for America's Infrastructure: Energy (D+)." American Society of Civil Engineers, January 17, 2017. https://infrastructurereportcard.org/cat-item/energy-infrastructure/.

[lxxxi] Smith, Adam B. "U.S. Billion-Dollar Weather and Climate Disasters, 1980 - Present (NCEI Accession 0209268)." NOAA National Centers for Environmental Information, 2020. https://doi.org/10.25921/STKW-7W73.

[lxxxii] Cochran, Courtney. "Fortifying the Grid in the Southeastern U.S. through Microgrids: Navigating an Uncertain Regulatory Environment." *Environmental Progress & Sustainable Energy* 43, no. 1 (2024): 1–16. https://doi.org/10.1002/ep.14337.

[lxxxiii] "2025 Report Card for America's Infrastructure: Energy (D+)." American Society of Civil Engineers, January 17, 2017. https://infrastructurereportcard.org/cat-item/energy-infrastructure/.

[lxxxiv] "2025 Report Card for America's Infrastructure: Energy (D+)." American Society of Civil Engineers, January 17, 2017. https://infrastructurereportcard.org/cat-item/energy-infrastructure/.

[lxxxv] "2025 Report Card for America's Infrastructure: Energy (D+)." American Society of Civil Engineers, January 17, 2017. https://infrastructurereportcard.org/cat-item/energy-infrastructure/.

[lxxxvi] "2025 Report Card for America's Infrastructure: Energy (D+)." American Society of Civil Engineers, January 17, 2017. https://infrastructurereportcard.org/cat-item/energy-infrastructure/.

[lxxxvii] Directors, Clarion Energy Content. "Going Underground: European Transmission Practices." *Factor This™* (blog), October 1, 2011. https://www.renewableenergyworld.com/power-grid/grid-modernization/going-underground-european-transmission-practices/.

[lxxxviii] Biggar, Darryl R., and Mohammad Reza Hesamzadeh. "Crises in Texas and Australia: Failures of Energy-Only Markets or Unforeseen Consequences of Price Caps?" *Energy Economics* 137 (September 1, 2024): 107810. https://doi.org/10.1016/j.eneco.2024.107810.

[lxxxix] Biggar, Darryl R., and Mohammad Reza Hesamzadeh. "Crises in Texas and Australia: Failures of Energy-Only Markets or Unforeseen Consequences of Price Caps?" *Energy Economics* 137 (September 1, 2024): 107810. https://doi.org/10.1016/j.eneco.2024.107810.

[xc] Biggar, Darryl R., and Mohammad Reza Hesamzadeh. "Crises in Texas and Australia: Failures of Energy-Only Markets or Unforeseen Consequences of Price Caps?" *Energy Economics* 137 (September 1, 2024): 107810. https://doi.org/10.1016/j.eneco.2024.107810.

[xci] Biggar, Darryl R., and Mohammad Reza Hesamzadeh. "Crises in Texas and Australia: Failures of Energy-Only Markets or Unforeseen Consequences of Price Caps?" *Energy Economics* 137 (September 1, 2024): 107810. https://doi.org/10.1016/j.eneco.2024.107810.

[xcii] Biggar, Darryl R., and Mohammad Reza Hesamzadeh. "Crises in Texas and Australia: Failures of Energy-Only Markets or Unforeseen Consequences of Price Caps?" *Energy Economics* 137 (September 1, 2024): 107810. https://doi.org/10.1016/j.eneco.2024.107810.

[xciii] Schittekatte, Tim, Dharik Mallapragada, Paul L. Joskow, and Richard Schmalensee. "Electricity Retail Rate Design in a Decarbonizing Economy: An Analysis of Time-of-Use and Critical Peak Pricing." *The Energy Journal* 45, no. 3 (May 1, 2024): 25–56. https://doi.org/10.5547/01956574.45.3.tsch.

[xciv] Biggar, Darryl R., and Mohammad Reza Hesamzadeh. "Crises in Texas and Australia: Failures of Energy-Only Markets or Unforeseen Consequences of Price Caps?" *Energy Economics* 137 (September 1, 2024): 107810. https://doi.org/10.1016/j.eneco.2024.107810.

[xcv] "UHV Power Transmission - an Overview | ScienceDirect Topics." Accessed June 18, 2025. https://www.sciencedirect.com/topics/engineering/uhv-power-transmission.

[xcvi] Arciniegas Rueda, Ismael, Fiona Quimbre, Henri van Soest, and Avery Krovetz. "The U.S. Must Close the Long-Distance Power Transmission Gap with China," January 16, 2024. https://www.rand.org/pubs/commentary/2024/01/the-us-must-close-the-long-distance-power-transmission.html.

[xcvii] Davis, Lucas W, Catherine Hausman, and Nancy L Rose. "NBER WORKING PAPER SERIES," n.d.

[xcviii] "Accelerated Transmission Line Approvals For Priority Projects | Norton Rose Fulbright." Accessed June 25, 2025. https://www.projectfinance.law/publications/2024/may/accelerated-transmission-line-approvals-for-priority-projects/.

[xcix] Alassi, Abdulrahman, Santiago Bañales, Omar Ellabban, Grain Adam, and Callum MacIver. "HVDC Transmission: Technology Review, Market Trends and Future Outlook." *Renewable and Sustainable Energy Reviews* 112 (September 1, 2019): 530–54. https://doi.org/10.1016/j.rser.2019.04.062.

[c] "On the Road to Increased Transmission: High-Voltage Direct Current | NREL." Accessed June 18, 2025. https://www.nrel.gov/news/detail/program/2024/on-the-road-to-increased-transmission-high-voltage-direct-current.

[ci] "Invenergy | Grain Belt Express Awards $1.7B to U.S. Contractors Quanta and Kiewit." Accessed June 23, 2025. https://invenergy.com/news/grain-belt-express-awards-1-7b-to-u-s-contractors-quanta-and-kiewit-to-build-largest-transmission-line-in-u-s-history.

[cii] Energy.gov. "DOE Announces $11M in High Voltage Direct Current Transmission Projects," November 5, 2024. https://www.energy.gov/oe/articles/doe-announces-11m-high-voltage-direct-current-transmission-projects.

[ciii] MIT News | Massachusetts Institute of Technology. "Startup Aims to Transform the Power Grid with Superconducting Transmission Lines," June 26, 2024. https://news.mit.edu/2024/veir-transforms-power-grid-with-superconducting-transmission-lines-0626.

[civ] Maguire, James, and Joseph McNamara. "Holbrook Substation Superconductor Cable System, Long Island, New York Final Report." Report. UNT Digital Library. American Superconductor Corporation, June 25, 2010. https://doi.org/10.2172/1046827.

[cv] "ComEd and AMSC Announce Successful Integration of Resilient Electric Grid System in Chicago - AMSC." Accessed June 25, 2025. https://www.amsc.com/comed-and-amsc-announce-successful-integration-of-resilient-electric-grid-system-in-chicago/.

[cvi] Tuballa, Maria Lorena, and Michael Lochinvar Abundo. "A Review of the Development of Smart Grid Technologies." *Renewable and Sustainable Energy Reviews* 59 (June 1, 2016): 710–25. https://doi.org/10.1016/j.rser.2016.01.011.

[cvii] Businelli, Nicole. "2024 Assessment of Demand Response and Advanced Metering," 2024.

[cviii] "Grid Resilience and Innovation Partnerships (GRIP) Program | Department of Energy." Accessed June 26, 2025. https://www.energy.gov/gdo/grid-resilience-and-innovation-partnerships-grip-program.

[cix] "Public Power Utility Projects Funded by DOE Include Microgrids, Smart Grid, and Grid Resilience | American Public Power Association." Accessed June 26, 2025. https://www.publicpower.org/periodical/article/public-power-utility-projects-funded-doe-include-microgrids-smart-grid-and-grid-resilience.

[cx] Khalid, Haris M., Farid Flitti, Magdi S. Mahmoud, Mutaz M. Hamdan, S. M. Muyeen, and Zhao Yang Dong. "Wide Area Monitoring System Operations in Modern Power Grids: A Median Regression Function-Based State Estimation Approach towards Cyber Attacks." *Sustainable Energy, Grids and Networks* 34 (June 1, 2023): 101009. https://doi.org/10.1016/j.segan.2023.101009.

[cxi] Phadke, Arun G., and Tianshu BI. "Phasor Measurement Units, WAMS, and Their Applications in Protection and Control of Power Systems." *Journal of Modern Power Systems and Clean Energy* 6, no. 4 (July 1, 2018): 619–29. https://doi.org/10.1007/s40565-018-0423-3.

[cxii] "Synchrophasors - GridWise Alliance," July 18, 2024. https://gridmap.gridwise.org/technologies/synchrophasors/.

cxiii Energy.gov. "Pumped Storage Hydropower." Accessed June 18, 2025. https://www.energy.gov/eere/water/pumped-storage-hydropower.

cxiv "Rye Development - DOE Grant Announcement." Accessed June 26, 2025. https://www.ryedevelopment.com/rye-development-doe-grant-lewis-ridge-pumped-storage.html.

cxv Zhang, Huamin, Wenjing Lu, and Xianfeng Li. "Progress and Perspectives of Flow Battery Technologies." *Electrochemical Energy Reviews* 2, no. 3 (September 1, 2019): 492–506. https://doi.org/10.1007/s41918-019-00047-1.

cxvi MIT News | Massachusetts Institute of Technology. "Flow Batteries for Grid-Scale Energy Storage," April 7, 2023. https://news.mit.edu/2023/flow-batteries-grid-scale-energy-storage-0407.

cxvii Nikolewski, Rob, and The San Diego Union-Tribune. "California Flips Switch on First Grid-Connected Flow Battery." GovTech, May 6, 2019. https://www.govtech.com/fs/California-Flips-Switch-on-First-Grid-Connected-Flow-Battery.html.

cxviii Sagadevan, Suresh, Mohd Rafie Johan, A. R. Marlinda, Omid Akbarzadeh, Karuppasamy Pandian, M. M. Shahid, Faruq Mohammad, and Jiban Podder. "Chapter One - Background of Energy Storage." In *Advances in Supercapacitor and Supercapattery*, edited by Numan Arshid, Mohammad Khalid, and Andrews Nirmala Grace, 1–26. Elsevier, 2021. https://doi.org/10.1016/B978-0-12-819897-1.00003-3.

cxix "Solid Power Selected by U.S. Department of Energy for Up to $50 Million Award Negotiation for Continuous Production of Sulfide-Based Solid Electrolyte Materials for Advanced All-Solid-State Batteries." Accessed June 23, 2025. https://www.solidpowerbattery.com/investor-relations/investor-news/news-details/2024/Solid-Power-Selected-by-U.S.-Department-of-Energy-for-Up-to-50-Million-Award-Negotiation-for-Continuous-Production-of-Sulfide-based-Solid-Electrolyte-Materials-for-Advanced-All-Solid-State-Batteries/default.aspx.

cxx Design and Development Today. "U.S. Department of Energy Funds $20 Million Toward Solid-State Batteries Maker," June 26, 2024. https://www.designdevelopmenttoday.com/industries/manufacturing/news/22913667/us-department-of-energy-funds-20-million-toward-solidstate-batteries-maker.

cxxi Dasgupta, Priyanka. "Balancing the Grid with Hydrogen Storage." IEC e-tech, February 8, 2024. https://etech.iec.ch/issue/2024-01/balancing-the-grid-with-hydrogen-storage.

cxxii Egeland-Eriksen, Torbjørn, Amin Hajizadeh, and Sabrina Sartori. "Hydrogen-Based Systems for Integration of Renewable Energy in Power Systems: Achievements and Perspectives." *International Journal of Hydrogen Energy* 46, no. 63 (September 13, 2021): 31963–83. https://doi.org/10.1016/j.ijhydene.2021.06.218.

cxxiii "H2@Scale: Enabling Affordable, Reliable, Clean, and Secure Energy across Sectors," n.d.

cxxiv "H2@Scale | Department of Energy." Accessed June 18, 2025. https://www.energy.gov/eere/fuelcells/h2scale.

cxxv "How Iron-Air Batteries Could Fill Gaps in Renewable Energy," August 23, 2023. https://www.pbs.org/wgbh/nova/article/iron-air-battery-renewable-grid/.

cxxvi "Form Energy Secures $405M to Speed Development of Long-Awaited 100-Hour Battery | AP News." Accessed June 23, 2025. https://apnews.com/article/climate-battery-energy-storage-iron-822f329c8a4f7518f4db6b24d6fcd15c.

cxxvii "Form Energy Receives $30M CEC Grant for Its 100-Hour Iron-Air Battery System." Accessed June 23, 2025. https://www.renewableenergyworld.com/energy-storage/long-duration/form-energy-receives-30m-cec-grant-for-its-100-hour-iron-air-battery-system/.

[cxxviii] "Publications | NREL." Accessed June 25, 2025. https://www.nrel.gov/research/publications.

[cxxix] IEA. "AI Is Set to Drive Surging Electricity Demand from Data Centres While Offering the Potential to Transform How the Energy Sector Works - News," April 10, 2025. https://www.iea.org/news/ai-is-set-to-drive-surging-electricity-demand-from-data-centres-while-offering-the-potential-to-transform-how-the-energy-sector-works.

[cxxx] Arévalo, Paul, and Francisco Jurado. "Impact of Artificial Intelligence on the Planning and Operation of Distributed Energy Systems in Smart Grids." *Energies* 17, no. 17 (January 2024): 4501. https://doi.org/10.3390/en17174501.

[cxxxi] "Publications | NREL." Accessed June 25, 2025. https://www.nrel.gov/research/publications.

[cxxxii] PricewaterhouseCoopers LLP. *How AI Can Enable a Sustainable Future*. In association with Microsoft Corporation. London: PwC UK, April 16, 2019. https://www.pwc.co.uk/sustainability-climate-change/assets/pdf/how-ai-can-enable-a-sustainable-future.pdf.

[cxxxiii] McKinsey. Smartening up with Artificial Intelligence (AI). Accessed June 26, 2025. https://www.mckinsey.com/~/media/mckinsey/industries/semiconductors/our%20insights/smartening%20up%20with%20artificial%20intelligence/smartening-up-with-artificial-intelligence.ashx.

[cxxxiv] "Generative Artificial Intelligence for the Power Grid | Grid Modernization | NREL." Accessed June 18, 2025. https://www.nrel.gov/grid/generative-artificial-intelligence-for-the-power-grid.

[cxxxv] Energy.gov. "Grid Modernization Initiative." Accessed June 18, 2025. https://www.energy.gov/gmi/grid-modernization-initiative.

[cxxxvi] Copley, Michael. "U.S. Electricity Demand Is Set to Explode. That Will Make It Harder to Cut Climate Pollution." *NPR*, January 17, 2025, sec. Climate. https://www.npr.org/2025/01/16/nx-s1-5251454/electricity-demand-data-centers-climate-change-natural-gas-fossil-fuel.

[cxxxvii] AI Is Set to Drive Surging Electricity Demand from Data Centres While Offering the Potential to Transform How the Energy Sector Works - News - IEA." Accessed May 29, 2025. https://www.iea.org/news/ai-is-set-to-drive-surging-electricity-demand-from-data-centres-while-offering-the-potential-to-transform-how-the-energy-sector-works.

[cxxxviii] World Economic Forum. "AI and Energy: Will AI Reduce Emissions or Increase Power Demand?," July 22, 2024. https://www.weforum.org/stories/2024/07/generative-ai-energy-emissions/.

[cxxxix] "Annual Energy Outlook 2025 - U.S. Energy Information Administration (EIA)." Accessed June 23, 2025. https://www.eia.gov/outlooks/aeo/.

[cxl] "Publications | NREL." Accessed June 25, 2025. https://www.nrel.gov/research/publications.
"Publications | NREL." Accessed June 25, 2025. https://www.nrel.gov/research/publications.

[cxli] "The Attack on Colonial Pipeline: What We've Learned & What We've Done Over the Past Two Years | CISA," May 7, 2023. https://www.cisa.gov/news-events/news/attack-colonial-pipeline-what-weve-learned-what-weve-done-over-past-two-years.

[cxlii] "Publications | NREL." Accessed June 25, 2025. https://www.nrel.gov/research/publications.

[cxliii] Gorman, Will, Julie Mulvaney Kemp, Joseph Rand, Joachim Seel, Ryan Wiser, Nick Manderlink, Fredrich Kahrl, Kevin Porter, and Will Cotton. "Grid Connection Barriers to Renewable Energy Deployment in the United States." *Joule* 9, no. 2 (February 19, 2025). https://doi.org/10.1016/j.joule.2024.11.008.

[cxliv] Gorman, Will, Julie Mulvaney Kemp, Joseph Rand, Joachim Seel, Ryan Wiser, Nick Manderlink, Fredrich Kahrl, Kevin Porter, and Will Cotton. "Grid Connection Barriers to Renewable Energy Deployment in the United States." *Joule* 9, no. 2 (February 19, 2025). https://doi.org/10.1016/j.joule.2024.11.008.

[cxlv] Gorman, Will, Julie Mulvaney Kemp, Joseph Rand, Joachim Seel, Ryan Wiser, Nick Manderlink, Fredrich Kahrl, Kevin Porter, and Will Cotton. "Grid Connection Barriers to Renewable Energy Deployment in the United States." *Joule* 9, no. 2 (February 19, 2025). https://doi.org/10.1016/j.joule.2024.11.008.

[cxlvi] Giacobone, Phoebe Skok, Bianca. "The US Interconnection Queue Is Twice Its Installed Capacity." *Latitude Media* (blog), April 11, 2024. https://www.latitudemedia.com/news/the-us-interconnection-queue-is-twice-its-installed-capacity/.

[cxlvii] Gorman, Will, Julie Mulvaney Kemp, Joseph Rand, Joachim Seel, Ryan Wiser, Nick Manderlink, Fredrich Kahrl, Kevin Porter, and Will Cotton. "Grid Connection Barriers to Renewable Energy Deployment in the United States." *Joule* 9, no. 2 (February 19, 2025). https://doi.org/10.1016/j.joule.2024.11.008.

[cxlviii] Gorman, Will, Julie Mulvaney Kemp, Joseph Rand, Joachim Seel, Ryan Wiser, Nick Manderlink, Fredrich Kahrl, Kevin Porter, and Will Cotton. "Grid Connection Barriers to Renewable Energy Deployment in the United States." *Joule* 9, no. 2 (February 19, 2025). https://doi.org/10.1016/j.joule.2024.11.008.

[cxlix] Gorman, Will, Julie Mulvaney Kemp, Joseph Rand, Joachim Seel, Ryan Wiser, Nick Manderlink, Fredrich Kahrl, Kevin Porter, and Will Cotton. "Grid Connection Barriers to Renewable Energy Deployment in the United States." *Joule* 9, no. 2 (February 19, 2025). https://doi.org/10.1016/j.joule.2024.11.008.

[cl] Gorman, Will, Julie Mulvaney Kemp, Joseph Rand, Joachim Seel, Ryan Wiser, Nick Manderlink, Fredrich Kahrl, Kevin Porter, and Will Cotton. "Grid Connection Barriers to Renewable Energy Deployment in the United States." *Joule* 9, no. 2 (February 19, 2025). https://doi.org/10.1016/j.joule.2024.11.008.

[cli] Gorman, Will, Julie Mulvaney Kemp, Joseph Rand, Joachim Seel, Ryan Wiser, Nick Manderlink, Fredrich Kahrl, Kevin Porter, and Will Cotton. "Grid Connection Barriers to Renewable Energy Deployment in the United States." *Joule* 9, no. 2 (February 19, 2025). https://doi.org/10.1016/j.joule.2024.11.008.

[clii] Gorman, Will, Julie Mulvaney Kemp, Joseph Rand, Joachim Seel, Ryan Wiser, Nick Manderlink, Fredrich Kahrl, Kevin Porter, and Will Cotton. "Grid Connection Barriers to Renewable Energy Deployment in the United States." *Joule* 9, no. 2 (February 19, 2025). https://doi.org/10.1016/j.joule.2024.11.008.

[cliii] "Explainer on the Interconnection Final Rule | Federal Energy Regulatory Commission," 2023. https://www.ferc.gov/explainer-interconnection-final-rule.

[cliv] "Explainer on the Transmission Planning and Cost Allocation Final Rule | Federal Energy Regulatory Commission," 2024. https://www.ferc.gov/explainer-transmission-planning-and-cost-allocation-final-rule.

[clv] Alanazi, Manar, Abdun Mahmood, and Mohammad Chowdhurry. "SCADA Vulnerabilities and Attacks: A Review of the State-of-the-art and Open Issues - ScienceDirect." *ScienceDirect*, Computers & Security, 125 (2023). https://doi.org/10.1016/j.cose.2022.103028.

[clvi] Alanazi, Manar, Abdun Mahmood, and Mohammad Chowdhurry. "SCADA Vulnerabilities and Attacks: A Review of the State-of-the-art and Open Issues - ScienceDirect." *ScienceDirect*, Computers & Security, 125 (2023). https://doi.org/10.1016/j.cose.2022.103028.

[clvii] Cerf, Emily. "Ukraine Blackouts Caused by Malware Attacks Warn against Evolving Cybersecurity Threats to the Physical World." *News* (blog), May 17, 2024. https://news.ucsc.edu/2024/05/ukraine-cybersecurity/.

[clviii] Cerf, Emily. "Ukraine Blackouts Caused by Malware Attacks Warn against Evolving Cybersecurity Threats to the Physical World." *News* (blog), May 17, 2024. https://news.ucsc.edu/2024/05/ukraine-cybersecurity/.

[clix] Salazar, Luis, Sebastián R. Castro, Juan Lozano, Keerthi Koneru, Emmanuele Zambon, Bing Huang, Ross Baldick, Marina Krotofil, Alonso Rojas, and Alvaro A. Cardenas. "A Tale of Two Industroyers: It Was the Season of Darkness," 312–30. IEEE Computer Society, 2024. https://doi.org/10.1109/SP54263.2024.00162.

[clx] Salazar, Luis, Sebastián R. Castro, Juan Lozano, Keerthi Koneru, Emmanuele Zambon, Bing Huang, Ross Baldick, Marina Krotofil, Alonso Rojas, and Alvaro A. Cardenas. "A Tale of Two Industroyers: It Was the Season of Darkness," 312–30. IEEE Computer Society, 2024. https://doi.org/10.1109/SP54263.2024.00162.

[clxi] Salazar, Luis, Sebastián R. Castro, Juan Lozano, Keerthi Koneru, Emmanuele Zambon, Bing Huang, Ross Baldick, Marina Krotofil, Alonso Rojas, and Alvaro A. Cardenas. "A Tale of Two Industroyers: It Was the Season of Darkness," 312–30. IEEE Computer Society, 2024. https://doi.org/10.1109/SP54263.2024.00162.

[clxii] Drake, Ryab, Ridder, Evan. "Healthcare Cybersecurity Vulnerabilities." *Proceedings of the International Conference on Cybersecurity and Cybercrime,* no. 9 (2022): 49-56. https://doi.org/10.19107/cybercon.2022.06

[clxiii] Cuffari, J. V. (2023, March 3). *CISA made progress but resources, staffing, and technology challenges hinder cyber threat detection and mitigation* (OIG-23-19-Mar23). U.S. Department of Homeland Security, Office of Inspector General. https://www.oig.dhs.gov/sites/default/files/assets/2023-03/OIG-23-19-Mar23.pdf

[clxiv] Easterly, Jen. "The Attack on Colonial Pipeline: What We've Learned & What We've Done Over the Past Two Years | CISA." CISA.gov, May 7, 2023. https://www.cisa.gov/news-events/news/attack-colonial-pipeline-what-weve-learned-what-weve-done-over-past-two-years.

[clxv] Wood, Kimberly. "Cybersecurity Policy Responses to the Colonial Pipeline Ransomware Attack." The Georgetown Environmental Law Review, March 7, 2023. https://www.law.georgetown.edu/environmental-law-review/blog/cybersecurity-policy-responses-to-the-colonial-pipeline-ransomware-attack/.

[clxvi] Wood, Kimberly. "Cybersecurity Policy Responses to the Colonial Pipeline Ransomware Attack." The Georgetown Environmental Law Review, March 7, 2023. https://www.law.georgetown.edu/environmental-law-review/blog/cybersecurity-policy-responses-to-the-colonial-pipeline-ransomware-attack/.

[clxvii] Wood, Kimberly. "Cybersecurity Policy Responses to the Colonial Pipeline Ransomware Attack." The Georgetown Environmental Law Review, March 7, 2023. https://www.law.georgetown.edu/environmental-law-review/blog/cybersecurity-policy-responses-to-the-colonial-pipeline-ransomware-attack/.

[clxviii] Wood, Kimberly. "Cybersecurity Policy Responses to the Colonial Pipeline Ransomware Attack." The Georgetown Environmental Law Review, March 7, 2023. https://www.law.georgetown.edu/environmental-law-review/blog/cybersecurity-policy-responses-to-the-colonial-pipeline-ransomware-attack/.

[clxix] The White House. "Executive Orders Archives," June 19, 2025. https://www.whitehouse.gov/presidential-actions/executive-orders/.

[clxx] Wood, Kimberly. "Cybersecurity Policy Responses to the Colonial Pipeline Ransomware Attack." The Georgetown Environmental Law Review, March 7, 2023. https://www.law.georgetown.edu/environmental-law-review/blog/cybersecurity-policy-responses-to-the-colonial-pipeline-ransomware-attack/.

[clxxi] Easterly, Jen. "The Attack on Colonial Pipeline: What We've Learned & What We've Done Over the Past Two Years | CISA." CISA.gov, May 7, 2023. https://www.cisa.gov/news-events/news/attack-colonial-pipeline-what-weve-learned-what-weve-done-over-past-two-years.

[clxxii] Wood, Kimberly. "Cybersecurity Policy Responses to the Colonial Pipeline Ransomware Attack." The Georgetown Environmental Law Review, March 7, 2023. https://www.law.georgetown.edu/environmental-law-review/blog/cybersecurity-policy-responses-to-the-colonial-pipeline-ransomware-attack/.

[clxxiii] The White House. "Executive Orders Archives," June 19, 2025. https://www.whitehouse.gov/presidential-actions/executive-orders/.

[clxxiv] The White House. "Executive Orders Archives," June 19, 2025. https://www.whitehouse.gov/presidential-actions/executive-orders/.

[clxxv] The White House. "Executive Orders Archives," June 19, 2025. https://www.whitehouse.gov/presidential-actions/executive-orders/.

[clxxvi] Restrepo-Linarez, Daniel Felipe. "PROPUESTA DE POLÍTICAS PÚBLICAS PARA LA PROMOCIÓN E INCENTIVO DEL CRECIMIENTO DE LA GENERACIÓN DE ENERGÍA EÓLICA EN ESTADOS UNIDOS." *Fuentes, El Reventón Energético* 21, no. 2 (August 1, 2023): 121–32. https://doi.org/10.18273/revfue.v21n2-2023008.

[clxxvii] The White House. "Executive Orders Archives," June 19, 2025. https://www.whitehouse.gov/presidential-actions/executive-orders/.

[clxxviii] "Advancing Offshore Wind Energy in the United States: Highlights," n.d.

[clxxix] "Coastal Virginia Offshore Wind | Bureau of Ocean Energy Management." Accessed June 20, 2025. https://www.boem.gov/renewable-energy/state-activities/CVOW-C.

[clxxx] CORPORATIVA, IBERDROLA. "Vineyard Wind 1, Our First Offshore Wind Farm in the United States." Iberdrola. Accessed June 20, 2025. https://www.iberdrola.com/about-us/what-we-do/offshore-wind-energy/vineyard-wind-offshore-wind-farm.

[clxxxi] "Electricity Generation, Capacity, and Sales in the United States - U.S. Energy Information Administration (EIA)." Accessed June 25, 2025. https://www.eia.gov/energyexplained/electricity/electricity-in-the-us-generation-capacity-and-sales.php.

[clxxxii] Vineyard Wind. "Vineyard Wind 1." Accessed June 20, 2025. https://www.vineyardwind.com/vineyardwind-1.

[clxxxiii] "Wind Turbine Sg 11 0 200 Dd." Accessed June 25, 2025. https://www.siemens-energy.com/global/en/home/products-and-services/offshore/wind-turbine-sg-11-0-200-dd.html.

[clxxxiv] tno.nl/en. "Bifacial Solar Panels | TNO." Accessed June 17, 2025. https://www.tno.nl/en/technology-science/technologies/bifacial-solar-panels/.

[clxxxv] Sun, Xingshu, Mohammad Ryyan Khan, Chris Deline, and Muhammad Ashraful Alam. "Optimization and Performance of Bifacial Solar Modules: A Global Perspective." *Applied Energy* 212 (February 15, 2018): 1601–10. https://doi.org/10.1016/j.apenergy.2017.12.041.

[clxxxvi] Ovaitt, Silvana. "Understanding the Bifacial Modeling & Field Research Space," n.d.

[clxxxvii] John Fitzgerald Weaver. "US Government Reinstates Bifacial Solar Module Tariffs." *Pv Magazine International* (blog), May 17, 2024. https://www.pv-magazine.com/2024/05/17/us-government-reinstates-bifacial-solar-module-tariffs/.

[clxxxviii] Kennedy, Anne Fischer and Ryan. "Bifacial Panels, Representing 98% of U.S. Solar Imports, May Soon Be Subject to Tariffs." *Pv Magazine International* (blog), April 18, 2024. https://www.pv-magazine.com/2024/04/18/bifacial-panels-representing-98-of-u-s-solar-imports-may-soon-be-subject-to-tariffs/.

[clxxxix] "Perovskite Solar Cells | Department of Energy." Accessed June 18, 2025. https://www.energy.gov/eere/solar/perovskite-solar-cells.

[cxc] "NREL Researchers Outline Path Forward for Tandem Solar Cells | NREL." Accessed June 18, 2025. https://www.nrel.gov/news/detail/program/2024/nrel-researchers-outline-path-forward-for-tandem-solar-cells.

[cxci] Energy.gov. "Advancing U.S. Thin-Film Solar Photovoltaics Funding Program." Accessed June 25, 2025. https://www.energy.gov/eere/solar/advancing-us-thin-film-solar-photovoltaics-funding-program.

[cxcii] Nazakat, Abdul Ahad. "Following the Sun: The Impact of Tracking Systems on Solar Efficiency." AZoCleantech, June 5, 2025. https://www.azocleantech.com/article.aspx?ArticleID=1985.

[cxciii] Bolinger, Mark, Joachim Seel, Julie Mulvaney Kemp, Cody Warner, Anjali Katta, and Dana Robson. "Utility-Scale Solar," 2023.

[cxciv] "Utility-Scale Solar, 2023 Edition: Empirical Trends in Deployment, Technology, Cost, Performance, PPA Pricing, and Value in the United States | Energy Markets & Policy." Accessed June 25, 2025. https://emp.lbl.gov/publications/utility-scale-solar-2023-edition.

[cxcv] "Nextracker Raises $638 Million in Year's Largest IPO." Accessed June 23, 2025. https://www.axios.com/2023/02/09/nextracker-years-largest-ipo.

[cxcvi] "China: Builds Massive Floating Solar Panel Farm." Accessed June 17, 2025. https://time.com/china-massive-floating-solar-field/.

[cxcvii] "Biden-Harris Administration Announces $19 Million from Investing in America Agenda for Innovative Solar Panel Installation Over Canals | U.S. Department of the Interior." Press Release, April 4, 2024. https://www.doi.gov/pressreleases/biden-harris-administration-announces-19-million-investing-america-agenda-innovative.

[cxcviii] Rodgers, Erica, Ellen Gertsen, Jordan Sotudeh, Carie Mullins, Amanda Hernandez, Hanh Nguyen Le, Phil Smith, and Nikolai Joseph. "Space-Based Solar Power," n.d.

[cxcix] California Institute of Technology. "In a First, Caltech's Space Solar Power Demonstrator Wirelessly Transmits Power in Space," June 1, 2023. https://www.caltech.edu/about/news/in-a-first-caltechs-space-solar-power-demonstrator-wirelessly-transmits-power-in-space.

[cc] "Tidal Energy." Pacific Northwest National Laboratory. Accessed June 17, 2025. https://www.pnnl.gov/explainer-articles/tidal-energy.

[cci] Maksumić, Zerina. "US DOE Allocates $6 Million for Development of Tidal Energy Demo Pilot Site." *Offshore Energy* (blog), February 7, 2024. https://www.offshore-energy.biz/us-doe-allocates-6-million-for-development-of-tidal-energy-demo-pilot-site/.

[ccii] Energy.gov. "Funding Notice: $45 Million Funding Opportunity Will Advance Tidal and Current Energy Development and Drive U.S. Leadership in the Sector." Accessed June 25, 2025. https://www.energy.gov/eere/water/funding-notice-45-million-funding-opportunity-will-advance-tidal-and-current-energy.

[cciii] "Hydrokinetic Energy - an Overview | ScienceDirect Topics." Accessed June 18, 2025. https://www.sciencedirect.com/topics/engineering/hydrokinetic-energy.

[cciv] "U.S. Department of Energy Announces $35 Million in Funding for Hydrokinetic Turbine Development | Department of Energy." Accessed June 18, 2025. https://www.energy.gov/articles/us-department-energy-announces-35-million-funding-hydrokinetic-turbine-development.

[ccv] U.S. Department of Energy. "Investing in America." U.S. Department of Energy. Accessed June 25, 2025. https://www.energy.gov/investing-in-america.

[ccvi] U.S. Department of Energy. "Investing in America." U.S. Department of Energy. Accessed June 25, 2025. https://www.energy.gov/investing-in-america.

[ccvii] American Society of Civil Engineers. "Energy." *2025 Report Card for America's Infrastructure* (blog), 2025. https://infrastructurereportcard.org/cat-item/energy-infrastructure/.

[ccviii] U.S. Department of Energy. "Investing in America." U.S. Department of Energy. Accessed June 25, 2025. https://www.energy.gov/investing-in-america.

[ccix] International Energy Agency. "World Energy Investment 2025." IEA, June 5, 2025. https://www.iea.org/reports/world-energy-investment-2025.

[ccx] Aniti, Lori. "Grid Infrastructure Investments Drive Increase in Utility Spending over Last Two Decades." U.S. Energy Information Administration, November 18, 2024. https://www.eia.gov/todayinenergy/detail.php?id=63724.

[ccxi] American Society of Civil Engineers. "Energy." *2025 Report Card for America's Infrastructure* (blog), 2025. https://infrastructurereportcard.org/cat-item/energy-infrastructure/.

[ccxii] Institute for Energy Research. "U.S. Utility Industry Needs $1.4 Trillion Investment." *IER* (blog), May 1, 2025. https://www.instituteforenergyresearch.org/the-grid/u-s-utility-industry-needs-1-4-trillion-investment/.

[ccxiii] International Energy Agency. "World Energy Investment 2025." IEA, June 5, 2025. https://www.iea.org/reports/world-energy-investment-2025.

[ccxiv] The White House. "Executive Orders Archives," June 19, 2025. https://www.whitehouse.gov/presidential-actions/executive-orders/.

[ccxv] The White House. "Executive Orders Archives," June 19, 2025. https://www.whitehouse.gov/presidential-actions/executive-orders/.

[ccxvi] Kaufman, Alexander C. "Energy Abundance Won't Fix Electricity Bills." *The Atlantic* (blog), June 16, 2025. https://www.theatlantic.com/science/archive/2025/06/energy-efficiency-trump/683164/.

[ccxvii] Takemura, Alison. "Trump's All-out War on Energy Efficiency." Canary Media. Accessed June 18, 2025. https://www.canarymedia.com/articles/energy-efficiency/trump-energy-star-liheap-building.

[ccxviii] The White House. "Executive Orders Archives," June 19, 2025. https://www.whitehouse.gov/presidential-actions/executive-orders/.

[ccxix] The White House. "Executive Orders Archives," June 19, 2025. https://www.whitehouse.gov/presidential-actions/executive-orders/.

[ccxx] West Monroe. "The Trump Administration's First 100 Days—Adapting to Energy Policy Shifts." West Monroe, March 14, 2025. https://www.westmonroe.com/insights/the-trump-administrations-first-60-days-adapting-to-energy-policy-shifts.

[ccxxi] Magill, Kate. "Clean Energy Manufacturers Cancel Projects as Trump-Era Policies Take Hold | Utility Dive." Utility Dive. Accessed June 17, 2025. https://www.manufacturingdive.com/news/inflation-reduction-act-canceled-projects-q1-2025-kore-freyr/745966/.

[ccxxii] The White House. "Executive Orders Archives," June 19, 2025. https://www.whitehouse.gov/presidential-actions/executive-orders/.

[ccxxiii] American Clean Power Association. "U.S. Energy Storage Industry Commits $100 Billion Investment in American-Made Grid Batteries." *American Clean Power* (blog), April 29, 2025. https://cleanpower.org/news/energy-storage-industry-commits-100-billion-for-american-grid-batteries/.

[ccxxiv] Sidley Austin LLP. "U.S. House's 'Big Beautiful Bill' Accelerates Repeal of Renewable Energy Tax Credits and Introduces New Restrictions." Accessed June 17, 2025. https://www.sidley.com/en/insights/newsupdates/2025/05/us-house-big-beautiful-bill-accelerates-repeal-of-renewable-energy-tax-credits.

[ccxxv] Motyka, Marlene, Keith Adams, Micah Bible, Kate Hardin, Jaya Nagdeo, and Brian Boufarah. "Funding the Growth in the US Power Sector." Deloitte Insights, February 26, 2025. https://www2.deloitte.com/us/en/insights/industry/power-and-utilities/funding-growth-in-us-power-sector.html.

[ccxxvi] International Energy Agency. "World Energy Investment 2025." IEA, June 5, 2025. https://www.iea.org/reports/world-energy-investment-2025.

[ccxxvii] Motyka, Marlene, Keith Adams, Micah Bible, Kate Hardin, Jaya Nagdeo, and Brian Boufarah. "Funding the Growth in the US Power Sector." Deloitte Insights, February 26, 2025. https://www2.deloitte.com/us/en/insights/industry/power-and-utilities/funding-growth-in-us-power-sector.html.

[ccxxviii] International Energy Agency. "World Energy Investment 2025." IEA, June 5, 2025. https://www.iea.org/reports/world-energy-investment-2025.

[ccxxix] International Energy Agency. "World Energy Investment 2025." IEA, June 5, 2025. https://www.iea.org/reports/world-energy-investment-2025.

[ccxxx] American Clean Power Association. "U.S. Energy Storage Industry Commits $100 Billion Investment in American-Made Grid Batteries." *American Clean Power* (blog), April 29, 2025. https://cleanpower.org/news/energy-storage-industry-commits-100-billion-for-american-grid-batteries/.

[ccxxxi] Schipper, Mark, and Tyler Hodge. "After More than a Decade of Little Change, U.S. Electricity Consumption Is Rising Again." U.S. Energy Information Administration, May 13, 2025. https://www.eia.gov/todayinenergy/detail.php?id=65264.

[ccxxxii] International Energy Agency. "World Energy Investment 2025." IEA, June 5, 2025. https://www.iea.org/reports/world-energy-investment-2025.

[ccxxxiii] International Energy Agency. "World Energy Investment 2025." IEA, June 5, 2025. https://www.iea.org/reports/world-energy-investment-2025.

[ccxxxiv] American Clean Power Association. "U.S. Energy Storage Industry Commits $100 Billion Investment in American-Made Grid Batteries." *American Clean Power* (blog), April 29, 2025. https://cleanpower.org/news/energy-storage-industry-commits-100-billion-for-american-grid-batteries/.

[ccxxxv] Motyka, Marlene, Keith Adams, Micah Bible, Kate Hardin, Jaya Nagdeo, and Brian Boufarah. "Funding the Growth in the US Power Sector." Deloitte Insights, February 26, 2025. https://www2.deloitte.com/us/en/insights/industry/power-and-utilities/funding-growth-in-us-power-sector.html.

[ccxxxvi] Flowers, Simon. "5 Trends Shaping the Energy World in 2025." World Economic Forum, March 3, 2025. https://www.weforum.org/stories/2025/03/5-energy-trends-2025/.

[ccxxxvii] The White House. "Executive Orders Archives," June 19, 2025. https://www.whitehouse.gov/presidential-actions/executive-orders/.

[ccxxxviii] The White House. "Executive Orders Archives," June 19, 2025. https://www.whitehouse.gov/presidential-actions/executive-orders/.

[ccxxxix] The White House. "Executive Orders Archives," June 19, 2025. https://www.whitehouse.gov/presidential-actions/executive-orders/.

[ccxl] Institute for Energy Research. "U.S. Utility Industry Needs $1.4 Trillion Investment." *IER* (blog), May 1, 2025. https://www.instituteforenergyresearch.org/the-grid/u-s-utility-industry-needs-1-4-trillion-investment/.

[ccxli] International Energy Agency. "World Energy Investment 2025." IEA, June 5, 2025. https://www.iea.org/reports/world-energy-investment-2025.

[ccxlii] American Clean Power Association. "U.S. Energy Storage Industry Commits $100 Billion Investment in American-Made Grid Batteries." *American Clean Power* (blog), April 29, 2025. https://cleanpower.org/news/energy-storage-industry-commits-100-billion-for-american-grid-batteries/.

[ccxliii] Motyka, Marlene, Keith Adams, Micah Bible, Kate Hardin, Jaya Nagdeo, and Brian Boufarah. "Funding the Growth in the US Power Sector." Deloitte Insights, February 26, 2025. https://www2.deloitte.com/us/en/insights/industry/power-and-utilities/funding-growth-in-us-power-sector.html.

[ccxliv] International Energy Agency. "World Energy Investment 2025." IEA, June 5, 2025. https://www.iea.org/reports/world-energy-investment-2025.

[ccxlv] American Society of Civil Engineers. "Energy." *2025 Report Card for America's Infrastructure* (blog), 2025. https://infrastructurereportcard.org/cat-item/energy-infrastructure/.

[ccxlvi] International Energy Agency. "World Energy Investment 2025." IEA, June 5, 2025. https://www.iea.org/reports/world-energy-investment-2025.

[ccxlvii] Cho, Sung, and Ty York. "Powering America: Investing in the Nation's Energy Future." Goldman Sachs Asset Management, February 25, 2025. https://am.gs.com/en-us/institutions/insights/article/2025/powering-america-investing-in-the-nations-energy-future.

[ccxlviii] Motyka, Marlene, Keith Adams, Micah Bible, Kate Hardin, Jaya Nagdeo, and Brian Boufarah. "Funding the Growth in the US Power Sector." Deloitte Insights, February 26, 2025. https://www2.deloitte.com/us/en/insights/industry/power-and-utilities/funding-growth-in-us-power-sector.html.

[ccxlix] Flowers, Simon. "5 Trends Shaping the Energy World in 2025." World Economic Forum, March 3, 2025. https://www.weforum.org/stories/2025/03/5-energy-trends-2025/.

[ccl] Cho, Sung, and Ty York. "Powering America: Investing in the Nation's Energy Future." Goldman Sachs Asset Management, February 25, 2025. https://am.gs.com/en-us/institutions/insights/article/2025/powering-america-investing-in-the-nations-energy-future.

[ccli] Motyka, Marlene, Keith Adams, Micah Bible, Kate Hardin, Jaya Nagdeo, and Brian Boufarah. "Funding the Growth in the US Power Sector." Deloitte Insights, February 26, 2025. https://www2.deloitte.com/us/en/insights/industry/power-and-utilities/funding-growth-in-us-power-sector.html.

[cclii] Motyka, Marlene, Keith Adams, Micah Bible, Kate Hardin, Jaya Nagdeo, and Brian Boufarah. "Funding the Growth in the US Power Sector." Deloitte Insights, February 26, 2025. https://www2.deloitte.com/us/en/insights/industry/power-and-utilities/funding-growth-in-us-power-sector.html.

[ccliii] Motyka, Marlene, Keith Adams, Micah Bible, Kate Hardin, Jaya Nagdeo, and Brian Boufarah. "Funding the Growth in the US Power Sector." Deloitte Insights, February 26, 2025. https://www2.deloitte.com/us/en/insights/industry/power-and-utilities/funding-growth-in-us-power-sector.html.

[ccliv] International Energy Agency. "World Energy Investment 2025." IEA, June 5, 2025. https://www.iea.org/reports/world-energy-investment-2025.

[cclv] Olasolo, P., M. C. Juárez, M. P. Morales, Sebastiano D´Amico, and I. A. Liarte. "Enhanced Geothermal Systems (EGS): A Review." *Renewable and Sustainable Energy Reviews* 56 (April 1, 2016): 133–44. https://doi.org/10.1016/j.rser.2015.11.031.

[cclvi] Energy.gov. "FORGE." Accessed June 20, 2025. https://www.energy.gov/eere/geothermal/forge.

[cclvii] GeoEnergy, Think, and Carlo Cariaga. "Utah FORGE Secures 4-Year Extension, More Funding for Enhanced Geothermal Research," October 3, 2024. https://www.thinkgeoenergy.com/utah-forge-secures-4-year-extension-more-funding-for-enhanced-geothermal-research/.

[cclviii] Ingersoll, Daniel T. "5 - Enhancing Nuclear Safety." In *Small Modular Reactors*, edited by Daniel T. Ingersoll, 71–89. Boston: Woodhead Publishing, 2016. https://doi.org/10.1016/B978-0-08-100252-0.00005-7.

[cclix] "Nuclear Waste from Small Modular Reactors | PNAS." Accessed June 23, 2025. https://www.pnas.org/doi/10.1073/pnas.2111833119.

[cclx] "NRC Approves First U.S. Small Modular Reactor Design | Department of Energy." Accessed June 20, 2025. https://www.energy.gov/ne/articles/nrc-approves-first-us-small-modular-reactor-design.

[cclxi] "US Approves NuScale's Bigger Nuclear Reactor Design | Reuters." Accessed June 20, 2025. https://www.reuters.com/business/energy/us-approves-bigger-nuclear-reactor-design-nuscale-document-says-2025-05-29/.

[cclxii] Ohshima, Hiroyuki, and Shigenobu Kubo. "Sodium-Cooled Fast Reactors (SFRs)." In *Handbook of Generation IV Nuclear Reactors*, 173–94. Elsevier, 2023. https://doi.org/10.1016/B978-0-12-820588-4.00006-2.

[cclxiii] TerraPower. "TerraPower Natrium | Advanced Nuclear Energy." Accessed June 20, 2025. https://www.terrapower.com/natrium/.

[cclxiv] "TerraPower Begins Construction at 345-MW Advanced Reactor Site in Wyoming | Utility Dive." Accessed June 20, 2025. https://www.utilitydive.com/news/terrapower-smr-advanced-nuclear-reactor-bill-gates/718722/.

[cclxv] Serp, Jérôme, Michel Allibert, Ondřej Beneš, Sylvie Delpech, Olga Feynberg, Véronique Ghetta, Daniel Heuer, et al. "The Molten Salt Reactor (MSR) in Generation IV: Overview and Perspectives." *Progress in Nuclear Energy* 77 (November 1, 2014): 308–19. https://doi.org/10.1016/j.pnucene.2014.02.014.

[cclxvi] "US Nuclear Regulators to Issue Construction Permit for a Reactor That Uses Molten Salt | AP News." Accessed June 20, 2025. https://apnews.com/article/nuclear-energy-kairos-power-reactor-molten-salt-cop28-f6066bc945d59c5c36a54b1487d37dd9.

[cclxvii] Kairos Power. "U.S. Department of Energy and Kairos Power Execute Novel Performance-Based, Fixed-Price Milestone Contract." Accessed June 20, 2025. https://kairospower.com/external_updates/u-s-department-of-energy-and-kairos-power-execute-novel-performance-based-fixed-price-milestone-contract-to-enable-investment-in-advanced-reactor-demonstration-project/.

[cclxviii] Nuclear Energy Agency (NEA). "High-Temperature Gas-Cooled Reactors." Accessed June 18, 2025. https://www.oecd-nea.org/jcms/pl_20497/high-temperature-gas-cooled-reactors.

[cclxix] "X-Energy Completes $40 Million Project to Further Develop High-Temperature Gas Reactor | Department of Energy." Accessed June 23, 2025. https://www.energy.gov/ne/articles/x-energy-completes-40-million-project-further-develop-high-temperature-gas-reactor.

[cclxx] "What Is Nuclear Fusion?" Text. IAEA, August 3, 2023. https://www.iaea.org/newscenter/news/what-is-nuclear-fusion.

[cclxxi] Andrew. "Congress Provides Record Funding for Fusion Energy." *Fusion Industry Association* (blog), December 21, 2022. https://www.fusionindustryassociation.org/congress-provides-record-funding-for-fusion-energy/.

[cclxxii] "SPARC: Proving Commercial Fusion Energy Is Possible." Accessed June 20, 2025. https://cfs.energy/technology/sparc.

[cclxxiii] Halper, Evan. "No One Has Made Fusion Power Viable yet. Why Is Big Tech Investing Billions?" *The Washington Post*, June 23, 2025. https://www.washingtonpost.com/climate-solutions/2025/06/23/fusion-energy-climate-science/.

[cclxxiv] International Energy Agency. "World Energy Investment 2025." IEA, June 5, 2025. https://www.iea.org/reports/world-energy-investment-2025.

[cclxxv] Schipper, Mark, and Tyler Hodge. "After More than a Decade of Little Change, U.S. Electricity Consumption Is Rising Again." U.S. Energy Information Administration, May 13, 2025. https://www.eia.gov/todayinenergy/detail.php?id=65264.

[cclxxvi] Leonzio, Grazia, and Nilay Shah. "Recent Advancements and Challenges in Carbon Capture, Utilization and Storage." *Current Opinion in Green and Sustainable Chemistry* 46 (April 1, 2024): 100895. https://doi.org/10.1016/j.cogsc.2024.100895.

[cclxxvii] "Carbon Capture and Storage in the United States | Congressional Budget Office," December 13, 2023. https://www.cbo.gov/publication/59832.

[cclxxviii] Segal, Mark. "U.S. Grants $890 Million for Carbon Capture Projects at Coal and Gas Power Plants." *ESG Today* (blog), December 18, 2023. https://www.esgtoday.com/u-s-grants-890-million-for-carbon-capture-projects-at-coal-and-gas-power-plants/.

[cclxxix] "Carbon Capture and Storage in the United States | Congressional Budget Office," December 13, 2023. https://www.cbo.gov/publication/59832.

[cclxxx] "Exxon Makes a Long-Shot Bet on Climate Tech - Barron's." Accessed June 20, 2025. https://www.barrons.com/articles/exxon-mobil-carbon-air-capture-climate-costs-0102a5e1.

[cclxxxi] Energy.gov. "Regional Direct Air Capture Hubs." Accessed June 20, 2025. https://www.energy.gov/oced/DACHubs.

[cclxxxii] Energy.gov. "OCED Announces up to $1.8 Billion in New Funding for Transformational Direct Air Capture Technologies," December 19, 2024. https://www.energy.gov/oced/articles/oced-announces-18-billion-new-funding-transformational-direct-air-capture.

[cclxxxiii] IEA. "Unlocking the Potential of Direct Air Capture: Is Scaling up through Carbon Markets Possible? – Analysis," May 11, 2023. https://www.iea.org/commentaries/unlocking-the-potential-of-direct-air-capture-is-scaling-up-through-carbon-markets-possible.

[cclxxxiv] "Supercritical Coal Plant - Energy Education." Accessed June 17, 2025. https://energyeducation.ca/encyclopedia/Supercritical_coal_plant.

[cclxxxv] Southwestern Electric Power Company (SWEPCO). *John W. Turk, Jr. Power Plant Fact Sheet*. Rev. March 21, 2013. Hempstead County, Arkansas. https://www.swepco.com/lib/docs/community/projects/TurkPowerPlantFactSheetrev3-21-13v3.pdf.

[cclxxxvi] "Assessment of Supercritical Power Plant Performance." Accessed June 17, 2025. https://www.epri.com/research/products/cs-4968.

[cclxxxvii] Hack, Horst, and Robert Purgert. "Final Results of the U.S. Advanced Ultra-Supercritical Component Test Project for 760°C Steam Conditions," 284–95. ASM International, 2024. https://doi.org/10.31399/asm.cp.am-epri-2024p0284.

[cclxxxviii] netl.doe.gov. "Oxy-Combustion." Accessed June 3, 2025. https://netl.doe.gov/node/7477.

[cclxxxix] "Oxy-Fuel Combustion | Southwest Research Institute." Accessed June 3, 2025. https://www.swri.org/markets/energy-environment/power-generation-utilities/advanced-power-systems/oxy-fuel-combustion.

[ccxc] "Annual Electric Power Industry Report, Form EIA-860 Detailed Data with Previous Form Data (EIA-860A/860B) - U.S. Energy Information Administration (EIA)." Accessed June 25, 2025. https://www.eia.gov/electricity/data/eia860/.

[ccxci] "Natural Gas Combined-Cycle Power Plants Increased Utilization with Improved Technology - U.S. Energy Information Administration (EIA)." Accessed June 20, 2025. https://www.eia.gov/todayinenergy/detail.php?id=60984.

[ccxcii] "GE Vernova Announces More than $160 Million Investment in Greenville Facility | GE Vernova News." Accessed June 20, 2025. https://www.gevernova.com/news/press-releases/ge-vernova-announces-more-160-million-investment-greenville-facility.

[ccxciii] International Energy Agency. "World Energy Investment 2025." IEA, June 5, 2025. https://www.iea.org/reports/world-energy-investment-2025.

[ccxciv] Flowers, Simon. "5 Trends Shaping the Energy World in 2025." World Economic Forum, March 3, 2025. https://www.weforum.org/stories/2025/03/5-energy-trends-2025/.

[ccxcv] The White House. "Executive Orders Archives," June 19, 2025. https://www.whitehouse.gov/presidential-actions/executive-orders/.

[ccxcvi] Lam, Pun-Lee. "Energy in China: Development and Prospects." *China Perspectives* 2005, no. 3 (June 1, 2005). https://doi.org/10.4000/chinaperspectives.2783.

[ccxcvii] The White House. "Executive Orders Archives," June 19, 2025. https://www.whitehouse.gov/presidential-actions/executive-orders/.

[ccxcviii] Sidley Austin LLP. "U.S. House's 'Big Beautiful Bill' Accelerates Repeal of Renewable Energy Tax Credits and Introduces New Restrictions." Accessed June 17, 2025. https://www.sidley.com/en/insights/newsupdates/2025/05/us-house-big-beautiful-bill-accelerates-repeal-of-renewable-energy-tax-credits.