The Sustainable Energy Interconnection: Challenges Facing the Future Electric Grid

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Foreword

About the Author

Ryan Alimento is a senior at the University of Southern California (USC) concurrently pursuing a bachelor's degree in Chemical Engineering and a master's degree in Green Technologies. He currently serves as Vice President of Academic Affairs for the USC chapter of the American Institute of Chemical Engineers and is an active member in the Trojan Knights — the Official Hosts of USC. After graduating, he hopes to apply systems thinking to coordinate an international and inclusive response to climate change.

About the WISE Program

The Washington Internships for Students in Engineering (WISE) program formed in 1980 from a collaborative endeavor between several professional engineering societies. WISE prepares future leaders in engineering who are well-equipped to confront important issues at the intersection of science, technology, and public policy. The 9-week program exposes WISE students to the critical role of engineers in the legislative and policymaking processes. Interns interact with leaders in U.S. Congress, the Administration, and federal agencies, industry, and non-governmental organizations to develop policy recommendations for a topic of their choice. Interns present conclusions in the House Committee on Science, Space, and Technology hearing room and are published in the Journal of Engineering & Public Policy. For more information about the WISE Program, visit www.wise-intern.org.

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Acronyms

AC	Alternating Current
ADOT	Arizona Department of Transportation
CAISO	California Independent System Operator
CE	Categorical Exclusion
CEQ	Council on Environmental Quality
DC	Direct Current
DOE	U.S. Department of Energy
EA	Environmental Assessment
EIS	Environmental Impact Statement
EPAct	Energy Policy Act
ERCOT	Electric Reliability Council of Texas
ERO	Electric Reliability Organization
EV	Electric Vehicle
FONSI	Finding of No Significant Impact
GAO	Government Accountability Office
FERC	Federal Energy Regulatory Commission
FHA	Federal Highway Administration
FPA	Federal Power Act
FTR	Financial Transmission Right
HVDC	High-voltage Direct Current
IIJA	Infrastructure Investment and Jobs Act
INPCT	Interagency NEPA & Permitting Collaboration Tool
IRA	Inflation Reduction Act
ISO	Independent System Operator
kWh	Kilowatt-hour
MISO	Midcontinent Independent System Operator
NARUC	National Association of Regulatory Utility Commissioners
NEPA	National Environmental Policy Act
NERC	North American Energy Reliability Corporation
NG	Natural Gas
NIETC	National Interest Electric Transmission Corridor
NOPR	Notice of Proposed Rulemaking
NREL	National Renewable Energy Laboratory
PJM	Pennsylvania-New Jersey-Maryland Interconnection
PUC	Public Utility Commission
RIBA	Royal Institute of British Architects
RTO	Regional Transmission Operator
VRE	Variable Renewable Energy

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Executive Summary

Underlying the shift towards renewable energy generation is the lesser known — but equally essential — transformation of America's electric grid. The grid facilitates the transportation of electricity; it moves energy produced at power plants to the homes and businesses where it is consumed. But while the clean energy economy grows at an unprecedented rate, the infrastructure needed to accommodate this growth is actively degrading [1], [2]. In this way, a faulty electric grid restricts the continued adoption of renewable energy — a transition that is vital to reducing greenhouse gas emissions and minimizing the effects of anthropogenic climate change. Upgrades to the grid must proceed expeditiously to guarantee uninhibited growth of the clean energy economy.

This endeavor is easier said than done. Many aspects of transmission line management intermingle to create a highly complex regulatory landscape. These include vague laws, convoluted grid oversight, poor communication, outdated permitting policies, and many more issues that are complicated even before melding with others. Estimates for the cost of improvements vary but there is widespread consensus on the need for monumental investments. The National Renewable Energy Lab (NREL) predicts costs ranging from $330 billion to $740 billion while a study from Wood Mackenzie arrived at a staggering $4.5 trillion of foreseeable expenditures [3], [4]. Additionally, modernization of the electric grid must occur by 2050 to meet the Biden Administration's timeline for nationwide net-zero emissions [5]. Altogether, the odyssey to improve the electric grid seems unintelligibly complicated.

While many aspects of the challenge have yet to be understood, so too can many actions be taken in the near future to significantly kickstart this endeavor. The Biden Administration can set timeline goals for grid upgrades that are required to achieve emissions reductions goals. Congress can amend ambiguities in energy laws that have contributed to the current grid's disorganization. Permitting processes can be hastened with collaboration between federal agencies and state and local governments; permit reviews can also be improved by integrating digital technologies to share data. Artwork and transparent communication can improve regional engagement and decrease legal disputes that stem from civilians feeling ignored and excluded. Creative tax programs and market adjustments can balance corporate profits with uplifting historically marginalized communities.

Some policies are already being passed and investments made, but much more progress must be realized at a much faster pace. This will require unprecedented levels of collaboration and efficiency — traits of effective governance that often go overlooked. A necessary advancement for improving the grid is the acknowledgement that legal alterations and economic programs alone are not sufficient solutions. Trust between federal, state, and local governments must be fostered, and public perception of electric towers must be improved. Most importantly, all stakeholders must understand the importance of a resilient electric grid and the urgency with which modernization must occur.

Introduction

Electricity delivery in the United States depends on an aging and entangled patchwork of power generation facilities: a 600,000 foundation of transmission lines (240,000 miles of which are considered high-voltage), and around 5.5 million miles (23 times the distance from the Earth to the Moon) of local distribution lines that criss-cross between federal, state, tribal, and local regulatory jurisdictions [6], [7].

The transmission system is responsible for providing safe, reliable, and cost-effective electricity to customers. But the majority of the grid is aging, with over 70% of transmission lines exceeding their 50-year lifespan [2]. These dilapidated structures are unable to efficiently move energy around the country from the places where it is produced to the places where it is needed. The locations of fossil fuel power plants are relatively flexible and can thus be built close to major population hubs. Here, they can easily serve the nearby high demand. Coal or natural gas fuel can be shipped in, and few transmission lines need to be built. In contrast, renewable energy facilities are much more dependent on geography. Solar farms must have plentiful access to sunny weather, wind turbines need access to strong winds, and hydroelectric facilities need access to rivers. These natural features are often located far from cities, requiring the construction of many more transmission lines than what would be needed for a fossil fuel plant.

Current progress toward reaching ambitious clean energy goals accentuates the vast amount of renewable transmission that must be constructed in the coming years. The Biden Administration set national goals for 50% renewable energy generation by 2030 and 100% by 2050 [5]. 2022 numbers show that only 15% of American electricity was sourced from renewable sources [8]. To this end — in the coming decade — an electricity infrastructure large enough to accommodate 35% of today's generation must be built *and* made resilient to ensure electricity access stays reliable.

At the same time, US demand for electricity continues to rise. In 2022, 4.05 trillion kWh was consumed: 2.6% more than 2021, and 14 times the consumption in 1950 [9]. This trend has no indication of stopping and, in fact, appears to be speeding up.

The amalgam of these developments presents a daunting challenge for the future of American electricity. To incorporate renewable energy sources, much more transmission needs to be connected to a dysfunctionally old system. All the while, the nation will be demanding historic levels of electricity — energy that must be supplied by the very system undergoing a technological overhaul. The situation can be likened to changing the tires of a Formula 1 race car without the driver noticing.

It is no hyperbole to state that the ramifications of failure affect every aspect of modern society. Continued delays to the clean energy transition prolong anthropogenic climate change and its myriad risks. Insufficient adaptation of the electric grid affects water, communications, food supply, air conditioning, heating, manufacturing, and much more. Already, an inadequate grid has cost the nation billions of dollars and endangered public health — even taking lives. Improvements need to be made. Yet, progress continues to be stymied by an immensely complex network of technological, legal, economic, and social considerations. This paper seeks to delineate the terrain of electric grid management and identify key areas of necessary improvement.

Background

Electrical Sciences Primer

Understanding the energy grid, surrounding policies, and potential solutions requires some familiarity with concepts of electrical sciences.

Three main parameters describe the behavior of electricity through a wire:

Voltage, measured in volts (V), represents the force with which electricity flows through the system. It can be compared to the pressure that pushes water through a pipe.

Electric current, measured in amperes (A), refers to the movement of electricity. It quantifies the amount of electricity that flows past a certain point, similar to measuring the rate at which water exits a faucet.

Resistance, measured in ohms (Ω), is the internal opposition of electric flow in a wire. It can be considered analogous to a thin section of pipe or gravel in a pipe restricting water flow.

Power, measured in watts (W), combines the voltage force that pushes electricity through a wire and the current describing how much energy is transferred through a wire. Small household appliances use 10 to 100 W; bigger appliances use around 1000 W.

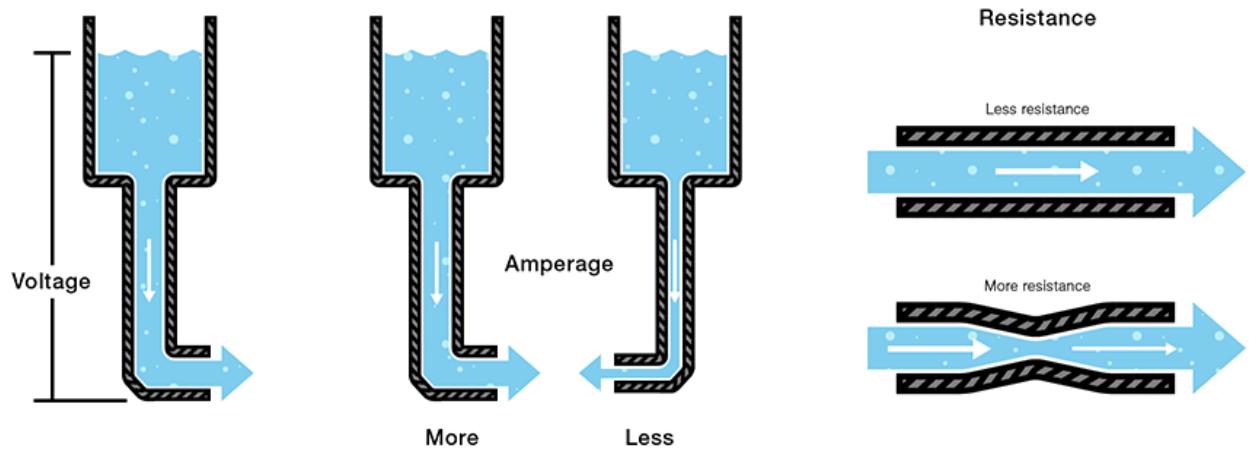

Figure 1: Hydraulic Equivalents of Electricity [10]

Electricity can also move in two distinct ways, alternating current and direct current.

Alternating current (AC) is a form of electrical energy characterized by its periodically changing direction of flow. Direct current (DC) instead flows in a constant direction, AC exhibits a cyclical flow pattern akin to the swinging motion of a pendulum. The oscillation occurs at a specific frequency, measured in hertz (Hz), which indicates the number of directional changes per second. The U.S. electric grid operates at 60 Hz, meaning that electricity changes direction 60 times every second. This rapid back-and-forth movement of AC current allows for easy adjustments to voltage levels, making it flexible for use in small appliances that require little energy as well as long-range transportation of high amounts of electricity.

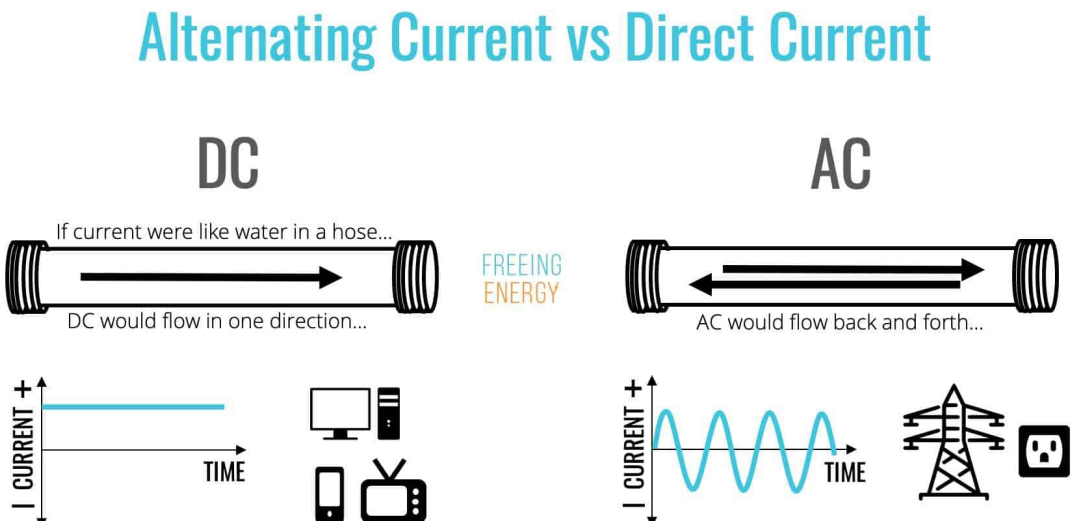

Figure 2: Comparing DC and AC [11]

Unlike the flow of water, however, electricity has no physical form. As a form of pure energy, electricity moves through wires at nearly the speed of light, approximately 299,792 kilometers per second (about 186,282 miles per second). Energy produced by remote power plants instantly reaches homes and businesses that are hundreds of miles away. This feature of electricity requires precise management of energy production and consumption to ensure electricity entering the grid matches what gets taken out. Additionally, all components of the grid — be it generators, power lines, or devices — must operate at the same 60 Hz frequency. Failure to balance electricity inputs and outputs or large deviations from 60 Hz can compromise grid stability and reliability; in extreme cases, operational failures can cause widespread blackouts.

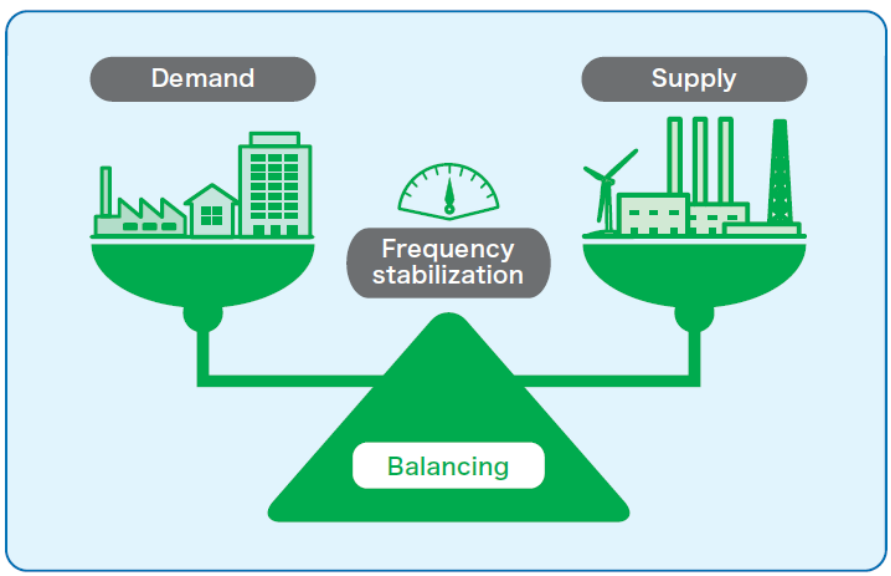

Figure 3: Balancing Electricity Supply and Demand [12]

Physical Organization

Electricity begins at generative facilities like coal plants or solar farms. These power plants transfer their produced electricity to transmission lines — the system that transports high-voltage electricity over long distances. When electricity from transmission reaches its intended region, it

transfers from transmission lines to local distribution lines. Distribution lines carry lower-voltage electricity over shorter distances. By carrying less electricity, distribution lines more compatibly connect to homes and businesses where the electricity ultimately gets used by even lower-voltage appliances.

Between each of these steps, electricity moves through a transformer — a device that increases or decreases voltage in a wire. It can be considered equivalent to a pump that adjusts water pressure in a pipe. These allow for use of high-voltage electricity that experiences fewer losses in long distance transport. They also allow electricity to enter a building and a device at appropriate voltages. Just as faucets would break under the water pressure of a geyser, distribution lines and buildings are not built to handle the same electricity that travels through high-voltage transmission lines. The facilities that connect transmission and distribution are called substations. They house step-down transformers and other management systems to ensure reliable delivery of electricity to homes and businesses.

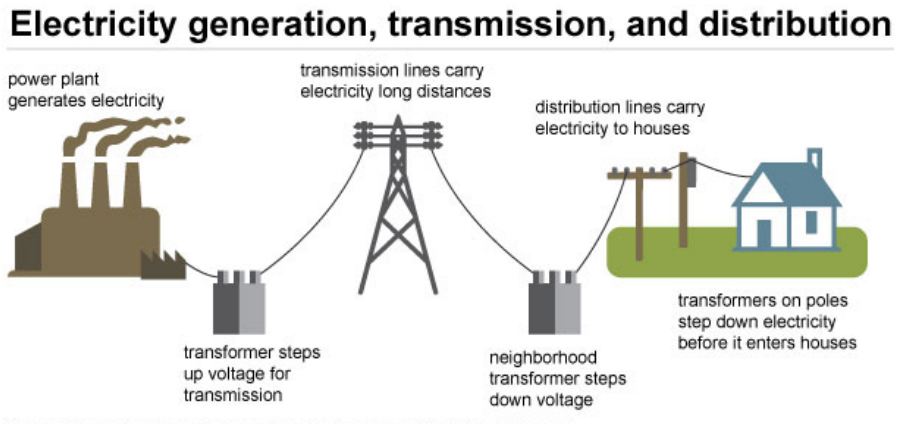

Figure 4: Electricity's Path from Generation to Consumption [13]

At a much larger scale, the US electric grid is divided into three interconnections: the Eastern Interconnection, the Western Interconnection, and the Electric Reliability Council of Texas (ERCOT). Each interconnection is significantly connected internally. Between interconnections, however, there exists little capacity for transferring electricity. This system arose arbitrarily over many years as the electric grid expanded. The Rocky Mountains created a geographic barrier to connecting the East and West, resulting in the Eastern and Western Interconnections. Texas independently chose to separate from the rest of the nation's grid to avoid invoking the Interstate Commerce Clause of the Constitution that necessitates adherence to federal laws. Such created the three Interconnections that exist today.

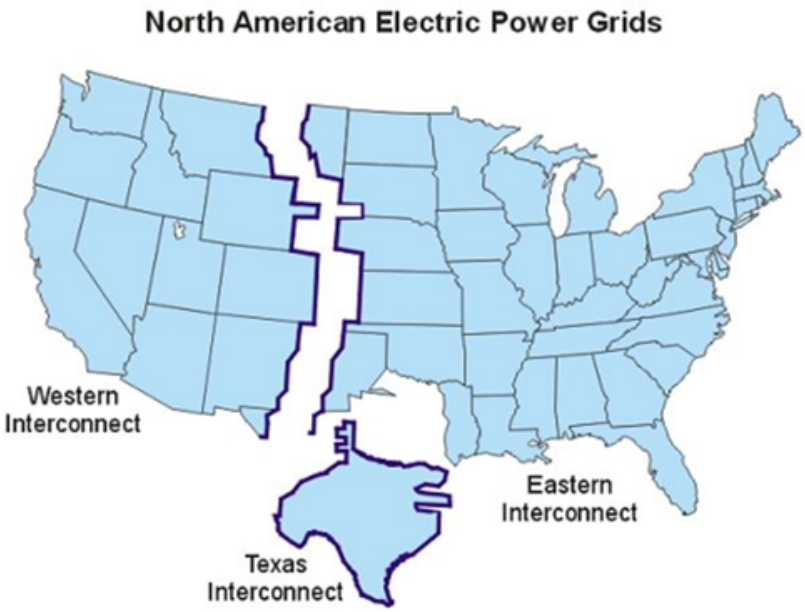

Figure 5: American Interconnections [14]

All North American interconnections operate with the same AC frequency of 60 Hz, but interconnections are not synchronized with each other. As such, connecting interconnections with AC lines is unfeasible. Instead, high-voltage DC lines and large transforming substations are used. These DC stations convert AC from one region into DC, then back into the corresponding AC frequency for the target grid. These facilities are more expensive than traditional transmission which contributes to their limited use to connect Interconnections.

Key Legislation

The legislative history of the electric grid is tied to the history of electricity in the US — a history that begins in 1882 with Thomas Edison finishing construction of the nation's first power station, Pearl Street Station in New York City. The first transmission line was built across the country in 1889 to connect Willamette Falls, Oregon to Portland, Oregon. A mere 13 miles, this transmission line was nevertheless innovative for its time.
Years passed, and electric appliances like lights spread across the nation, necessitating a similar growth in the infrastructure that produces electricity and that delivers it to homes.

The **Federal Power Act (FPA)** was enacted in 1920 to govern the growing electric grid as well as hydroelectric power facilities. The FPA created the Federal Power Commission — now known as the Federal Energy Regulatory Commission (FERC) — and gave this commission some authority over the burgeoning electricity market. It also established general procedures for the commission's proceedings and recordkeeping.

Specifically, the FPA gives FERC jurisdiction over "the transmission of electric energy in interstate commerce and to the sale of electric energy at wholesale in interstate commerce" [15]. The FPA defines "wholesale" electricity selling as sale for resale — that is, the exchange between suppliers [15]. Contrast this with retail electricity selling which sells to consumers. States retain authority over intrastate transmission and distribution of electricity, as well as intrastate wholesale and retail sales of electricity. The FPA empowers FERC to interfere in the market should it identify practices that are "unjust, unreasonable, unduly discriminatory or preferential" [15].

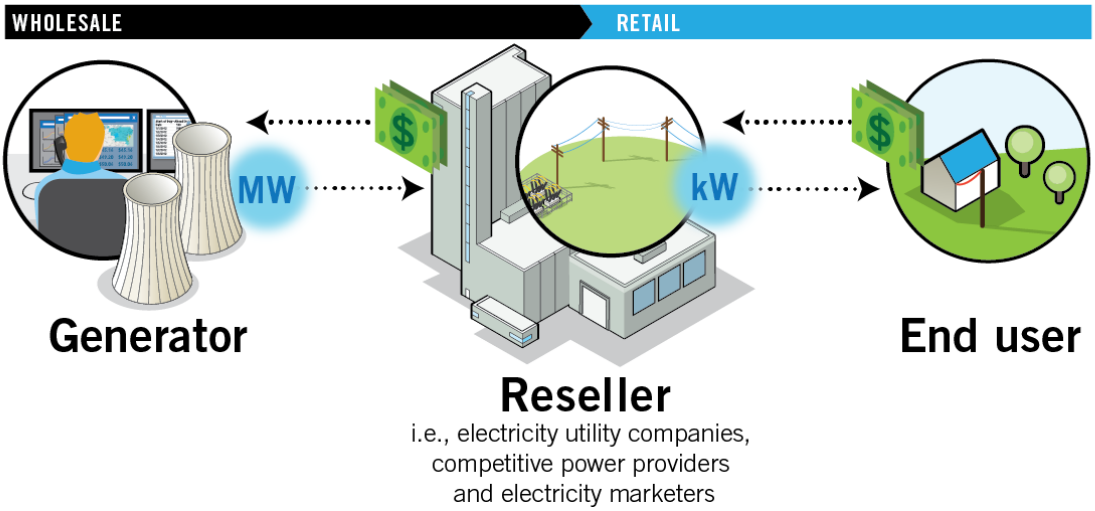

Figure 6: The Electricity Market [16]

The Energy Policy Act of 2005 (EPAct) added Section 215 to the FPA, directing FERC to designate an Electric Reliability Organization (ERO) responsible for maintaining electricity reliability. FERC thus officiated the North American Electric Reliability Corporation (NERC) as the ensurer of the nation's electricity reliability. NERC divided into six Regional Entities to better accommodate geographic differences in enforcing NERC's reliability standards.

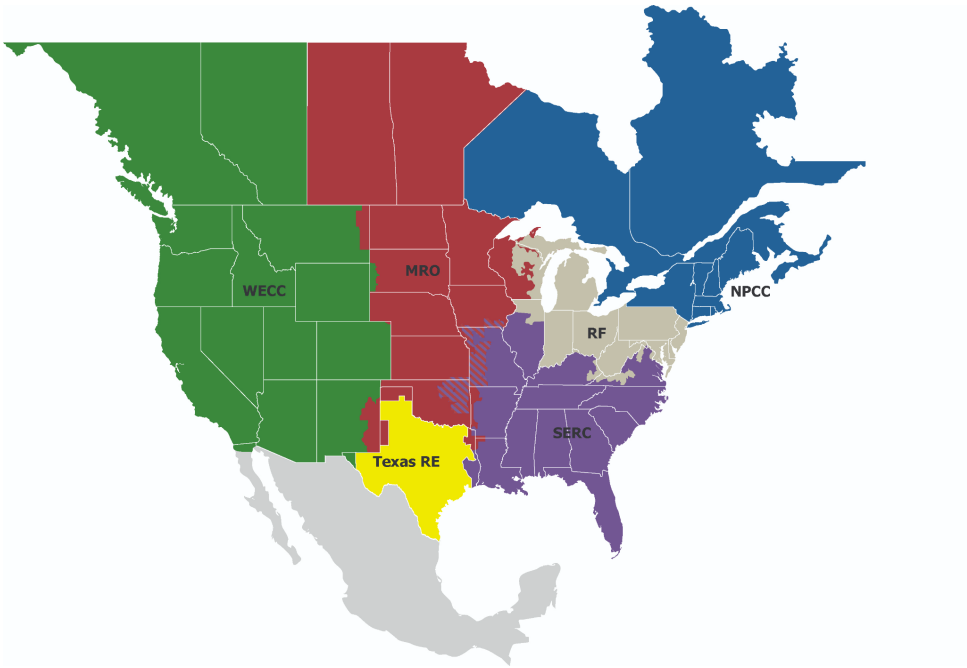

Figure 7: NERC Regional Entities [17]

The EPAct also added Section 216 to the FPA, giving FERC some authority over the siting of transmission — a power that previously lay entirely with the states. The EPAct's changes created a process for FERC and the DOE to award siting permits in some cases where states "withheld approval for more than a year." First, the Secretary of Energy can designate an area experiencing electric congestion as a National Interest Electric Transmission Corridor (NIETC), provided they

consult with affected states prior to the designation. If a state withholds approval for a siting permit application for more than a year, and the transmission project aims to relieve congestion in a NIETC, FERC can circumvent the state's lack of action to issue a permit. This new authority is known as backstop siting.

Two court cases significantly hindered FERC's ability to use its backstop siting authority.

After the passing of the EPAct, FERC issued a Notice of Proposed Rulemaking (NOPR) to receive public commentary on how the new law should be interpreted. Responding to comments raising concerns about withholding approval remaining undefined, FERC explicitly stated that withholding of approval includes a state's non-action (neither approval nor denial) and state denial of a permit application.

In **Piedmont Environmental Council v. FERC** (4th Circuit, 2009), the Fourth Circuit court determined that FERC cannot use its backstop siting powers if a state has taken the administrative action to deny a permit application.

In 2011, the DOE performed electricity congestion studies and designated NIETCs accordingly. The legality of these NIETCs were challenged by the California Wilderness Coalition in **California Wilderness Coalition v. U.S. Department of Energy**. The Ninth Circuit Court determined that DOE failed to consult with affected states prior to NIETC designation, as required by the FPA. In doing so, the Court vacated the contested NIETC designations. Additionally, the Court determined that the declaration of a NIETC constitutes a major federal action that may significantly affect the quality of the human environment. Therefore, NIETC declarations are pursuant to the National Environmental Policy Act, the stipulations of which FERC failed to follow.

The **National Environmental Policy Act (NEPA)** is a foundational environmental law enacted in 1970. Its primary purpose is to promote environmentally responsible decision-making in federal government actions "significantly affecting the quality of the human environment." NEPA outlines two key types of environmental analyses for federal agencies to follow when evaluating the environmental consequences of their actions: Environmental Assessments (EAs) and Environmental Impact Statements (EISs). Depending on the proposed action, an agency must complete an EA, EIS, or both. Prior to declaring the above NIETCs, the DOE wrote neither an EA nor an EIS. The Ninth Circuit's decision that NEPA applies to the designation of a NIETC thus provided a second point against the DOE's case.

An EA is a "concise public document" designed to determine whether a proposed federal action would significantly affect the environment [18]. In contrast, an EIS is a "detailed written statement" that analyzes the environmental impacts of a proposed action in addition to the impacts of reasonable alternatives [19]. A more thorough outline of NEPA requirements will be discussed later in relation to the contemporary electricity policy landscape.

Piedmont Environmental Council v. FERC and *California Wilderness Coalition v. DOE* decreased FERC's siting authority. Since then, no NIETC designations have been attempted, and backstop siting has not been used. The **Infrastructure Investment and Jobs Act (IIJA)** in November of 2021 amended specific wording in the NIETC and backstop siting clauses to make the legal pathway of backstop siting viable once again. The IIJA clarifies the point of contention in *California Wilderness Coalition v. DOE* to allow backstop powers to be invoked even if a state denies an application. It also expands the definition of a NIETC to encompass areas expected to experience unreliable electricity (broadened from only areas experiencing congestion). FERC is actively deciding how to incorporate these changes into their practices prior to invoking backstop siting once again.

Evolution of FERC Powers

Federal Power Act (FPA), 1920

- FERC controls the transmission of electric energy in interstate commerce and the sale of electric energy at wholesale in interstate commerce

Energy Policy Act (EPAct), 2005

- Directs FERC to designate NERC as the national ERO tasked with ensuring electricity reliability
- DOE — in collaboration with states — can designate as a NIETC an area experiencing transmission capacity constraints or congestion
- FERC can use backstop siting authority to give siting permits if:
  (1) a project will serve a NIETC and;
  (2) the affected state has withheld approval for more than 1 year

Piedmont Environmental Council v. FERC (4th Circuit), 2009

- Limits definition of "withholding approval" only to a state not taking action. State permit denials are final

California Wilderness Coalition v. DOE (9th Circuit), 2011

- NEPA documents must be prepared for the DOE to designate a NIETC
- Introduces uncertainty as to what constitutes adequate "collaboration" between the DOE and states for NIETC designation

Infrastructure Investment and Jobs Act (IIJA), 2021

- FERC can now use its backstop permit authority when a state has denied an application
- Expands definition of a NIETC to also include areas expected to experience transmission capacity constraints or congestion

National Environmental Policy Act (NEPA)

NEPA exclusively applies to "major federal actions significantly affecting the quality of the human environment." An EA explores whether or not an action will affect the environment and to what degree. Should the findings of an EA provide evidence of significant environmental impact, NEPA requires that said impacts be explored further through an EIS. If, after conducting an EA, the agency finds that the action will have no significant impact on the environment, they issue a Finding of No Significant Impact (FONSI), allowing the action to proceed without the need for a full EIS. Actions that are determined to not have a significant impact without needing an EA study are known as Categorical Exclusions (CEs).

EISs document a comprehensive evaluation of an action's potential environmental consequences, including direct and indirect effects, as well as cumulative impacts. EISs are subject to public review and comment, ensuring that stakeholders and the general public have an opportunity to participate in the document's creation.

The preparation of an EIS involves scoping, public involvement, and a thorough analysis of the proposed action's environmental effects. Agencies must evaluate a range of alternatives, including the "no action" alternative, to identify the most environmentally preferable course of

action. The agency must also publish the draft EIS to receive comments and address these comments before a final version can be made.

For large projects, EISs often fall under the jurisdiction of multiple agencies. To expedite coordination, a "lead agency" takes charge of writing the EIS. The other "cooperating agencies" provide data analysis and assess the aspects of a project's impact that falls within their specialty. This information is shared with the lead agency that writes the final EIS.

Economic Organization

Prior to 1996, most participants in the electric market were vertically integrated. Individual companies owned and operated generation, transmission, and distribution. Electricity could be produced, travel long distances, and reach its destination under the jurisdiction of a single entity. Such private ownership of transmission lines made exclusivity common. Companies would only allow certain generation facilities to send power into their lines. In this way, transmission owners limited the freedom to join the electricity market as a generator. FERC determined that this practice was "unjust, unreasonable, unduly discriminatory or preferential," and subsequently issued **Orders 888 and 889**. Together, these Orders forced transmission service providers to make transmission access available to all generators. One way to comply with the new regulations was to secede control of transmission lines to an Independent System Operator (ISO). As a nonprofit, third-party entity, an ISO facilitates wholesale electricity purchases and sales and provides ancillary services — necessary actions that maintain a continuous and reliable electricity supply. A major goal of ancillary services is to match energy supply and demand in real time, but physical properties of electric systems also necessitate other forms of maintenance.

Examples of Ancillary Services

Frequency Control | Keeping AC frequency within a specific range of 60 Hz, the standard grid frequency. Overly deviating from 60 Hz increases electricity losses and (in severe cases) shut power down.

Scheduling & Dispatch | Without large-scale storage, energy input must equal energy output. Scheduling preemptively assigns generators to produce electricity, while dispatch adjusts generators in real-time to match production with real-time demand.

Operating Reserves | Energy sources that can rapidly be turned on and off to quickly address sudden changes in demand

Reactive Power Control | Similar to frequency control, power control incorporates losses from traveling through wires to determine how much generation to dispatch

Black Start | The restoring of electricity after a large grid shutdown. Black starts require significant coordination and are extremely expensive to perform.

As a reconciliation for deprivatizing the transmission industry, FERC developed a unique economic system to ensure that transmission owners still receive a strong return on investment.

Prices of electricity produced by generators are set based on long-term contracts. Transmission operators purchase electricity at these constant prices which guarantees generators constant income and a well-defined return on investment.

ISOs and RTOs prioritize the purchase of cheaper electricity via a system known as merit order. Merit order organizes available supply by marginal cost (cost/MWh), then sets the retail price at the marginal cost of the most expensive energy. As seen in the figure below, less demand (the horizontal axis) would result in cheaper retail prices (vertical axis) since all demand can be met by the cheapest resources. As demand increases — say during a hot day when every home turns on air conditioning — more expensive power plants must turn on to also increase supply. To turn a profit after buying expensive energy during periods of high demand — or congestion — utilities charge customers more.

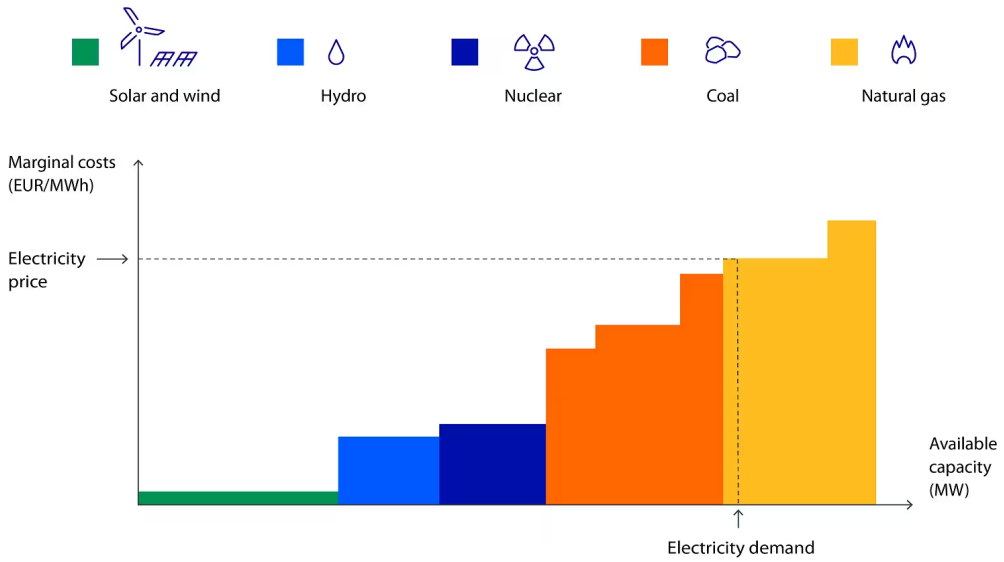

Figure 8: Marginal Costs of Energy [20]

Sales at wholesale from transmission to distributor relies on a modified version of merit order. The colored area of the above figure can be viewed as the amount that transmission pays for generated electricity. Selling to distributors at the same prices wouldn't yield a profit. Additionally, it is impossible to determine the source of electricity once it enters a transmission line; whether it comes from solar or coal, the electricity in a line is homogenous. To balance this lack of information with a need for profit, wholesale prices to distributors are (more or less) set at the marginal price of the most expensive electricity generated at the time. All cheaper generator's electricity is also sold at this higher cost. The area under the dashed line labeled "electricity price" and to the left of the "electricity demand" line represents the revenue for transmission from wholesale transactions. Having purchased the electricity at the cost of the colored regions' areas, the remaining empty space in the price-demand curve is the profits made by transmission.

ISOs and RTOs, however, are non-profit transmission line operators. They take some of these profits to cover the costs of providing ancillary services. Afterwards, the remainder is distributed amongst entities that pay in advance for financial transmission rights (FTRs). Similar to purchasing stock in a company, individuals or corporations pay an RTO/ISO for the corresponding number of FTRs, guaranteeing them a portion of the excess capital from wholesale sales. Since periods of congestion yield higher marginal costs for generation, the excess capital grows when

more electricity is consumed. FTR owners essentially bet on the presence of congestion to drive up prices and make the most profit from their purchases. The FTR system also allows companies that build transmission to earn money on their investment without privately owning and operating the lines. The companies are guaranteed some — but not all — of a line's FTRs; the remainder are put up for biddings.

Not all utilities chose to enter into ISOs and RTOs, however. The figure below shows where ISOs and RTOs exist in the US. In the southeastern and western areas with no designation, individual utilities still own generation, transmission, and distribution. With no competition in delivering energy, they hold exclusive market power. The monopoly lessens competition but decreases reliability.

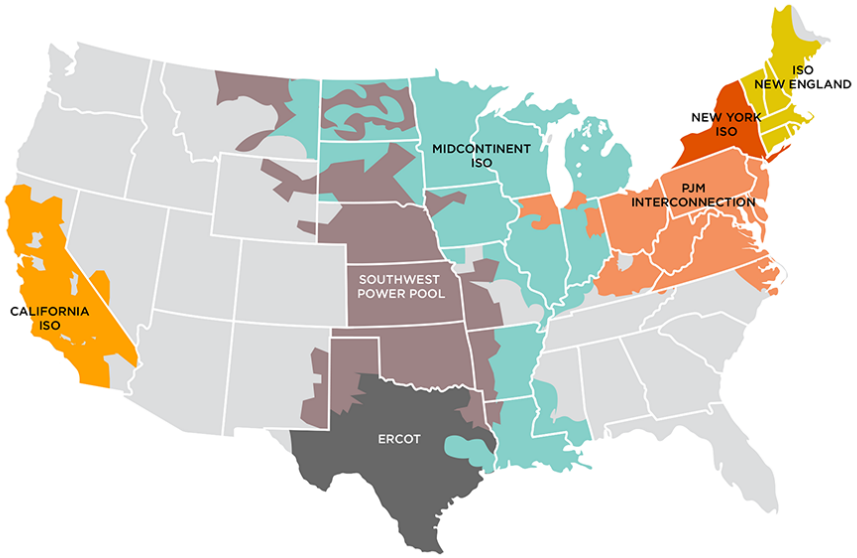

Figure 9: ISOs and RTOs [3]

Key Conflicts & Concerns

Sources of NEPA-Associated Delays Remain Unidentified

Issuing a federal permit — for example, to cross federal lands, impact US waters, or site a transmission line — activates the "major federal actions significantly affecting the quality of the human environment" clause, thus mandating NEPA adherence. The process required to obtain federal permits is notoriously inefficient. This inefficiency consumes significant time and capital for both private companies and the government.

Precise information about the timeline and costs of completing an EA/EIS is almost nonexistent. A 2014 US Government Accountability Agency (GAO) report on this topic is aptly titled "Little Information Exists on NEPA Analyses," as a lack of standardized data collection practices between agencies limited the depth of analysis.

Of the scarce data, the average cost from 2003-2012 for the DOE to hire an EIS contractor was $6.6 million, ranging from a low of $60,000 to a high of $85 million [21]. A 2003 report to the Council on Environmental Quality (CEQ) reported an EIS cost range of $250,000 to $2 million (upwards of $3 million in 2023 dollars) [22]. In 2012, the average EIS took 4.6 years to complete — a likely underestimate according to agency officials whom the study interviewed.

	Completion Time	Cost (USD)*			
		Min	Max	Median	Average
EIS (CEQ, 2003)	Average of 4.6 years	$250,000	$2 million		
EIS (DOE, 2003-2012)		$60,000	$85 million	$1.4 million	$6.6 million
EA (CEQ, 2003)	Average of 13 months	$5,000	$200,000		
EA (DOE, 2003-2012)		$3,000	$1.2 million	$65,000	

**Not adjusted for inflation*

Yet, NEPA itself may not cause these delays. A 2023 Oversight and Investigations Subcommittee hearing received expert testimony attesting to NEPA delays reflecting poor inter-agency communication, delays resulting from compliance with other laws, unstable budgets, and outdated technologies [23]. Due to NEPA's broad statutes, EAs and EISs often encompass other laws, such as the Endangered Species Act or the Clean Water Act.

The Fiscal Responsibility Act of 2023 acknowledges the presence of outdated technologies, appropriating $500,000 for the CEQ to study use of a cloud to streamline data sharing and communication; set limits on EAs and EISs, limiting EAs to 75 pages and EISs to 150 pages or 300 pages if extraordinarily complex; and imposed deadlines of 1 year for EA completion and 2 years for EIS completion [24].

Considerable expenditures and lengthy timelines for EISs suggest that these changes will greatly reduce NEPA-associated project delays. Or, NEPA-associated delays may simply be the superficial symptoms of other issues facing the US government. As of this report's publication, no information exists to corroborate or dispute these claims, and data to perform an adequate study are not collected.

Renewables and Electrification: Increasing Strain

States and the nation are setting ambitious clean energy goals

22 states as well as the District of Columbia and Puerto Rico have ambitious goals for renewable energy portfolios and greenhouse gas emissions [25]. The target years for these goals range from 2035 to 2050, aligning with the nation's goal for achieving net-zero emissions by 2050 [5]. The global threat posed by anthropogenic climate change undoubtedly warrants such measures. But promoting such large-scale infrastructural change must be accompanied by the proactive addressing of likely externalities.

Renewables are growing at unprecedented rates

In 2020, renewables (solar, wind, biomass, geothermal, and hydropower) accounted for the largest portion of new generating capacity for the first time [26]. The nation's reliance on renewably-sourced electricity is only expected to increase. Renewable generation grew 19.6% from 2021-22, dropped to 8.3% from 2022-23, but 22.9% is predicted from 2023-24 [8]. Compared to coal dropping 7.7% in 2021-22, 23.6% in 2022-23, and 2.9% expected for 2023-24, clean energy production will very likely continue to surpass fossil fuels as the nation's primary source of electricity.

Generation Source	Growth Rate		
	2021-2022	2022-2023	2023-2024
Coal	-7.7%	-23.6%	-2.9%
Natural Gas	7.4%	4.7%	-2.1%
Petroleum	22.5%	-20%	9.5%
Nuclear	-1.0%	0.6%	2.6%
Conventional Hydroelectric	4.2%	-0.5%	8.4%
Other Renewables	16.4%	5.4%	13.7%

The magnitude of generation that is queued for regional and federal review further demonstrates the tempo at which clean energy facilities are expected to be built. At the end of 2022, over 1,350 GW of generation — 947 GW of solar and 300 GW of wind — was in queue for interconnection [27]. For comparison, this is more than the entire nation's generative capacity in 2022 (~1,250 GW) [28]. On July 27, 2023, FERC issued Order 2023 to begin the process of reforming this queue. Of note, the commission made the queue now "first ready, first serve" instead of "first come, first serve" as well as implementing more provisions to discourage immature projects from clogging the queue and diverting resources from viable applications [29].

Clean energy — while needed — presents new reliability issues

Some sources of clean energy, particularly solar and wind, are known as variable renewable energy (VRE) sources, as their electricity production fluctuates uncontrollably. This inconsistency is mostly caused by weather; solar panels don't function without sunlight, and wind turbines don't function without wind. In contrast, nuclear, hydropower, and fossil fuels continually produce electricity — a feature that gives system operators more control over the total supply of electricity to match the demand.

The variability and geographic specificity of renewables makes them significantly less reliable than fossil fuels. Both of these traits require more transmission. Connecting renewable energy between distant locations allows for excess electricity produced in one area to serve the needs of another. For example, if solar panels in New Mexico are not generating energy due to cloud cover, transmission can carry in excess wind energy from Nebraska. This addresses reliability issues by facilitating nationwide energy sharing and also connects remote clean power plants to population hubs. Without transmission, though, too hasty a transition to VRE sources endangers electricity security across the nation. Aiming for expeditious and widespread decarbonization is noble, but instituting rapid technological change without thoroughly considering transmission introduces new dangers.

Electrification will increase the amount of electricity used

At the same time, households and businesses are beginning to demand much more electricity. In a phenomenon known as electrification, technologies that previously did not need electricity are quickly being replaced by versions that do. Notable examples include electric heat pumps for controlling indoor temperatures, electric stoves, and electric vehicles (EVs). While the reasons for electrification of different products varies — electric heat pumps are 3 to 4 times more

efficient than alternatives, electric stoves don't release indoor air pollutants, and EVs emit almost no greenhouse gases — the transition is undoubtedly taking place [30]–[32]. In fact, enough electrification is expected to occur that researchers predict over 300% growth in electricity demand by 2050 [33].

In the case of EVs, this change is necessary. The transportation sector releases the most greenhouse gas emissions in the US, around 29% [34]. Achieving national net-zero emissions requires advancement beyond the internal combustion engine, and EVs are a highly-viable alternative. This electrification of transportation is expected to contribute most to the extreme increase in electricity demand. In this way, the path to decarbonization and the need for a resilient electric grid are intertwined.

The electric grid can't handle this new supply and demand

Therein lies the problem. When a device plugs into an outlet, the transmission and distribution that moves energy from power plants to a home have physical limitations. Only so much electricity can flow through lines before failures occur, and there are not enough lines to handle a large increase in supply. Clear trends show unprecedented growth in electricity demand and energy generation, yet the necessary transmission infrastructure remains overlooked and underdeveloped. Adopting renewables requires transmission to connect generation with consumption and to ensure that renewably-sourced electricity stays on.

Failure to invest in transmission modernization will inevitably result in a grid that is operating near its critical capacity. That is, the grid is more "fragile" and susceptible to being overloaded. Unforeseen interruptions of any kind — wildfires, unexpectedly high demand, strong winds — become more dangerous. Factoring in the increased frequency and intensity of climate paints an even more dire picture. Another such unforeseeably interruption could be a malicious cyber-attack.

More electrification increases harms of infrastructure failures and attacks

A planned cyber-attack on electricity infrastructure may sound fictitious, but rapid digitization and increased reliance on electricity suggest otherwise.
In 2021, 1 in 2 American Internet users had their accounts breached; in the first half of 2022 alone, around 236.1 million ransomware attacks occurred globally [35]. With increased inter-device connection for systems like an Internet of Things and human error causing 85% of data breaches, compromising a single device could cascade into a grid-wide shutdown [35].

An incident like this is not a confined hypothetical. On December 23, 2015, three Ukrainian substations experienced unexpected power outages, turning off power for about 225,000 citizens. Analysis by a collaborative team of US and Ukrainian agencies sourced these outages to a highly-coordinated cyber-attack from Russian actors. The malware was reportedly delivered via spear phishing emails with malicious Microsoft Office attachments. A deliberate, infrastructural attack of this degree — operated completely remotely — exemplifies the liability that an outdated grid poses to national security [36].

Additionally, reliance on clean energy increases the relative value of baseline generative facilities, such as hydropower or nuclear power. Removal of such facilities — due to maintenance or a foreign attack — could destabilize electricity reliability.

> "No infrastructure design which isn't hardened against deliberate information attack can be considered resilient; failure to design security into infrastructure from the beginning is a major source of fragility and vulnerability" [37].

Ramifications of electric grid failures

The idea of a small or moderate blackout may seem innocuous. A home fuse breaking can be fixed by restarting a circuit breaker. Intentional rolling blackouts typically resolve in an hour or two. Large-scale, unexpected energy loss lies at a different magnitude altogether.

Electricity's convenience and the promise of cleaner energy production are driving modern technologies to rely — in many cases exclusively — on electricity.

Heating and cooling of homes is increasingly reliant on electricity, meaning that a power outage could prevent affected homes from regulating temperature. During a cold spike or heat wave, this can — and has proven to — be deadly. Days without electricity to power a refrigerator could lead to food spoilage. Water pumps are often driven by electricity, so no power functionally turns off the water supply. Electricity-dependent medical equipment like ventilators could fail.

Communications are also mostly powered by electricity, so none of the hardships faced by suffering individuals could be communicated to first-responders. Coordinating responses to address critical infrastructure failures would be stymied.

Economically, large blackouts also cost the entire nation. Cutting off Internet access in an era of remote work, collaborative & online documents, email, etc disrupts work at a massive scale. Not to mention, many companies rely on computing clusters to drive myriad other programs; on average, outages at data centers cost $740,000 each [38]. Nationwide, power outages cost the US economy around $27 billion annually [38]. The continued growth of EVs means that cutting off electricity also cuts off a critical sector of transportation.

The immense degree to which contemporary society relies on electricity exemplifies the grid's role as critical infrastructure. Looking to past grid failures highlights this even more, and retrospection can identify additional areas where improvement is necessary.

North American Blackout of 2003

In the largest North American blackout to date, power was cut off to 50 million customers; most power returned within hours, but some areas of the US were without electricity for days. Some locales in Ontario had weeks without power. NERC analysis concluded that failed coordination between the Midcontinent ISO (MISO) and the Pennsylvania-New Jersey-Maryland Interconnection (PJM) reliability coordinators contributed to the crisis.

(1) Transmission line failed due to errors making voltage adjustments. This didn't cause the blackout but rather eliminated a key alternative route for electricity that would have provided capacity once other transmission lines failed. (2) The regional control center's alarm system failed, so operators had no indication of grid failures. (3) Heavy demand caused transmission lines to sag into overgrown tree canopy, shutting down. (4) Failure of these systems sent electricity through numerous other routes that weren't able to handle the amount of energy input, causing a cascade of transmission line outages. (5) MISO operator corrected a line's carrying status but forgot to reset the automatic state estimator to every five minutes.

Within less than a minute-and-a-half, thousands of events shut off electricity to much of the Northeast in a massive chain reaction driven by physics and failure of automatic system

equipment to adjust to the scenario.

A number of individual events merged to cause this catastrophe, a salient few of which include:

- Different interpretations of the functions, responsibilities, authorities, and capabilities needed to operate a reliable power system.
- In some regions, data used to model loads and generators were inaccurate due to a lack of verification with actual system data and field testing.
- Planning studies, design assumptions, and facilities ratings were not shared and were not peer reviewed between operating entities
- Several entities violated NERC operating policies and planning standards, and those violations contributed directly to the start of the cascading blackout.
- Other causes include: lack of a standardized definition of "critical infrastructure," different delegations of reliability authority between regions, vertical communication failure within a balancing authority, lack of ability to backup power to come from another source, and failure to conduct interregional transmission studies

> The causes of the blackout described here did not result from inanimate events, such as "the alarm processor failed" or "a tree contacted a power line." Rather, the causes of the blackout were rooted in deficiencies resulting from decisions, actions, and **the failure to act of the individuals, groups, and organizations involved**. These causes were preventable prior to August 14 and are correctable. Simply put — blaming a tree for contacting a line serves no useful purpose. The **responsibility lies with the organizations and persons** charged with establishing and implementing an effective vegetation management program to maintain safe clearances between vegetation and energized conductors. [39]

2021 Texas Power Crisis

Texas weather in mid-February of 2021 shattered state records of low temperatures and defied power operator predictions. Dubbed Winter Storm Uri, this period of unprecedented cold weather caused over 4.5 million homes and businesses to lose power, some for days on end. The ensuing crisis cost Texas an estimated $200 billion and killed 246 people.

The seeds for this failure were planted in 1990 when Texas deregulated its power grid to allow for competitive rate setting; however, poor oversight in this transition allowed utilities to boost profits by cutting expenditures on reliability and safety. In 1996, Texas officially separated from the national electric grid to form ERCOT, with the intent to avoid federal electric market oversight. The few links between ERCOT and the other interconnections were far from adequate to provide Texas with the support it needed during Winter Storm Uri.

Failure to properly weatherize infrastructure like wind turbines and natural gas facilities exacerbated the grid's failures. Poor coordination led rolling blackouts — intended to reduce demand from civilian consumers — to also cut off power to pumps for natural gas pipelines that supplied power plants. So many of these issues compounded that ERCOT was mere minutes away from losing control of the entire grid. Most power facilities are programmed to shut off after ~9

minutes of an AC frequency below 59.4 Hz, but Texas stayed in that range for ~4 minutes. Failure to such a scale would require a black start — a complete resetting of the grid — that is extremely complicated and expensive, requiring equipment across the state to be inspected and replaced.

ERCOT also failed to moderate the market for both producers and consumers. Some firms went bankrupt while others picked up the extra load. Now holding a temporary, partial monopoly over electricity, they drove retail prices up. In a misguided attempt to ameliorate the situation, ERCOT commissioners decided to artificially set wholesale prices to the market cap: $9000/MWh. It's estimated that this decision will charge Texas residents as much as $37.7 billion in surplus costs [40]. These prices continued for about 2 days after the blackouts ended.

Japan Tōhoku Earthquake & Tsunami Grid Meltdown

Japan's system is slightly different from ours in that the west operates at 60 Hz while the east operates at 50 Hz. This physical difference between regions prevented the exchanging of electricity, much as how the US has limited transfer capacity between interconnections. Japan's struggles to reconcile with the aftermath of the Fukushima reactor meltdown after the 2011 Tōhoku Earthquake & Tsunami exemplifies the risk being perpetuated by a lack of action in the US.

The Fukushima disaster affected the eastern region, which relied heavily on nuclear power for electricity generation. Following the meltdown, the majority of nuclear power plants in the eastern region were shut down for safety inspections, resulting in a significant drop in available electricity supply.

The lack of sufficient interconnection and transmission capacity between the eastern and western grids prevented the sharing of excess electricity from the western region to meet the heightened demand in the eastern region. This exacerbated the eastern imbalance in power supply and demand, resulting in weeks of electricity shortages and rolling blackouts.
The consequences of such actions — necessary to maintain an operational grid but avoidable had more interconnection existed — had severe economic and social impacts. Industries, businesses, and households experienced disruptions, affecting productivity, daily activities, and overall quality of life. The situation highlighted the critical importance of having a more interconnected and flexible transmission grid capable of efficiently redistributing electricity during emergencies or unexpected events.

In the aftermath of the Fukushima disaster, Japan recognized the necessity of enhancing transmission interconnection to improve grid resilience. The country is embarking on initiatives to upgrade and expand its transmission infrastructure, increase inter-regional capacity, and synchronize the frequencies of the eastern and western grids. In particular, Japan aims to increase its interregional electricity exchange capacity from 1.2 GW to 3 GW by 2027 [41]. In comparison, the US has 1.3 GW of existing transfer capacity between the Eastern and Western Interconnections [42].

The lessons from Japan's experience after the Fukushima reactor meltdown underscore the importance of transmission interconnection in promoting grid stability and disaster preparedness. The US should not wait for further disasters to take action; preemptive investment in the grid will prevent avoidable losses of life and — as seen by the Texas Power Crisis of 2021 — potentially billions of dollars that would be spent on recovery.

California 2020 Heat Waves

In the summer of 2020, California experienced a series of extreme and prolonged heat waves that brought scorching temperatures to the state. As temperatures soared, electricity demand surged as people cranked up their air conditioning to seek relief from the heat. The increased energy demand puts immense pressure on the power grid, leading to concerns about potential blackouts and grid instability. The California Independent System Operator (CAISO) — responsible for managing the state's electric grid — issued warnings of potential power shortages and called for voluntary energy conservation efforts to alleviate the strain on the grid.

During this period, several power outages were experienced across the state, affecting millions of residents. Rolling blackouts were implemented in certain areas to prevent a complete grid collapse and prioritize power for essential services. These blackouts were ordered by CAISO to manage the heightened electricity demand and maintain grid stability [43].

The heat waves also posed severe health risks to residents, with prolonged exposure to high temperatures leading to heat-related illnesses and exacerbating existing health conditions. Vulnerable populations, including the elderly and those without access to air conditioning, were particularly at risk during these extreme weather events.

The 2020 heatwaves in California highlight the vulnerability of the state's energy infrastructure to extreme weather conditions and underscored the need for better planning, grid management, and energy conservation measures to ensure resilience in the face of future heat waves and climate change impacts. It also raises concerns about the increasing frequency and intensity of extreme weather events due to global climate change and the necessity of taking adaptive measures to protect public safety and ensure a reliable energy supply.

Consumers pay for exorbitant costs of generation and transmission

The costs of a transmission project ultimately fall upon consumers. An ideal model allocates an increase in retail sale prices with the amount of utility — or benefit — that an individual gains. In this way, a transmission line's cost is distributed according to who it serves most. Unfortunately, it is nearly impossible to quantify such effects accurately enough for use as a price basis. A given transmission line affects a great deal of people in a wide geographic range, yet current practice is to assume that a line serves nearby consumers more and allocates costs accordingly. This method fails to account for the dispersive nature of electricity and isn't backed by quantitative evidence; there is no definitive technique to quantify a household's benefit from a new connection in the grid.

Transmission delays also increase the investment needed for generation companies to obtain project approval and connect it to the grid — another cost that becomes the burden of American citizens.

With more generation capacity waiting in the queue than the entire nation's capacity, inability to quickly roll out transmission further bottlenecks their approval. A new solar project in Arizona is rendered useless without interconnection to reach consumers in Los Angeles. On top of this, a place in the queue does not guarantee project approval; power plant developers can invest considerable time and capital in a project only for it to get denied [33]. Spending millions of dollars on a NEPA document and paying to keep one's spot in the erratic approval queue compound the sky-high costs of construction and manufacturing. This uncertainty translates to financial risk, increasing a project's expected costs and driving investors to pursue higher returns. High costs also increase the barrier to entry for new technologies. Innovative generation technologies that are more

reliable and clean but that require a high initial investment become stifled. Overall, this decreases competition-driven advancements in technology. It also pushes generation facilities to increase their base energy prices — a cost that market organization ensures trickles down to consumers.

Some RTOs have explored the concept of a "first ready, first served" policy that encourages more thorough project submissions. Previously, many projects in queue weren't fully developed but were queued anyways in hopes of at least one being approved. FERC just recently adopted this policy and a number of others to disincentivize packing the queue with low-quality project submissions [29]. This, however, doesn't change the fact that transmission lines face years of legal hurdles to navigate before construction can even commence.

While incremental advancements are necessary to create a working approval system, they should not detract attention from more important policy reforms. The backlogged generation queue is a direct product of transmission-related issues. So long as new transmission continues to stall, so too will the new generation; only a focus shift towards bettering transmission can amend these delays.

Policy Alternatives

Declare a National Plan for the Electric Grid

First and foremost, the nation must reflect on the historical regulations — or a lack thereof — that cultivated today's increasingly dysfunctional electric grid.

Historically, electric line networks grew mostly independent of oversight. New lines were built to serve a company's consumers and without consideration of communal interests. There existed no official, long-term vision for how energy should be delivered in the US. Yet, both public and private entities have long explored a solution to optimize energy use from coast-to-coast: a National Interconnection.

The first exploration of a National Interconnection was first explored in 1923 in *The Chicago Sunday Tribune* in 1923 [42]. Organizations continued to study the concept over the next century, culminating in a large body of contemporary research — including work from Princeton and the NREL — that looks at the cost, siting, and capacity of potential National Interconnections [42], [45]. With modern computing power and modeling techniques, these studies provide an unprecedented and clear view into the benefits of a National Interconnection.

With American energy shifting overwhelmingly to variable energy sources, grid upgrades must accommodate their inconsistency. If the US hopes to meet its clean energy commitments, it can no longer afford disorganized electric grid growth. A National Interconnection serves as a theoretical goal for the grid that should be an inextricable precursor to the goal of reaching net-zero nationwide emissions. Similar to aiming for net-zero emissions by 2045, an established electricity development plan sets a timeline and clarifies the steps needed to make meaningful progress.

Define Interstate Electricity Trading

Electricity flows through power grids based on the principles of physics, particularly the path of least resistance. When electricity is generated, it seeks the most efficient and direct route to reach its destination, regardless of political boundaries or regions of more dense interconnection. In other words, electricity follows the path of least resistance to minimize energy losses and ensure efficient transmission.

This concept challenges the idea that national electric grids are neatly separated into distinct interconnections and regions. While there may be physical infrastructure and administrative

divisions, electricity itself does not recognize these artificial borders. Instead, it dynamically adjusts its path based on the available routes and the electrical demand at different locations.

Regulating electricity transmission as if it were isolated into separate regions fundamentally opposes the electrical sciences. Jurisdictions help to compartmentalize the governance of this highly complex system, but the physical laws governing electricity flow are not constrained by organizational boundaries. The interconnected nature of power grids necessitates coordination among various entities involved in managing and operating the grid, both within and across borders. Utilities districts, ISOs, RTOs, cities, and states must work together. Beliefs of divided sovereignty and competing interests directly impede this necessary collaboration.

Vagueness in legal definitions contributes to such contention, particularly state-state and state-federal conflicts. Specifically, the US Code lacks an explicit definition for interstate trading of electricity. Intuition suggests limiting the definition to transmission lines that cross state borders. As a physical manifestation of electricity transport, interstate transmission lines can be likened to interstate natural gas pipelines or highways. But electricity lacks a physical form and behaves in ways that defy typical notions of trade. The lack of a codified definition allows for countless interpretations of how one can trade a nonphysical resource across physical boundaries. This comes at the expense of much needed interstate collaboration.

The definition of an interstate transmission facility should be tied to the capacity of the line in question and should explicitly include both DC and AC lines. It can be reasonably considered that transmission lines over a certain capacity transport enough electricity that the grid directs at least some of that electricity to another state. The Supreme Court case *Florida Power Light Co. v. FERC* determines that electricity in a Florida-confined transmission line comingles with — and is therefore transported to — electricity traveling interstate. Judges deferred to expert testimony as evidence of the decision because of the difficulty to obtain definitive and quantitative evidence [46]. Said evidence would require an overly exhaustive tracing test of the grid's electromagnetic response to an input of electricity. The Court comments on the inapplicability of such extensive testing used in a 1942 case, *Jersey Central Power & Light Co. v. FPC*:

> "We note, moreover, that *Jersey Central*-type tracing studies become less feasible as interconnections grow more complicated… The requirement of *Jersey Central*-type tracing might encourage the artificial and wasteful complication of interconnections for the purpose of avoiding federal jurisdiction. More important, as interconnections proliferate and energy pools grow larger, jurisdictional hurdles like those erected by the Court of Appeals would become ever more difficult to clear."

Jurisdictional hurdles, in this case, references a requirement for test-based evidence to consider a line as participating in interstate commerce. Thus, *Florida Light Power Co. v. FERC* sets — at default — any interconnected transmission facility subject to federal law via the Commerce Clause. Substantial scientific and legal evidence exists to warrant Congressional action to amend the FPA with an explicit definition of interstate electricity trade. Further exploration may be warranted to gauge at what capacity it becomes reasonable to conclude that some electricity traverses a border.

Permitting Improvements

Applying for federal permits to site transmission lines requires significant resources and time. Project proposals must adhere to applicable laws to receive a permit, meaning that NEPA compliance and delays precede the grant of a permit.

Communication is a critical yet undervalued component of the permitting process. At any stage, federal agencies; state, local, and Tribal governments; community members; ISOs; RTOs; and utilities are sharing laws, regulations, data, conflicts, timelines, and more. Often dismissed as unavoidable bureaucracy, these dialogues are essential to make a project's analysis worthwhile. The question arises, then: Is communication occurring in the most efficient manner possible?

The answer is a resounding no.

No single line of correspondence for any single topic can be labeled as the culprit. Instead, marginal delays at each stage of communication add up to drastically prolong permit approval. Much of this delay stems from disagreements — namely, conflicts of interest and incompatible procedures of operation — that cannot be hastened by simply imposing a time limit (as done by the Fiscal Responsibility Act of 2023). Compliance with such "blanket" legislation may come at the expense of quality environmental considerations and public participation. Making meaningful permitting improvements will require much more nuance and a deeper understanding into the policies and beliefs of every involved stakeholder.

Resolve conflicting agency procedures

At the federal level, much delay stems from uncoordinated interagency communication. Assessing the numerous environmental impacts of transmission facilities requires involvement from many disparate agencies. Often, each agency has contrasting procedural policies for carrying out an impact study. These may include — but are not limited to — different timelines, views on key assumptions, and methods for both public participation and data-heavy calculations. A Government Accountability Office report notes an example of disagreeing procedures between the Forest Service and a land management agency in assessing what course of action most mitigates environmental effects:

> "In our work on the Forest Service's decision making process, we noted that the land management agencies' disparate missions and responsibilities resulted in differing evaluations of environmental effects and risks. This, in turn, could lead to disagreements among agencies on whether and how the requirements of environmental laws and regulations can best be met. We found, for example, that the Forest Service may be willing to accept a greater level of risk to the recovery of a threatened or endangered species under its multiple-use and sustained-yield mandates than would the Fish and Wildlife Service or the National Marine Fisheries Service, both of which are charged unambiguously with conserving and protecting species threatened with extinction. As illustration, disagreements among these agencies … have resulted in delays in the Forest Service's plans and projects" [47].

With differing statutory missions, agencies face institutionalized roadblocks to resolving these issues. The ambiguity inherent in analyzing an action's potential environmental impacts makes it nearly impossible to reach agreement on what constitutes a "best" decision, as each agency may value the same environmental protection differently. Compromise may require breaching agency

policy, causing a gridlock in decision-making for which no official resolutions exist. When considering the host of environmental impacts for a transmission line, these value-judgment issues pile up quickly.

One solution for these dilemmas may be the creation of a "statement of conflict" clause in NEPA documents. Should such subjective disagreements exist, a statement of conflict would require each entity to describe its conclusions. No consensus would be necessary; rather, a reader can engage with the arguments and arrive at conclusions independently.

Consolidate federal, state, and local environmental reviews

Communication issues also extend beyond the federal government to involve state and regional governments. Large projects like transmission serve the greater public, but they can oppose the interests of locales that they travel through. Some legal statutes mandate a small level of communication with these stakeholders, but these laws can be followed without genuinely considering stakeholder concerns. Ethically, however, transmission should avoid sacrificing the needs of the few to satisfy the needs of the many.

An important precedent to consider is the siting authority allocated to FERC for natural gas (NG) pipeline siting. FERC has much stronger authority to site natural gas pipelines than it does to site critical transmission infrastructure. If FERC's oversight over a project correlates to the project's net societal benefit, maintaining NG siting powers while not providing the same for transmission places pipelines as providing more public utility than transmission lines. The pivotal role of transmission in providing reliable electricity definitively puts it as — at the very least — equally valuable to pipelines. This utilitarian argument validates the IIJA expansion of FERC's siting authority, but FERC and DOE siting powers raise concerns that the federal government is moving away from genuine community involvement.

Organizations representing state governments — such as the National Association of Regulatory Utility Commissioners (NARUC) — have spoken out about the IIJA's policies constituting an overconsolidation of federal power:

> Concerning transmission siting, the [IIJA] contains a provision that preempts state siting jurisdiction and eminent domain powers as they relate to siting electric transmission projects. The legislation provides [FERC] with siting jurisdiction and federal eminent domain powers in Department of Energy-established [NIETCs] when states fail to approve a project within one year. NARUC interprets this new provision as an ultimatum to states: Approve the project or FERC will approve it for you.
>
> The public interest would be better served by Congress determining – through independent analysis or study – whether state regulatory action or inaction is actually preventing electric transmission lines from being sited and constructed. As NARUC has stated previously, the major impediments are, in fact, public opposition to transmission facilities, federal permitting issues, economic viability, cost of the projects and cost allocation.
>
> NARUC opposes, and is deeply troubled by, this unnecessary pre-emption of state jurisdiction. While Congress has been considering this draconian pre-emption of state jurisdiction, NARUC worked with its federal counterparts at FERC to establish the first-ever federal-state task force on electric transmission, the mission of which is to collaboratively resolve the issues collectively identified as the greater impediments to building transmission projects.
>
> "This effort is a model of cooperative federalism, which is really what Congress should be striving for, instead of undermining state authority," said NARUC Executive Director Greg White. "One undeniable thing that state regulatory commissions do is assure that the affected citizens receive due process. This legislation would remove the affected communities' and landowners' right to due process. Everyone should be deeply troubled by that prospect" [48].

Time spent countering state opposition to NIETC designation and NEPA-focused litigation could be more cooperatively directed to collaborating with local and state agencies. What resources is the federal government using to push through opposition from which it could extract more utility via an inclusive approach?

As NARUC discusses in its above letter, state and federal cooperation can prevent redundant environmental studies and hasten the permitting process. CEQ has a strong foundation upon which this effort can build: memoranda that compare and contrast state and local environmental review laws with NEPA [49]. CEQ should continue to update these documents and encourage their use by all federal NEPA offices. At the same time, federal agencies should put more emphasis on developing relationships with state and local officials. Comparing the utility of transmission to the utility of NG pipelines supports recent increases in federal siting authority; however, the use of backstop siting — and associated circumvention of community interests — can be minimized with good-spirited relations and open communication.

In addition to avoiding repetitive regulations, federal collaboration with state and local agencies can cut labor costs and time for completing studies. Lead agencies should better take advantage of NEPA procedures that allow non-federal organizations to be conferred with cooperating agency status. With official standing as a NEPA collaborator, state and local agencies can directly contribute their unique expertise. Regional governments are more familiar with local constituents, geography, laws, topology, and much more. Given the complexity of NEPA documents, such insight is invaluable to make accurate environmental impact predictions and to develop viable alternatives.

Incorporate digital and cloud technologies

Modern digital technologies can hugely improve community involvement and resolve a number of the logistical challenges associated with legal overlap. Furthermore, digital systems can simplify highly dense EIS datasets, thousands of public comments, and coordination between tens of agencies. Efficient data sharing and communication between an applicant and federal, state, and local agencies would drastically slash the time needed for a project to obtain necessary permits. Solutions for conflicting policies and poor deadline enforcement should be supplemented with a robust platform to plan these highly complex environmental documents. At the moment, however, it appears that agencies fail to utilize commonplace digital technologies to achieve this end.

Of note is the lack of a NEPA-focused cloud system — a relatively simple-to-implement platform with the potential to address multiple permitting roadblocks. There already exists a widespread use of cloud technology for data storage and sharing; a 2021 study found that 71% of Americans used a cloud service [50]. Despite this extensive use, there exist no interagency cloud platforms for drafting NEPA documents or for permit tracking. The Fiscal Responsibility Act of 2023 takes a small step by appropriating $500,000 for CEQ to study the potential use of digital technologies to improve the permitting process. But the year-long *study* of a *potential* digital tool is essentially useless given the clear benefits of communally-accessible file storage.

Within the federal government, a NEPA permitting cloud would eliminate delays associated with case-by-case file sharing. The applicant and agencies can upload documents and quickly grant access to all parties.

A cloud system can also connect regional governments with federal agencies to streamline "vertical" communication. Local and state laws can be uploaded for comparison alongside federal laws. In this way, a project's demonstration of adherence to multiple, similar regulations can be consolidated and redundant analyses eliminated.

Real-time viewing and commenting on the same documents allows for faster identification and resolution of disputes between federal agencies or between federal and state agencies.

Interaction with the same technical data (such as geospatial images) can be done collaboratively.

And more.

Alone, the costs and timeframe of the Fiscal Responsibility Act's study do not constitute major financial or temporal setbacks. Instead, the very act of requiring a study demonstrates that Congress lacks an understanding of modern digital technology and the permitting process. It also highlights the failure of CEQ to independently determine the need for a digital tool and proceed with its development.

CEQ, however, need not build a cloud program without any foundation. The Federal Highway Administration (FHA) already has a program known as the Interagency NEPA & Permitting Collaboration Tool (INPCT). CEQ can disseminate the INPCT to involve other agencies and expand upon it to include more facets of the NEPA process [51].

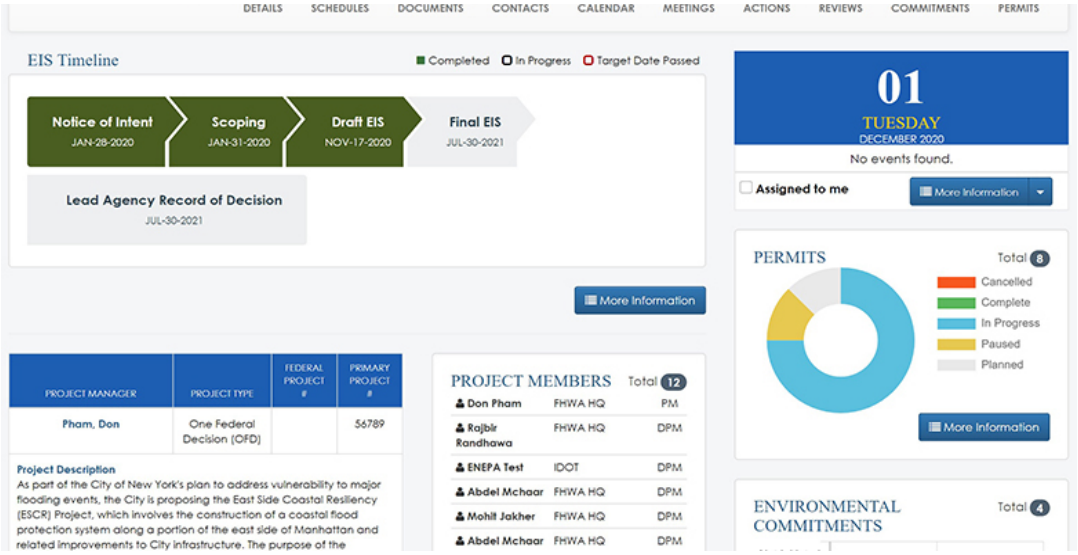

Figure 10: Dashboard of FHA's Permitting Collaboration Tool [51]

Similarly, an interactive EIS is a more ambitious tool to emulate nationally, but successful implementation could yield spectacular improvements to NEPA timelines and costs. The Arizona Department of Transportation (ADOT) and the FHA collaboratively published an interactive EIS in 2021 that connected federal and state agencies during the document's formation and supports more thorough public engagement [52]. Current, static-text NEPA documents require a minimum of 45 days in the Federal Register for public comment. After this comment period ends, so too does transparency with the public. With a document as complex as an EIS, a single, limited window for comment is not enough to constitute meaningful public engagement. ADOT's interactive EIS opens opportunity for comment much earlier in the process and for longer. Interactive maps and other, dynamic details streamline the complex information and lower the knowledge barrier that may discourage communal participation. A cloud and digital-based collaboration can also improve data collection processes — an area in which federal practices can improve greatly.

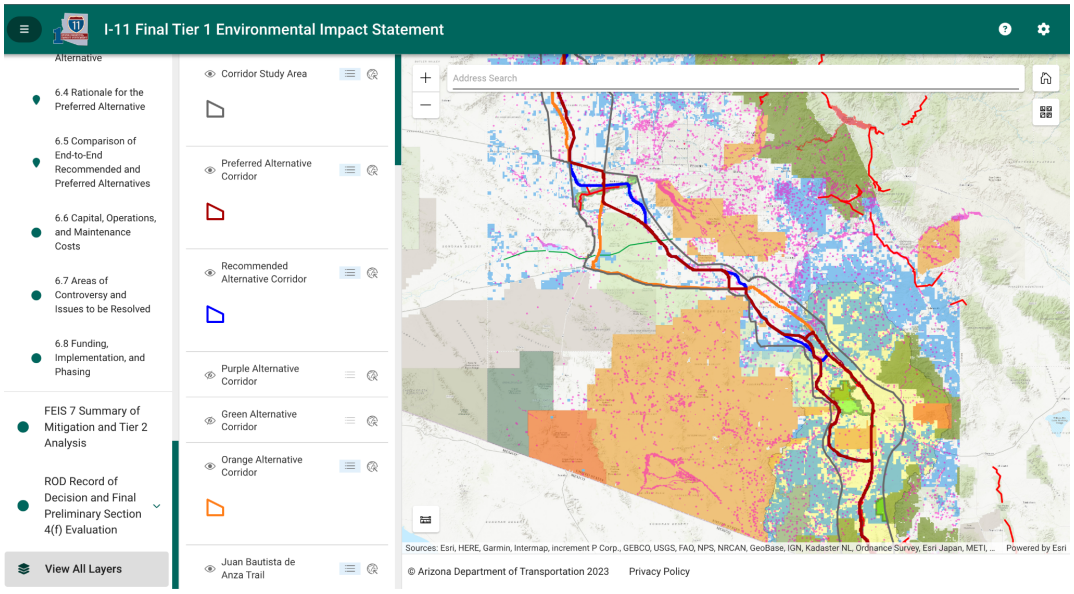

Figure 11: Interactive EIS [52]

Set Data Collection Standards Across the Entire Government

Without standardized data collection across the US government, there is no way of knowing what issues stall permitting operations. Businesses keep meticulous records of communication and financial statements, often performing efficiency studies to identify project bottlenecks, extraneous expenditures, and training employees on adapting to managerial or logistical changes. The government should operate with similar principles; further attempts at blind permitting reform will liken to struggling at blowing smoke away from a building without quenching the fire burning inside. The symptoms get treated while their root cause endures.

A possible baseline implementation was proposed in a NOPR on July 31, 2023 by the CEQ on amending their NEPA regulations [53]. The CEQ plans to require EAs and EISs to be assigned a unique identification number that would allow for tracking through the NEPA process and to clarify references to the document in future reports. These identification numbers can be used in a database for tracking time of NEPA adherence as well as related costs. The same NOPR, however, proposes to remove regulations requiring the inclusion of an estimated preparation cost on the front page of an EIS. The NOPR's reasoning follows that "it was not clear whether tracking such costs provided useful information for agencies or the public," that "tracking costs added a significant new burden on staff," and that "the methodology for estimating costs is inconsistent across agencies." [53].

This reasoning fundamentally contradicts the philosophy on which NEPA itself resides. A study by the CEQ to commemorate NEPA's 25th anniversary reports on how much NEPA improved federal decision-making [54]. A comparison of the study's findings with the ideas presented in the recent NOPR draws direct attention to the contradiction:

CEQ NEPA Assessment Report (Summary)	CEQ NOPR on NEPA Changes (Quotes)
NEPA requirements to assess an action's environmental impacts added a significant new burden on staff	"tracking costs added a significant new burden on staff"
Tracking such environmental impact data provided useful information for agencies and the public	"It was not clear whether tracking such costs provided useful information for agencies or the public"
CEQ regulations establish a mandatory methodology for estimating environmental impacts that is consistent across agencies	"the methodology for estimating costs is inconsistent across agencies"

Though NEPA increased agency workloads, the consideration of environmental impact data undoubtedly led to better federal decision-making. CEQ regulations standardized the requirements of NEPA documents; without them, each agency would have independently developed incompatible NEPA procedures. Now, the CEQ recommends agency-specific cost tracking and removing the only regulation that mandates publicly accessible cost estimates.

The success of the very law that created the CEQ suggests that delocalizing cost-tracking is counterproductive. In fact, NEPA's success indicates that the CEQ should *increase* oversight and develop regulations for a standard government-wide procedure to track EIS costs. In this way, meaningful data gathering and efficiency analyses would drive informed decisions.

Agencies can also expedite the permitting process by collecting EIS timeline data. Insight into the facets of the NEPA process that most stall a project's completion allow for targeted improvements. The documents themselves can be made more accurate — and less prone to litigation — by reviewing how accurate previous studies' environmental impact predictions were to measured impacts.

A dearth of empirical data about important metrics prevents the government from understanding what reforms would tangibly improve the NEPA process. Blanket page limits and time limits — while beneficial in the short-term — are only temporary solutions. Such policies ignore the root causes, leaving them to fester and proliferate. Proper data collection and analysis can prevent this outcome and is essential to ensure that permitting serves its intended purpose. In an increasingly data-driven society, the effects of governmental failure to incorporate common data practices ripple across every agency. And with critical infrastructure like transmission caught in the crossfire, the American people are the ones who end up suffering.

Give FERC explicit federal preemption for transmission siting

An alternative to facilitating more communication with state and local laws could entail expanding federal siting powers even more. This starkly contrasts with efforts to develop good-natured regional relationships. It is nevertheless a potential solution; much time can be saved by cutting through NEPA-like laws instead of incorporating them.

Consider a proposed line to connect a power plant in one state with consumers in another, but the line would need to pass through a third state. The state producing generation and the state receiving energy both profit and support the line. The middle state determines that negative externalities from suboptimal land use outweigh a few, new construction jobs and opposes the line.

In today's regulatory environment, the transmission line would fail to be sited because of a single state's dissent. National benefits denied by a single state's decision creates a backwards regulatory hierarchy in which individual state desires outweigh the nation's needs.

Explicitly declaring federal transmission line permits as preempting local and state laws — on the condition that genuine consultation with tribal, local, and state governments occurs — allows for a more appropriate process with power focused in the hands of the national government to address a nationwide issue.

This option presents far more substantial action than alternatives, requiring that legislation pass through Congress and minimizing the influence of lower governments. However, it guarantees simplification and expedition of the permitting process by entirely cutting out legal considerations at the state and local levels. It would also reduce bureaucratic delays associated with backstop siting (requiring 1 year of state nonaction and a NIETC designation from the Secretary of Energy). Whether such drastic consolidation of siting authority in federal hands is warranted remains questionable. More likely than not, federal preemption will remain a possible course of action available for implementation only if a national need for transmission outweighs this encroachment on states' rights.

Codify CEQ regulations into law

In addition to contrasting procedures, agencies also disagree on timelines for each stage of permit review. The core problem is not that there exists no common deadlines that apply to all involved entities. Instead, much blame can be ascribed to the weak enforcement system for missing established deadlines.

Lead agencies are responsible for managing the creation of a NEPA document. This includes setting timelines for coordinating agencies to follow. Particularly, CEQ regulations require lead agencies to "develop a schedule, setting milestones for all environmental reviews and authorizations required" [55]. The regulations also direct Coordinating Agencies to adhere to the schedule. However, Congress includes in NEPA no authorizations for the CEQ to develop regulations that federal agencies are bound to follow by law.

The mandate for agencies to follow CEQ regulations instead came from Executive Order 11991 which amended Executive Order 11514 to direct federal agencies, "In carrying out their responsibilities under [NEPA], comply with the regulations issued by the [CEQ]" [56]. The Constitution allows the President and the Executive Branch to oversee the enforcement of laws but does not give them authority to make laws — such power is constitutionally endowed to Congress, exclusively. An executive order may only be legally valid if they adhere to the President's only two sources of power: Article II of the Constitution or a delegation of power from Congress [57]. *Karuk Tribe of Cal. v. Ammon* sets precedent that "a President may only confer by Executive Order rights that Congress has authorized the President to confer," that is, an Executive Order can only codify CEQ regulations if NEPA itself provides the President that power [58]. As such, an executive order that confers legal status upon CEQ regulations without Congressional guidance exceeds the President's constitutional powers and is thus invalid.

Carter's actions are the only ties that CEQ regulations have to a semblance of a legal basis. Amending the Executive Order would eliminate a need for agencies to adhere exactly to the CEQ regulations, eliminating a big source of litigation.

Youngstown Sheet & Tube Co. v. Sawyer explicitly demonstrates the application of this notion to an executive order that unlawfully performs a lawmaking action. In this case, Justice Robert Jackson developed a system for framing the relationship between the powers of the President and Congress. Essentially, he divided Presidential actions into three categories: (1) Acting in agreement with explicit Congressional authorization; (2) Acting under the lack of explicit Congressional support or opposition, leaving the Congress's implicit stance up to interpretation; and (3) Acting against Congress's explicit or implicit desires [59].

NEPA only designates CEQ with the function to "assist and advise the President in the preparation of" EAs and EISs [60]. Nowhere in NEPA does there exist a statement — implicit or explicit — of Congressional will to grant CEQ authority for developing legally-binding NEPA guidelines. NEPA also doesn't confer authority onto the President to make the CEQ's regulations official rules; *Dubois v. US Dep't of Agriculture* even admits that "NEPA did not confer rulemaking authority on the President." [61] Executive Order 11991 thus falls under the second category of Justice Jackson's framework. Per the framework and *Youngston Sheet & Tube Co. v. Sawyer*, Executive Order 11991 is valid only if it properly exercises the President's Article II powers:

> The President shall be commander in chief of the Army and Navy of the United States, and of the militia of the several states, when called into the actual service of the United States; he may require the opinion, in writing, of the principal officer in each of the executive departments, upon any subject relating to the duties of their respective offices, and he shall have power to grant reprieves and pardons for offenses against the United States, except in cases of impeachment.
>
> He shall have power, by and with the advice and consent of the Senate, to make treaties, provided two thirds of the Senators present concur; and he shall nominate, and by and with the advice and consent of the Senate, shall appoint ambassadors, other public ministers and consuls, judges of the Supreme Court, and all other officers of the United States, whose appointments are not herein otherwise provided for, and which shall be established by law: but the Congress may by law vest the appointment of such inferior officers, as they think proper, in the President alone, in the courts of law, or in the heads of departments.
>
> The President shall have power to fill up all vacancies that may happen during the recess of the Senate, by granting commissions which shall expire at the end of their next session. [59]

The Executive Order clearly references none of these, rendering it unlawful. Since the mandatory nature of the CEQ regulations is entirely rooted in this Executive Order, CEQ regulations cannot be treated as law. Without capacity for legal enforcement, there exists no true requirement for agencies to adhere to any deadlines or statutes of standardization. Lead agencies that set timelines have no ability to ensure compliance. There may appear to be a system for timely cooperation on paper, but CEQ regulations constitute nothing more than guidelines without a firm root in law.

The logical solution to this dilemma would be for Congress to enshrine CEQ regulations into law. Agencies would thus be legally accountable for their timeline assignments and begin to properly create EAs and EISs. As will be discussed later, however, codifying CEQ regulations solidifies other delays caused by NEPA litigation.

Legal Considerations

Since its inception, NEPA has been a common target for legal contention. Its loose-ended statutes and wording allow for a more organic approach to environmental analyses. The same vagueness serves as ripe grounds for legal battles that have long been used to delay undesired construction. Taking proactive action to resolve potential sources of litigation can help avoid unnecessary legal battles and associated holdups.

Amend the Executive Order that mandates NEPA procedural adherence

As discussed above, President Carter's Executive Order 11991 directs that federal agencies "shall comply with" CEQ's NEPA regulations, essentially codifying the recommended regulations into a quasi-law. The CEQ regulations are frequent targets of NEPA litigation. Agency failure to adhere to CEQ procedures and claims of inadequacy through NEPA studies are the most common points of quarrel. However, the analysis of the Executive Branch's lawmaking powers reveals that CEQ regulations cannot be treated as law. This also means that failing to follow CEQ regulations does not

constitute legal noncompliance. In other words, CEQ regulations cannot be used as the basis for a court case.

Knowing this, making agency compliance with CEQ regulations optional doesn't actually change the current legal structure. Instead, amending Executive Order 11991 may signal that CEQ regulations are not to be treated as law in courts. Changing CEQ regulations to be non compulsory also conflicts with the above solution for poor adherence to timelines. Codifying CEQ regulations ensures continued NEPA litigation delays but can improve project completion times.

The decision of what actions to take surrounding CEQ regulations thus boils down to a tradeoff. What causes more delays: stalled deadlines when making a NEPA document or legal disputes after a document's completion? The ideal next step cuts down time at both points while still providing NEPA guidance for agencies.

Amend the FPA to give FERC eminent domain over state land

IIJA changes to FERC's backstop siting authority expand the criteria for declaring a NIETC from "experiencing congestion" to "expected to experience congestion." FERC is actively working to define criteria that can be considered to validate a prediction of congestion. Nevertheless, the interpretable nature of this clause opens it up to litigation from individuals seeking to delay a project.

The IIJA also now allows FERC to implement its backstop siting powers if a state has outright denied an application. The intent of strengthening backstop siting in this way was to set FERC's siting authority over state siting authority so as to reduce delays associated with federal-state coordination. A likely point of legal contention arises in this new dynamic.

A large transmission project is almost guaranteed to cross either state or private land. Even with a backstop siting permit, permit holders cannot begin construction until they own said land. The FPA acknowledges this and allows permitholders to use eminent domain powers to acquire property along a project's sited path. The FPA does not, however, explicitly give permit holders *federal* eminent domain authority. Such an ambiguity is likely to be the target of litigation. Eminent domain is exercised via lawsuit, but states experience sovereign immunity — the notion that a state is immune to lawsuit unless it consents to being sued. A legal dispute of this nature strongly favors permit holders, though, given precedent set by PennEast Pipeline Co. vs. New Jersey.

In this case, the Supreme Court ruled that eminent domain gives the federal government authority to seize state lands with appropriate compensation. Permitholders (in this case, for NG pipelines) were conferred the power of federal eminent domain and thus were legally to be treated as extensions of federal authority. Additionally, the use of federal eminent domain was determined to inherently apply to state land, as states "surrendered their immunity from the exercise of the federal eminent domain power when they ratified the Constitution." [62]

Given the high likelihood of a legal case arising when eminent domain is used for transmission, Congress should amend the FPA to give permit holders federal eminent domain authority. Doing so eliminates what is likely to be an unnecessary legal contention.

> "Over the course of the Nation's history, the Federal Government and its delegates have exercised the eminent domain power to give effect to that vision, connecting our country through turnpikes, bridges, and railroads—and more recently pipelines, telecommunications infrastructure, and electric transmission facilities. And we have repeatedly upheld these exercises of the federal eminent domain power— whether by the Government or a private corporation, whether through an upfront taking or a direct condemnation proceeding, and whether against private property or state-owned land."

Amend NEPA to reduce grounds for litigation

NEPA, although a landmark environmental law, has become more involved and data-intensive. As the law and its associated CEQ regulations have aged, vague language has continually invited litigation. With each case, the procedural requirements for an EA and EIS — as well as the documents themselves — grow longer and more complicated. In particular, legal challenges often target a NEPA document's inadequate consideration of alternatives or inadequate analysis of externalities [63]. With unclear regulatory language and exhaustively long documents to apply them to, proving proper regulatory adherence becomes a herculean task. Refusing to hear any and all legal grievances would inadvertently silence cases with legitimate grounds.

Amending NEPA to allow for a small threshold of innocuous, procedural infractions could address some delays that stem from antipathetic litigation. To this end, CEQ proposed to include new wording for "trivial violations" to allow more leeway around these documents post-drafting [64]. Solutions like this don't exclude concerned entities from voicing genuine concerns about a project's impact. Additionally, improvements in good-natured engagement with the public can help reduce adversarial litigation by getting citizens involved and have their voices heard [54].

Socioeconomic Considerations

Federal tax on retail electricity

Distributing the costs of building new transmission must be addressed, else there exist a continual barrier for utilities to construct such massive projects. Yet understanding every building's individual benefits from a new line is computationally infeasible, and crude estimates may introduce bias, unfairly affecting geographically clustered socioeconomic groups.

A solution may lie in a simple, yet equitable assumption: every American will benefit from a national expansion of transmission. As such, imposing a blanket federal tax on retail electric sales can contribute to a fund for softening the effects of transmission-related retail price increases. Based on National Energy Institute data (Appendix A) on each state's average, end-use electricity sales, a $0.01 federal tax on retail electricity sales could raise about $330 billion ($330,000,000,000) over the course of a decade [65]. NREL's 100% renewable by 2035 study predicted a lower bound of about $300 billion, just below the minimum projected cost [3].

Eminent domain remedies

The unique stipulations in the FPA allows FERC to delegate a permit holder with the power of federal eminent domain. As economically-driven entities, it's natural to seek to minimize a project's expenditures — one of which entails compensating affected landowners with the value of the seized land. Simple cost minimization suggests implementing eminent domain in areas with less valuable land.

The racially-divided socio economic landscape of American urban and suburban regions injects complications into this analysis. Nationwide, homes in predominantly white neighborhoods were valued at triple the value of homes in neighborhoods of color [64]. Irrespective of racial biases, however, using eminent domain in communities of color would significantly lower associated costs for a permit holder.

The alternative — using eminent domain to build transmission in wealthier regions — would unnecessarily raise a project's cost while also introducing a higher likelihood of targeted litigation. This is because residents in wealthier neighborhoods can better finance lawsuits — the cheapest of which cost as much as $10,000 [66]. For construction companies, additional financial or temporal hurdles to expanding transmission heightens the risk of a catastrophic system failure.

Valuing this land differently fails to address the moral dilemma baked into the conditions of eminent domain. Land is not just land. It's the property earned by emancipated slaves and passed down through generations of family. It's farmland that fed a farmer's ancestors during the Depression when food was too expensive. It's holy land for cultures older than America itself.

Yet, we need more transmission built, and we need it *now*. To safeguard the health of our planet and to ensure the well-being of all Americans, our energy infrastructure needs expansion. What is uprooting 100 livelihoods compared to security for the other 300 million?

There is no definitive solution to this question, and the following recommendations do not purport to entirely resolve the quandary. But current eminent domain policies are, without a doubt, relics of an intolerant and inconsiderate past. A life and the value one ascribes to property cannot be nicely bottled into a number; even the most complex of statistical analyses can't change that fact.

Access to reliable and cleanly sourced electricity *should* be considered a right for all. But the government does not serve the interests of the American population. It serves the interest of each individual American, and it does so 300 million times.

As noted when considering methods to reduce litigation, feelings of communal animosity towards large public service projects can be alleviated with more robust engagement. While eminent domain inherently supersedes a landowner's voice, there exist potential methods to make forced land acquisition more just.

Another proposition gives landowners guaranteed, long-term financial transmission rights for the transmission line built on their property. In this way, land compensation does not entail a single payment. Rather, landowners can continue receiving financial support throughout the major process of adapting to the loss of a valuable asset. Permitholders may take issue with this program, as it eliminates sources of revenue. However, a fairer compensation for property may reduce communal opposition and associated construction delays.

Reducing delays allows construction to begin earlier which decreases interest accumulation on loans and makes a project less risky. Over 10 years, monthly payments on a $500 million loan and a monthly-compounding interest rate of 6% total to $166,123,011.65. If equitable eminent domain practices cut out just a year of delays, that figure drops a whopping $18 million to $148,310,480.07 — almost a 10% improvement.

Such a program can also be extended to communities or states. Awarding a heavily-impacted region with financial transmission rights brings money into the community. In this way, it may help transmission lines be viewed as an investment in the community rather than a federal imposition. Partial financial ownership also incentivizes local caretaking of a transmission line, as continued operation yields direct monetary benefits.

This program can be made even more robust by partnering communal ownership with an apprenticeship or similar job training. Citizens who live near the line and in a community that makes

money from the line can be trained and receive professional credentials to perform regular upkeep. For utilities companies, on-site maintenance staff reduces expenses for employee travel and energy losses from undetected wear. Local employees can also ensure continual adherence to reliability regulations. This could entail reporting physical sabotage, serving as security at critical assets, or managing overgrown vegetation (a major point of system failure during the Northeast Blackout of 2003) [67].

Regardless of the extent, communal considerations must be taken into account as more transmission gets built. Performing the bare minimum public engagement required by law may reach the same end goal, but such behavior fosters distrust and hostility. Transmission is an inherently public infrastructure that operates to serve the people; it should not be viewed as a manifestation of an inconsiderate and draconian government.

Social Considerations

Engage communities with art

A large, buzzing metal structure doesn't exactly exude a positive neighborhood presence. Not only do many people feel that transmission lines are ugly, there also exists a common belief that the lines can cause cancer [68]. Opposition to the construction of noisy, carcinogenic towers that serve no apparent purpose is only natural. These misconceptions contribute to an aversion of transmission lines which manifests in lower property values for buildings located near towers [69]. Despite the false grounds for such beliefs, they continue to be perpetuated. Addressing poor awareness about transmission lines, their safety, and their important role in society is key to promoting public support.

A potential way to lessen the apathy towards these structures is to normalize them in the public eye. For many, transmission towers aren't a common sight; the structures can appear intimidating and mysterious. Art can simultaneously communicate the importance of transmission infrastructure while also lightening public perception. Commissioning benign, transmission-like public sculptures could assuage fears about the lines and potentially garner national attention for the issue facing the electric grid. This endeavor can be accomplished via partnerships with local artists, larger art exhibits, and message-focused art NGOs. Around the world, countless installations have been created to draw attention to the effects of climate change. The same principles can easily extend to transmission lines via creative use of trusses; just look at the Eiffel Tower or Tokyo Tower.

Figure 12: Warming Warning [70]

Figure 13: Hands Rising Out from Sea Level Rise [71]

Figure 14: A Pyramid of Garbage [72]

Art as a medium to shift the perceptions around transmission lines isn't limited to non-functional structures. With some creativity, *functioning* transmission lines can be designed to be more visually palatable and — in the process — engage with the American public (Appendix B). In 2011, the Royal Institute of British Architects (RIBA) partnered with the United Kingdom's Department of Energy and Climate Change and the energy company National Grid to increase public participation in the clean energy movement. RIBA launched a national competition to solicit new transmission tower designs that better considered the needs of communities and preserved natural beauty. Winners were awarded $10,000, consideration for the design in functioning lines, and an exhibition at the London Design Festival [73]. The DOE, FERC, or Grid Deployment Office can collaborate with the robust artistic community in the US to institute a similar program.

The solution to ensure a just expansion of the grid must entail more than high-level debates on policy and technology. Just like a functional transmission tower design, there exist many other ways to promote public awareness. Educational programs need not be limited to classrooms or constrained to informative lectures and videos. The dynamic and engaging nature of art presents untapped potential to shed light on the critical infrastructure that ensures the lights stay on.

Limitations and Future Considerations

The actions discussed above are not comprehensive solutions to the multifaceted issues facing transmission growth. The complex and interwoven terrain of economic forces, laws, social impacts, and physical infrastructure eliminates the possibility of an all-encompassing solution. Rather, the best next steps are those that maximize the utility of capital investments while minimizing negative externalities.

Attempts at quantifying the costs and benefits for grid modernization approaches are — at best — rough estimates. The incremental growth of the energy system over the past century has reached such complexity that the aggregate is no longer understood. Each new power plant,

transmission line, or even distribution line further complicates the already labyrinthine system. Additionally, the electric grid is no longer an independent facet of the nation's critical infrastructure. Consider the 2003 Northeastern blackout also impacting water, communication, transportation, and industry. The complex grid and the infrastructure dependent on it make accurate reliability assessments and failure-scenario models nigh impossible to perform. This makes modeling the viability of solutions similarly difficult while the need for action remains.

Some measures become hindered by an inability to forecast. Mainly affected are the more nebulous delays, the solutions to which are tied to subjective moral judgements or uncertain causes. Streamlining overlap between federal, state, and local environmental laws conflicts with giving FERC federal preemption of said laws. The ramifications of neither action can be predicted, so the choice boils down to personal judgements about the value of federalism. Making CEQ regulations official law may help hold agencies to strict timelines, but it also guarantees that NEPA litigation has a valid legal basis. Do agency officials need the threat of punishment to keep to a schedule, or is there a source of the delays that has yet to be identified? On the other hand, do CEQ regulations need to change to reduce legal backlash, or does the issue lie with community discontent with their degree of involvement? The full picture is not fully understood making it difficult to pinpoint the optimal target for improvements.

Other measures provide clear benefits but have yet to be implemented. A program for coordinating NEPA adherence or interactive NEPA documents are objective improvements from current practices. The same can be said for continuing to collect financial data and beginning to track timelines. The need for employee training could be a potential barrier for these actions, but it does not constitute a large enough cost to rationalize non-action.

Moving forward, involved parties must hold more conversations about these uncertainties. Efficiency within a single political sphere is no longer the limiting factor for transmission rollout. The crux of the issue — and the solution — lies with the links between groups and how effectively teams can form and work together. Efforts that advance this objective should be the government's top priority in the near future. With hope, creating a robust framework for intergovernmental collaboration will expedite the clean energy revolution and allow for more adaptability when tackling new issues in this tumultuous transition.

Conclusion

America's electric grid faces an uncertain future, the outcome of which can either advance the fight against climate change or intensify its risk. This critical infrastructure has no comparable equal and is not fully understood, yet it requires a transformation of unprecedented complexity. The grid's transformation must proceed alongside its growth to serve a growing electricity demand and renewable energy sector. All the while, it must continue to reliably operate water pumps, communications, data centers, heating and cooling, lighting, manufacturing, and much more. Potential solutions span far and wide, necessitating changes to laws, governance structures, the energy market, permitting, public perception, and physical facilities. And no individual sector can be addressed without affecting the others. Altogether, the obstacles facing the electric grid culminate in a seemingly insurmountable challenge.

But reaching the goal is by no means impossible. Governments and agencies at all levels can streamline communication and overcome disagreements. Businesses can boost profits from involving communities and improving reliability. The nation can unite under the banner of 100% environmentally benign electricity. The next steps remain uncertain, but creative and informed policymaking can engender energy transition that benefits all.

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Appendices
Appendix A

Sales of Electricity to Ultimate Customers by End-Use Sector, by State, April 2023 and 2022 (Thousand Megawatt Hours)

	Residential		Commercial		Industrial		Transportation		All Sectors	
Census Division and State	April 2023	April 2022	April 2023	April 2022	April 2023	April 2022	April 2023	April 2022	April 2023	April 2022
New England	3,233	3,507	3,655	3,822	1,172	1,271	38	36	8,097	8,636
Connecticut	839	848	821	835	219	229	14	9	1,893	1,921
Maine	383	397	303	310	194	184	0	0	880	891
Massachusetts	1,337	1,491	1,816	1,901	470	540	22	25	3,645	3,957
New Hampshire	325	338	307	305	150	153	0	0	781	796
Rhode Island	191	275	264	326	40	56	2	2	496	659
Vermont	158	159	145	144	99	110	0	0	402	413
Middle Atlantic	8,695	9,133	10,704	10,971	5,933	6,004	270	268	25,602	26,376
New Jersey	1,676	1,762	2,560	2,739	479	504	19	23	4,734	5,028
New York	3,401	3,541	5,407	5,466	1,307	1,351	207	198	10,322	10,556
Pennsylvania	3,618	3,830	2,737	2,765	4,147	4,149	45	48	10,546	10,792
East North Central	12,241	12,763	12,999	13,026	14,621	15,025	25	30	39,886	40,844
Illinois	2,775	2,901	3,396	3,466	3,253	3,323	21	26	9,445	9,716
Indiana	2,122	2,208	1,672	1,715	3,258	3,552	1	1	7,053	7,476
Michigan	2,334	2,459	2,764	2,727	2,318	2,270	0	0	7,417	7,456
Ohio	3,384	3,543	3,421	3,371	3,932	4,030	3	3	10,739	10,947
Wisconsin	1,626	1,651	1,745	1,747	1,861	1,851	0	0	5,231	5,250
West North Central	7,328	7,426	7,637	7,601	8,207	7,796	4	3	23,175	22,826

Iowa	1,021	1,077	895	937	2,225	2,074	0	0	4,141	4,087
Kansas	826	832	1,171	1,145	903	961	0	0	2,901	2,938
Minnesota	1,719	1,709	1,690	1,694	1,631	1,567	1	2	5,041	4,973
Missouri	2,203	2,305	2,110	2,161	1,034	1,066	2	2	5,350	5,534
Nebraska	716	689	714	696	960	1,007	0	0	2,390	2,393
North Dakota	411	408	669	589	1,200	863	0	0	2,281	1,859
South Dakota	431	406	388	379	253	258	0	0	1,071	1,043
South Atlantic	25,705	25,143	25,552	24,996	11,204	11,943	79	80	62,541	62,162
Delaware	331	357	282	314	151	168	0	0	765	839
District of Columbia	167	159	537	506	14	15	25	19	743	699
Florida	10,301	9,777	8,170	7,866	1,532	1,622	6	6	20,008	19,272
Georgia	3,774	3,756	3,553	3,471	2,661	2,737	11	11	9,999	9,975
Maryland	1,727	1,785	1,964	1,933	266	281	34	33	3,992	4,032
North Carolina	3,796	3,776	3,675	3,667	2,084	2,022	1	1	9,557	9,466
South Carolina	2,022	1,931	1,882	1,565	2,050	2,378	0	0	5,953	5,874
Virginia	2,896	2,869	4,974	5,148	1,297	1,521	2	9	9,169	9,547
West Virginia	691	733	515	526	1,149	1,197	0	0	2,355	2,457
East South Central	7,624	7,728	6,700	6,619	7,780	8,256	0	0	22,105	22,603
Alabama	1,975	2,015	1,690	1,638	2,523	2,519	0	0	6,188	6,171
Kentucky	1,655	1,720	1,370	1,382	2,118	2,523	0	0	5,142	5,626
Mississippi	1,154	1,158	1,023	1,010	1,264	1,340	0	0	3,441	3,508
Tennessee	2,840	2,835	2,618	2,589	1,875	1,875	0	0	7,333	7,298
West South Central	13,900	14,572	15,316	16,014	16,935	17,010	14	15	46,165	47,610
Arkansas	1,117	1,162	836	834	1,473	1,495	0	0	3,427	3,491
Louisiana	1,903	1,846	1,737	1,695	3,333	3,307	1	1	6,974	6,848
Oklahoma	1,367	1,387	1,622	1,492	1,801	1,876	0	0	4,790	4,754

Texas	9,512	10,177	11,121	11,994	10,328	10,332	14	14	30,975	32,517
Mountain	7,270	7,124	7,797	7,795	6,853	6,866	13	12	21,934	21,797
Arizona	2,363	2,400	2,390	2,345	1,135	1,131	1	1	5,890	5,876
Colorado	1,415	1,401	1,580	1,634	1,294	1,260	7	7	4,296	4,302
Idaho	734	710	511	513	618	636	0	0	1,863	1,859
Montana	472	455	400	409	385	381	0	0	1,257	1,244
Nevada	818	812	951	972	983	1,004	1	1	2,753	2,788
New Mexico	459	433	704	693	981	917	0	0	2,144	2,044
Utah	756	676	968	944	648	716	5	4	2,377	2,340
Wyoming	253	237	294	286	807	821	0	0	1,354	1,344
Pacific Contiguous	10,646	10,438	11,024	12,548	5,906	6,650	64	68	27,641	29,705
California	5,771	5,543	7,312	8,873	3,011	3,596	54	56	16,149	18,067
Oregon	1,625	1,624	1,349	1,330	1,308	1,248	2	2	4,284	4,204
Washington	3,249	3,271	2,363	2,345	1,587	1,806	9	11	7,208	7,433
Pacific Noncontiguous	379	372	435	429	392	390	0	0	1,205	1,191
Alaska	166	159	210	206	115	116	0	0	492	481
Hawaii	212	212	224	223	277	274	0	0	713	710
U.S. Total	97,020	98,206	101,819	103,820	79,004	81,212	508	513	278,350	283,751

Appendix B

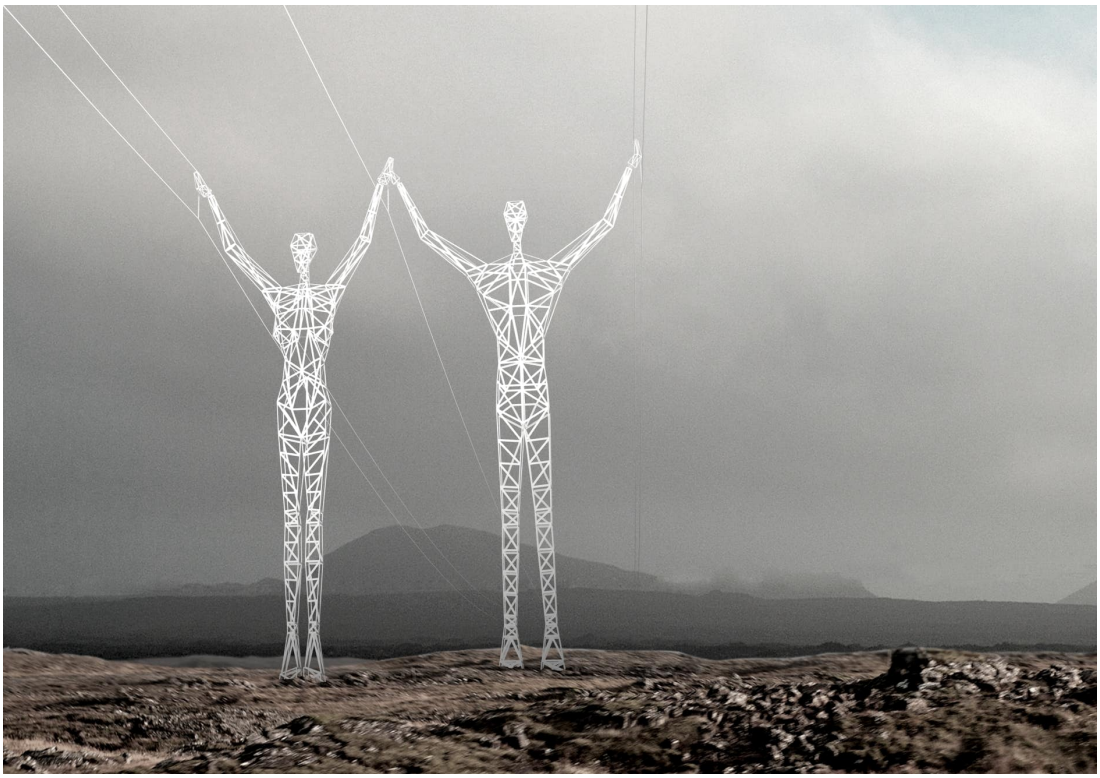

Figure 15: Transmission Giants (1) [74]

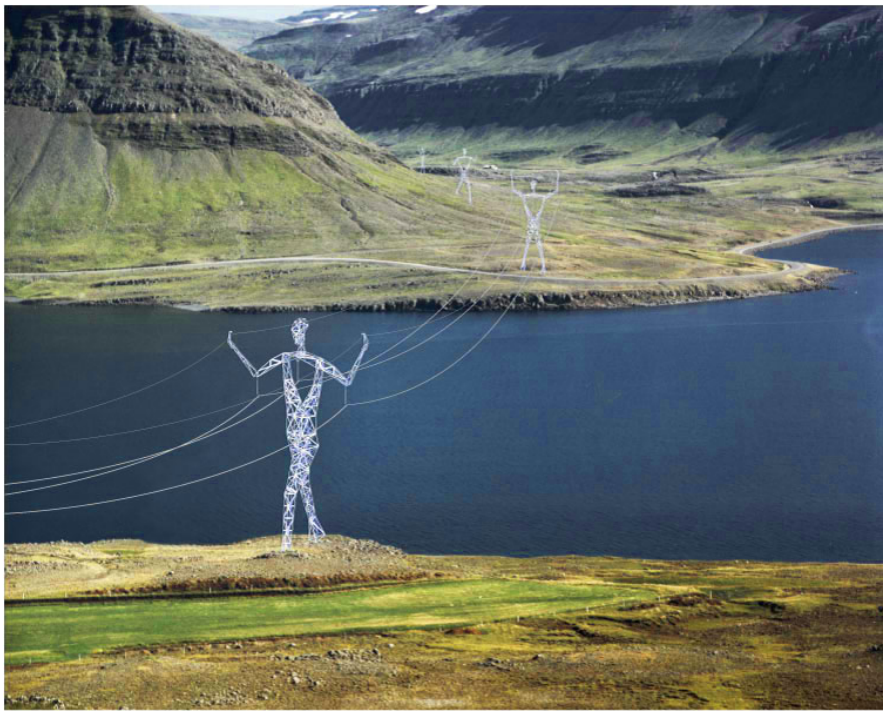

Figure 16: Transmission Giants (2) [75]

Figure 17: Deer Transmission [75]

Figure 18: Stained Glass Transmission Tower [76]