center for
ENERGY STUDIES
Rice University's Baker Institute for Public Policy

HISTORICAL CASES FOR CONTEMPORARY ELECTRICITY DECISIONS

Julie A. Cohn, Ph.D.
Research Historian, Center for Public History, University of Houston

February 2020

Acknowledgements

Many thanks to Michael Maher and Olivera Jankovska for careful reading of earlier drafts of this paper and for their extremely useful suggestions. Thank you also to numerous interviewees and email correspondents, including John Berger, Aaron Bloom, Daniel Burmeister, Jill Engel-Cox, Mike Skelly, L.M. Sixel, Andrew Levitt, and Annette Werth.

Julie A. Cohn, Ph.D.
"Historical Cases for Contemporary Electricity Decisions"

https://doi.org/10.25613/2DP6-6H47

Introduction

In the 21st century, Americans face the task of addressing human-made contributions to potentially disastrous climate change. Along with longstanding worries about resource depletion, ecosystem damage, pollution, and attendant human health effects, these concerns provide the impetus for integrating renewables into energy systems to displace hydrocarbons. Governments, activists, and even corporations have adopted various goals—all trending toward using more, and in some scenarios exclusively, renewable energy resources to generate electricity. The primary resources under consideration include wind, sunshine, geothermal energy, and hydro.[1]

Today power systems experts offer multiple approaches to integrating renewables. Proponents argue for nanogrids, microgrids, smart grids, supergrids, macrogrids, and global grids as the models for introducing solar and wind power, energy storage, and advanced system controls. At one extreme, advocates call for complete disaggregation of large networks in favor of tiny, locally controlled systems and at the other they encourage intercontinental connection around the globe. Naysayers warn against excessive cost, excessive government intervention in the private sector, technological and physical shortcomings, environmental downsides, and threats to stability, reliability, and resilience. The characteristics of renewable energy resources—the intermittency of wind and solar in particular, and the scales of some new technologies both very large and very small—will introduce new challenges to power system stakeholders.

After nearly 150 years of expansion and increased integration of power networks in the United States, investors, generators, owners, operators, regulators, and customers have grown accustomed to aspects of electrification that are most certainly mutable over time. When the vast majority of customers turn on a wall switch in this country, they expect immediately available power to turn on lights that will not flicker and machines that run steadily for as long as desired, without interruption, and at a reasonable cost. Investors, generators, and transmission line owners alike expect a fair return—whether by regulation or market competition—for the cost of doing business. They expect regulators and operators to reasonably protect their infrastructure from sudden shutdowns, sudden excessive demand, and sudden changes in rules, costs, and revenues. Operators expect to be able to dispatch power to meet demand while maintaining system reliability. The processes by which all of this occurs developed piecemeal. New generating technologies, new ownership regimes, new storage opportunities, new scales of operations, and relatively new primary energy resources are already causing disruptions. The priorities of the past—for example, increasing integration into state and regional grids in order to realize

[1] Portions of this paper draw on research completed by the author for earlier publications. For more about early conservation ideas and the power industry, see Julie Cohn, *The Grid: Biography of an American Technology* (Cambridge, MA: MIT Press, 2017), 13-40; Julie Cohn, "Utilities as Conservationists? The Paradox of Electrification During the Progressive Era in North America," in *Green Capitalism?: Business and the Environment in the Twentieth Century*, ed. Adam Rome and Hartmut Berghoff, Hagley Perspectives on Business and Culture (Philadelphia, PA: University of Pennsylvania Press, 2017), 94-111.

economies of scale and also improve system reliability—may not apply in the future. Tomorrow's homeowner may prefer the green credentials, local control, and resilience offered by rooftop solar panels with a battery wall setup. That same owner may or may not seek the reliability offered by a grid connection; and may or may not be willing to pay for the necessary infrastructure to keep the rest of the grid running. Or, a different customer may lobby for green power only, from a giant windfarm located several states away, regardless of the cost of transmission. That customer may or may not acknowledge the need for giant storage facilities and/or interconnection with other generating sources to assure reliability.

How will Americans navigate the decisions ahead? Herein lies an opportunity to consider historical trends and exceptions. Were there periods in the past when utilities (or others) debated the relative merits of independence and integration for power generation? If so, who made the decisions, what were they, and how did different factors influence the outcome? Can these experiences help us frame choices we face today as we try to bring more renewables into our systems?

In fact, these debates occurred regularly throughout the history of electrification in the United States. Often negotiations over more or less integration occurred outside matters of economy, technical feasibility, energy efficiency, and customer satisfaction.[2] For example, in the early years, tension between government-owned power companies and privately owned utilities characterized American electrification and as a result, physical interconnection was often conflated with holding company, or private sector, expansion. Municipal utilities and rural cooperatives at times sought participation in networks to access power generated by larger and more efficient facilities; at other times, they resisted interconnection because it was seen as further domination by investor-owned utilities.

Over time, considerations evolved, as did technologies, political preferences, economic context, and questions of national defense and industrial development. This research paper offers three case studies that illustrate the array of issues framing movement toward increased interconnection over the course of the 20th century:

Case 1. From "Fashion" to Wartime Necessity, 1900-1918. In the early 20th century, industrial manufacturers transitioned from a strong preference for operating their own in-house generating plants to acquiring (renting) power from central stations.[3] In this first case

[2] Hydro, the 20th century's primary renewable resource, did not lend itself to independent operation. Good sites for hydroelectric development were generally located far from centers of power use. Hydro development, therefore, proceeded hand-in-hand with long-distance transmission, and after the 1890s, typically entailed interconnection with other systems in order to reach customers and to address seasonal variations in water flow. With very few exceptions, the cost and scale of hydroelectric development exceeded the investment capacity of single small power companies, thus coordination among multiple companies and, later, investment by the federal government, was typical. While utilities, government leaders, and customers debated whether the public or private sectors should control hydroelectric development, the process overall propelled greater integration of power systems.

[3] At the time, power accessed from a central station was termed *rented* power. To maintain historical accuracy, I will use this term in this case.

study, the dominant issues included "fashion," shifting and expanding operating costs, technical innovations, resource shortages, and, ultimately, the pressures of a world war.[4] Today's proposed nanogrids and microgrids resemble the early isolated plants, along with some of the attendant benefits and costs for owners and operators. Key technological differences, however, may lead to different choices and different outcomes in the future.

Case 2. Defense Considerations, 1935-1945. Throughout the 1930s, utilities and federal authorities argued over war readiness and the need for central government control. Different planners called for both new installed generating capacity at the sites of defense manufacturing and increased integration of existing capacity. Once the United States joined World War II as a combatant, the focus shifted almost entirely to expanded interconnections. In this second case study, the compelling issues were time, resource availability, and defense necessity, and the process resulted in technical innovation. This case brings the focus to how significantly a major crisis can influence the direction of electrification, thwarting even the proposals that look most reasonable and logical in favor of strategies that can be adopted most quickly. It further illustrates the degree to which the American power industry, though compliant during wartime, resists central control.

Case 3. The Biggest Interconnection, 1960-1975. In 1967 utilities and the US Bureau of Reclamation completed alternating-current (AC) links between the Eastern and Western Interconnected Systems, creating a nationwide grid. This took place against the backdrop of the 1965 Northeast blackout and public debate about the merits of interconnection. Within eight years, following unstable operations, the utilities abandoned the links. Between 1975 and 1987, however, utilities installed direct-current (DC) links that allowed for the scheduled exchange of power without requiring synchronized operation. The DC-linked interconnected systems no longer formed a nationwide grid. In this third case study, nationwide interconnection proceeded despite technical inadequacy and doubts about the efficacy of the project; it was followed by integration through new technologies. A return to DC connection sidestepped the trend of expanding AC interconnections over the prior 75 years. When contemplating macrogrids and large high voltage direct current (HVDC) connections, this case offers a reminder that what seems the logical next step of a synchronized nationwide grid may not be the feasible next step. Further, for the largest infrastructure projects proposed, buy-in across a very broad community of stakeholders will be crucial.

By revisiting these stories, we can examine historical tensions within American power systems and consider how they might affect 21st century decision-making. Trade journals, government reports and statistics, national archival materials, and secondary literature provide details and insights regarding the evolution of power networks throughout the 20th century. One striking issue emerges: different stakeholders pushed the decisions in particular directions at different times. This reflects the organic development of America's power systems. No central government authority, no single private sector company, no

---

[4] The notion of "fashion" as a reason for choosing a particular path to electrification appeared in an article in *Electrical World* in 1897, "The Central Station and the Isolated Plant," *Electrical World* 30, no. 23 (1897): 657.

comprehensive technical solution dominated the process at any time. As one researcher describes it, the American power system operates under “nodal governance,” that is, decision-making authority is dispersed.[5] In assessing options for bringing more renewables into the system, it would be wise to keep this salient feature in mind. At any point in the process, particular stakeholders, unexpected concerns, major diplomatic or political events, or innovative technologies may influence the path forward in ways that are difficult to anticipate based on the choices of the past.

The sections of the paper are organized as follows:

Background—An overview of power systems today, focusing on the composition of generating sources, status of interconnections, ownership of elements, and governance structure in the United States.

Integrating Renewables—A short summary of past efforts to increase the contribution of renewable resources to power production, with particular focus on federal and state rule changes that incentivized development of wind and solar industries.

Visions of the Renewable Future—A brief description of the myriad approaches available for increasing the share of renewables in our power systems. It contrasts the “small is beautiful” approach of nanogrids and microgrids with the “bigger is better” approach of macrogrids, supergrids, and global grids.

The Case Studies

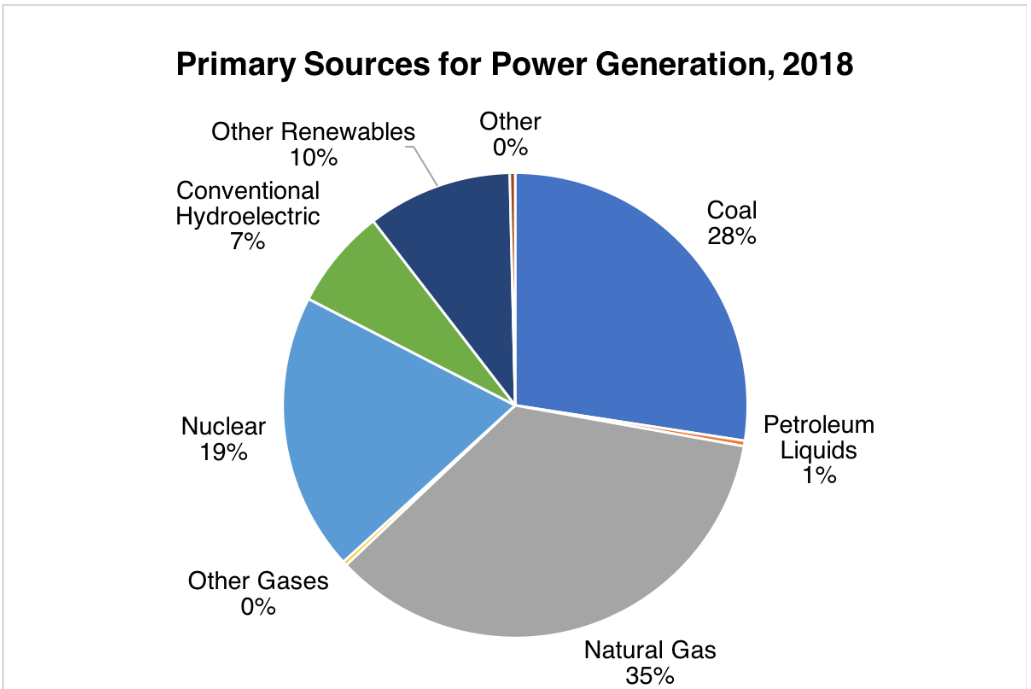
Conclusion—Observations about the historical cases and how they frame contemporary decisions about adding more renewables through greater or lesser integration.

[5] Alison Gocke, "Nodal Governance of the U.S. Electricity Grid," *Duke Environmental Law & Policy Forum* 29, no. 205 (Spring 2019): 205-71.

Background: US Power Systems Today

Marking a trend begun in the late 19th century and lasting until 2010, the United States led the world in total electricity generated and consumed.[6] In 2018, utilities, independent power producers, the commercial sector, and the industrial sector together generated 4,177,810 thousand megawatt-hours of electricity.[7] Of that, renewables account for 17% of power generation, with just under 7% coming from hydroelectric plants.[8] Figure 1 illustrates the components of US power generation in all sectors in 2018.

Figure 1. Net Generation by Fuel Source, All Sectors 2018

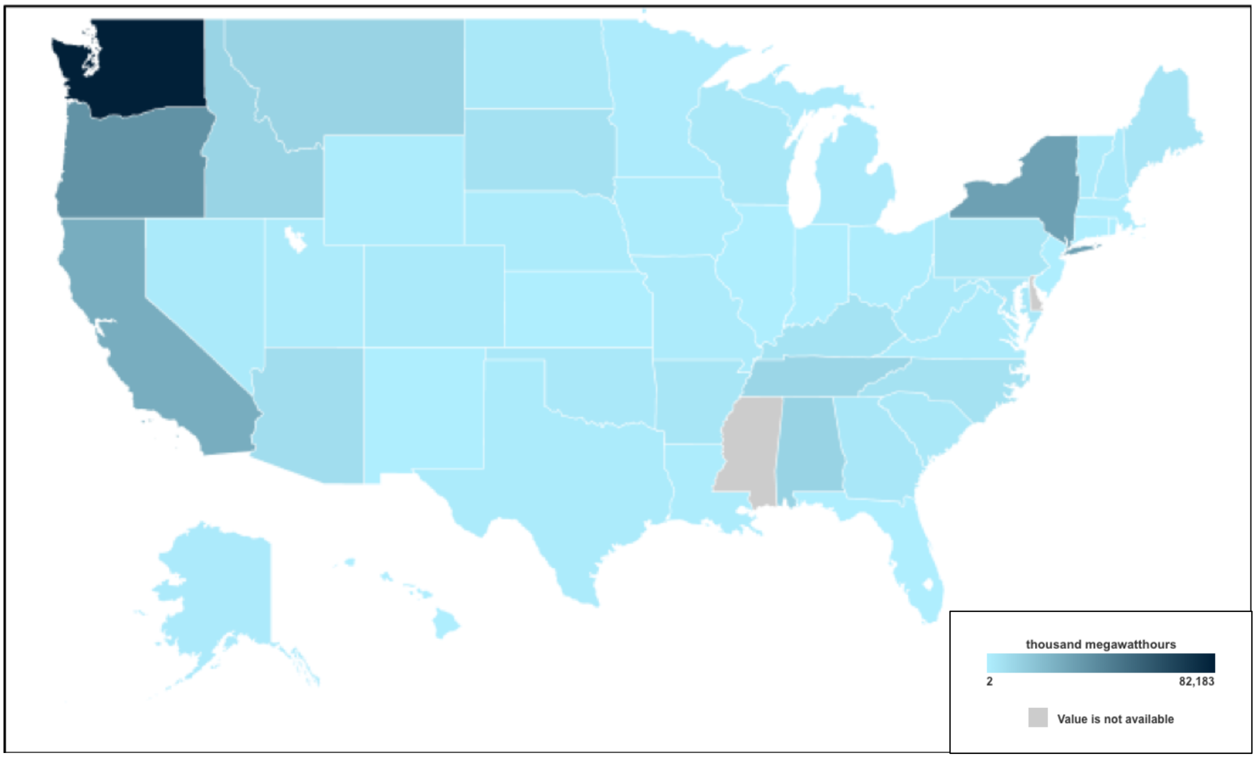


Source: US Energy Information Administration Electricity, https://www.eia.gov/electricity/data/browser/.

[6] In 2011, China surpassed the United States in total electricity produced.
[7] Electricity Data Browser, Data set: Net generation, United States, all sectors, annual, https://www.eia.gov/electricity/data/browser/, accessed June 12, 2019; Monthly Energy Review, Table 7.2a, Electricity Net Generation, Total (All Sectors), https://www.eia.gov/totalenergy/data/monthly/pdf/sec7_5.pdf, accessed June 12, 2019; *Historical Statistics of the United States, 1789-1945,* Series G 159-170–Power–Annual Supply of Energy from Mineral Fuels and Water Power: 1819 to 1945 (Washington, D.C.: Government Printing Office, 1949), 155.
[8] Hydro represented the most important source of renewable energy for the first half of the 20th century, providing about one-third of all US electricity during that time. It was prized for its near-continuous and "free" availability. Conservationists and utility operators alike sought to maximize use of hydro while minimizing the amount of other fuels used for every kilowatt-hour (kWh) of electricity generated. Between 1950 and 1987, the hydro share dropped from 30% to 10%, and dropped again to about 7% in 2000, where it has remained. Utility scale wind and solar facilities account for most of the remaining 10% of renewables in 2018.

US power systems are old and new—some elements dating back to the late 1800s are still in operation.[9] Researchers value the systems at about $2 trillion, with an estimated replacement cost of more than $5 trillion.[10] Geography and weather patterns determine the location of renewable resources, while economics and state policies frame their development for electricity. Nearly half the nation's hydroelectric facilities are found in the Pacific Northwest, and Washington state leads with 82,183 thousand megawatt-hours produced in 2018.[11] Oregon, New York, and California follow, in that order. Figure 2 illustrates the dominance of hydropower in the mountainous and riverine regions of the country. Wind and sunshine are found in abundance in other regions of the country, and utility scale generating facilities have followed. Figures 3 and 4 illustrate the intensity of wind and solar energy in particular states.

Figure 2. Net Generation Conventional Hydroelectric, All Sectors 2018

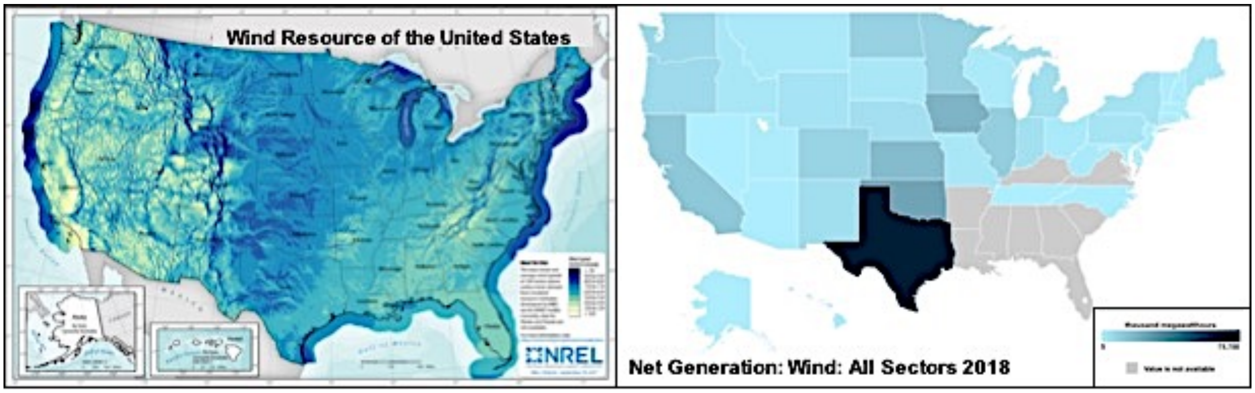


Source: US Energy Information Administration Electricity Data Browser, https://www.eia.gov/electricity/data/browser/.

---

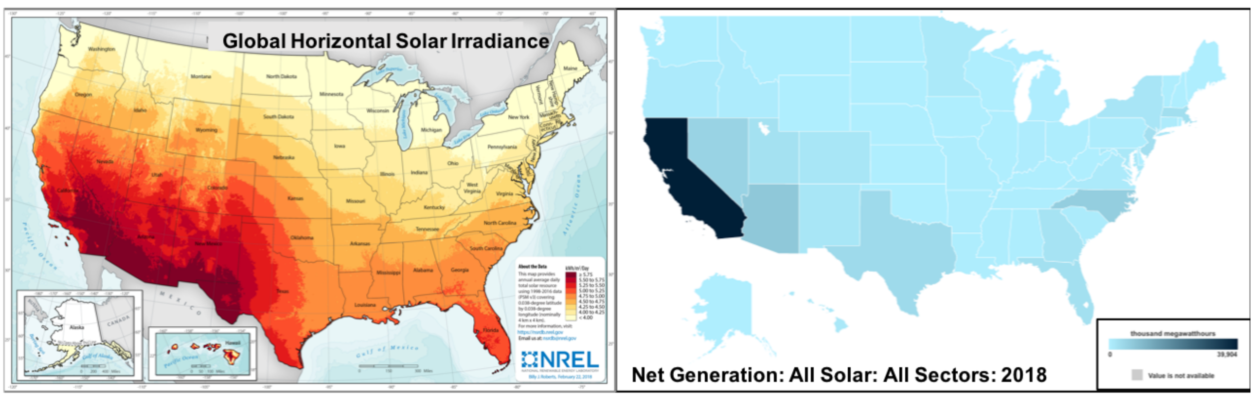
[9] The Snoqualmie Falls Hydroelectric Plant, for example, went into operation in 1899 and continues to generate power today.
[10] Joshua D. Rhodes, "The Old, Dirty, Creaky US Electric Grid Would Cost $5 Trillion to Replace. Where Should Infrastructure Spending Go?," *The Conversation* (March 16, 2017), https://theconversation.com/the-old-dirty-creaky-us-electric-grid-would-cost-5-trillion-to-replace-where-should-infrastructure-spending-go-68290.
[11] Electricity Data Browser, Data set: Net generation for conventional hydroelectric, 2018.

Figure 3. US Wind Speed and Net Generation



Sources: Left, US Annual Average Wind Speed at 100 meters map, courtesy of National Renewable Energy Laboratory. Right, 2018 US net wind generation map, from Electricity Data Browser, eia.gov. Note disparity between locations of wind intensity and locations of wind power development.

Figure 4. US Horizontal Solar Irradiance and 2018 US Net Solar Generation



Sources: Left, irradiance map, courtesy of National Renewable Energy Laboratory. Right, 2018 US net solar generation map, from Electricity Data Browser, eia.gov.

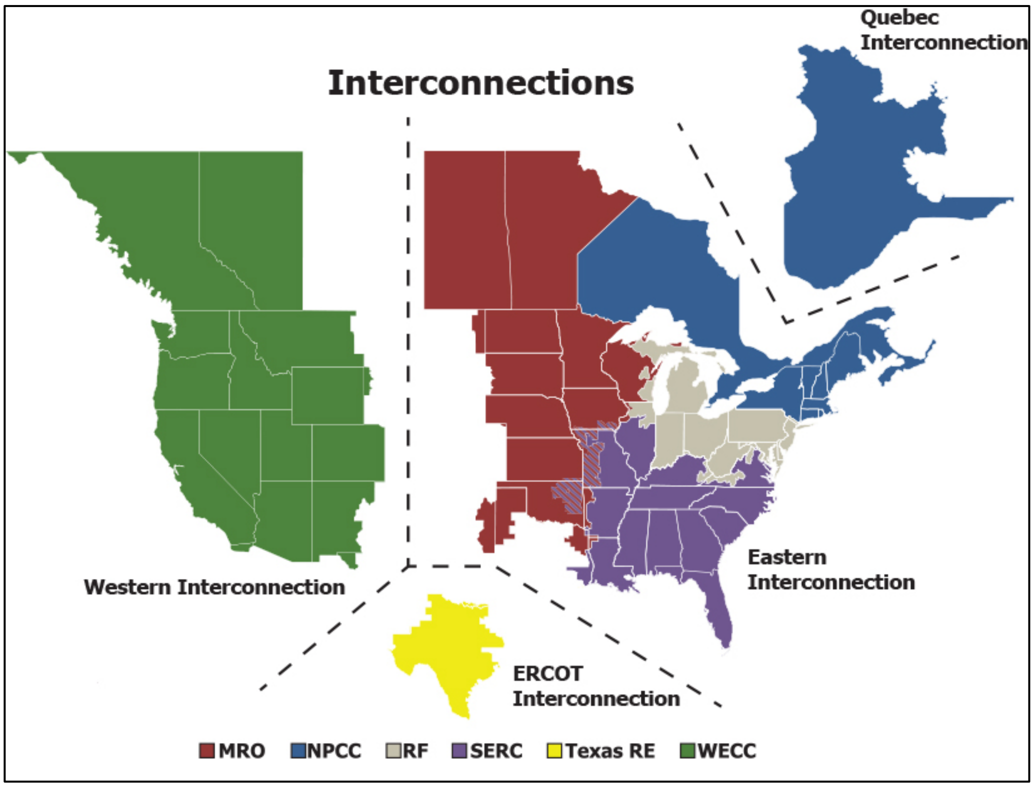
States provide differing incentives for solar and wind producers. For example, the map in Figure 3 indicates excellent opportunities for utility-scale wind along a swath of the United States that includes the Texas Panhandle. Starting in the 1990s, Texas legislators passed a series of measures that, along with federal tax credits, provided Texas wind-power producers with a favorable climate for expansion.[12] Texas wind farms generated nearly 28% of the nation's wind power in 2018. Notably, Texas is also home to lots of sunny days, but

[12] Changes included establishment of competitive wholesale and retail power markets, creation of renewable portfolio standards and competitive renewable energy zones, and investment of billions in transmission infrastructure. Kate Galbraith, *The Great Texas Wind Rush: How George Bush, Ann Richards, and a Bunch of Tinkerers Helped the Oil and Gas State Win the Race to Wind Power*, Peter T. Flawn Series in Natural Resources, (Austin: University of Texas Press, 2013); Peter R. Hartley, Kenneth B. Medlock, and Olivera Jankovska, *Electricity Reform and Retail Pricing in Texas*, Center for Energy Studies, Rice University's Baker Institute for Public Policy (Houston, TX, 2017).

utility-scale solar has not been as successful.[13] In 2018, California produced 40% of the nation's solar power, followed by North Carolina, Arizona, Nevada, and then Texas. Based on the map in Figure 4, North Carolina does not have particularly impressive solar resources. Yet the state's appearance as the second-largest solar power producer indicates the importance of state policy in promoting a particular energy source.

The majority of the country's installed generating facilities are connected to other facilities through 240,000 miles of high-voltage transmission lines and another 360,000 miles of lower voltage lines.[14] Three autonomous networks operate in the continental United States: The Eastern Interconnection, the Western Interconnection, and the ERCOT Interconnection. As shown in Figure 5, the Eastern Interconnection includes links into Canada; the Western Interconnection includes links into Mexico and Canada; and the ERCOT Interconnection operates entirely within Texas.

Figure 5. Map Illustrating Major Interconnected Systems in North America



Source: © North American Electric Reliability Corporation. All Rights Reserved. This content may not be reproduced in whole or in part without prior express written permission from the North American Electric Reliability Corporation.

[13] Leah Stokes, *Short Circuiting Policy: Interest Groups and the Battle Over Clean Energy and Climate Policy in the American States* (Oxford: Oxford University Press, forthcoming 2020). Stokes argues that opponents of the solar industry blocked implementation of targets for new solar power.

[14] High voltage transmission lines are used to increase the efficiency of long-distance transmission of power while minimizing the loss of energy along the way. Lower voltage lines are used for the distribution of power over shorter distances because it is safer.

Physical links between power networks do not necessarily equal interconnections. In power systems work, an interconnection, by definition, represents an alternating current (AC) network in which all the components are synchronized.[15] In other words, all the components operate at the same frequency, which by standard practice is 60 Hz in the United States.[16] Notably, direct current (DC) links between the giant interconnections allow for scheduled non-synchronous exchanges of power. These DC connections do not, however, indicate that one giant grid serves all of North America.[17]

The simplicity of the maps above belies the complexity of grid operations and oversight. While there are three major interconnected networks in the United States, there are numerous other entities that manage transmission systems and assure reliability.[18] In 2003, Congress mandated the creation of an Electricity Reliability Organization (ERO), certified by the Federal Energy Regulatory Commission (FERC). This marked the first time since start of electrification that the federal government established responsibility for the reliability of the nation's electric power supply. Prior to this, industry participants voluntarily coordinated reliability practices and standards. In 2006, FERC certified the North American Electric Reliability Corporation (NERC) as the ERO.[19] NERC in turn designated eight Regional Entities to establish and review reliability standards for 105 balancing authorities that manage grid operations. In addition, FERC recognizes 12 transmission planning regions, not including the ERCOT area.

---

[15] "Glossary of Terms Used in NERC Reliability Standards," North American Electric Reliability Corporation (NERC) website, https://www.nerc.com/files/glossary_of_terms.pdf, updated May 13, 2019. The term interconnection is defined as follows: "A geographic area in which the operation of Bulk Power System components is synchronized such that the failure of one or more of such components may adversely affect the ability of the operators of other components within the system to maintain Reliable Operation of the Facilities within their control."

[16] Alternating current (AC) is an electric current that continuously switches direction. On an AC power network, every part from the generator to the appliance in a customer's home must be synchronized at the same speed and cycle or the system will fall apart. With transformers, it is possible to increase the voltage to allow for transmission over long distances with reduced loss of energy, and then reduce the voltage for delivery. Direct current (DC) is an electric current that moves in only one direction. High voltage direct current transmission allows for lower cost transmission of electricity with lower loss of energy over long distances and under water. With conversion equipment, it is possible to link two AC networks with an HVDC line. This allows each AC network to operate in synchrony internally, without requiring synchronization between the two AC networks.

[17] These DC connections differ from high voltage direct current transmission (HVDC) lines, which allow for energy-efficient transmission of power over very long distances. A 2018 Department of Energy report lists 21 high voltage direct current (HVDC) projects operating in the United States, of which the oldest dates back to 1970, and 13 began operation before 2000. The report lists an additional 12 proposed projects, none of which have yet gone into service. "Assessing HVDC Transmission for Impacts of Non-Dispatchable Generation," Report by ICF Incorporated, LLC, for Independent Statistics & Analysis, U.S. Energy Information Administration (Washington, D.C.: US Department of Energy, 2018).

[18] NCR Active Entities List as of June 14, 2019, Organization Registration and Organization Certification webpage, NERC website, https://www.nerc.com/pa/comp/Pages/Registration.aspx; Appendix 5A, Organization Registration and Certification Manual, Effective Date: October 31, 2016, Rules of Procedure, NERC website, https://www.nerc.com/AboutNERC/Pages/Rules-of-Procedure.aspx.

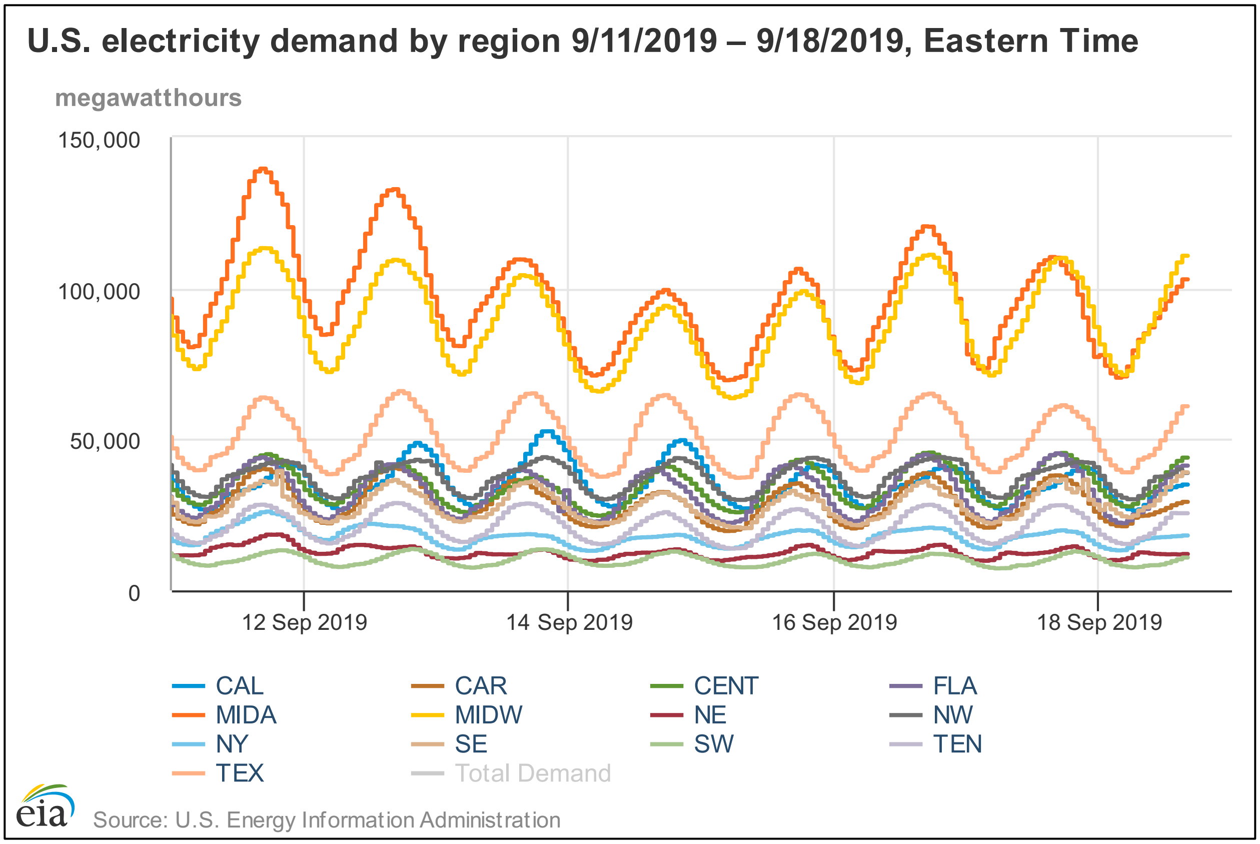
[19] NERC is the legacy organization of two initiatives of the investor-owned utilities dating back to the 1960s: The North American Power Systems Interconnection Committee (established in 1963) and the National Electric Reliability Council (established in 1968). Cohn, *The Grid,* 142-6, 169-70.

There are nearly 1,500 entities that use, own, and/or operate the nation's bulk power supply system. Of these about 330 are transmission owners, about 180 are transmission operators, and some are both. In addition, there are transmission planners and service providers, resource planners, generator owners and operators, reserve sharing groups, reliability coordinators, and planning authorities that all have a role in assuring grid reliability. Beyond this, thousands of entities own and operate generating facilities, from rooftop solar panels on individual homes to giant nuclear power plants, that are connected to the interconnected systems.

Quotidien operation of AC transmission networks is rife with challenges. A grid operator's primary duty is to match demand with supply at the instant, and historically without access to stored electricity. Figure 6 illustrates the variability of demand from hour-to-hour and day-to-day across 13 regions of the country. While sophisticated algorithms help predict demand and calculate the next most efficient source of supply, a degree of unpredictability inheres in human behavior. A sudden factory shutdown or startup, for example, might undermine scheduled power system operations at the local or regional level. In addition, from weather events to accidents to animal incursions to malefactors, grid operators juggle many potential system interruptions. Further complicating the process, operators strive to maintain a steady frequency across the grid, while delivering power at the voltages needed. Voluntary reliability standards adopted more than 50 years ago are still in place, while advanced computing and control technologies facilitate the work. But changing approaches to power generation and storage complicate the already difficult process. Right now, for example, grid operators have no authority to manage homeowners' rooftop solar power generation, but they must account for it when balancing supply and demand, and therefore regulating frequency.[20]

[20] Grid operators account for generation by homeowners by either estimating its impact as a resource or accepting it as additional volatility in load forecasts. In some instances, they are developing or contracting with a third party for distributed energy resource management systems (DERMS) to monitor and control those resources. DERMS that aggregate rooftop solar often communicate with the solar customer (especially when the installation is leased to the consumer). Per personal communication with Bob Cummings, Senior Director of Engineering and Reliability Initiatives, North American Electric Reliability Corporation, November 25, 2019.

Figure 6. US Electricity Demand by Region



Source: EIA.gov.

This very brisk summary of interconnections and energy resources in the early 21st century suggests that future directions in electrification will likely develop organically. With no central authority over power system development, little consistency across states, a wide range of energy resource attributes from region to region, and technology innovation always on the horizon, a clear-cut approach appears elusive.

Integrating Renewables in the United States

Over the past several decades, both state and federal governments have adopted incentives to encourage increased development of renewables. Congress offered the first pathways for new sources of renewable energy with passage of the Public Utility Regulatory Policies Act of 1978 (PURPA).[21] From 1935 to 1978, federal law and policy, and most state laws, strongly supported investor-owned utilities as the primary provider of electric power to Americans. During those years, industrial manufacturers produced power for their own facilities, but in general did not sell excess to other customers. By the 1970s, as various energy crises

[21] Richard F. Hirsh, *Power Loss: the Origins of Deregulation and Restructuring in the American Electric Utility System* (Cambridge, MA: MIT Press, 1999); Robert Lifset, ed., *American Energy Policy in the 1970s* (Norman: University of Oklahoma Press, 2014).

brought attention to wasted energy in the US economy, some industrial manufacturers pushed for a change in laws that would allow them to sell excess electricity into local power networks. This was especially attractive for companies that generated steam for industrial processes and generated electricity as a byproduct. PURPA required monopoly utilities to purchase power from co-generators at a price reflecting the cost of generating the next increment of power on the utility's system. PURPA also required utilities to purchase power in a similar manner from small independent generating facilities. This opened the door for those experimenting with new technologies and renewable energy sources such as solar and wind power. Co-generation doubled within the first 10 years of PURPA and doubled again in the next 10 years.[22] New solar and wind facilities grew much more slowly.

Congress and FERC took additional steps to broaden participation in electricity markets. The Energy Policy Act of 1992 and several FERC orders required transmission line operators to offer equitable access to more types of power generating entities.[23] In addition, state legislators across the country established new rules for wholesale and retail power markets. Dating back to 1907, most states had established regulatory commissions that guaranteed monopoly markets for investor-owned utilities in return for regulated prices and fair customer access.[24] In 1996, some state legislatures began to restructure electricity markets, in some cases establishing competitive wholesale markets, in others competitive retail markets. These markets improved opportunities for new types of power companies to offer electric power to customers. While market-oriented regulatory changes of the 1990s benefitted the renewables industry, policymakers were far more focused on market structure and price to consumers. This changed in the early 2000s as states increasingly established goals for integration of renewable resources into the energy mix for electric power.

With a variety of grants, loans, subsidies, and tax credits, the federal government and each state offer financial incentives for wind and solar power development. In addition, numerous indirect government interventions, such as environmental regulations and state carbon markets, further encourage the use of renewable resources for power generation. West Virginia is the least munificent, with only 13 programs designed to encourage renewables; California is the most enthusiastic, with 217 policies and incentives for renewables.[25] States adopted two key policy strategies for expanding renewable power

[22] Meegan Kelly, Blog Post, "A Brief History of CHP Development in the United States," American Council for an Energy-Efficient Economy webpage, February 26, 2016, https://aceee.org/blog/2016/02/brief-history-chp-development-united.

[23] The Energy Policy Act of 1992, 42 U.S.C. § 134; Federal Energy Regulatory Commission, "Promoting Wholesale Competition through Open Access Non-Discriminatory Transmission Services by Public Utilities and Recovery of Stranded Costs by Public Utilities and Transmitting Utilities," Order No. 888; Federal Energy Regulatory Commission, "Regional Transmission Organizations," Order No. 2000.

[24] While the majority of states had rate and entry regulation in place by 1920, in 1975 Texas was the last state to implement state-level regulation. Nebraska required public ownership of power systems beginning in 1933.

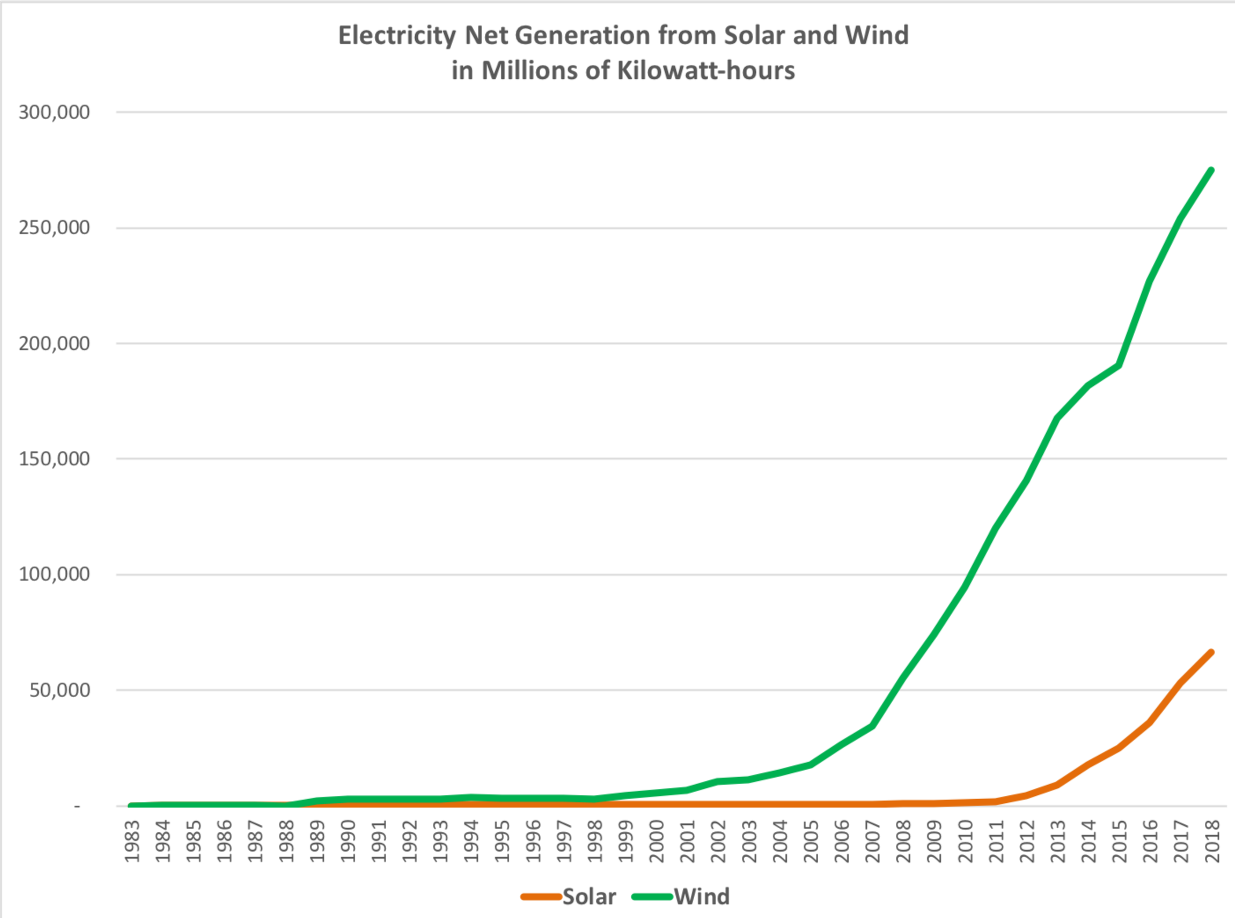
[25] "Database of State Incentives and Policies for Renewables & Efficiency," NC Clean Energy Technology Center, North Carolina State University, https://www.dsireusa.org/, accessed June 24, 2019.

generation—renewable portfolio standards (RPS) and voluntary renewable energy goals.[26] RPS establish required date and percentage targets for adding renewables to the state's energy mix. Voluntary goals are just that—voluntary. Currently, 29 states, Washington, D.C., and three territories have RPS. An additional eight states and one territory have voluntary renewable energy goals. Most standards set renewable targets ranging from 10% to 45%, to be achieved by dates ranging from 2015 to 2040. California and Hawaii have the most ambitious goal of reaching 100% renewable energy resources for electricity by 2045. Texas and Iowa differ, with total megawatt rather than percentage targets for renewables. States deploy different approaches for achieving the RPS, including specific goals for particular energy resources or technologies, credit multipliers, and net metering.

Over the past two decades, combined state and federal policies established an environment in which renewable technologies flourished. In addition, the unit costs of installing and operating wind and solar facilities have dropped while the technologies are more efficient and long-lasting. Figure 7 illustrates the growth of wind and solar power generation dating back to 1983. As the line graphs indicate, growth lagged after passage of PURPA. Wind power took off in the early 2000s and solar power in the 2010s, and these trends track implementation of additional state and federal policies, as well as improvements in generating technologies.

[26] "State Renewable Portfolio Standards and Goals," National Conference of State Legislature, updated February 1, 2019, http://www.ncsl.org/research/energy/renewable-portfolio-standards.aspx.

Figure 7. Electricity Net Generation from Solar and Wind



Source: May 2019 Monthly Energy Review, Table 7.2a, Electricity Net Generation (All Sectors), eia.gov.

Overall, the United States has realized a huge increase in power generated by renewables in the past 20 years.[27] Wind provides the largest share of new power from renewables, and the total generated increased by almost 4,000% since 2001. Utility-scale solar increased by nearly 5,400%, while small-scale solar increased by a stunning 29,542,900%, though still only a tiny fraction of the nation's total (0.7%). These data suggest a strong trend toward increased integration of renewables into the nation's power systems, but do not capture the array of ideas circulating for how this will continue into the future.

Visions of the Renewable Future

Engineers, policymakers, politicians, manufacturers, and advocates offer an array of strategies for increasing the use of renewable energy resources in American power systems. In some scenarios, individual homeowners could operate nanogrids incorporating rooftop

[27] Electricity Data Browser, Data set: Net Generation, United States, all sectors, annual.

solar panels, storage batteries, and perhaps back-up generators, without connection to larger networks. In others, multiple stakeholders could share in the cost of building and operating microgrids that can operate either in synchrony with larger power pools or in isolation. Alternately, utility-scale solar and wind installations could gradually displace coal-fired power plants, natural gas plants, and nuclear plants within existing interconnected systems. Others imagine new HVDC transmission lines connecting east to west and north to south to move power from huge wind and solar installations across the country. In the most ambitious scenarios, power networks could operate globally, taking advantage of sun that shines and wind that blows somewhere every day. In most scenarios, energy storage is key, whether in the form of batteries, pumped storage, thermal energy storage, or virtual storage via a neighboring region's excess generation.

Nanogrids

Speaking to the University of Houston Energy Symposium in the fall of 2018, John Berger, CEO of Sunnova Energy Systems, argued that it would be a mistake to expect a linear continuation of grid development based solely on the past.[28] He pointed out that within the prior two years, multiple technologies had converged to make nanogrids that operate isolated from larger transmission networks feasible. With solar panels, new battery technologies, and importantly, new control electronics, homeowners can "cut the cord."[29] As Berger puts it, the industry is now able to push "intelligence … to the end of the system."[30] Puerto Rico offers a case in point.[31] In 2017, Hurricane Maria destroyed the island's electric power grid. PREPA, the monopoly government-owned utility that operates the grid, projected that it will take five years and billions of dollars to rebuild and harden the transmission network. In the meantime, communities in remote areas are installing small solar panel/battery combinations to provide electricity immediately.

Nanogrids are characterized by several elements: very small size (according to some sources, 100 kw when linked to a larger interconnection, which can provide backup power and five kw when completely isolated), local control, and a single building or load.[32] Some define a nanogrid according to its function—power distribution for a single load or customer—and exclude the power generating source.[33] Others define a nanogrid by its scale—a system

[28] Presentation by John Berger, CEO, Sunnova Energy Corporation, "Future of the Electric Grid: Renewed or Gridlocked?" University of Houston Energy Symposium, September 17, 2018, Houston, Texas, http://www.uh.edu/uh-energy/energy-symposium-series/symposium-1_2018/.
[29] Ibid., minute 56:25.
[30] Ibid., minute 1:00:20.
[31] Marisa Peñalosa, "Puerto Rico Harnesses the Power of the Sun for a Renewable Energy Future," July 5, 2019, on *All Things Considered*, https://www.npr.org/2019/07/05/738164642/puerto-rico-harnesses-the-power-of-the-sun-for-a-renewable-energy-future.
[32] Linda Hardesty, "What's a Nanogrid?" *Energy Manager Today*, March 25, 2014, https://www.energymanagertoday.com/whats-a-nanogrid-099702/.
[33] Bruce Nordman, "Nanogrids: Evolving Our Electricity Systems from the Bottom Up," presentation to Darnell Green Building Power Forum, May 2010, available at http://nordman.lbl.gov/; Bruce Nordman, Ken Christensen, and Alan Meier, "Think Globally, Distribute Power Locally: The Promise of Nanogrids," *Computer* 45, no. 9 (2012): 89-91.

belonging to a single home or building.[34] In either case, conceptually nanogrids offer an approach to electrification that happens at the most local level. A small number of nanogrids currently provide electrification in remote areas with no access to large interconnected systems.[35] Nanogrids may operate singly, connected to each other, or connected to a larger transmission network. In a future of renewables, millions of individuals and small entities, or segments of larger entities, might decide to install small renewable generating technologies and small distribution networks that are controlled locally.

Microgrids

Microgrids are, as the name implies, small networks of power generator(s), transmission and distribution facilities, and power users. The US Department of Energy defines a microgrid as "a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode."[36] This is technologically similar to current Balancing Authority Areas, only much, much smaller.[37] A microgrid may be a nanogrid, but also may be composed of multiple nanogrids.[38] Microgrids are distinguished from nanogrids by the fact that a microgrid may include numerous smaller systems that are not autonomously controlled. Crucially, a microgrid incorporates internal controls so that it faces the larger network as a single entity, unlike a delineated collection of generating sources, distribution lines, and customers that rely on the larger system for control.[39] In advocating a microgrid future, proponents cite numerous ways in which renewable distributed generation can be beneficial: lower capital investment due to the reduced need for long-distance transmission lines; reduced power loss over shorter links between generating sources and customers; improved reliability—especially on DC or partial DC systems; and use of energy-efficient

---

[34] Daniel Burmester et al., "A Review of Nanogrid Topologies and Technologies," *Renewable and Sustainable Energy Reviews* 67 (2017): 760-75.

[35] Annette Werth, Nobuyuki Kitamura, and Kenji Tanaka, "Conceptual Study for Open Energy Systems: Distributed Energy Network Using Interconnected DC Nanogrids," *IEEE Transactions on Smart Grid* 6, no. 4 (2014): 1621-30; Liyao Wu et al., "Development of a Solar-power-based Nanogrid System for Village Huts in Haiti Mountain Area," presentation to North American Power Symposium, Denver, CO, September 18-20, 2016, IEEExplore.

[36] Dan T. Ton and Merrill A. Smith, "The U.S. Department of Energy's Microgrid Initiative," *The Electricity Journal* 25, no. 8 (October 2012): 84. A microgrid does not necessarily rely on solar or wind power. The newly opened TWA Hotel at Kennedy Airport relies entirely on a fully isolated microgrid with natural gas generators and local storage. Ken Silverstein, "Newly Opened, JFK's TWA Hotel is Always Grid Independent," Microgrid Knowledge wesbiste, https://microgridknowledge.com/twa-hotel-microgrid/, June 7, 2019.

[37] By definition, a Balancing Authority Area is "The collection of generation, transmission, and loads within the metered boundaries of the Balancing Authority. The Balancing Authority maintains load-resource balance within this area." *Glossary of Terms Used in NERC Reliability Standards,* Updated May 13, 2019 (Atlanta, GA: North American Electric Reliability Corporation, 2019), https://www.nerc.com/files/Glossary_of_Terms.pdf.

[38] Burmester et al., "A Review of Nanogrid Topologies and Technologies."

[39] Adriel M. Rizzalo Lede et al., "Microgrid Architectures for Distributed Generation: A Brief Review," presented to IEEE PES Innovative Smart Grid Technologies Conference–Latin America, Quito, Ecuador, September 20-22, 2017, IEEExplore.

generating technologies. Some predict that microgrids will comprise 20% of the power industry by 2035.[40]

Microgrids harken back to the isolated plants of the early years of electrification and to the earliest links between small central stations. The reconceptualization of these small networks as microgrids evolved along with control software innovations, the idea of managing demand via smartgrids, interest in small-scale solar generation, and, crucially, concern for resilience.[41] While stability and reliability long interested power system engineers, the issue of resilience—that is, the ability to withstand or quickly recover from unplanned outages—has come to the fore in recent years. The extended power outages following Hurricane Sandy in 2012, for example, illustrated the benefits of smaller networks that could operate with internal controls when separated from large-scale interconnected systems. Currently, testbed projects abound across the United States.[42] In Texas, businesses concerned about summertime power shortages within ERCOT are increasingly installing small-scale generators—including rooftop solar—to ensure resilience.[43] Interestingly, the city of Boston, along with a few others, has established a policy that promotes microgrid readiness in new buildings—that is, districts should have the ability to separate ("island") from the interconnected system when needed.[44] This is in contrast to early 20th century expectations that city codes would require elimination of isolated power plants, as discussed below.

Macrogrids, Supergrids, and Global Grids

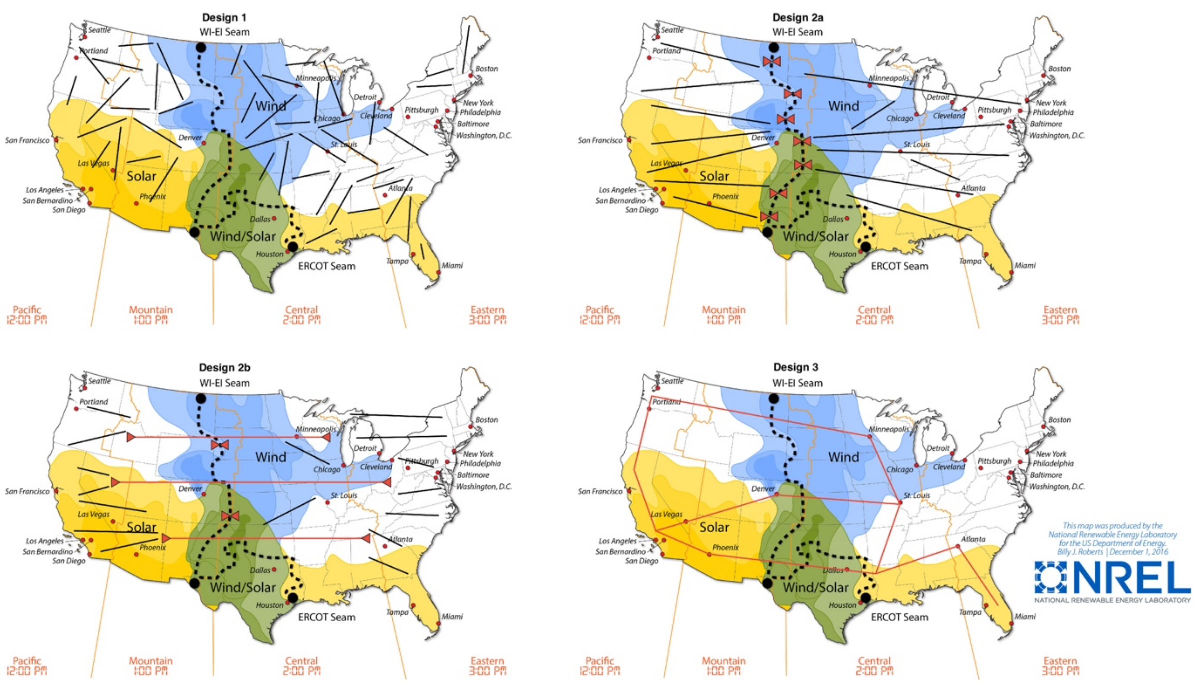
In the clean energy future, utility-scale solar and wind still hold untapped potential. Advocates call for a variety of approaches to increase use of these energy sources, from market-based reforms to government-imposed investments and requirements. The multi-billion-dollar question is how to most effectively move electric power from the areas of abundant wind, sun, hydro, and geothermal potential to the areas of intense electricity use. As the number and size of utility-scale wind and solar power installations increase, proposals for redeveloping existing transmission networks, overlaying them, and linking

---

[40] Steve Pullins, "Why Microgrids are Becoming an Important Part of the Energy Infrastructure," *The Electricity Journal* 32, no.5 (June 2019): 17-21.
[41] Pullins, "Why Microgrids are Becoming an Important Part of the Energy Infrastructure"; Gene Wolf, "A Short History: The Microgrid," *Transmission and Distribution World: Digital Innovations* (October 24, 2017), https://www.tdworld.com/digital-innovations/short-history-microgrid.
[42] Wei Feng et al., "A Review of Microgrid Development in the United States–A Decade of Progress on Policies, Demonstrations, Controls, and Software Tools," *Applied Energy* 228 (2018). See the map of current test bed projects on page 1659.
[43] L.M. Sixel, "Firms Installing Their Own Power Supplies," *Houston Chronicle*, March 30 2019.
[44] Pullins, " Why Microgrids are Becoming an Important Part of the Energy Infrastructure," 2; "Smart Utilities Policy for Article 80 Development Review–2018," Boston Planning and Development Agency, accessed online on September 18, 2019, http://www.bostonplans.org/getattachment/7b87a301-95da-4723-b3a9-02bfebd1b109, 3.

them across greater distances abound.[45] In its 2018 Interconnections Seam Study, the National Renewable Energy Lab modeled four design scenarios, illustrated in Figure 8, that reflect the range of approaches to adding new utility-scale renewables. In Design 1, represented by the map in the upper left corner of Figure 8, no additional links are added between the existing interconnected systems. In Design 2a, in the upper right corner, new higher capacity DC nodes are added. In Design 2b, in the lower left corner, both DC nodes and DC transmission lines are added. In Design 3, in the lower right corner, a new HVDC network overlays the older AC systems. The latter concept offers the most radical large-scale departure from existing networks.

Figure 8. Four Design Concepts Offered in NREL Interconnections Seam Study



Source: Aaron Bloom, Interconnections Seam Study; design numbers added by author.

---

45 Aaron Bloom, "Interconnections Seam Study," Powerpoint presentation to TransGrid-X Symposium, Ames, IA, National Renewable Energy Laboratory, July 26, 2018, https://www.terrawatts.com/seams-transgridx-2018.pdf; Steve Bullock, John Carney, and Jeff Colyer, Letter to the Federal Energy Regulatory Commissioners Re: Interconnection Seams Study [*sic*], November 9 2018, Governors' Wind & Solar Energy Coalition website, http://governorswindenergycoalition.org/wp-content/uploads/2018/11/GWSC-Interconnection-Seams-Study-FERC-Letter-11-9-18.pdf; Armando Luis Figueroa-Acevedo, "Opportunities and Benefits for Increasing Transmission Capacity Between the US Eastern and Western Interconnections" (Ph.D. Diss., Iowa State University, 2017); Rob Gramlich, Michael Goggin, and Katherine Gensler, "Green Power Superhighways: Building a Path to America's Clean Energy Future," American Wind Energy Association and Solar Energy Industries Association, 2009, https://www.smartgrid.gov/document/green_power_superhighways_building_path_americas_clean_energy_future; Colin A. Young, "Governors Say Cost, Reliability, Renewable Benefits Would Flow from Unified Power Grid," news release, November 13, 2018.

Already, investors and executives have offered specific projects along these lines. The Tres Amigas project in New Mexico, initiated in 2009, proposed to link all three AC interconnections through a DC multihub.[46] This would carry wind power from the Great Plains to both coasts, hydropower from the Pacific Northwest to Chicago, and Texas wind to both east and west. Over a similar period, Cleanline Energy proposed to build HVDC lines to carry wind power from Oklahoma to the east and west.[47] The leadership of both of these projects have since scaled back and sold off assets, reducing the visionary systems to more pragmatic investments in smaller technologies. At the very same time, Massachusetts—in order to meet its RPS goals—seeks an HVDC transmission line across neighboring states to Quebec to access hydropower resources.[48]

New HVDC links between and across the four existing interconnected AC systems in North America would address three key concerns related to utility-scale renewables. First, as noted previously, the areas with large endowments of wind, sunshine, and hydro tend to be located far from centers of intensive power use. HVDC transmission offers a cost-effective method for moving electric power across long distances. Second, as critics point out, the intermittency of wind and solar create challenges for power systems operation.[49] While physical energy storage offers the most direct method of countering intermittency, connections across large regions of the country provide virtual energy storage. When the wind is blowing too much in, say, western Oklahoma, the generators can ship extra power to California; and when the wind dies, Oklahomans can access power from somewhere else. Third, using HVDC links allows power systems operators to avoid the technical problems encountered when linking giant AC interconnections. As the third case in this study explains, it is very difficult to maintain stable links between such large systems. HVDC transmission lines and nodes allow each interconnection to maintain synchronous operation internally, and do not require synchronous operation across the links.

Visions for global interconnections look beyond the boundaries of the continental United States, and even beyond the countries within North America, for a fully green future. In these imaginaries, links between North and South America, or across the oceans, will ensure that power users can take advantage of sunshine and wind blowing somewhere at all

---

[46] Tres Amigas, LLC, "The Tres Amigas Superstation," Powerpoint presentation to FERC Technical Conference, Washington, D.C., June 26, 2013, https://www.ferc.gov/whats-new/comm-meet/2010/031810/E-12.pdf; Susan Montoya Bryan, "New Mexico Grid Linkup Plan Scaled Back to $200M Project," *AP*, February 15 2017; Edward Klump, "Tres Amigas Aims Smaller After 'Ambitious' Plan Stalls," *E&E News*, November 23 2016, https://www.eenews.net/energywire/2016/11/23/stories/1060046180; Jean Kumagai, "The US May Finally Get a Unified Power Grid?," *IEEE Spectrum* 53, no.1 (2016): 35-6.

[47] Russell Gold, "Building the Wind Turbines was Easy. The Hard Part Was Plugging Them In," *Wall Street Journal*, June 22, 2019; Ros Davidson, "Ambitious Clean Line Energy 'Wrapping Up'," *WindPower Monthly* (February 1, 2019), https://www.windpowermonthly.com/article/1523646/ambitious-clean-line-energy-wrapping-up.

[48] Jon Chesto, "Settlement May Be Near for Quebec-to-Mass. Power Line," *Boston Globe*, February 20 2019.

[49] Robert H. Schulte and Fredric C Fletcher, "100% Clean Energy: The California Conundrum," *The Electricity Journal* 32, no. 2 (2019): 31-6; Robert Blohm, "The Green New Deal's Impossible Electric Grid," *Wall Street Journal*, February 20, 2019.

times.[50] These visions are not new. Nicola Tesla first imagined a global wireless power system in the 1890s.[51] Buckminster Fuller famously promoted a global grid in the latter half of the 20th century.[52] Glenn Seaborg, then chairman of the US Atomic Energy Commission, gave the concept greater credibility in 1970.[53] This scale of integration, of course, brings with it attendant increased costs, sociopolitical challenges, and technical requirements yet to be met in a practical way.[54]

The future of North America's legacy grid lives at the heart of these different imaginaries. Will new small-scale technologies augment or displace larger interconnected systems? Will HVDC simply link existing transmission networks or overlay them? Will the current transmission infrastructure continue to serve as the backbone of the nation's power system?

The Case Studies

Case 1. From Fashion to Wartime Necessity, 1890-1919

The current networks of linked AC transmission lines originated with choices made by utilities at the turn of the last century. But even as power companies found economic and conservation advantages in building networks, certain customers resisted.[55] Industrial manufacturers prized the autonomy and flexibility inherent in operating their own power plants. The two-decade process of integrating the industrial sector into power networks represents a decisive turn in America's process of electrification and merits fairly detailed examination.

<u>Two Paths to Electrification</u>
Almost from the outset, pioneers in electrification recognized that there were at least two paths to providing light and power to interested customers. Edison United Manufacturing Company, for example, offered both central station service arrangements and freestanding

[50] Arman Aghahosseini et al., "Analysing the Feasibility of Powering the Americas with Renewable Energy and Inter-regional Grid Interconnections by 2030," *Renewable and Sustainable Energy Reviews* 105 (May 2019): 187-205; Mohammed Safiuddin and Robert Finton, "Global Renewable Energy Grid Project–Integrating Renewables via High-voltage Direct Current and Centralized Storage," in *Medium Voltage Direct Current Grid: Resilient Operation, Control and Protection*, ed. M.M. Eissa (London: Academic Press, 2019).
[51] Nikola Tesla, "The Transmission of Electrical Energy Without Wires," *Electrical World* 43, no. 10 (1904): 429-31.
[52] GENI Newsletter, Global Energy Network Institute website, Second Quarter, 1995, https://www.geni.org/globalenergy/library/newsletters/1995/buckminster-fuller-on-the-global-energy-grid.shtml.
[53] Sam Pope Brewer, "Seaborg Foresees World Grid for Electric Power Distribution," *New York Times*, August 11, 1970.
[54] Dan Shreve and Wade Schauer, *Deep Decarbonisation Requires Deep Pockets: Trillions Required to Make the Transition*, Wood Mackenzie website, June 2019, http://www.decarbonisation.think.woodmac.com/summary/,http://www.decarbonisation.think.woodmac.com/summary/.
[55] For more detailed investigation of how and why central station service expanded in the early years of electrification, see Thomas Parke Hughes, *Networks of Power: Electrification in Western Society, 1880-1930* (Baltimore: Johns Hopkins University Press, 1983); Harold L. Platt, *The Electric City: Energy and the Growth of the Chicago Area, 1880-1930* (Chicago: University of Chicago Press, 1991).

generating plants.[56] By 1890, Edison counted 1,000 central stations in the United States and many more abroad. Within another 10 years, many investor-owned utilities and municipal power companies had expanded their systems to link together central stations and substations, and even two or more central stations.[57] By the early 1900s, larger and larger central stations served customers across growing regions. At the very same time, however, electrification in certain sectors took place in-house, as industrial manufacturers, hoteliers, and department stores opted instead for isolated plants.[58] As one reporter noted, "One of the most serious problems now confronting central station managers is the growth of the fashion for the installation of isolated plants in large buildings."[59]

By the late 1890s, just as utilities in California and Utah built early interconnections, others predicted that the number of isolated plants would increase in the near future. Engineers debated the advantages and disadvantages of both approaches. While the most prevalent concerns were capital investment and operating costs, other issues clouded decision-making. In 1898, for example, *Electrical World* summarized the advantages of isolated plants: isolated plants often had capacity equivalent to central stations, the load factor was better, the owner could use the exhaust steam for heating, little additional labor was required for operation, there was no need for additional investment in distribution circuits, and the depreciation was less than a central station.[60] Owners often installed storage batteries or backup generators with their isolated power plants to ensure reliability.[61] One year later, engineer Percival Robert Moses illustrated the variability in cost and value of an isolated plant depending on the type of building and the activity underway inside.[62] While

---

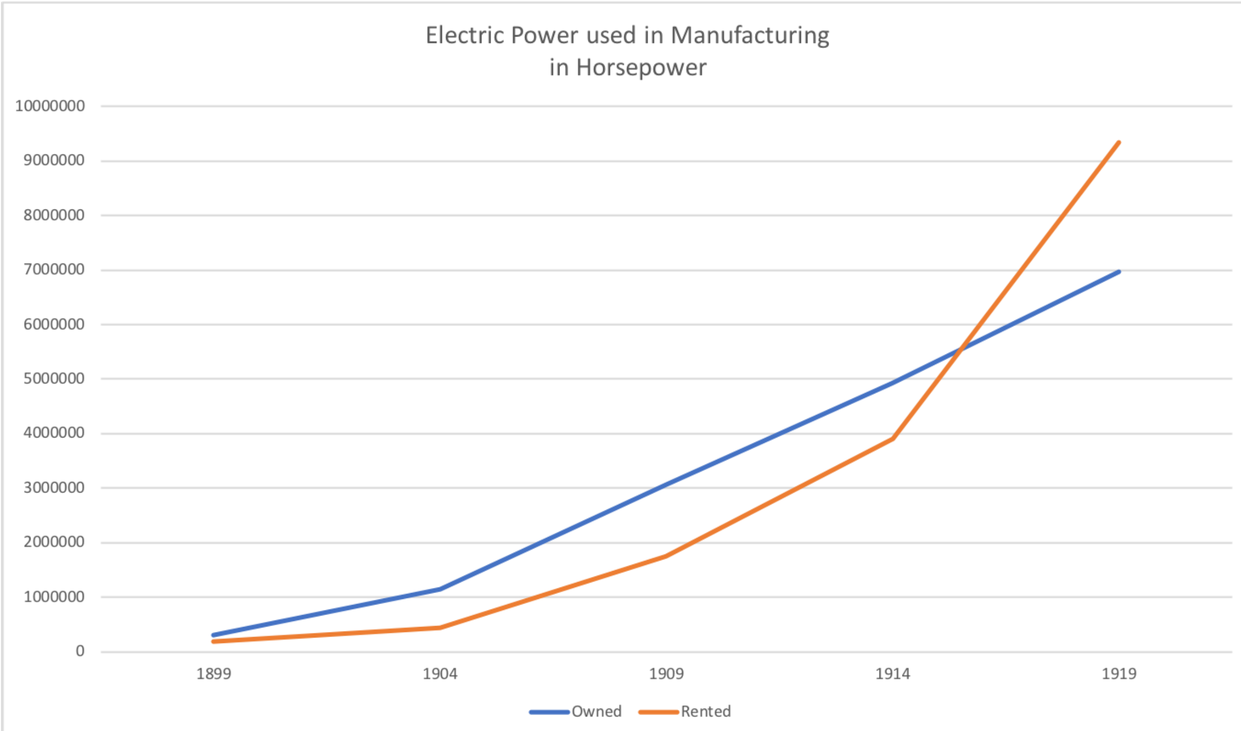
[56] "Edison Electric Light and Power System," Engineering and Technology History Wiki, last modified January 24, 2018, https://ethw.org/Edison%27s_Electric_Light_and_Power_System.
[57] Cohn, *The Grid*, 610; Carl Hering, "Centralization of the Supply of Electricity," Digest of Current Technical Electrical Articles Compiled from Foreign and American Journals, *Electrical World* 30, no. 16 (1897): 459.
[58] "Storage Battery and Electric Elevators for New Waldorf Hotel, New York City," *Electrical World* 29, no. 4 (1897): 148; *Central Electric Light and Power Stations, 1902*, (Washington, D.C.: Government Printing Office, 1905), 3.
[59] "The Central Station and the Isolated Plant."
[60] Carl Hering, "Isolated Plants," Digest of Current Electrical Literature American and Foreign, *Electrical World* 31, no. 3 (1898): 100.
[61] These early batteries used lead, nickel, cadmium, zinc, and other elements. Lithium batteries arrived on the market in the late 20th century. A search of the Hathitrust database produces dozens of references to the term "storage battery" published between 1880 and 1990 in journals, books, and government documents relevant to electrification. Similar searches in *IEEExplore* and *ScienceDirect* produce 40 and 233, respectively. The "largest" storage battery in 1897 provided backup to the newly installed dynamos in the Waldorf Astoria Hotel in New York City, "Storage Battery and Electric Elevators for New Waldorf Hotel, New York City," *Electrical World* 29, no. 4: 148. In 1912 the backup battery for the Baltimore, MD utility, occupied a warehouse floor with 152 cells weighing 616.5 tons, and could deliver power for between six minutes and one hour. "Largest Single Storage Battery Installation in the World." *Electrical World* 59, no. 24: 1390.
[62] Percival Moses, "The Cost of Electricity in Some Typical Buildings in New York City," *Transactions of the American Institute of Electrical Engineers* 16 (June 26, 1899): 305-27.

some affirmed the dual benefits of isolated plants that provided both heat and power to a building, a utility in Missouri offered the same pair of services to a dense urban area.[63] This reflected the importance of geography as customers determined how they wanted to approach electrification.

Debates continued in 1902. Engineers took sides at the meeting of the Chicago Electrical Association.[64] Engineer C.H. Hines wrote about the increasing use of in-house electric plants in steel and iron mills. Hines underscored the importance of the in-house chief electrician, who had to "understand his routine work thoroughly" and also "be prepared for any emergency that may arise day or night."[65] Isaac Parsons published a study comparing isolated plants and central station service in New York City buildings.[66] He noted that the growing number of electricity-using facilities in large buildings, as well as the desire for steam heat, made isolated plants more economical and desirable, but the attendant noise and vibration might make central station service more appealing. Parsons found that for office buildings of any size, the isolated plant offered a marked economic advantage.[67] As illustrated in Figure 9, isolated plant installations in manufacturing facilities grew much more quickly at first than access to central station service.

[63] Carl Hering, "Central Stations and Isolated Plants," Digest of Current Electrical Literature, *Electrical World* 35, no. 19 (1900): 711; "Heading Off Isolated Plant," *Electrical World* 36, no. 22 (1900): 850.
[64] "The Isolated Plant versus the Central Station–Discussion at the Chicago Electrical Association," *Electrical World* 39, no. 19 (1902): 817.
[65] "The Application of Electricity in Steel and Iron Mills," Digest of Current Electrical Literature, *Electrical World* 39, no. 19 (1902): 813.
[66] Isaac Parsons, "The Economy of Isolated Electric Plants," *The Engineering Magazine* 22, no. 4 (1902): 573-88; Parsons, "The Economy of Isolated Electric Plants," *The Engineering Magazine* 22, no. 5 (1902): 721-36.
[67] Parsons, "The Economy of Isolated Electric Plants," 583.

Figure 9. Comparison of Source of Electricity for Manufacturing, 1899-1919



Source: "Abstract of the Census of Manufactures 1919." Washington, D.C.: Government Printing Office, 1923.

The United States released census data in 1902 that showed an enormous industrial market for electrification.[68] Of roughly 500,000 manufacturing establishments surveyed, only 33% used "power" of any type, and only 10% of those relied on electric power.[69] Where manufacturers used electricity, two-thirds reported in-house production, and only one-third rented from central stations.[70] This illustrated two important points for electrical manufacturers and central station operators alike. First, there was an important market ready to take advantage of increased electrification, and second, within this market, the contest between isolated plants and central station service was tilted toward isolated plants. At the very same time, utilities reported not only growth in the total power generated at central stations, but also geographic expansion of systems through the use of longer-distance transmission lines and substations.[71]

[68] *Twelfth Census of the United States Taken in the Year 1900: Manufactures, Part I, United States by Industries*, William R. Merriam, Director (Washington, D.C.: Government Printing Office, 1902).
[69] *Twelfth Census of the United States Taken in the Year 1900: Manufactures*, cccxvi. This does not include manufacturers that "rented" power from a central station. The census provides data on the total horsepower rented from a central station, but not the number of manufacturers renting rather than owning.
[70] "Power in Manufactures," Editorial, *Electrical World* 40, no. 19 (1902): 733.
[71] "The Growth of Central Station Practice," Editorial, *Electrical World* 40, no. 22 (1902): 842.

Cost, Independence, New Technologies

By 1904, engineers compared the unit cost of generation at one large central station to multiple small, isolated plants producing the same amount of power.[72] Noted electrical engineer Lewis Stillwell claimed that a large station used only three pounds of coal per kilowatt-hour while small plants used 10. He further suggested that one 50,000-horsepower plant could do the work of small plants aggregating 75,000 to 100,000 horsepower.[73] Stillwell argued that the cost of transmission of power from a distant coal field was greater than the cost of coal transport, in contrast to those who advocated for power plants located at the mouth of the coal mine. When *Electrical World* introduced a special section on Central Station operations in 1908, competition with isolated plants for customers became a key theme.[74]

In 1910, the American Institute for Electrical Engineers (AIEE) and the American Society of Mechanical Engineers held a joint session to examine the merits and costs of isolated plants and central station service. MIT professor Dugald Jackson offered that industrial plants could achieve continued economies by “concentrating” power generation in larger steam-turbine plants.[75] This could mean both within a single industrial plant with multiple activities underway or by connecting to a central station. The advent of large, steam-turbine technology provided the critical element for Jackson’s case. In 1910, manufacturers and plant operators had barely begun to realize the economies of scale this new technology offered. Within just a few years, it changed the calculus for how best to advance electrification.[76] Jackson argued that dense industrial areas stood to benefit enormously from integration. In his sample case, Philadelphia, he noted that “tens of thousands of horse power are used for manufacturing in establishments crowded together in city blocks,” each with its own plant and none achieving economy or energy efficiency. By consolidating that power generation into two or three powerhouses, the city could realize lower costs per kilowatt-hour, release valuable space for manufacturing activity, minimize smoke and dirt in the neighboring area, and reduce the inconveniences related to supplying coal and removing waste.[77]

Others offered additional perspectives. R.S. Hale, for example, reported that in side-by-side engineering estimates of ten 2,000 horsepower plants and a single 20,000 horsepower

---

72 "Electric Power Transmission," Digest of Current Electrical Literature, *Electrical World* 44, no. 2 (1904): 70.

73 "Electric Power Transmission," 1904; Lewis B. Stillwell, "The Development of Electric Power Transmission," *Cassier's Magazine* 26, no. 2 (1904): 120-1.

74 "Central Station Management, Policies and Commercial Methods," *Electrical World* 52, no. 2 (1908): 89-93; "Private Plants in Central-Station Territory," *Electrical World* 52, no. 12 (1908): 632-3; W. F. Lloyd, "Isolated Power Plant Costs and Their Relation to Central Station Service," *Electrical World* 52, no. 22 (1908): 1182-3.

75 Dugald C. Jackson, "The Applicability of Electrical Power to Industrial Establishments," *Proceedings of the American Institute of Electrical Engineers* 29, no. 2 (1910): 100.

76 Hughes, *Networks of Power*, 209-12; Platt, *The Electric City,* 114-5; Richard F. Hirsh, *Technology and Transformation in the American Electric Utility Industry* (Cambridge: Cambridge University Press, 1989).

77 Jackson, "The Applicability of Electrical Power to Industrial Establishments," 203.

plant, the single central plant would realize a 25% savings over the isolated plant.[78] He asked why, then, did central stations charge more for their power? Hale argued that sellers of isolated plant equipment tended to underestimate actual operating costs, while central stations charged for less obvious expenses like billing and bookkeeping and actual power loss over distribution lines. He broached the notion of utility stations as wholesalers of power, rather than retailers. In contrast, Charles T. Main explained that for textile mills, central station service would be advantageous under only very limited circumstances.[79] While the cost of generating electric power was cheaper at the larger central station, the isolated plant offered other cost-saving advantages—for example, steam heat as a byproduct. One engineer predicted cities would pass laws in the near future that would favor central stations over isolated plants.[80] He imagined that citizens would be fed up with the unnecessary wear and tear on streets and traffic congestion related to fuel delivery and waste disposal for isolated plants. He gave credit to the notion that manufacturers did enjoy the greater control over their workplace that accompanies the isolated plant, but argued that reliability was secured by connecting to a central station, "I feel that you will agree with me that the transmission of energy by electricity over wires permanently and substantially installed, and not liable to be affected by strikes, hold-ups, wash-outs, snow-storms, floods and other natural causes to nearly the extent that the transmission of fuel is, demonstrates this last item to be fully as, if not more, reliable than the other."[81] In contrast with these concerns of the early 20th century, fuel delivery is not an issue for 21st century solar- and wind-powered installations.

As early as 1911, advocates for interconnection predicted that linked power lines would eventually "cover the country."[82] They argued "transmission lines are the highways of power. Having made power portable and universally applicable by reducing it to the electric form, it is inconceivable that the highways over which it travels will not be vastly more useful if interconnected."[83] Critics argued, however, that line losses over long distances would cancel the benefits of greater interconnection.[84] In 1912, Samuel Insull, president of Commonwealth Edison Company in Chicago, argued for consolidation of all potential electric loads in Chicago into a single network. He estimated that the maximum load for isolated plants was 50% greater than Commonwealth Edison's networked load and

---

[78] R.S. Hale, "The Supply of Electrical Power for Industrial Establishments from Central Stations," *Proceedings of the American Institute of Electrical Engineers* 29, no. 2 (1910): 219-27.
[79] Charles T. Main, "Central Stations versus Isolated Plants for Textile Mills," *Transactions of the American Institute of Electrical Engineers* 29, no. 1 (1910): 115-27.
[80] J.C. Parker, "Discussion on 'The Applicability of Electrical Power to Industrial Establishments,' 'Central Stations vs. Isolated Plants for Textile Mills,' 'The Supply of Electrical Power for Industrial Establishments from Central Stations,' 'Illumination for Industrial Plants,' and 'The Requirements for an Induction Motor from the User's Point of View,'" *Proceedings of the American Institute of Electrical Engineers* 29, no. 1 (1910): 156.
[81] Ibid., 158.
[82] Robert A. Philip, "Economic Limitations to Aggregation of Power Systems," *Transactions of the American Institute of Electrical Engineers* 30, no. 1 (1911): 597-630; "Steinmetz on the Future of the Electrical Industry," *Electrical World* 60, no. 18 (1912): 911-2.
[83] Philip, "Economic Limitations to Aggregation of Power Systems," 601.
[84] Charles L. Warner, "Limits of Greater Electrical Networks," Letter to the Editor, *Electrical World* 58, no. 1 (1911): 53-4.

claimed, "We are trying there to do all we can to get the isolated plants out of existence."[85] Numerous experts shared competing responses to Insull's claims. John Lieb, vice president of New York Edison Company, predicted technical challenges in combining service to users with different frequency needs and different voltages.[86] Jackson of MIT applauded the broad approach taken by Insull, while others claimed it would bring a new era in which diversified electrical systems combined into a universal system serving entire communities. Stillwell, however, forecast practical limits to consolidation of multiple systems. Several proposed that Insull's scheme worked only if central stations charged lower rates. One engineer imagined a newly rebuilt New York in which there would be no isolated plants because all would use integrated service.[87]

Despite the efforts of Insull and his colleagues, neither approach prevailed for industrial consumers. As Percival Moses lamented, operating engineers "regard central stations as an enemy ready to shut down their plants, regardless of whether the rate obtained will pay a profit or not."[88] He further noted that with inconsistent records from apartment buildings, hotels, and department stores and only slightly better records from larger manufacturing facilities, it was impossible to report on the cost of fuel, water use, load factors, or burner efficiency of isolated plants in general. He offered tables of comparative costs for individual building managers to consider, but he failed to recommend one approach over the other.[89] Publication of this report in the AIEE *Proceedings*, its flagship journal, suggests that many power users were ambivalent about which way to proceed and were looking for hard data to help in decision-making.

<u>World War I</u>

The advent of World War I brought definitive change to manufacturers and their choice of power source. As Figure 9 illustrates, between 1909 and 1915 the amount of electric power used by manufacturers grew at the same pace for both in-house plants and for central station service, then rented power took a sharp upturn after 1915. Even before the United States engaged directly in the war, demand for American defense manufactures rose; and during the 18 months of US participation, defense production accelerated, demand for coal and other natural resources climbed as did demand for electrical power, and the industry workforce shrank as men joined the war effort.[90] Manufacturers with in-house plants found it difficult to meet wartime demands for increased production, while central station service offered quicker access to needed power.

---

[85] Samuel Insull, "The Relation of Central Station Generation to Railway Electrification," *Proceedings of the American Institute of Electrical Engineers* 31, no. 7 (1912): 1484; "Consolidation of Energy Supply Systems," Editorial, *Electrical World* 59, no. 15 (1912): 784.
[86] Power users had not yet converged on 60 Hz frequency in the United States.
[87] "Concentrated Electrical Energy Production," *Electrical World* 59, no. 15 (1912): 789-90.
[88] Percival Moses, "Some Notes on Isolated Plants," *Proceedings of the American Institute of Electrical Engineers* 31, no. 1 (1912): 67-98.
[89] "The Geneva Electrical Congress," *Electrical World* 28, no. 9 (1896): 242.
[90] Col. Charles Keller, *The Power Situation During the War*, Document No. 1039 (Washington, D.C.: Government Printing Office, by Authority of the Secretary of War, 1921).

In October 1917, the editor of *Electrical World* projected that "After this conflict the principle of supply from a central source will be established more firmly than ever, for the war has proved that efficiency of production is more important than accumulated wealth."[91] Of great concern was the pending shortage of coal. While coal production had increased, it was insufficient to meet demand, and "the transportation facilities of the country have already broken down." In the few years between 1912 and 1917, coal-fired generating technology had improved so much that a larger, more modern plant used one pound less coal per kilowatt-hour than the older plants. The editor theorized that by replacing old plants with new, the central station industry could save 15,000,000 tons of coal and become "a potential conserver of fuel and a benefactor of mankind." He noted that the war had brought about a turning point and "establishments operating from isolated plants have been forced by the exigencies of war to turn to the central stations for added power, or by reason of inability to obtain coal or because of its high cost have been content to let the local lighting company carry their entire load."[92] He predicted that most would never return to isolated plants.

The importance of access to power continued. *Electrical World* reported, "The overnight establishment of war industries has also revealed very clearly the fallacy of the isolated-plant principle. Many manufacturers using central station service found it was a simple matter to expand their facilities to take care of war business. On the other hand, many of those who were burdened with their own generating plants found that they had not the extra capacity for the new business, nor for that matter could they have secured additional labor and fuel without a great deal of difficulty. So they turned to the central station."[93] In proposing a comprehensive system of interconnected mine-mouth steam plants and hydro-electric plants, engineer R.J. McLelland defined the inadequacies of isolated plants.[94] For each factory to expand its in-house plant, it would require fuel, transportation, and manpower of "unthinkable wastefulness, and in fact … physical impossibility."[95] They would require four times as much coal as central stations, a resource in high demand, and for which transportation facilities were limited. In addition, isolated plants failed to take advantage of diversity of load, which even on only two interconnected systems could result in greater efficiencies and greater power generation. By contrast, interconnection allowed for prompt increase of generating capacity, fuel economy, and a framework for a future comprehensive power supply. Finally, McLelland argued in favor of mine-mouth plants because "it is cheaper to transmit power over wires than to haul over railroads the amount of coal required" to produce equivalent local power.[96]

Post-war reports documented the definitive switch from isolated power production to central station connection. In 1921, Col. Charles Keller of the Corps of Engineers reported in detail to the president in "The Power Situation During the War," highlighting the

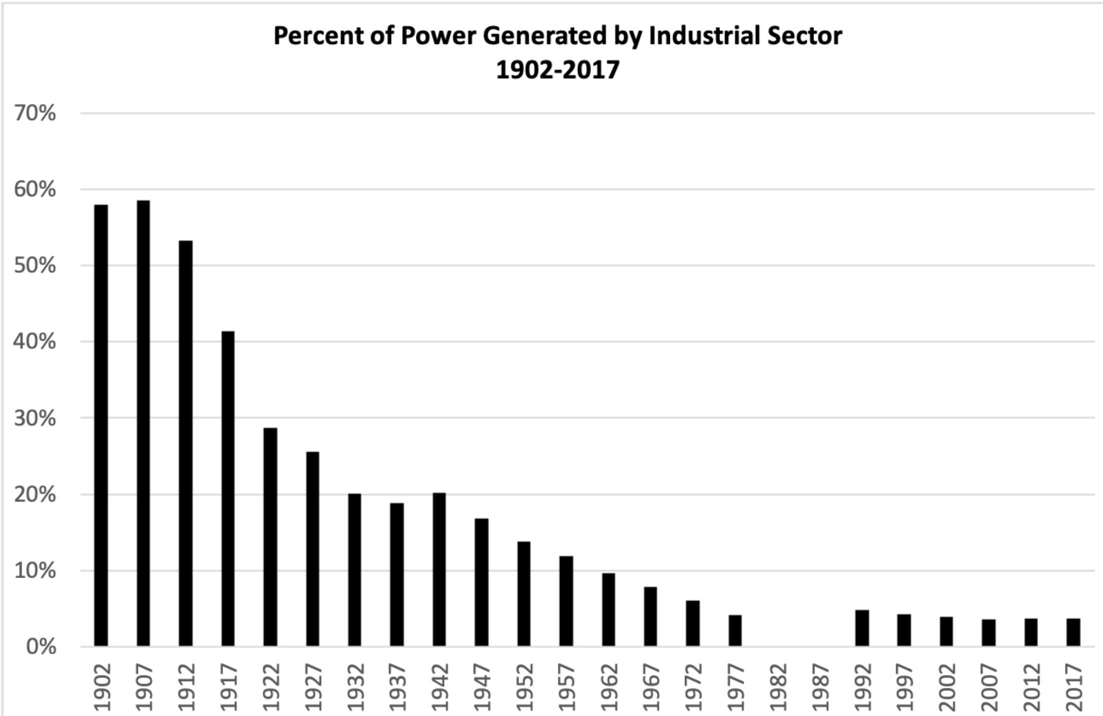
---

[91] William H. Onken, Jr., "The Central Station Industry in War Time," *Electrical World* 70, no. 17 (1917): 806.
[92] Onken, " The Central Station Industry in War Time," 807.
[93] "Present War Production Made Possible by Utilities," *Electrical World* 72, no. 12 (1918): 544.
[94] R. J. McClelland, "Electric Power Supply for War Industries," *Electrical World* 72, no. 3 (1918): 101.
[95] Ibid., 101.
[96] Ibid., 104.

economies achievable through the deployment of larger central stations.[97] But Keller lamented that current laws did not offer sufficient incentives for investors to build the new large-scale infrastructure needed. At the same time, technical innovation, particularly in the area of long-distance transmission, contributed critically to the growth of power use for manufacturing.[98] Following World War I, numerous engineers, professors, and politicians proposed schemes to integrate hydroelectric plants, new large mine-mouth coal-fired plants, and urban systems in order to reduce reliance on coal, reduce the cost to customers, and increase access to electricity across the country.[99] While subsequent growth of interconnected systems during the 1920s took place primarily through the investments and choices of individual utility companies, the concept of large-scale linked systems had taken firm hold in the United States. Further, as shown in Figure 10, industrial manufacturers' contribution to power produced dropped off significantly after World War I.

[97] Keller, *The Power Situation During the War*.
[98] Ibid., 105-6. Keller's report noted that advances in steam turbine and electric generator technologies as well as the ability to transmit power for longer distances made access to electric power more attractive to industry over the preceding years. In 1902, experts predicted an outside limit of a 60,000-volt transmission line, yet by 1914 *Electrical World* reported nearly 4,000 miles of transmission lines at or above 70,000 volts around the world. In addition, in 1906, the longest high-voltage transmission line stretched 160 miles; by 1914 transmission lines reached distances of 281 miles. "Limits of Power Transmission," Digest of Current Electrical Literature, *Electrical World* 40, no. 16 (1902): 631; "The Niagara-Syracuse Transmission," Editorial, *Electrical World* 47, no. 15 (1906): 768-9; "The 110,000-volt Transmission System of the Province of Ontraio," *Electrical World* 59, no. 1 (1912): 33-8; "The World's Largest Transmission Line," Editorial, *Electrical World* 63, no. 2 (1914): 71; Selby Haar, "High-Voltage Transmission Systems of the World," *Electrical World* 63, no. 17 (1914): 925-6.
[99] Cohn, *The Grid*, 41-50.

Figure 10. Industrial Power Production as a Percent of Total Power Production in Five-year Increments, 1902-2017.



Sources: US Historical Statistics from Colonial Times to 1970, Series S 44-52. Net Production of Electric Energy by Class of Ownership: 1902 to 1970, p. 821; Statistical Abstract of the United States: 1973, Section 19: Power, Table No. 833, Electric Energy Production and Installed Generating Capacity, By Class of Ownership and Type of Prime Mover: 1950-1972, p. 509; Statistical Abstract of the United States: 1980: Section 20, Energy. Table No. 1043. Electric Energy Production and Installed Generating Capacity, by Type of Prime Mover and Consumption of Fuels: 1960 to 1979, p. 611; Electricity Data Browser, EIA.gov website, Net Generation all fuels (utility scale), all sectors, annual. No data available for industrial power production 1980-1990.

This early 20th century case study illustrates the variety of concerns considered by industrial manufacturers when planning for access to electric power. While cost was certainly a driving issue, it was not uncomplicated. Indeed, early on the difference in unit costs between isolated plants and central stations was debatable. Merely accounting for the cost of acquisition, installation, and operation, a plant owner might initially favor a small in-house generating facility. In addition, the isolated plant owner benefited from control of the facility, sole responsibility for its reliability, the opportunity to generate and use heat as well as power, and the ability to be fashionable. But he or she might also fail to acknowledge the ongoing costs associated with coal purchases—for example, labor strikes and transportation shut-downs; with operations—for example, equipment failures and regular maintenance requirements; and with in-house know-how. At the same time, the owner weighed these costs and benefits against the challenges of rented power—including high prices that hid the full range of services provided by the utility and line losses if a factory operated some distance from a power plant.

By the 1910s, numerous aspects of power generation changed the equation. Technical innovation was a critical factor. Central stations brought down the unit cost through installation of larger and more efficient generating plants as well as longer-distance and higher capacity transmission lines. Through economies of scale, the average price of electricity charged by utilities dropped from about 4.5 cents per kWh in 1902 to less than 1 cent per kWh by 1917.[100] More importantly, however, wartime production demands created an imperative for manufacturers to expand their output as quickly as possible. Those with in-house power plants simply could not increase their power supply as quickly as those with access to central station service. Shortages of coal supply compounded the problem. Most importantly, the shift away from isolated plants to integrated systems took place without a directive from a central agent. During World War I, federal officials did attempt to direct electricity generation and delivery to sites of war production, but in general, manufacturers made individual decisions that in the aggregate solidified the path of integration for the next decades. It was not until the 1930s that the federal government became much more involved in electrification projects through new laws, presidential priorities, and agency projects.

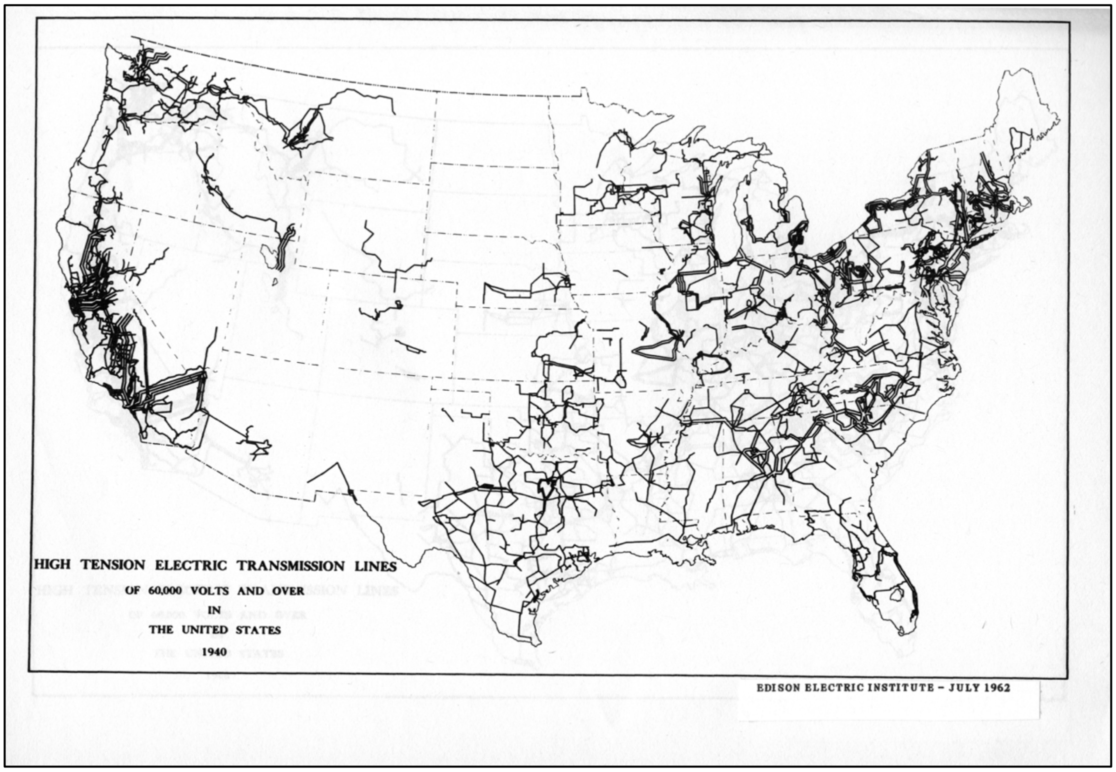
Case 2. Defense Considerations, 1935-1945

As much as the demands of World War I influenced choices made by manufacturers in the late 1910s, the challenges of World War II influenced decisions made by power system operators in the early 1940s. The energy shortages experienced during World War I weighed heavily on utilities and government officials during the interwar years. Americans did not suffer the severe privations experienced in England and other European countries, but coal shortages and related power shortages in the United States cast a long shadow. Throughout the 1930s, concerns about how to ensure sufficient electricity in the event of war cropped up in government reports as well as utility sector publications. By these years, utilities had expanded their interconnected systems significantly, and the skeleton of today's power grids was clearly visible in maps from the era, as shown in Figure 11. In addition, the federal government had stepped into the business of building and operating power system infrastructure through federal dam programs, regional transmission development, public works projects, rural electrification loans, and other financing and rule-making techniques. There was still debate, however, about how best to meet wartime needs. As tensions increased in Europe, federal agencies in the United States considered the efficacy of increasingly large interconnected systems. On the one hand, new power generation installed close to likely centers of defense manufacturing appeared to make a great deal of sense. On the other, power networks were considered a strong defense against enemy attack. In the end, time, technical innovation, geography, and access to resources framed the decisions made by government authorities and investor-owned utilities.[101]

---

[100] "History of Electricity," Institute for Energy Research website, https://www.instituteforenergyresearch.org/history-electricity/, accessed July 11, 2019.
[101] Cohn, *The Grid*, 99-120; Julie Cohn, Matthew Evenden, and Marc Landry, "Waterpowers: The Second World War and the Mobilization of Hydro-Electricity in Canada, the United States, and Germany," *Journal of Global History* 15, no. 1 (forthcoming, 2020).

Figure 11. Transmission Lines and Links, 1940



Source: Edison Electric Institute, Report on the Status of Interconnected Power Systems, 1962.

<u>The 1935 Power Survey</u>

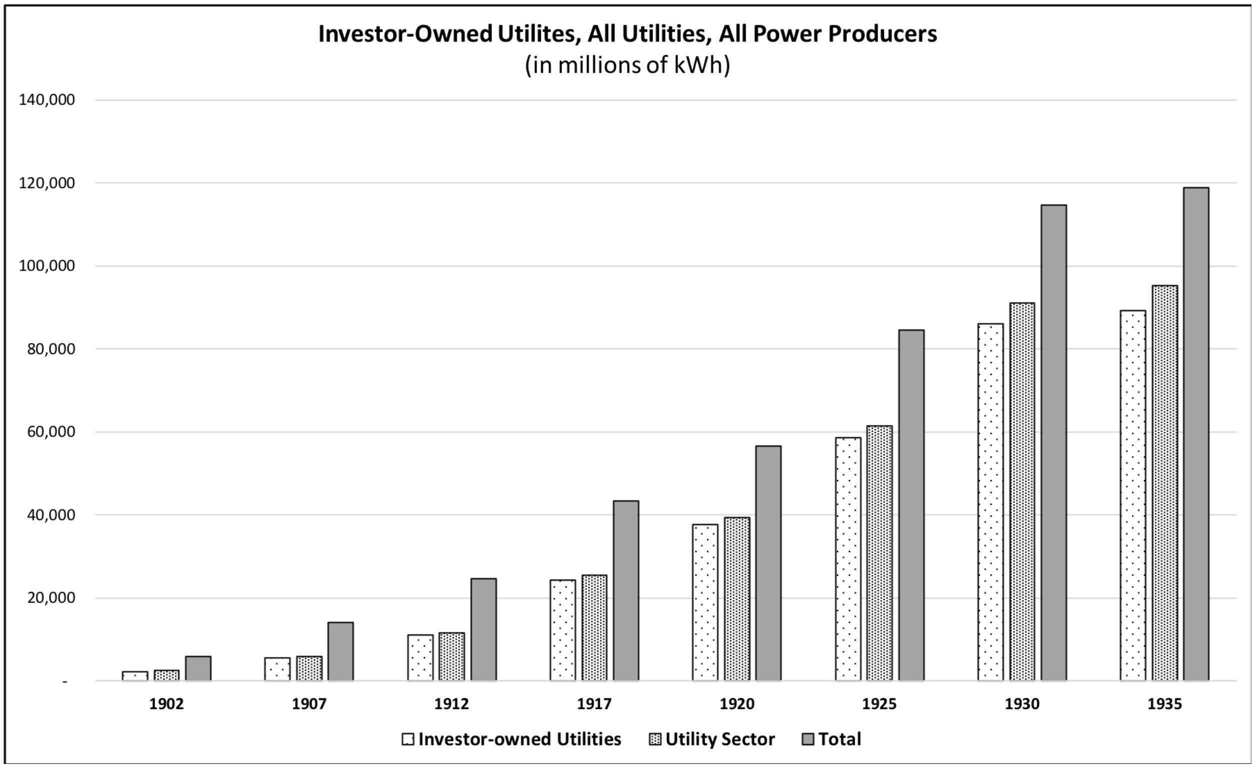
Between 1900 and 1935, investor-owned utilities controlled an increasingly large segment of the power industry. As Figure 12 illustrates, investor-owned utilities produced more than 90% of power generated by all utilities during these years, and an increasing share of all power produced. A variety of government initiatives threatened to rein in the private sector. These ranged from adoption of the Federal Water Power Act in 1920, to Gifford Pinchot's proposed Giant Power Plan in Pennsylvania in the early 1920s, to congressionally ordered Federal Trade Commission investigations of holding companies in the late 1920s.[102] In addition, by 1920, a majority of state legislatures had established utility commissions to regulate power company rates and areas of service—although the utilities generally welcomed the official monopoly status gained as a result.[103] By the early 1930s, a small number of holding companies dominated the industry.

---

[102] Federal Water Power Act of 1920, 16 U.S.C. § 791 (1920); Jean Christie, "Giant Power: A Progressive Proposal of the Nineteen-Twenties," *The Pennsylvania Magazine of History and Biography* 96, no. 4 (1972): 480-507; Thomas Parke Hughes, "Technology and Public Policy: The Failure of Giant Power," *Proceedings of the IEEE* 64, no. 9 (1976): 1361-71; *Control of Power Companies* (Washington, D.C.: Government Printing Office, 1927).

[103] For information about individual state regulatory commissions, see "Regulatory Commissions," National Association of Regulatory Utility Commissioners website, https://www.naruc.org/about-naruc/regulatory-commissions/.

Figure 12. Comparison of Power Production by Sectors



Source: Historical Statistics of the United States, 1789 to 1945. Series G 183-190. Power–Electric Energy, Production by Class of Ownership: 1902-1945, p. 156.

Note: From 1900 to 1920, the Census Bureau collected data on power generation every five years beginning in 1902. From 1920 going forward, the bureau collected data every year.

President Franklin Roosevelt took a strong stand for public intervention in an industry historically dominated by private sector interests.[104] His administrative and legislative programs included establishment of the Tennessee Valley Authority, passage of the Public Utility Holding Company Act, creation of the Securities Exchange Commission, expansion of the authority of the Federal Power Commission (FPC), and huge investments in dams and transmission lines. Roosevelt called for a national power survey, the first of its kind, in 1933. The FPC completed an interim report in 1935, and this laid out explicitly the importance of war concerns to the country.[105] In the introduction, the report stated, "Such a survey of the Nation's power resources and power requirements is an essential factor of national defense."[106] The authors noted that "the critical shortage of existing generating capacity most seriously affects the great industrial districts of the East and Middle West. It would, therefore,

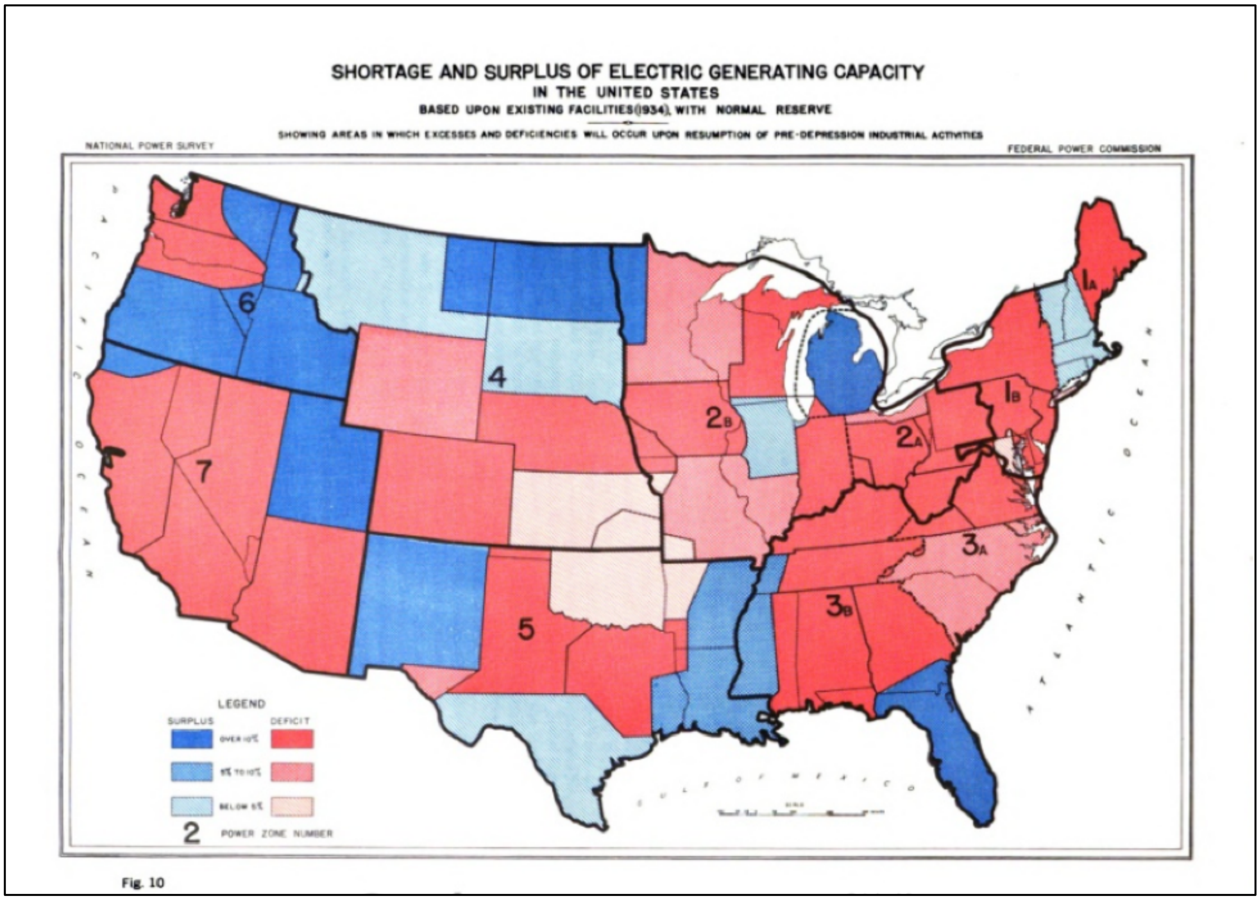
[104] Philip J. Funigiello, *Toward a National Power Policy: The New Deal and the Electric Utility Industry, 1933-1941* (Pittsburgh: University of Pittsburgh Press, 1973); Thomas K. McCraw, *TVA and the Power Fight, 1933-1939* (Philadelphia: Lippincott, 1971).
[105] *National Power Survey, Interim Report, Power Series No. 1* (Washington, D.C.: Government Printing Office, 1935).
[106] Ibid, p. ix.

be disastrous in case the United States should become involved in war."[107] The FPC advocated for careful planning under federal supervision and described the interim report as "a chart for the future development of the electrical resources of the United States."[108]

The interim report spoke to an expected return to pre-Depression-era economic activity. One map illustrated regions that were projected to have excess generating capacity and those with excess demand (reproduced in Figure 13). The FPC addressed new transmission links and interconnections to alleviate those imbalances, noting, "the installation of a considerable part of the new capacity required could be avoided by the interconnection and coordination of existing facilities."[109] To prepare for another war emergency, the FPC strongly recommended construction of large generating stations in regions likely to house major defense industry activity, development of interconnections between defense industry districts, and immediate planning for new large hydroelectric dams. With regard to interconnection, the FPC underscored its potential value during an emergency to facilitate transfers of power from one region to another as needed and called for detailed technical studies like the one it was then undertaking. The FPC lamented the haphazard approach to interconnection to date, noting that it had been inhibited by "intercompany rivalry and prejudices and by artificial barriers, such as State lines, prohibitory laws and a lack of uniformity in tax laws in adjoining communities."[110] While exhibiting consideration for the role of investor-owned utilities, the commission seemed to be advancing the notion that central planning would be advantageous for the nation's economic security and future defense during wartime.

[107] Ibid, p. x.
[108] Ibid, p. xi.
[109] Ibid, p. 30.
[110] Ibid., p. 54.

Figure 13. Shortage and Surplus of Electric Generating Capacity in United States, 1935.



Source: National Power Survey, Series no. 1 (appears between pp. 28 and 29).

Importantly, the FPC specifically noted that it had participated in the Northeast Super-Power Committee survey and report completed in 1924. This project recommended where to locate large power plants and related transmission lines and interconnections.[111] Though federal agencies never implemented the recommendations, the FPC averred that the industry had largely followed the report on its own. As a result, “There appears to be little question that large savings were effected which were not passed on to consumers because no adequate method of governmental control had been provided.”[112] The fate of the Super-Power plan indicates both the limited direct influence exercised by the federal government on actual electrification projects and the ability of the investor-owned utilities to independently develop and profit from critical power system infrastructure.

[111] W. S. Murray et al., *A Superpower System for the Region Between Boston and Washington*, ed. United States Geological Survey Department of the Interior (Washington, D.C.: Government Printing Office, 1921); W. S. Murray, "The Superpower System as an Answer to a National Power Policy," *General Electric Review* 25, no. 2 (February 1922): 72-6; "Northeast Calls for Power," *Wall Street Journal*, July 29, 1924.
[112] *National Power Survey, Interim Report,* p. 55.

War Preparations

By 1938, numerous entities produced reports and statements regarding the country's war-readiness, with particular concern for electric power resources.[113] The National Association of Railroad and Utility Commissions issued a warning in 1938 that the country would need more installed generating capacity in advance of a war.[114] President Roosevelt established the National Defense Power Committee in 1938, concerned "1) with the creation of an adequate reserve of generating capacity in the chief war-materiel centers and (2) with the construction of a system of interconnections linking power sources and load centers in order to make the country less vulnerable to attack in time of war, less vulnerable to the emergencies of peace, and better prepared for the continuing problems of peacetime development of the country."[115] The War Department advocated for reduced reliance on large networks and increased investment in new generating facilities co-located with defense manufacturing.[116] The FPC, on the other hand, promoted increased interconnections. As the interim National Power Survey had found in 1935, planning and construction of new steam-powered plants took at least two years, while large hydroelectric dams took seven.[117] This calculation favored completion of new installed capacity well in advance of wartime conditions, but the country did not have the opportunity to leisurely plan for and build these facilities.

While federal and state agencies advanced war planning programs, the investor-owned utilities offered their own assessments. In 1940 and 1941, utilities claimed that there was an undisclosed reservoir of electric power potentially available for wartime production activity.[118] The utilities seemed to be reassuring the public that they were already prepared for potential emergency power demands without the intervention of government agencies. They did not want direction from the central government, nor did they want help. They did, however, collaborate with the FPC on mapping out power supply areas for defense work.[119] Despite the earlier claims, however, by 1942 utilities projected a need for 10 million kilowatts of new installed generating capacity.[120] This suggested that as the reality of

---

[113] Cohn, *The Grid*, 105-09; Cohn, Evenden, and Landry, "Waterpowers"; Philip Funigiello, "Kilowatts for Defense: The New Deal and the Coming of the Second World War," *The Journal of American History* 56, no. 3 (1969): 604-20; Funigiello, *Toward a National Power Policy*; McCraw, *TVA and the Power Fight*.

[114] "Report of the Committee on Generation and Distribution of Electric Power," *Proceedings of the Fiftieth Annual Convention of the National Association of Railroad and Utilities Commissioners,* New Orleans, Louisiana, November 15-18, 1938, Roosevelt Hotel. (1938): 642-58.

[115] *Energy Resources and National Policy,* report of the Energy Resources Committee to the National Resources Committee (Washington, D.C.: Government Printing Office, 1939), 29; Decisions of the Comptroller General of the United States (Washington, D.C.: US Government Printing Office, 1939).

[116] Funigiello, *Toward a National Power Policy*.

[117] *Energy Resources and National Policy*, 427.

[118] "Sees Utilities Set for Defense Task," *New York Times*, August 10, 1940; "Power for Arms is Called Ample," *New York Times*, August 30, 1941; M. W. Smith, "War Emergency Power from Present Systems," *Electrical World* 112, no. 3 (1939): 45-94; Thomas P. Swift, "Utilities Geared to Aid Defense," *New York Times*, June 5, 1940; Thomas P. Swift, "Utilities Pledge Aid For Defense," *New York Times*, June 6, 1940; Thomas P. Swift, "Defense is Theme of Utility Session," *New York Times*, June 2, 1940; H. S. Bennion, "Electric Power in American Industry," *Military Engineer* 32, no. 186 (1940): 393-6.

[119] *Twentieth Annual Report of the Federal Power Commission*, 1, vol. 21 (Washington, D.C.: Government Printing Office, 1941).

[120] L. Elliott, "Meeting Power Demand During War," *Mechanical Engineering* 64, no. 12 (1942): 873.

wartime production arrived, the investor-owned utilities were more willing to realistically assess their capabilities and shortcomings.

Even before the United States directly joined hostilities, defense production in certain regions demanded more power than was readily available. In the spring of 1941, six months before the Japanese bombed Pearl Harbor, the FPC implored citizens in drought-stricken southeastern states to curtail their use of electricity in favor of regional defense industries.[121] The FPC also issued seven orders for investor-owned utilities in the region to interconnect.[122] Leland Olds, chairman of the FPC, met with utility executives in several areas to assess the power situation. [123] Shortly thereafter, a special unit of the Office of Production Management announced plans to create giant power pools in the Southeastern states and in the New York-New England areas.[124] The agency called for use of the industry's reserve capacity to its maximum capacity to supply defense manufacturing. The TVA deployed engineers to assist with the development of the power pools.

<u>Wartime Electrification</u>

After the United States formally entered the war in December 1941, President Roosevelt increased government coordination of power activities. Several policies specifically favored increased integration of power networks. In August 1942, the War Production Board (WPB) limited construction of new installed generating capacity. While the industry had previously projected a need for 10,000,000 new kilowatts, the order limited the increase to 5,500,000 kW. As the WPB explained, "The necessity for diverting critical materials and equipment to the direct war program makes it impossible to carry out a utility expansion program that would preserve the standards of reliability of service observed in peacetime."[125] The FPC established a new rule that allowed investor-owned utilities to join interstate power pools without falling under federal regulation, provided they disconnected within 90 days of the end of the war.[126] This was important to utilities in Texas. Numerous large Texas companies had carefully avoided interstate power

---

[121] "Why Power Curtailment is Necessary," *The Tuscaloosa News*, November 5, 1941; "Black-Outs Must Continue so Factories Can Run Full-time," *The Tuscaloosa News*, November 26, 1941; "Southeast Power Put Under Curbs," *New York Times*, June 29, 1941; "Rationing of Power Faces Southeast Due to Wide, Long Extended Drought," *Christian Science Monitor*, May 27, 1941; "Southeast to Pool Power for Defense," *New York Times*, May 26, 1941; "Power Rationing Plan Ready for Southeast," *Wall Street Journal*, June 7, 1941; Raymond Daniell, "Drought Dims Lights in Dixie to Save Power," *Washington Post*, June 15, 1941.

[122] *Opinions and Decisions of the Federal Power Commission, With Appendix of Selected Orders in the Nature of Opinions*, ed. Federal Power Commission, vol. 2 (Washington, DC: Government Printing Office, 1943), 990-9.

[123] "Parleys to Weigh Power Emergency," *New York Times*, June 2, 1941.

[124] W.H. Lawrence, "Power Unit Set Up to Spur Defense," *New York Times*, July 22, 1941.

[125] "Third General and Executive Session," *Electrical World* 73, no. 21 (1919): 15.

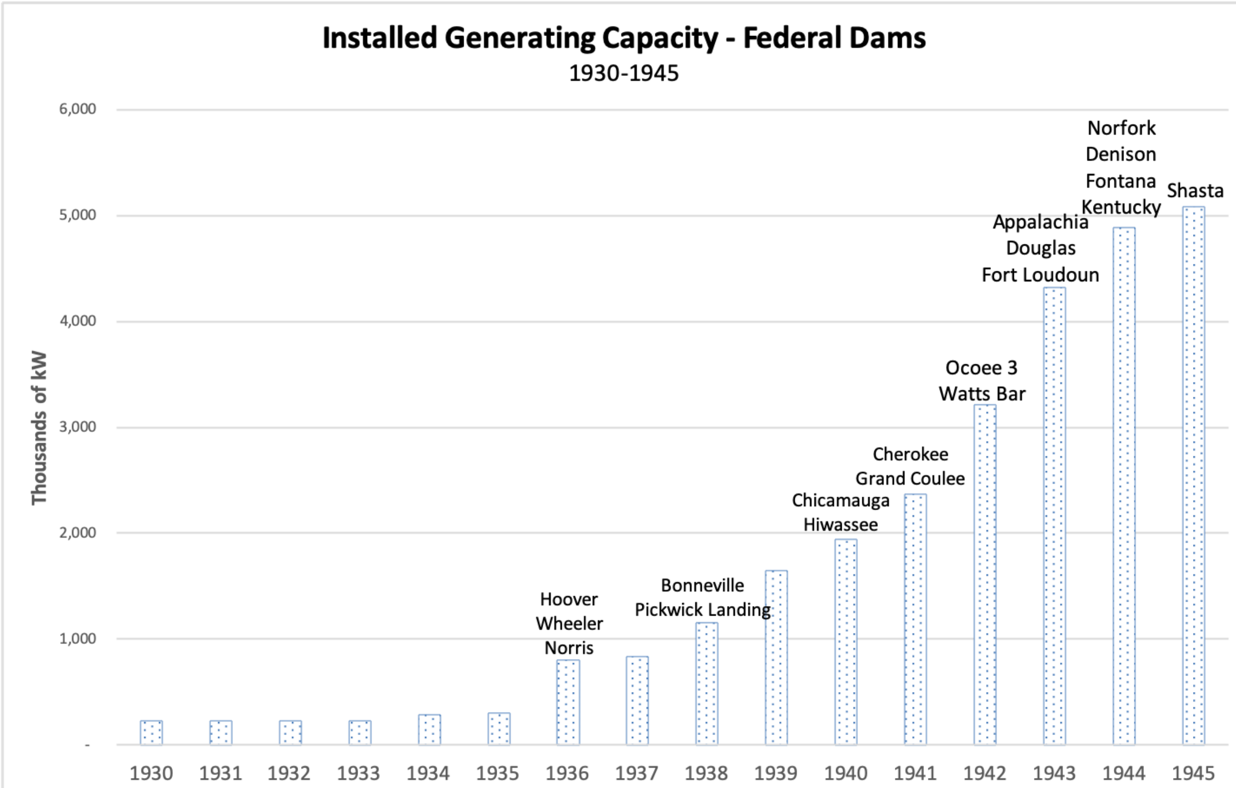
[126] "F.P.C. Waives Policy on Power Connections," *New York Times*, October 17, 1942; *Opinions and Decisions of the Federal Power Commission*, 990–8, 1021–6, 1059–60, 1095–6; *Opinions and Decisions of the Federal Power Commission, with Appendix of Selected Orders in the Nature of Opinions, vol. 3* (Washington, D.C.: Government Printing Office, 1944), 668–9, 678–9, 712–6, 750–1, 765–6, 777–80, 795–9, 834–6, 846–51, 859–62, 869–73, 889–91, 912–6, 920–2, 930–2, 934–5, 1072–7; *Opinions and Decisions of the Federal Power Commission, with Appendix of Selected Orders in the Nature of Opinions, vol. 4* (Washington, D.C.: Government Printing Office, 1946), 406–8, 420–5, 431–4, 438–44, 506–8, 515–7, 528–33, 615–8, 713–5.

connections in order to dodge federal regulation. But aluminum factories in Arkansas needed Texas power. All told, the FPC ordered 45 emergency interconnections during the war. Notably, in all but seven cases, the utilities that participated in FPC-ordered connections withdrew by 1947.[127]

Federal investment in hydroelectric dams directly and indirectly influenced the expansion of interconnected systems. By the early 1940s, a number of federal dam projects initiated in the prior decade reached completion. Figure 14 below illustrates the installed capacity of hydroelectric dams before and during World War II. In general, the financial efficacy of large federal hydroelectric dams, typically located far from urban and industrial areas, depended upon access to centers of intense power use—and this required long-distance transmission, interconnection, and coordination with other power producers. Congress vested authority in both the Tennessee Valley Authority and the Bonneville Power Administration to transmit power from federal dams to distant customers. As a matter of wartime policy, both agencies placed a high priority on directing power to war industries, including the top secret Manhattan Project. In the Pacific Northwest the federal government called for the establishment of a power pool that connected the new Bonneville and Grand Coulee dams to existing networks in Washington, Oregon, Idaho, Montana, and Utah.[128] Through financial investment, stated policy, and secret defense planning, Roosevelt's administration engaged investor-owned, municipal, and cooperative utilities in large pools that proved effective for increasing efficiency for all participants and for ensuring sufficient power for war industries.

[127] Horace M. Gray, "The Integration of the Electric Power Industry," *The American Economic Review* 41, no. 2 (1951): 538-49.
[128] W. C. Heston, "Kilowatt-hours Pooled for War," *Electrical West* 92, no. 3 (1944): 51-63.

Figure 14. Installed Generating Capacity of Federal Dams, 1930-1945



Sources: Historical Statistics of the United States, Colonial Times to 1970, Series S 74–85, 824; Bureau of Reclamation website (https://www.usbr.gov/); Tennessee Valley Authority website (https://www.tva.gov/); US Army Corps of Engineers website (http://www.usace.army.mil/).

Note: Names of major federal dam projects above year in which completed.

The limitations on resources, the federal interventions both requiring and favoring interconnections, the latent capacity in existing power facilities, the completion of several federal dams, and the speedier process of building transmission lines versus new power plants framed an environment in which utilities opted for more and better integration to meet defense industry demands. By the end of the war, utility executives and government administrators alike reported on the tremendous increase in power production achieved with a minimal investment in new generating facilities.[129] Total installed generating capacity increased by only 25% between 1940 and 1945, while total power production increased by 60%.[130] This was due to the expansion of integrated systems, operation of power plants at their full capacity, drastic reduction of reserve power margins, and

[129] "1944 Electricity Production Measured Country's War Effort," *Edison Electric Institute—Bulletin* 13, no. 5 (1945): 125-32; *Electric Power Requirements and Supply in the United States, 1940-1945: War Impact on Electric Utility Industry* (Washington, D.C.: Federal Power Commission, 1945); E. Falck, "Power Pooling During War," *Power Plant Engineering* 49, no. 10 (1945): 84-6; J.M. Gaylord, "Integration of Power Systems," *Engineering and Science Monthly* 8, no. 6 (1945): 3-13.
[130] *Historical Statistics of the United States*, Series S 74-85, 821; "Electric Power Requirements and Supply in the United States, 1940– 1945," 2.

improved techniques for power control in interconnected systems.[131] The result offers strong support for greater integration of regional grids. Will future moves toward disaggregation result in the loss of significant economic benefit?

In this case study, investor-owned utilities responded to wartime pressures quickly and cooperatively. The federal government imposed a variety of requests, requirements, and enticements to shape the direction of electrification. Importantly, government agencies and the utilities managed to maintain the delicate balance between central command and the complete autonomy that had marked the American power industry from the start. From the private sector perspective, federal agencies embraced the "vital importance of power" and undertook "drastic action to bring about full co-ordination of the utility."[132] At the same time, the director of the WPB's Office of War Utilities explained that utilities arranged operations on their own to achieve federal policy directives.[133] It was the "impetus of a national emergency" that allowed a level of cooperation otherwise avoided by the industry.[134] After World War II ended, utilities variously remained in power pools, expanded them, or in several cases returned to less integrated operation, to suit their own financial and operating interests. The majority chose to continue with greater interconnection for several reasons: technologies and operating strategies had made interconnected operation more efficient and reliable, companies found they could expand markets more quickly, and investment in larger power plants called for participation in larger power networks. But specific concerns—for example, the desire to avoid federal regulation—led a significant minority to choose independent pathways.

Case 3. The Biggest Interconnection, 1960–1975

In 1967 the vast majority of public and private, large and small utilities, excluding most of those in Texas, joined a project to link power systems from coast-to-coast. The vision of a single grid serving the power needs of the nation dates back to the 1910s. Engineers spoke of the possibility of coast-to-coast interconnections in the context of technological advances that made large-scale electrification more efficacious, and in some cases, profitable. At the same time, they recognized the limits to building those links: geography, cost, operating practices, the diverse make-up of the industry, and autonomous decision-making by each power company. The idea never disappeared, however, and by the early 1950s engineers spoke of a single interconnected system as a probability rather than a possibility. In 1967, a task force composed of federal officials and utility engineers completed links between the eastern and western interconnected systems and realized the dream of the century—the world's largest machine.[135]

---

[131] Cohn, *The Grid*, 109-20.
[132] Gaylord, "Integration of Power Systems," 3.
[133] Falck, "Power Pooling During War," 84.
[134] Gaylord, "Integration of Power Systems," 3; John P. Callahan, "Office Ends Today for War Utilities," *New York Times*, September 30, 1945.
[135] Cohn, *The Grid*, 151-79; Julie Cohn, "When the Grid Was the Grid: the History of North America's Brief Coast-to-coast Interconnected Machine [Scanning Our Past]," *Proceedings of the IEEE* 107, no. 1 (2019): 232-43.

Preparations for a nationwide grid began years before a group of utilities and the US Bureau of Reclamation (USBR) formally established a project task force. Beginning in the 1930s, members of the Interconnected Systems Group (ISG), a power pool originating in western Pennsylvania, Ohio, and West Virginia, formed a "test committee" to address "the tremendous frequency control problem" they faced on their linked systems.[136] Over the ensuing decades, the small power pool grew into the single largest network on the continent. Throughout those years, members of the test committee worked together to define standards of operation that would allow the disparate power companies to share power without upsetting the stability of their respective systems. In general, but not always, the participating power companies adopted the voluntary standards, as did companies in other interconnected systems.[137] In the case of a control setting, for example, that determined how much one generating facility would help another in the event of operating trouble, different entities within ISG engaged in bitter debate for two years before converging on a standard in 1957.[138] Later the North American Power Systems Interconnection Committee (NAPSIC) adopted the standard as its own. In this regard, ISG was the trendsetter both in the United States and internationally.

In 1959 the test committee began to seriously contemplate "the possibility in future years of a coast-to-coast network."[139] Over the next several years, the test committee carefully orchestrated a series of meetings to bring other power pool engineers together for grid planning. In 1963, the resulting entity—NAPSIC—convened for the first time. NAPSIC offered a venue in which representatives from 10 operating areas or power pools could coordinate future integration; and NAPSIC standards provided the basis for the later nationwide grid.

Politicians and government agency officials also anticipated coast-to-coast interconnections.[140] In 1962, President John Kennedy called for a new national power survey to set out the broad plan for interconnecting power resources across the continent.[141] As part of his conservation message to Congress, he explicitly linked concerns for resource shortages to the advantages offered by large-scale transmission networks. The FPC produced the survey in 1964; and offered a map (reproduced in Figure 15) showing how power might move across the country by 1980. Note that hydroelectric facilities—the renewable resources of the day—offered important capabilities to offset polluting coal-fired plants. As had been the case in the 1930s, investor-owned utilities participated in development of the survey, despite protests that the private sector had already completed the necessary studies and the federal

[136] Cohn, *The Grid*, 135-6.
[137] Ibid., 133-42.
[138] Julie Cohn, "Bias in Electric Power Systems. A Technological Fine Point at the Intersection of Commodity and Service," in *Electric Worlds/Mondes Électriques: Creations, Circulations, Tensions, Transitions (19th-21th C.)*, ed. Alain Beltrain et al., History of Energy (Brussells: P.I.E. Peter Lang, S.A., 2016), 271-93.
[139] Interconnected Systems Group Test Committee Meeting, Sheraton-Jefferson Hotel—St. Louis, Missouri, February 18–19, 1960, Minutes, February 29, 1960, 2, Electrical Power Systems Records, Box 3, Folder 7 (Accession 2612) Hagley Museum & Library, Wilmington, Delaware 19807; Cohn, *The Grid*, 142-6.
[140] Cohn, *The Grid*, 146-50.
[141] Ibid., 173-4.

initiative signaled a "prelude to nationalization of all utility companies."[142] Once the FPC released the survey, however, it garnered widespread support.[143] Importantly, the FPC chair calmed the private sector by stating that the survey was not intended as a blueprint, that it did not promote new regulations, and that the federal government would not itself build the suggested transmission network.[144] Rather, the FPC offered a proposed path for reducing the cost of power to consumers across the country.

Figure 15. FPC Projection of Power Exchanges

Source: National Power Survey: A Report by the Federal Power Commission, 1964 (Washington, D.C.: Government Printing Office, 1964), Figure 115, p. 213.

[142] Peter Braestrup, "National Power Survey is Urged as Step to Cut Consumer Costs," *New York Times*, January 24, 1962; "How to Save the Taxpayers, $380,000," *Wall Street Journal,* February 6, 1962; "EEI Task Force Study Reveals 1970 Pooling Plans," *Electrical World* 158, no. 5 (1962): 30.
[143] Gene Smith, "Utilities Study National Power Survey and Relax," *New York Times*, December 20, 1964.
[144] "U.S. Survey Sets Goal For Electricity Price Cut," *The Washington Post, Times Herald,* December 13, 1964.

The National Power Survey reinforced the expectations of the NAPSIC members. A nationwide grid appeared as a likely part of the industry's future. In 1966, NAPSIC with the USBR appointed an East-West Task Force to "plan, execute, and monitor the E-W closure."[145] The term "closure" meant the establishment and operation of AC links between interconnected systems. Frank Lachicotte, USBR power systems operation officer, directed the project. The East-West closure was a true public-private partnership.

Entities within the task force looked forward to the closure for different reasons. In Nebraska, for example, several cooperatives projected power shortages and high coal costs.[146] For them, access to hydroelectric power from the west promised to alleviate these issues. Other power producers had excess capacity and were looking for new markets.[147] The journal *Electrical World* explained that the closure offered "more efficient utilization of water and hydropower, both seasonally and on day-to-day basis," supporting earlier conservation themes advocated by President Kennedy and the Federal Power Commission.[148] At the time of the closure, a USBR official told the *New York Times* that the nationwide grid would also improve reliability, and "generating plants from coast to coast will respond to power emergencies in any part of the nation."[149] This was an especially compelling argument as the United States had experienced its first major cascading power failure in November of 1965.[150] The Northeast blackout precipitated debates about whether or not increased interconnection was a wise choice for the country. Nonetheless, the task force proceeded with the project. In retrospect, participants reflected that the engineers involved wanted to prove that they could do it.[151] The naysayers mainly focused on who controlled the power, not whether or not it was a good idea. The *Chicago Tribune,* for example, speculated in late 1966 that the planned closure was a power grab of the political type on the part of Stewart Udall, secretary of the interior.[152] Although historically, municipal utilities and rural cooperatives feared the undue influence of investor-owned utilities on any federal initiative, several participated in the closure project.[153] By and large, those who knew about the planned closure tended to support it.

Despite the general enthusiasm across power companies and within the USBR for a nationwide grid, the real issue at stake was technical. Never before had such a large interconnected system operated successfully and the task force members planned for

---

[145] "Changing Patterns of Power Pooling," *Electrical World* 166, no. 20 (1966): 102.
[146] Don Schaufelberger, former president, Nebraska Public Power Company, telephone conversation with the author, September 11, 2017.
[147] James Movius, former engineer with Public Service Company of Colorado, telephone conversation with the author, August 11, 2017.
[148] "East-West Ties Hold; US Systems in Phase," *Electrical World* 167, no. 8 (1967): 50.
[149] "U.S.-Canada Power Grid Passes Test," *New York Times*, February 8, 1967.
[150] David E. Nye, *When the Lights Went Out: a History of Blackouts in America* (Cambridge, MA: MIT Press, 2010).
[151] Movius, telephone conversation with the author.
[152] "Mr. Udall's Empire Grows," *Chicago Tribune,* November 16, 1966.
[153] Gene Smith, "F.P.C. Seeks Cut in Power Costs," *New York Times*, December 13, 1964.

stability problems. The closure took place on February 7, 1967.[154] Within months, however, the inadequacy of the relays and control devices led the participants to request that Lachicotte open the ties—that is, halt interconnected operation between the east and west. He complied in early August and the task force regrouped to develop better controls. With new equipment in place Lachicotte reclosed the ties in December, and the utilities carried on with nationwide operations for another eight years. But the problems continued. In the areas closest to the ties, the companies experienced frequent instability and had to separate from the network regularly. The coast-to-coast connections brought about less reliability rather than more. At the same time, advances in DC transmission over long distances offered an attractive alternative. In 1975, the utilities permanently opened the ties. By 1987, making independent choices rather than working through a task force, different operating groups installed several DC links between the Eastern and Western Interconnections that allowed periodic exchanges of power rather than the synchronous, continuous operations afforded by AC interconnections. With the DC ties, Americans access electrical power from several loosely connected grids, rather than a single grid.

This case illustrates that technical factors are just as important as economic, political, and strategic factors in determining the path of development. Multiple trends seemed to predict a nationwide grid. By the late 1950s, the utilities and large federal power agencies had already built giant regional networks that allowed for rapid industrial, suburban, and urban expansion. The federal dam-building program reached its peak in the 1950s and 1960s, as did rural electrification.[155] The newest generating technologies, including nuclear power, favored large-scale power plants that operate most efficiently within large-scale networks. The system operators had adopted operating strategies and techniques that allowed for closer control of power on interconnected systems. And power system engineers were eager to test their abilities by completing the largest machine in the world. At a more local level, individual power producers sought to buy power from, or sell power to, those on the other side of the system divide. Together, these trends helped build a broad consensus among power experts and certain stakeholders in favor of the nationwide grid.

Other factors weighed on the decisions made by the team involved in building the east-west links. Perhaps most significantly, the Northeast blackout of 1965 suggested two issues. First, the blackout triggered doubt about the efficacy of interconnections, and this may be why the East-West Closure Task Force worked in relative obscurity. Second, the blackout reminded the task force members that success was paramount. If the closure failed, it would aid the naysayers who favored independence over integration. In addition, the task force members were acutely aware of the potential for stability problems. In the end, the technical limits of power control on interconnected AC systems undermined the dreams of

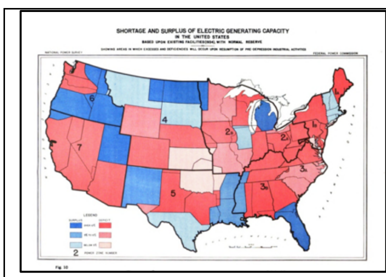
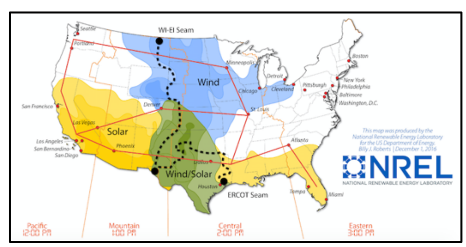
[154] Frank W. Lachicotte, "The East-West Tie Closure, Staff Information letter, February 27, 1967" (Washington, D.C.: Bureau of Reclamation, Office of Chief Engineer, 1967); "East-West Ties Hold"; "East-West Power Intertie Closure Test Scheduled February 7," *United States Department of the Interior News Release*, January 26, 1967.
[155] National Inventory of Dams online database, Army Corps of Engineers, https://nid.sec.usace.army.mil/ords/f?p=105:1::::::, accessed September 20, 2019. Between 1930 and 1960, rural electrification increased from 10% to nearly 100%.

a giant North American grid. In this case, less integration rather than more benefited power companies and customers. And unanticipated technical innovation in the form of DC connections later allowed for planned power exchanges on an as-needed basis, without an expanded grid.

Conclusion

While some might say that the old is new again, there are indeed new considerations when addressing old questions. Beginning with the "bigger is better" approach to bringing more renewables into the energy mix, let's revisit three maps, as shown in Figure 16. The first, dating to 1935, illustrates power installations versus likely centers of power use. The second, from 1965, suggests how to transmit power from areas with high hydro endowments to areas with high power needs. And the third, from 2018, offers a design for adding more utility-scale and significantly, intermittent solar and wind. All three suggest a longstanding interest in establishing a viable nationwide network in order to move power from areas of excess production to areas of increased need. These maps all indicate the misalignment between primary energy resource endowments and industrial and urban centers. They all hint at a future of greater integrated renewables in our power systems. The two older maps provide contextual lessons for the challenges of achieving the macrogrid dream. There were technical and geographic obstacles, there were high costs, there were economic and organizational challenges, and there were local interests that did not necessarily intersect with national goals. When contemplating the Design 3 Interconnections Seam Study map (reproduced in Figure 16 and originally in Figure 8), it may be helpful to remember what brought about greater integration in earlier eras. In the 1930s, it was the press of war that brought about greater integration, not the evidence of the first National Power Survey. In the 1960s, it was hubris and a sense of historical inevitability that brought forth the first nationwide grid, and both technical limitations and local objections that ended it.

Figure 16. Left to Right, Side-by-Side Comparison of Maps from Figures 13, 15, and 8

		
Source: 1935 National Power Survey Interim Report	*Source:* 1965 National Power Survey	*Source:* 2018 NREL Interconnections Seam Study

In 2018, technical innovation changes the picture. New designs for utility-scale wind and solar add new loci for renewable resources to the map. New HVDC technology offers integration different in kind from the AC interconnections of the past. In addition, Americans depend increasingly on electricity for everyday life. At the same time, a deeper understanding of the environmental problems facing the country leads many Americans to support investment in a reconfigured power system.

Questions for today's macrogrid must look beyond whether it will move us to 100% renewables, if it will work, and what it will cost. They should also address how to build consensus, who will build the new infrastructure, what will become of the older infrastructure, what rates will be charged to different customers with different reliance on the grid, and how the benefits can be immediately and adequately evident to the communities most affected by the alterations to the landscape. Further, what will provide the impetus for intergovernmental and public/private coordination? And, given the answers, is this still an efficacious path toward the renewable future?

When considering nano- and microgrids, technical innovation and preferences for local control may outweigh other considerations. For industrial manufacturers at the turn of the last century, connecting to a network may have offered economic value over installing and operating an in-house power plant, but other factors mattered. Early on, control over the facility, distrust of utilities, inconclusive cost comparisons, and the flexibility of combined heat and power generation all influenced individual choices. From today's perspective, certain challenges remain salient. The industrial manufacturer had to employ an in-house engineer to operate the power plant, or at least assign those duties to someone on the team. He or she most likely installed a storage battery to provide backup when the generator failed. Reliability was an issue, although in some cases manufacturers felt more confident of their own ability to keep a plant running than they did of the central station's capacity to ensure steady power. Strikes, bad weather, transportation problems, or preferential distribution periodically cut off coal supplies. At the same time, measurement and control technologies that became the industry standard by the mid-20th century were not available to operators of isolated plants

Today the outlook for an isolated plant operator is a bit different. The homeowner with a solar array and a battery pack must still consider how to address operations, maintenance, repair, and replacement. But he or she will not have to worry about coal delivery and its attendant challenges. As control technologies become more fine-grained and storage batteries more long-lasting and less expensive, the possibilities for deploying renewables-based, very small-scale, energy efficient, and reliable systems are growing. Scenarios range from completely off-grid operations with smart usage of appliances and smart deployment of energy storage to a grid connection for backup power. In addition, new technologies promise to link multiple isolated plants—nanogrids, that is—in much the same way that large networks function as power pools. These linked nanogrids and microgrids may or may not connect to traditional power networks in useful ways.

Questions for those considering the smallest and most local power systems include: Where do nanogrids and microgrids offer the most efficacious use of renewable resources? Who will own, install, operate, and maintain these small power systems? Will every building owner employ a power system engineer, or will the manufacturers of these systems become maintenance utilities? Should small power systems always be linked to larger interconnected systems, are they more resilient if they are not, or are there different contexts in which different configurations make sense? If they are linked to larger networks, who covers the costs of operating and maintaining those networks? Small power systems may offer resilience, but what about the proliferation of the control technologies? Can they be depended upon for consistent and reliable operation, or will the dissemination of thousands of these systems require development of yet another maintenance workforce focused solely on software? Can or should a new type of physical network of small power systems displace our current large-scale systems? Will “fashion,” distrust of utilities, and preferences for local control outweigh other considerations as individuals and small entities make their power choices? And in a future of nanogrids or microgrids, where do different government authorities fit in?

History does not offer answers; rather, it poses questions. Most Americans obtain electric power from a relatively reliable, dispatchable, nodally governed system. The decisions of stakeholders in the past brought us to a present-day configuration of giant interconnections. As we consider pathways to a renewable energy future, we can test our options against the issues that framed earlier choices. Beyond measurable economic benefits and costs, unpredictable and unmeasurable factors will also shape future power systems. If the technologies of nanogrids advance quickly, it is easy to imagine thousands of individuals in intensely sunny locales choosing small-scale networks that may not be grid-connected, despite the costs and problems this will cause existing power systems. At the moment it is hard to imagine a scenario short of imminent disaster that will muster a consensus around a completely new HVDC network replacing current AC networks at a cost of billions or trillions of dollars. There are many in-between routes that will add renewables incrementally, will require more modest restructuring of markets and regulatory regimes, and will fall short of the fully green imaginary. If history is the guide, organic and somewhat unpredictable development is the future.