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Renovating America's Electrical Grid: Renewable Sources and Resilient Delivery

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Abstract

Since the late 1800s, America’s electrical grid systems have relied primarily upon fossil fuels for sources of electricity. Due to the outdated structural foundations and glaring holes in distribution networks, the existing electrical grids struggle with electricity escaping, and modern issues such as cybersecurity, resilience, and weather-related events associated with climate change. This essay discusses ongoing problems with current electric grid systems and aims at explaining the importance of incorporating renewables as a solution for these problems into a new grid system. In the first chapter, a detailed explanation is provided regarding the current issues present in America's grid systems. The second chapter offers insight into how America built its grid systems and how this old foundation has led to many ongoing problems. The third chapter offers a perspective on the economic impact of renewable energy implementation. More specifically this chapter covers the short-term costs and long-term benefits of renewable investment as well as the amount of potential financial savings from cybersecurity issues, natural events as a result of climate change, and overall maintenance. The fourth chapter explains the socio-political impact of developing a new grid system and how communities across all incomes will participate in this system. The fifth chapter concludes with how renewable energy grid-based policy recommendations will move America toward a future of resiliency and sustainability.

Key words: cyber security, resilience, sustainability, electricity, renewable energy, grid system

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Introduction

Currently, the United States electrical grid systems are being powered overwhelmingly by fossil fuels. About 79% of all United States electricity comes from fossil fuels. In 2019, natural gas produced the largest share of electricity at 38% in the U.S. with coal coming in second at 23%, and nuclear following with 20%. Renewable sources are producing just 17% of electricity with 7.3% coming from wind and 6.6% coming from hydropower, (EPA 2019). In 2019, wind power passed hydropower as the most productive renewable source for the first time. Other sources of renewable energy, like solar, biomass, and geothermal combine for a minor share in overall electricity production from renewables. Despite their small share in national electricity production, renewable sources have been growing the most out of all other sources. Solar and wind especially have been growing rapidly. According to the United States Energy Information Administration, renewable sources are expected to contribute 24% of total electricity, (USEIA 2022). Fossil fuel electricity production is expected to continue falling steadily. In 2023, it is expected that electricity derived from coal will fall about 2-3%.

The growth of renewable technologies is reflected in employment opportunities as well as these technologies are experiencing the highest growth in the energy industry. Falling costs in renewables and simultaneous employment growth contribute to the national economy and improve efficiency within the electric grid system. Building new decentralized and localized grid systems will be significantly cheaper than building new fossil fuel power plants. The construction of these projects will be labor intensive and require thousands of workers. This will boost local economies and increase revenues. Energy burdens and utility bills will also be lowered with decentralized and localized grid systems, as transmission and distribution lines will not be required to travel long distances. The long distances between transmission and distribution lines inside the current centralized grid system is generally unreliable and lack resiliency during severe climate change weather-related events. Installing decentralized and localized grid systems will strengthen community resiliency by providing viable electricity storage systems.

These types of systems in combination with microgrids will increase resiliency against cyber-attacks as well. As electricity demands continue to rise, there will need to be systems that can handle capacities in each city and town. Relying on outdated transmission and distribution lines interconnected to a unidirectional grid system is unsustainable and will cost trillions to upgrade. Instead building new, bidirectional, grid systems with renewable electricity generation will be more economically viable. Both state and national economies will benefit greatly from the adoption of renewable-generated electricity grid systems. Investments and electricity lost between the expansive transmission lines will no longer occur. The opportunity to increase renewable industry growth will be beneficial for the U.S. in foreign markets as well. The demand for electricity and grid systems is growing across developing countries. Renewables can be more cheaply manufactured and delivered to developing countries than fossil fuels. Renewable source implementation in developing countries will contribute to energy equity and accessibility as well as progress in global decarbonization goals. The U.S. is already a leading exporter of renewable technologies and implementing policies to support national industries will boost supply-chain resiliency as the U.S. will not have to rely as heavily on Chinese renewable imports. Improving supply-chain resiliency will strengthen the American economy. Ultimately, basing America's energy model on renewable energy sources will require substantial investment from the federal government to upgrade transmission lines and establish substantive regulation of energy markets.

Chapter One: Current Issues with Electric Grid Systems

Electrical Energy and Ecosystem Services

Ecosystem goods and services create life-sustaining benefits humanity derives from nature (EPA). These benefits include but are not limited to, clean air and water, energy, fertile soil, and pollination. Ecosystem services provide for human health and well-being and maintain the American economy. Electricity is a crucial ecosystem service that is generated from renewable and non-renewable sources. Renewable sources cannot be depleted and can provide continuous clean electricity. The most popular examples of renewable energy sources are wind and solar power, geothermal technologies, biomass power, and hydropower (EPA). Non-renewable energy commodities are natural sources that cannot be naturally produced at a pace to maintain growing consumption. Fossil fuels such as oil, coal, and natural gas are all examples of limited natural sources that cannot be produced sustainably. Unlike renewable sources, the combustion of fossil fuels for electricity production emits carbon dioxide and other harmful greenhouse gases (GHGs) into the atmosphere. Nuclear energy does not emit harmful GHGs, however, the natural sources necessary to generate electricity in this process are finite, thus nuclear energy is non-renewable. Using fossil fuels for electricity generation is environmentally degradational and threatens the health of important ecosystem services. This will be covered more in-depth later in this chapter under the Generation Source Problems subsection.

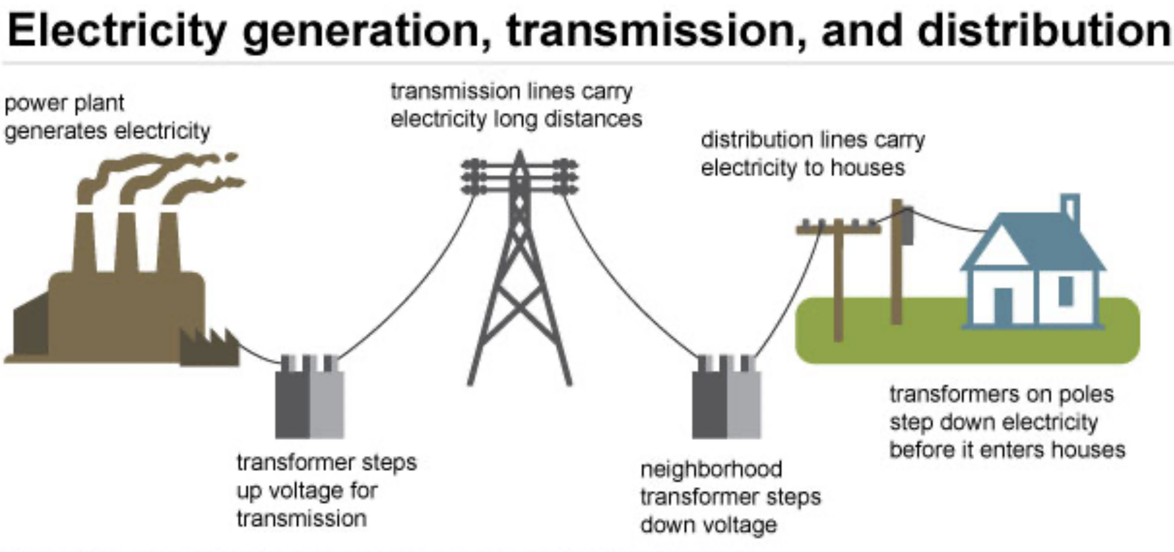
Electricity is a provisioning and cultural service for Americans. Every day, Americans use electricity for lighting, heating, cooling, refrigeration, computing systems, electronics, machinery, and public transportation. Electricity is used to power healthcare equipment in hospitals. Household devices like ovens, refrigerators, toasters, and microwaves are necessary for producing and maintaining food. Reliable wireless networks are now a necessity in American homes, especially as more people have transitioned to working from home post-pandemic. Electricity is used daily to power other devices like smartphones, smart TVs, smartwatches, and electric shaving equipment. Without electricity, public transportation cannot function. The modern economy and American lifestyle are supported by an electrical foundation. In 2021, the total U.S. electricity consumption was 3.93 trillion kWh (EIA 2021). According to the U.S. Energy Information Administration (EIA), there is projected to be about a 1% growth each year in end-use electricity consumption between now and 2050. However, this growth is not a future guarantee, as severe weather events may become more frequent due to climate change. Electricity demands will continue to increase as the physical infrastructure of the current electric grid systems ages. This raises questions about the viability of American grids and the generation sources which power them.

Description of the US Physical Electric Grid System

To understand the issues that have accumulated over time with the early electric grid systems founded by Edison and others, it will be important to establish knowledge of the grid technologies operating in the United States. Power supplies are electric devices that convert the electric current coming from power sources to the necessary voltage and currents used for powering a load. The primary function of the power supply is to provide the right voltage and current for different electronic applications. The current being supplied to these applications must be controlled with an accurate voltage to a variety of loads. This must be done simultaneously without letting changes occur in input voltages or connected devices so that output remains unaffected. Power supplies can be external, like laptops or desktop computers.

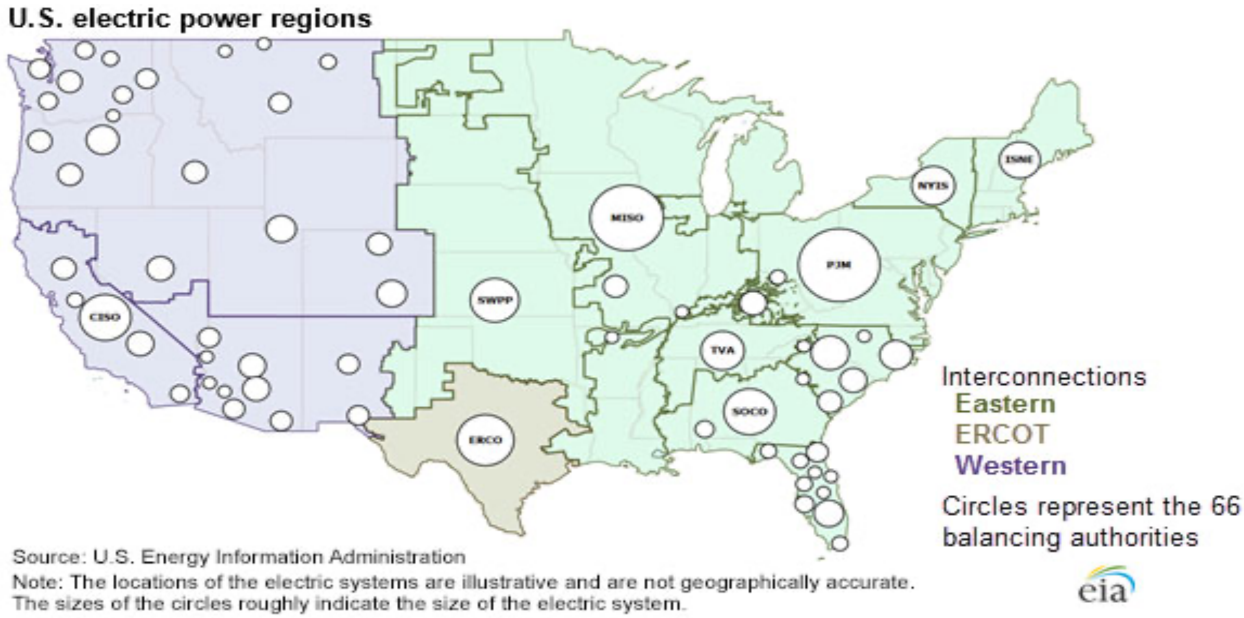
Power supplies vary in size, but all share the responsibility of taking electricity from the input source, transforming this electricity, and then deliver to this load to an output.

Electricity is generated at centralized power plants which are then moved through the electric grid, made up of electricity substations, transformers, and power lines. The U.S. electric grid is comprised of over 7,300 power plants, nearly 160,000 miles of high-voltage power lines, and millions of miles of low-voltage power lines and distribution transformers, connecting over 145,000 consumers nationally, (EIA 2016). These collective parts of the grid connect electricity producers and consumers. Most local grids are interconnected for commercial purposes and to also increase reliability (EIA 2022). These systems form larger, dependable networks, enhancing electricity coordination and supply. In the United States, the electric grid system consists of hundreds of thousands of miles of high-voltage power lines as well as millions of miles of low-voltage power lines with distribution transformers. These transformers connect thousands of power plants to the millions of electricity consumers across the country. The electric grid has expanded greatly in size since Edison's original structure, however, the current structure for the U.S. has largely stayed the same. Below is an infographic from the EIA displaying the grid system's basic functions of generation, transmission, and distribution.



Source: Adapted from National Energy Education Development Project (public domain)

Power plants generate electricity which is then delivered to customers through transmission and distribution power lines. Before electricity is transported to transmission lines, step-up transformers increase the voltage from the input to the output of the transformer (Wang 2021). Power companies rely on step-up transformers to efficiently transfer electricity over long distances. High-voltage transmission lines carry electricity over long distances across the country to meet consumers. These transmission lines are tall, metal structures that can typically be seen flanking fields or along highways. Transmission lines then transfer electricity to step-down transformers. Step-down transformers then decrease the voltage from input to output. Step-down transformers are critical for creating safe levels of AC to be used in various household products. Below is an image from the EIA of the three major interconnections of the U.S. electric grid. The following paragraph will explain the three interconnections in detail.



Vast electricity networks function through the connection of local grid systems. The 48 continental states are joined together through three major interconnections: functioning independently with limited exchanges of electricity. The Eastern Interconnection includes all states east of the Rocky Mountains and a small portion of Texas. The Western Interconnection covers all land west of the Rocky Mountains. The Electric Reliability Council of Texas (ERCOT) is responsible for the majority of Texas. The regional operation of the electric grid is managed by regional transmission organizations (RTOs). These organizations can also be referred to as balancing authorities (EIA). The ERCOT system is unique from the other two interconnections as the balancing authority, interconnection, and RTO operate under the same entity and physical system. The case of ERCOT and Texas will be analyzed in depth in the New Grids and its Challenges subsection of chapter 1. The politics of RTOs will be explained in detail in chapter 4.

Generation Source Problems

According to the EIA, only 20% of electricity came from renewable sources in 2021. The other 80% was made up of 1% petroleum, 19% nuclear, 22% coal, and 38% natural gas. Fossil fuels make up roughly 60% of electricity generation in the U.S. The EPA reports that electricity generation contributes 25% of total GHG emissions in the U.S. This is second to transportation which contributes roughly 27% of GHG emissions. America's continued reliance on fossil fuels for most of its electricity generation has serious implications for ecosystem services and naturally occurring chemical processes like the carbon and nitrogen cycles that provide for human well-being. The GHG compounds released from fossil fuel combustion are trapped in Earth's atmosphere for a long time, creating a blanket over the planet that traps heat, which increases the planet's overall temperatures and contributes to ocean acidification. Rising temperatures have significantly impacted seasonal processes by reducing the length of winter seasons while extending summers beyond the natural timeline. This has resulted in droughts, drier summers, and critical loss of water availability. These factors have impacted the agricultural sector, public transportation, and the American economy. Shorter winters and drier summers have impacted the growth of vegetation which has created challenges for biodiversity and vital ecosystem services. Wildfires have become more intense and prolonged due to the drier summer climate in western states. Fossil fuel generation also has led to the loss of air and water quality. Lastly, oil spills in the ocean have resulted in disastrous outcomes. Inefficiencies in the electricity generation process of fossil fuels continually add to environmental degradation.

During the carbon cycle, carbon is transferred between the atmosphere, ocean, and soil as well as living organisms. This process occurs on many different timelines. For example, during the process of photosynthesis, plants absorb carbon into their chemical structure, and this is passed on to herbivores that eat the plant. When this herbivore dies and decays, carbon is released back into the soil. The timeline for this process may take a few years or even decades.

Wildfires are an example of carbon being directly released into the atmosphere. The carbon cycle is essential for maintaining biodiversity and healthy environments in oceans and on land.

The burning of fossil fuels for human use is an intensive process that releases exorbitant amounts of carbon into the atmosphere. In 2019, the U.S. emitted 5,130 million metric tons of energy-related carbon dioxide (USGS 2019). Millions of carbon tons released into the atmosphere from fossil fuel electricity generation are also absorbed by the ocean. According to the National Oceanic and Atmospheric Administration (NOAA), the ocean absorbs roughly 30% of the carbon dioxide released in the atmosphere (NOAA 2023). The immense carbon dioxide emission rates from fossil fuel industries have expedited the detrimental ocean acidification process. Ocean acidification reduces the pH in oceans below a life-sustaining level. With the pH scale dropping, carbonate ions decrease in the ocean waters. Carbonate ions are a “building block” for structures such as shells and coral skeletons. The increase in ocean acidification impacts the ability of organisms like oysters, clams, sea urchins, and corals to calcify their biological structures. As a result, food webs are thrown off balance with declines in certain populations of organisms. Corals are also an important piece to marine ecosystems; with their decline, oceanic habitats are becoming unhealthy and unable to sustain life. Ocean acidification directly impacts human life because it reduces marine food sources. Declining oceanic health is of significant concern for coastal economies that rely on fishing.

Rising temperatures from the increased amount of carbon in the atmosphere have impacted life on land as well. Spring flower blooms, summer heat waves, freeze and thaw, growing seasons, and migration patterns are all examples of naturally occurring events that are seriously threatened due to climate change (EPA). Climate change affects the timing of natural events. For example, when rising temperatures cause shorter winters, spring seasons are coming earlier. When winter seasons end earlier, vegetation begins the process of evapotranspiration sooner. This process refers to the drawing of water from the soil into the sky. When greening starts earlier in the year, scientists are concerned that more moisture is removed from the soil than would naturally occur. This has serious implications for the summer season. Earlier spring greening leaves soils significantly drier in the summer (Climate Science Special Report 2017). Premature springs can cause disruptions in the biological schedules of organisms like honeybees that are responsible for pollinating crops and plants (Chini 2023). The queen honeybees are the only species of bees that hibernate through the winter. With honeybee queens waking up five days earlier than usual, honeybee colonies become more prominent, throwing off the balance between other bee species such as bumblebees (Chini 2023). Seasonal changes due to increases in temperature from carbon emissions of fossil fuel sources are a direct threat to biodiversity.

Drier summers make forests in the western U.S. more susceptible to wildfires. Wildfire seasons are increasing in length and potency. According to U.S. Geological Survey data, in the 17 years from 1984 to 2000, the average burned area in 11 western states was 1.69 million acres per year. For the next 17 years up to 2018, the average burned area across 11 western states was 3.35 million acres per year (Science Daily 2021). Additionally, the nine largest wildfire seasons occurred after 2005 (Mott 2021). Wildfires are serious threats to biodiversity in forests as vegetation is lost and animals are forced to migrate. Wildfires are serious threats to human activity as well. From 2021 to 2022, wildfires accounted for over $11.2 billion in damage across the U.S. (Sleight 2022). According to a 2021 study from the National Academy of Sciences, the main factor in the rise of wildfires in the western U.S. is the vapor pressure deficit. While wildfires are a naturally occurring process, researchers from the National Academy of Scientists have attributed 68% of the vapor pressure deficit was due to human-caused global warming

(Science Daily 2021). The burning of fossil fuels for electricity generation is the second-highest leading cause of GHG emissions and is a significant contributor to the vapor pressure deficit. By switching to renewables for electricity generation, the issue of vapor pressure deficit and wildfires can be mitigated.

The burning of fossil fuels for electricity generation has also critically impacted the agricultural sector. Increases in the number of GHGs in the atmosphere have raised the earth's temperatures steadily. The rise of temperatures has drastically affected normal seasonal patterns and water availability. Warmer winter temperatures are causing less precipitation to fall, decreasing the amount of snowpack (Center for Climate and Energy Solutions 2023). Decreased snowpack affects ecosystems by reducing cold water, needed for species like salmon, and increasing surface temperatures. Snowpack is an essential element in maintaining wildfire spread; with less snowpack on the ground, and an increase in droughts and dryness, it is much easier for wildfires to spread. The growth of wildfire seasons across the past few decades has posed threats to farmlands, as they are susceptible to burning. Warming also increases precipitation variability, indicating that there will be more periods of extreme precipitation and drought (Center for Climate and Energy Solutions 2023). Extreme precipitation can flood farmlands, decreasing crop yield.

Climate change has caused spring seasons to begin earlier, thus beginning the process of evapotranspiration much earlier. This process leaves less moisture in the soil later in summer, making it difficult for crops to grow. As a result of increasing temperatures from climate change, droughts have become longer and more intense. According to the EIA, since 2000, it has become regular for regions of the U.S. to experience abnormal drought conditions (EIA 2022). Droughts decrease crop yield and water supplies. In western states like California, there are legal limits and restrictions for water usage due to the lack of water supply. Water regulations are subject to constant revisions, the latest being the outlaw of drinking water for irrigation on "non-functional" areas of grass (James 2022). California is in its third year of an extreme drought, which has forced the State Water Resources Control Board to adopt emergency drought regulations. The state government has acted with local water suppliers to plan for a water shortage of up to 20% (James 2022).

Droughts have caused a multitude of concerning effects on the American economy. The lack of water supply in western states has decreased available water for drinking, cooking, cleaning, and watering plants. Droughts can and have led to increases in water costs, rationing, as well as the disappearance of water resources like wells (Center for Climate and Energy Solutions 2023). In June 2022, it was reported that the price of water on the Nasdaq Veles California Water Index reached an all-time high of $1,144.14 an acre-foot. This number was up 56% from the beginning of 2022, (Chediak and Chipman 2022). Droughts critically deteriorate agriculture as well by limiting production and thus increasing food prices. Food instability can cause illnesses and a lack of nutrition for growing children. Droughts affect transportation networks by drying up canals and rivers. Also, droughts can expedite the lifespan of roads and public transit cables. Drought-fueled wildfires can halt the use of roadways as well. Electricity demands increase when droughts occur which compounds stress on an old grid system. As droughts become more common across the U.S. there remain questions as to how the grid system will function in high demand.

Research from the University of Minnesota in 2020 revealed that 100,000 Americans die from air pollution each year. Half of the deaths result from fine particulate matter produced by the burning of fossil fuels (Henry 2020). The burning of fossil fuels for electricity generation is unsustainable for human health. By switching to renewable sources for electricity, air pollution from generation will be non-existent and save American lives.

Oil is a fossil fuel used for electricity generation which is used commonly for activities like the heating of homes. Oil spills in the ocean, lakes, and other bodies of water in the U.S. are dangerous and occur frequently. According to NOAA, thousands of oil spills occur in the U.S. each year (NOAA). While most of these oil spills are small, the repercussions are drastic and long-lasting. For example, when oil penetrates seabirds' wings, they can no longer fly, and when oil penetrates sea otters' fur, insulating properties are lost resulting in deaths from hypothermia (NOAA). The toxic compounds released from oil spills cause severe health problems for animals, humans, and vegetation. When oil spills happen, large populations of sea creatures are killed. The largest oil spill in U.S. history occurred in the 2010 Deepwater Horizon incident where an explosion on a drilling platform on the Gulf of Mexico claimed 11 humans and thousands of marine animal lives. The effects of this spill are still felt today, as aquatic biodiversity decreased immensely. The restoration process settlement was reached in 2016 at $8.8 billion. Disasters like this will no longer continue with the switch to renewable sources.

The pollution of GHGs from fossil fuel electricity generation presents a clear and present danger to the ecosystem services, health, and well-being of Americans. Food sources, air quality, and water quality are all impacted by the generation of fossil fuels. Ecosystem services are critically threatened when naturally occurring chemical cycles are no longer operating according to their biological schedules. Electricity is a vital ecosystem service for human life and well-being. However, to preserve biodiversity and other vital ecosystem services in the U.S. like air and water quality, and food sources, electricity must be generated from renewable sources. By converting to fully renewable electricity generation, GHG emissions will cease to exist. This will strengthen the earth's atmosphere, halt the degradation of critical habitats, reinvigorate ecosystem services, and preserve biodiversity.

The use of fossil fuels for electricity generation is extremely inefficient and wasteful. About 66% of the primary energy used to create electricity is wasted by the time the electricity reaches the customer. The EIA estimates that 59% is lost in the generation process with an additional 5-10% lost during the transmission process. Electricity is a secondary source derived from the burning of primary fossil fuel sources. Fossil fuel plants are old and lacking in proper technology that can efficiently produce electricity. The leading cause of electricity loss at fossil fuel plants is when heat escapes during the process of converting primary sources into electricity. Because most of the electricity is lost during the generation process, more fossil fuels must be burned for electricity demand, emitting more harmful GHGs into the atmosphere. Converting to renewable sources will eliminate the pollution of GHGs for electricity generation. However, for renewable implementation to work, issues in the delivery and transmission processes must be addressed.

Delivery and Transmission System Problems

Transmission lines have existed in the United States since the beginning of the electric grid in the 1880s. The current infrastructure for transmission lines has been replaced and updated since their initial creation, however, these systems are growing old. A lack of proper infrastructure upgrades has resulted in an average age of installed bases being more than forty years old (Bowie, Oumansour, Underwood, Yurkevicz 2020). More than a quarter of transmission lines across the grid are fifty years or older. While the system's longevity is notable, these systems are long overdue for significant upgrades. It is estimated that over the next three decades, upwards of 140,000 miles of transmission lines will become due for replacement.

Dated transmission lines have led to inefficiencies in electricity delivery, electricity loss, and lack of electricity conservation. These issues have led to financial loss and have caused serious environmental damage.

The dated U.S. electric grid system relies upon technologies that are significantly less cost-efficient and electricity-efficient than newer developments such as composite core conductors. The U.S. grid began utilizing Aluminum Conductor, Steel Reinforced (ACSR) cables over a hundred years ago. In the 1970s, the Aluminum Conductor, Steel Supported (ACSS) cables were introduced to the grid. These two cable cores share similar inefficiencies in the capacity of electricity stored within cables. Because less electricity can be stored within ACSR and ACSS transmission lines than composite core conductors, it can take longer for electricity to reach consumers. According to Gregg Rotenberg, CEO of Smart Wires, a company that develops power flow control technologies, "typically 50% of the lines, after contingency, are using less than 25% of their capacity," (Walton 2020). Transmission lines must have spare capacity to account for contingencies like damaging natural events or loss of generators. ACSR and ACSS transmission lines cannot efficiently handle contingencies. This leaves consumers vulnerable during intense natural events.

ACSR and ACSS transmission lines also require a higher sag. In transmission lines, sag refers to the vertical difference between levels of support. The highest point is the transmission tower, and the lowest point is the conductor. Sag is necessary for transmission lines because it relieves tension on the conductor. When sag is straight or level, transmission lines are at risk to detach from end supports by wind force and the elements. ACSR and ACSS transmission lines require significantly higher levels of sag than composite cores. By switching to composite cores, costs will be saved in the supporting structures of transmission lines. Transmission lines will also be able to span longer distances. This solution will be discussed in depth in the following subsection of chapter 1.

The U.S. electric grid loses about 5-10% of electricity during the transmission and distribution processes, (EIA 2022). The U.S. electric grid operates through centralized power stations meaning high-voltage electricity must travel long distances via transmission lines before it reaches the distribution network of end-use consumers. As electricity moves through this network, resistance in the ACSR and ACSS wires releases heat. This results in electricity being lost during the transmission process. Electricity losses during the transmission and distribution networks can be mitigated through the implementation of composite core wires and the decentralization of grid networks. Reducing the distance transmission lines must travel and improving the technology that carries electricity will greatly improve cost-efficiency and electricity efficiency as well as electricity conservation. With updates to the distribution and transmission networks, less electricity will be lost, allowing for greater conservation during high-demand events such as severe storms.

A common environmental issue across the U.S. concerning transmission and distribution networks is the spread of wildfires. In fact, from a stretch of 2014 to 2017, Pacific Gas and Electric (PG&E) transmission networks were responsible for more than 1,500 wildfires in California alone (McFall-Johnsen 2019). The company created networks with a lack of comprehensible safety strategy. This resulted in dated equipment being used to support the transmission network infrastructure. The high-voltage wires used for transmission and distribution were dated and did not have proper insulation to withstand sparks from erupting into fires. The sag of these networks was also very high, which is very susceptible to starting fires. High reliance on wooden poles for transmission networks was another factor that contributed to the widespread wildfires. The lack of monitoring on these networks was another cause of the network's failure. When centralized-based networks must travel long distances, it is significantly more challenging to shut power off to contain the spread of wildfires further. Decentralized transmission and distribution networks require shorter distances of wires, thus making it easier to contain deadly wildfires.

Transmission and distribution networks rely on dated technology such as ACSR and ACSS wires to deliver electricity to end-use consumers. These wires require higher sag which means more capital must be spent on building transmission towers. ACSR and ACSS wires are also more susceptible to causing and spreading wildfires due to the lack of insulation that composite core wires possess. Relying on dated systems for electricity delivery causes electricity inefficiency and electricity loss, and lack of electricity conservation. In the following subsection, solutions to problems with transmission and distribution networks will be examined in detail.

A New Grid and its Challenges

As previously stated, renewable energy comes from sources that are naturally replenishing such as solar, wind, and hydropower. Renewables do not rely on the burning of fossil fuels for electricity generation like coal, oil, and natural gas. Therefore, renewables do not produce harmful GHG emissions. This is one of the most significant benefits of renewable technology implementation. The adoption of renewables also presents significant economic benefits. chapter 3 will discuss the full environmental and economic benefits of renewable implementation.

In 2021, the EIA reported that out of the total electricity generation produced in the U.S. 20% came from renewable sources. Wind power was the leading generator of electricity, producing 9.2% of that renewable electricity (EIA). Wind-generated electricity is flow-limited, meaning that there is only so much electricity available at one time. This is because there is not always wind present to propel wind turbines to produce electricity inside the generator. Wind turbines can be operated effectively in both off-shore and on-shore sites. Land-based wind turbines vary in size and electricity production, however, greater investments in wind power structures have resulted in more efficient electricity generation. According to the Office of Electricity Efficiency and Renewable Energy (EERE), the average nameplate capacity of newly installed wind turbines was at 3 Megawatts (MW) in 2021. This was a 9% increase from 2020 (EERE). The blades of wind turbines are increasing in length as well. This increases the amount of electricity that wind turbines can produce. The installation of longer blades as well as other structural costs is decreasing in price, implementing wind turbines increasingly cost-efficient. The economic viability of renewable implementations including the decreasing installation costs will be discussed in detail in chapter 3.

In 2021, the EIA reported Hydropower generated 6.3% of renewable electricity. Hydropower generates electricity from moving water. Hydropower plants are located near moving water bodies such as rivers and waterfalls. The volume of water flow and elevation are both factors in the amount of electricity hydropower plants can produce. Greater water flow and height of elevation increase electricity production. At hydropower plants, water flows through a pipe and then propels blades in a turbine to produce electricity. Hydroelectric facilities include run-of-the-river systems and storage systems. Run-of-the-river systems force water currents to apply pressure on turbines. Facilities have systems to divert water into the pipes to push turbines. Storage systems are crucial for accumulating water from dams to release through turbines for electricity generation when needed. The dams are typically built in rivers and streams and stored in reservoirs.

In 2021, solar technology produced 2.8% of total renewable electricity generation. Solar panels capture electromagnetic radiation from the sun and transform this energy into electricity. The effectiveness of solar panels can be limited by the amount of sun that is received. Like wind turbines, solar technologies must be implemented strategically. Not every location offers viable sunlight for electricity generation. Solar technology utilizes photovoltaic (PV) materials and devices that convert sunlight into electricity. A single PV is known as a cell. Individual cells produce only 1-2 watts of power. Cells are composed of extremely thin semiconductor materials. Cells are protected from the elements through a combination of glass and plastics. PV cells are connected in chains to create larger units called modules or panels to increase power output. Modules can be used individually or connected to the electrical grid as a PV system. PV modules are very flexible and can meet any electric amount needed. These systems are mounted optimally toward the sun. Panels also include materials to convert the direct current (DC) into alternating current (AC) so that electricity can be used to power appliances for end-use consumers. The price of solar panel equipment and installation costs are at an all-time low, implementing these technologies into a new grid system extremely viable. More on this chapter 3.

Biomass accounted for 1.3% of renewable electricity produced in 2021. Biomass is a renewable organic material produced by animals and plants. Biomass contains stored chemical energy from the sun. Biomass can be burned for heat or converted to liquid and gaseous fuels through different processes. Examples of biomass include wood, crops, waste materials, biogenic materials such as paper and cotton, and lastly animal manure and human sewage. Biomass is converted to electricity through four main processes including direct combustion, thermochemical conversion, chemical conversion, and biological conversion. Burning biomass materials for electricity does not emit GHGs or other harmful chemicals and is sustainable long-term as the materials needed are widespread and variable.

In 2021, geothermal power contributed 0.4% of total renewable electricity generation. Geothermal resources are reservoirs of hot water underneath the earth's surface. These reservoirs can be both natural and human-made. Wells are drilled into the reservoirs at various lengths depending on the depth of the geothermal source. The hot water from these sources is recovered for multiple applications including electricity generation, cooling, and heating. In the U.S. most geothermal sources are in the western states. Geothermal is renewable as the heat flowing from the planet's interior is replenished regularly with the decay of naturally occurring radioactive elements. Geothermal power plants are very reliable and can run constantly despite unfavorable weather conditions. Geothermal plants are also very compact and use significantly less land for the electricity generation process than fossil fuel plants like coal.

While the growth of renewables has been increasing across the country, the infrastructure to support these innovations is derailing overall efficiency and success. The comprehensive installation of a new electric grid system is estimated to cost the U.S. government nearly $2 trillion (McLaughlin 2022). The networks of transmission systems, substations, and transformers are all collapsing with factors of critical underinvestment and extreme climate-related weather events adding more challenges. When new renewable sources like wind and solar farms are created, these sources must be connected to transmission lines so that this electricity can be used later. Improvements to existing transmission lines will be critical for the broader decarbonization of the U.S. electric grid, (Walton 2020). Adjusting existing transmission lines is incredibly difficult, however. As stated by Robert Gramlich, President of Grid Strategies, a power sector consulting firm, grid operators and transmission owners are “woefully slow and unpredictable in terms of what it costs to connect” (St. John 2021).

Political difficulties add layers of complexity to creating new transmission lines. The Federal Energy Regulatory Commission Order 2003, for example, allows independent system operators (ISOs) and regional transmission organizations (RTOs) to “hold developers of new generation facilities responsible for the costs of upgrades needed to interconnect their projects to the transmission grid” (St. John 2021). This policy aimed to avert cost-sharing systems, where costs would be covered by the utilities and customers within that broad base. While this practice was effective for adding large-scale natural gas generators to the grid, sited at convenient locations, it is no longer applicable when adding newer renewable sources. The political barriers against renewable implementation will be discussed in length in chapter 4.

Wind and solar farms are often located far away from concentrated load centers due to the amount of land these developments require. In densely populated neighborhoods, wind and solar farms cannot be constructed. Therefore, new transmission lines must be built to deliver this electricity to those customers. In 2021, wind and solar projects made up 90% of the new interconnection requests in the queues of ISOs and RTOs that manage transmission lines (Driscoll 2021). However, the bureaucratic permitting process of such transmission lines is often lengthy. It can take anywhere from six months to several years for a transmission project to receive the necessary permits to begin development. States all have differing requirements in the permitting process. For example, some states have established a “certificate of need,” which signifies that a transmission project will be beneficial for goals ranging from grid congestion relief to green energy targets, (Landolfi 2022). However, the development of new transmission lines depends on the financier or owner.

Transmission upgrade costs are threatening and delaying the development of renewable projects. According to data from Lawrence Berkeley National Laboratory, "average network upgrade charges have grown from about 10 percent of total project costs a few years ago to as much as 50 to 100 percent of those costs today," (St. John 2021). Surging prices will render novel improvements increasingly unattractive for developers responsible for transmission improvements. Due to these high costs and the multitude of difficulties from the permitting process, it is clear why transmission projects are so behind.

Various generation interconnection studies have shown that costs are forced onto the project at the front of the interconnection queue. These projects trigger the need for grid upgrades, and "when that project drops out under the weight of those costs, grid operators must redo their interconnection studies with the new mix of projects, leaving the next one in the queue to face the cost burden and drop out, and so on," (St. John 2021). The Midcontinent Independent System Operator (MISO) has seen almost every project from its 5 gigawatts of renewable energy plan canceled in the past two years. These projects already received Power Purchase Agreements (PPAs). The last remaining project working with MISO is facing $500 million in upgrade costs. For many projects, this way of financing upgrades is simply not financially feasible. While the queue for interconnection grows, the costs of upgrading transmission systems keep rising. Wind and solar projects are continuing to fall in cost over time, and with many states setting grid decarbonization goals, the interconnection process must hasten.

The U.S. grid system continually utilizes dated ACSR and ACSS wiring for transmission lines that are inefficient for delivery and typically lose between 5-10% of generated electricity each year (EIA). While this may appear paltry, this process contributes to electricity waste and drives electricity bills higher (Chen 2018). When utilities continue building transmission lines with antiquated wires, electricity is dissipated. Newer transmission wires utilizing carbon fiber cores and packed conductive metal cores are lighter, more durable, and more efficient. Conversely, conventional wire designs have aluminum conductor steel reinforced cables, which are heavier, weaker, and less effective. The implementation of newer transmission wiring across the country is a small but extremely effective method of improving electricity efficiency and resiliency. In Texas, these newer transmission wiring designs were implemented, cutting electricity losses by 40% and nearly doubling the carrying capacity of transmission lines (Chen 2018). The electricity savings within this new system saved residents an estimated $30 million in the first year. These electricity savings also cut the same amount of carbon emitted from 34,000 cars annually (Chen 2018). Tackling transmission and distribution efficiency is key because it will save millions in electricity bills, reduce electricity waste, reduce wiring maintenance costs, emit less carbon, and improve resiliency.

Resiliency is another critical issue of the U.S. electrical grid systems. This issue has two primary components—electric grid resilience against increasing climate-related events and resilience against cyber security and terrorist attacks. In February 2021, Texas experienced a major electric grid failure as three powerful storm events swept across the U.S. Since 1935, Texas has been self-regulating electricity separate from the rest of the country without federal oversight. Electricity generated in the state of Texas stays within the state borders. Almost a decade before the 2021 freeze, Texas experienced a very similar storm with similar effects. The Federal Energy Regulatory Commission called on Texas to winterize its natural-gas facilities, however, Texas is independent and therefore did not have to answer to federal suggestions. Texas does not often have to plan around extremely cold winters the same way states in the Northeast might.

This was reflected in the lack of necessary infrastructure to protect their electric grid systems as the extreme storms quickly dismantled electric transmission and distribution services. Electricity generated from all sources was slowed during this period. Natural gas facilities were inadequately prepared for extreme winterized conditions and began to fail very quickly as temperatures dropped below freezing. When the conditions worsened through the storms, the electricity demand surged. However, the grid was incapacitated by nearly 50% from natural gas powerplant failures, so intentional blackouts were launched as a way of closing the gap between electricity supply and demand. This caused over 5 million Texans to lose electricity for days on end while nearly 250 residents died of the frigid cold.

This crisis in Texas revealed several key lessons for strengthening the resiliency of electric grid systems. The ‘Winterization’ of outdated generators, transmission, and distribution systems is a concept of resilience that must be adhered to by all states. Climate-related weather events are continuing to occur more frequently throughout the year. Proper grid infrastructure will need to be adapted so that all states can handle the complex issues of extreme weather events. Transmission and distribution networks must be built so that each community can receive the electricity needed during cold winter months. Generators will need to be built to handle the extreme levels of demand during crisis events. Additionally, electricity storage must be improved so that when crises occur, supply can be properly managed to fit demand. This will eliminate the dangerous practice of intentional rolling blackouts which leave communities freezing. All these grid infrastructure upgrades will require investments from state and federal governments so that newer, resilient technologies can be utilized. These investments vary from state to state but will be large regardless. This means that prioritizations must change in state and federal governments so that infrastructure improvements are deployed quickly. The technology required for adapting old grid systems to become resilient already exists. Resilience implementation will depend on the proper investments and policy creations initiated by governments.

The U.S. needs to invest in regulatory cybersecurity measures to ensure the safety of the country's electric grid system. As of right now, there is a critical lack of investment in security with weak points in the grid distribution systems that carry electricity to consumers. Operational technology is becoming more remote allowing new areas of entry into important networks for cyberhackers. Cyber-attacks from abroad are of growing concern for national security. Countries like China and Russia present serious threats to the security of the U.S. electric grid. A planned attack on the U.S. electric grid could threaten the safety and well-being of all Americans who rely on electricity daily as well as the American economy. There have been some much-needed federal actions to increase grid resilience and security. In August of 2022, the DOE announced a $45 million plan that will incorporate next-generation cyber tools. This is a funding opportunity for new grid security technologies to be developed and implemented. As part of the Bipartisan Infrastructure Law, the Grid Deployment Office is conducting a $10.5 billion Grid Resilience and Innovation Partnership (GRIP). This program aims at enhancing grid flexibility, grid resilience, and cyber security. Lastly, in March 2023, the White House announced its National Cybersecurity Strategy that will involve key government organizations like the U.S. Department of Energy (DOE) and the Office of Cybersecurity, Energy Security, and Emergency Response (CESER). This strategy has developed plans for electric grid cybersecurity strategies. These recent federal developments in the electric grid cybersecurity space must be deployed effectively to ensure the safety of the U.S. grid system.

The U.S. electric grid system needs to improve its cybersecurity and climate resilience. Converting to renewable sources for electricity generation, as well as improving cybersecurity and resilience will be challenging. There are significant economic and political barriers that must be resolved to improve the U.S. grid system. Chapter 3 will explain the economic and environmental benefits that renewable sources will provide as well as the economic factors that are part of the process of conversion. Chapter 4 will discuss the political background of the U.S. grid system and how existing policies create difficulties in renewable implementation.

Chapter Two: History of Electric Grids in America

The Industrial Revolution 1750-1900

The Industrial Revolution caused exponential innovation and growth in energy and power. Factories shifted from using windmills and watermills to coal-power plants and steam engines. Windmills and watermills were the earliest form of renewable sources of power that supported mechanical processes like grinding grains and pumping water. Watermills ultimately proved insufficient due to a lack of water supply to move waterwheels and turbines in winter months. The transition to coal and steam power for factories offered significantly higher flexibility. Industries no longer had to rely on natural energy to provide power for mechanical processes.

Steam engines were a very important invention during the Industrial Revolution. Steam engines were primarily powered by the burning of coal. However, before the use of coal became widespread, wood was burned in the absence of oxygen to create charcoal which powered steam engines (Yale University). Steam engines were reliable sources of power for factories that had previously relied upon natural sources of energy. Developments in steam power were led by James Watt in 1769 after he patented a separate condenser. Before Watt, there had been little development with the Newcomen atmospheric engine. This engine was developed by Thomas Newcomen in 1712. The engine produced power through atmospheric pressure. This early edition of the steam engine was very fuel-inefficient and costly to assemble and install. Watt's separate condenser increased efficiency and was later scaled with help from Birmingham industrialist, Michael Boulton. Boulton provided the capital and resources that eventually led to the production of 500 engines between 1775 and 1800 in Britain, (Britannica).

Watt's patents put a temporary restriction on the development of high-pressure steam engines. However, when Watt's patents expired in 1800, high-pressure steam engine innovation grew rapidly. Cornish engineer, Richard Trevithick, was the first to construct higher steam-pressure engines in 1802 with American engineer Oliver Evans simultaneously building the first high-pressure steam engine in the U.S. (Britannica) High-pressure steam engines powered large factories, agriculture, and soon after Trevithick, transportation. Steam engines continued to develop through the turn of the century into 1900. Factories grew in size after 1830 with steam engines becoming increasingly more energy-efficient and cost-effective. The textile industry surged with the growth of factories in cities. The coal industry grew as steam engines proliferated across Europe and the U.S. The demand for coal coincided with the rise of steam engines, as more power was demanded by growing industrial economies. The growth of factories powered by steam resulted in higher levels of GHG emissions in cities. Coal and coal gas were also primary sources of heat for residents living in cities. Air quality quickly decreased as smog from coal pollution spread through cities. This critically impacted public health and well-being.

The Industrial Revolution sparked global economic growth as new industries emerged and expanded. The demand for energy to power factories surged resulting in the increase of environmental degradation through coal mining and GHG emissions. In the 1880s, the demand for power to generate electricity stimulated new thinking about steam engines. Michael Faraday's 1831 discovery of the relationship between electricity and magnetism propelled the development of the mechanical generation of electric current. Previously, electricity had only been derived from chemical reactions and voltaic piles. Substantial developments in mechanical generation and electric motors by many different scientists through the mid-1800s propelled historically great thinkers to consider the commercial feasibility of electricity generation.

Edison's Pearl Street Station 1882

For much of the 1800s, inventors in Europe and the U.S. were constructing ways to create electric lighting. Sir Humphry Davy was the first to demonstrate electric arc lighting in 1808. Arc lighting was best suited for large outdoor spaces due to structural maintenance and the glaring light it produced. Reaching commercialization in the 1870s in Europe and the U.S., it was recognized that different electric lighting would be needed for indoor usage.

Edison developed incandescent lighting in 1879 and soon worked to develop an entire system that would generate, deliver, and utilize direct current (DC) electricity for power. Direct current is the method in which electricity flows in one single direction. The voltage is always constant in direct currents. Edison sought to make the DC system commercially viable. In 1882, Edison launched the first electric power plant at the Pearl Street Station in Manhattan. He chose this area due to its dense population and diverse commercial and residential makeup. Edison recognized the importance of media coverage as a conduit for potential financial investment and believed this area, the First District, would be the best place to showcase the central power station.

Distribution systems were then created in Manhattan and New Jersey, utilizing direct current through copper wiring. Edison's Pearl Street Station was the foundation for how central electric power plants were constructed. The DC system that Edison utilized had several disadvantages. The most critical issue was the high line losses that limited the distance DC could be transmitted. As the Pearl Street Station matured and issues in DC were realized, competitors began creating new infrastructure.

Samuel Insull and Commonwealth Edison

In 1892, Samuel Insull began working at Chicago Edison, one of Edison's many national franchises. At the time over twenty electricity-producing companies existed in Chicago. Quickly, Insull began envisioning ways to improve electricity output. Insull recognized that Chicago Edison could make more money by incorporating a load factor into business practice. Load factor refers to the ratio of average daily electricity use to the maximum demand. Insull found that increasing off-peak electricity demand could increase company income without having to expand infrastructure. Insull developed plans to offer low rates for off-peak coverage to stimulate higher demand.

Insull looked to Europe to improve the electricity-generating technology for Chicago Edison as well. Companies across Europe switched from steam engines to more efficient steam turbines. Insull implemented the steam turbines in Chicago to increase productivity by reducing the amount of space dedicated to heavy machinery for electricity generation. The steam turbines reduced noise pollution, and space needed for expansive machinery, and significantly decreased the amount of money invested required for steam engine materials. The steam turbines were much cheaper to build and required substantially less space which presented a greater opportunity for economies of scale because more electricity could be produced at cheaper prices. In 1903, Insull ordered a turbine generator from General Electric that produced over 5,000 kW of power. Over time, Insull ordered more powerful generators that decreased electricity costs. Insull recognized the ability of AC transformers that could transmit high voltage over long distances. Quickly, the Edison companies switched to utilizing AC over DC.

George Westinghouse's Niagara Power Plant 1896

In 1896, the first alternating current line was established, connecting Niagara Falls to Buffalo, NY on the electric grid. In alternating currents (AC), the positive and negative sides are switched periodically which changes the flow of electricity accordingly. The U.S. now relies almost exclusively upon alternating currents, however, devices like computers, LED lightbulbs, solar cells, and electric vehicles all rely on DC electricity. Modern technologies like electric vehicles and solar cells utilize DC methods because this is the most efficient way for the charging and electricity distribution process. While these technologies are capable of using AC systems, DC electricity is usually the most compatible.

Early in the construction of electric grids, the decision to opt into AC versus DC systems was a major political battle. Thomas Edison and his partners created products specifically made for DC systems, and thus advocated for the implementation of such transmission systems. Edison's DC electricity generation was transmitted across several cities for several years after the Pearl Station launch. However, the DC transmission had a glaring weakness in its inability to travel far distances. For several years, Nikola Tesla worked under Edison and his company, repairing generators among other tasks. This is where Tesla developed designs for the AC generator, however, Edison had invested his time and resources into DC generators and was uninterested in AC.

While Edison and his companies pushed for the adoption of DC power, George Westinghouse and several European companies promoted the inventions of Tesla, which favored AC power. Tesla's inventions aimed at increasing current through higher voltages to make it easier to transmit electricity over long distances using thinner and cheaper wires. Edison and Tesla fought for the control of the electric grid for years, however, AC electric generation emerged as the standard for transmission, (Zakarin 2021).

The Progressive Era 1890-1920

By the early 1900s, more than 4,000 individual electric utilities were operating in isolation with no grid connecting them (EIA). While Insull had made strategic and lucrative investments in steam turbines and AC transmission systems, the competition was fierce between electrical utility companies. With many utility companies competing for electricity demand, Chicago Edison's steam turbines could not scale. Insull decided to consolidate Chicago Edison with other companies to improve scalability. As Chicago Edison began scaling its business, Insull turned the existing generating stations from utility companies into substations. The existing generating stations were then used for backup storage during peak demand. Insull increased load factor by expanding transmission lines to rural areas. Insull's business tactics proved very effective. By 1907, he had acquired 20 other electrical utility companies and consolidated power under the new Commonwealth Edison, (National Museum of American History).

Insull had monopolized electrical utility in Chicago. This was common practice across emerging industries at the time, like the railroad market. The progressive era dubbed these monopolized utility and railroad markets as “natural monopolies,” meaning that the extraordinary economies of scale necessary to build these markets were deemed to be conducted by one individual company. The railroad business, there required significant investment in the construction and development of facilities. This meant new companies in the market would waste large amounts of financial capital and resources that would necessitate higher prices for customers. The railroad business became a “natural monopoly” where the high cost of technology and investment led companies to not compete in the market.

This became the same story for the electrical utility market. Electrical utility companies consolidated power across the U.S. utilizing steam turbine generators and AC transmission systems. Politicians and economists dubbed these companies as “natural monopolies” as well. Progressive reformers contemplated how best to create rules and regulations for monopolies so that the American public would not be controlled by monopolized ownership. Two emerging political trends emerged, municipal ownership and state regulation. Reformers advocated for cities to enter purchase agreements over the monopolized markets, therefore, ensuring the benefits of natural monopoly would go directly to its citizens. Cities would be able to scale the business, dropping rates for citizens without having to respond to shareholders.

The municipalization of electric utilities grew steadily, however, reformers remained skeptical about city leadership over electricity generation and transmission. Reformers were critical that city officials would neglect regulatory maintenance, and capital investment, and cut salaries for electrical utility workers. Critics also questioned the feasibility of socializing utility companies in favor of retaining privatized ownership. Reformers called upon state regulation similar to that of states like Massachusetts which had established a state regulatory commission overseeing its railroads. Wisconsin and New York were two states pushing heavily for state regulation. In 1907, Wisconsin developed state regulations over electrical utility companies. New York soon followed thereafter and by 1914, 43 states established state government regulation over electrical utility companies. Municipal ownership peaked in 1922 with over 2,500 systems in existence. Since then, however, municipal ownership decreased over time and is no longer in existence.

The purpose of state regulation was for electrical utility companies to charge all customers reasonable rates that factored investment into equipment such as aboveground AC transmission lines plus a rate of return. Because electrical utility companies were directly involved in the regulation policy process, electrical utility companies were legitimized as monopolies within service areas. Electrical utility companies also gained eminent domain, which was previously only state power, (National Museum of American History). This meant companies could appropriate land for the construction of generating centers, transmission lines, and substations. Regulation protected companies from those who opposed anti-competitive industries. The regulation also allowed utility companies to raise capital easily in the form of stocks and bonds. During this early era of the American economy, public disclosure of accounts did not exist. However, regulators operated the finances for utility companies and allowed utility companies to pay lower and safer rates. Regulation ensured the financial security of utility companies. Through the 1910s and 1920s, electrical utility companies grew to match increasing demand. The electrical output from utility companies increased from 5.9 million kWh in 1907 to 75.4 million kWh in 1927 while the price of electricity dropped 55% (National Museum of American History).

Holding Companies 1900s-1920s

As electrical utility companies expanded in the 1920s, holding companies emerged as a viable financial strategy to fund operations. In this practice, equipment manufacturers accepted unfavorable stocks and bonds from utility companies in exchange for producing equipment. This allowed emerging utility companies to retain cash flow and build operations. The holding company utilized the securities of its subsidiaries as collateral to raise capital by issuing both stocks and bonds. Investors favored holding companies for their diverse portfolios and safe returns over individual companies. General Electric's Electric Bond and Share Company was the most popular holding company established in 1905 (National Museum of American History). Holding companies had very important roles in smaller utility companies as they began to expand, offering management and engineering services. Holding companies often consolidated the equipment produced for utility companies, aiding in the interconnection processes as larger companies monopolized. Holding companies played a critical role in catalyzing progress in utility expansion.

However, through the 1920s, holding companies became notorious for exploiting relationships with operating companies. Holding companies charged high rates for financial oversight of operating companies and provided capital for engineering beyond appropriated costs. Sub-holding companies were stacked in a pyramid to protect securities for the companies below. This gave access to investors to control other operating companies from the top down. Insull was one of the main culprits of such practice. In 1930, his $27 million investment gained him access to $500 million worth of assets in utility companies across 32 states (National Museum of American History). By 1932, 8 holding companies controlled 75% of all electrical utility businesses (National Museum of American History). The malpractices of holding companies eventually led to a 6-year Federal Trade Commission investigation in 1928. Public disdain for holding company politics increased when the stock market crashed. With the public calling for changes in the political and economic side of electrical utility companies, presidential candidate Franklin Delano Roosevelt (FDR) swore to change the industry.

Electricity Becomes Publicly Regulated 1935

Franklin Delano Roosevelt was elected president in 1932 and upheld his campaign promises of government intervention in the electrical utility industry. FDR and Congress passed legislation to create government agencies to generate and distribute electricity to Americans that were not connected to Investor-Owned Utility (IOUs) electric grids. IOUs neglected rural areas for electrical grid connection because of the projected loss of return on investment. However new federally administered organizations like the Tennessee Valley Authority and the Rural Electrification Administration demonstrated that providing electricity to poor areas could improve the standard of living and produce income (National Museum of American History). In 1930, 10% of American farms had electricity, and by 1945 45% of American farms were connected to the grid (National Museum of American History). FDR's government agencies set an example for IOUs in developing transmission lines to rural areas and later passed legislation to administer these organizations further.

In 1935, FDR passed the Public Utility Holding Company Act (PUHCA). Under this legislation, Congress abolished the pyramid structure that holding companies had been abusing. Holding companies were granted only two levels, with one holding company on top and two subsidiaries below. The PUHCA resulted in the dissolution of holding companies that did not have operating utilities located next to each other. This made the national interconnection of generation and distribution facilities feasible. In 1935, FDR established the Securities and Exchange Commission (SEC) which created stringent financial reporting laws for electrical utility companies. All stocks and bonds issued by the holding companies had to be approved by the SEC.

The PUHCA recognized the value of holding companies in establishing management and engineering practices for operating companies nationwide. Although, holding companies declined quickly, dropping from 216 in 1938 to 18 in 1958. While holding companies and operating companies were separated over time, the electrical utility industry stayed remained mostly the same.

Establishing the Three Interconnections 1965

There was never an overarching plan for grid expansion. The U.S. electric grid expanded as the electricity demand increased. Over time, it became common for electrical utility companies to consolidate with neighboring utilities to reach economies of scale. In 1965, the Northeast Blackout significantly impacted the operational network of the national grid system. What resulted was the establishment of the three major grid interconnections that are still functioning today. The regional framework created the Eastern Interconnection, Western Interconnection, and the Texas Interconnection. The borders for these three interconnections have remained the same After 1965, the North American Electric Reliability Council (NERC) was founded to oversee the reliability standards, operations of generation and distribution, and development of personnel to manage grid standards. In the 1960s the U.S. electric grid expanded transmission systems rapidly as the price of electricity dropped drastically. This made it easier for transmission lines and distribution centers to be constructed across the nation. In the 1960s, the number of transmission lines in the U.S. tripled in the last decade (ITC Holdings Corp).

OPEC Crisis and The Public Utility Regulatory Policies Act 1978

In 1973, the Organization of Petroleum Exporting Countries (OPEC) placed an oil embargo on the U.S. Three months after the oil embargo was enacted, the price of a barrel of oil increased from $3 to $12 (History). With prices of oil expected to reach incredible highs, the Public Utility Regulatory Policies Act (PURPA) was created to diversify U.S. power sources. PURPA was created with optimistic goals to increase energy conservation and also develop renewable energy sources. PURPA poured money into research and development of solar and wind electricity generation. PURPA set to implement the smaller renewable plants into a new class of energy facilities, Qualifying Facilities (Transformation Holdings). PURPA forced large, vertically integrated utility companies to diversify their energy portfolios by purchasing small-scale solar and wind generators. PURPA allowed large electrical utilities to purchase renewable energies below the cost of their electricity production.

The Clean Air Act of 1970

Over time, incremental policy changes led to the passage of the Clean Air Act of 1963. This signaled to large electrical utility companies that further environmental regulation was coming. In 1967, the Air Quality Act was passed to solidify federal responsibilities for emissions management. This act invigorated federal studies into air pollution from factories and electricity generation plants. In 1970, the Clean Air Act was added, creating substantial changes in the federal government's role in air pollution control. This law founded federal and state institutions to monitor and reduce air pollution. Four major regulation programs were initiated including the National Ambient Air Quality Standards (NAAQS, pronounced "knacks"), State Implementation Plans (SIPs), New Source Performance Standards (NSPS), and National Emission Standards for Hazardous Air Pollutants (NESHAPs). These standards enhanced air quality standards and pollution limitations. Furthermore, legal enforcement was strengthened by the creation of the Environmental Protection Agency (EPA) which oversaw the new legislation.

In 1977, major amendments were made to the Clean Air Act, specifically improvements to the Prevention of Significant Deterioration (PSD) of air quality in areas attaining the NAAQS. In 1990, further amendments were made to the Clean Air Act to enhance federal authority. Changes created federal government regulatory programs for the control of acid rain. NESHAPs were grouped into a complex program for toxic air pollutants control. Further provisions were added to strengthen the attainment and maintenance of NAAQs. The Clean Air Acts have proved very effective in the U.S., establishing rules and limitations for air pollutants and air quality. The Clean Air Act and its amendments have created invaluable standards for air quality and toxic pollutants that have protected public health and well-being and preserved vital ecosystem services.

The Energy Policy Act 1992

The Energy Policy Act (EPACT) of 1992 was passed to amend utility laws to expand clean energy use and improve electricity efficiency in the U.S. State utilities were required to develop new regulatory standards for resource planning as well as improvements in supply system efficiency. The Energy Policy Act aimed at transitioning away from foreign energy imports with incentives for renewables implementation. Renewable-generated electricity was granted the same access to the transmission grid that the utility companies would charge themselves for grid access. Renewable sources were given several tax incentives to support development as well. Extensions were given to investment credit for solar and geothermal projects. A production tax credit of \$0.015 per kWh was also given to wind and biomass projects (International Energy Agency). Publicly owned utilities were also given postproduction an incentive payment of $0.015/kWh (International Energy Agency). The Energy Policy Act was important for the supported development and inclusion of renewables into transmission systems and the overall promotion of energy efficiency in the U.S.

The EPACT also laid the eventual foundation for the deregulation of American electricity markets. Utility companies were now required to allow external organizations equal access to electric transmission systems across the grid. The Act intended for customers to choose their electricity supplier and pay for the transmission services to their property. New-generation sources were granted equal access to their regional transmission system. This new policy change saw the rise of independently owned generation sources entering the North American electricity markets. Predicting fierce competition, utility companies created power marketing departments to handle administrative duties. These vertically integrated utility companies favored their power marketing divisions and worked directly with transmission operators. This made it very difficult for independent generator owners to gain access to the transmission networks.

Regional Transmission Networks and Independent System Operators 1990s - Present

In 1996, FERC created Independent System Operators (ISOs) through Order 888 to increase wholesale market competition through open access, non-discriminatory transmission services. This order aimed at promoting competition and enforcing fair treatment of independent generation source owners and operators. FERC outlined six objectives to accomplish fair competition in the new electricity markets. All jurisdictional utility companies in the U.S. were required to administer and file an open-access transmission tariff. IOUs were required to disclose wholesale generation and power marketing for transmission services. The most important result of Order 888 was the creation of Independent System Operators (ISOs). The role of ISOs was to guarantee streamlined administration, creation, and distribution, as well as to ensure the integration of the market with the operations of the transmission system.

Order 889 was passed to establish a standard of conduct for how actors in the electricity markets should interact with transmission operators. The order created OASIS nodes which are secure, online, platforms that contain the latest information on transmission system market changes. OASIS nodes are entirely internet-based; however, public access is restricted. Power marketers and ISOs have full access to OASIS where existing transmission and service availability is posted. Transmission facilities have certain restrictions regarding power transfer limits that must be maintained for grid stability. Transmission operators conduct frequent studies to understand the transfer capacity required to power their regional load and how much capacity must be reserved for extreme events. Differences between capacity for regional load and capacity needed for extreme events can be viewed and purchased on OASIS.

Before OASIS existed, transmission owners gave operational control to ISOs. ISOs gave access to OASIS early in its creation, so notices of transmission service requests could be received across the whole network. Despite the role of OASIS, FERC pushed for the move of transmission assets to ISOs. Since FERC's push for ISOs to gain transmission assets, the number of OASIS nodes has been decreasing as ISOs have moved to consolidate the bulk of OASIS functions.

As ISOs gained prominence in the administration of transmission service markets, FERC moved to regionalize energy trading responsibilities as well as transmission system coordination and planning. With the passage of Order 2000, FERC established Regional Transmission Networks (RTOs). Order 2000 promoted transmission-owning organizations to implement or join an RTO so that regional high-voltage transmission systems would materialize. The differences between ISOs and RTOs are functionally nonexistent. Order 2000 developed criteria by which system operators could be deemed a FERC-approved RTO.

RTOs are administered by FERC and not the states where they operate. There are 7 existing RTOs that manage and supply roughly two-thirds of the total U.S. electricity demand (Penn State). Each RTO develops and leads its policy and markets. However, RTOs largely have the same responsibilities. First, RTOs manage the bulk power transmission system within their region. Second, RTOs ensure non-discriminatory access to the transmission grid to customers and providers. Third, RTOs deploy generation sources regarding supply and demand. Fourth, RTOs are responsible for the regional planning of generation and transmission projects. Fifth, RTOs manage markets for electricity generation services, excluding the Southwest Power Pool (SPP).

RTOs are very similar to the vertically integrated utility companies of the past, but there are several distinct differences. RTOs do not sell electricity to retail customers (Penn State). RTOs purchase electricity from generation sources and sell that electricity to utility companies in that region, which is then sold to end-use customers. RTOs do not earn profit during this process. RTOs do not own assets like generators, substations, transmission systems, or distribution lines. Instead, RTOs work with the operators of generators and transmission lines for project development. RTOs cannot control or force the operations of generators or transmission companies to build projects. RTO decision-making is administered by a stakeholder board comprised of electric sector continuances (Penn State). All policies passed by RTOs must be approved by FERC. RTOs must remain bi-partisan and neutral when making market decisions.

RTOs cannot force generation sources or transmission operators to build infrastructure. However, RTOs are responsible for reliable electricity delivery and grid functionality. RTOs manage regional planning of infrastructure and directly consult with generation source and transmission services operators where infrastructure needs to be built. RTOs create a variety of financial incentives for generation and transmission companies to invest in. One financial incentive commonly deployed for transmission services is the practice of fixed rates of return, approved by FERC.

Wholesale and Retail Electricity Markets

Roughly 40% of the U.S. electric grid system is run by utilities that generate electricity and sell it directly to customers. However, most electricity is purchased wholesale from a third party. Wholesale purchases can be made through bilateral contracts or the wholesale electricity markets managed by RTOs. In wholesale markets, generation sources are paid for 1. The energy provided to end-use customers 2. The standing capacity of electricity ready to provide at any time and 3. Ancillary services include a variety of operations such as frequency control, spinning reserves, and operating reserves (American Public Power Association). Ancillary services account for a very small share of market revenue.

Energy markets are the most important aspect of wholesale RTO markets. Energy markets are forward markets operated by RTOs to ensure that enough electricity generation is available on two timelines. The first is the “day-ahead market” which is used to determine which generators will operate during each hour of the following day. The second market is the “real-time market” which RTOs use to operate generators on an hourly basis. All energy prices are determined by RTOs under FERC verified legislation. Typically, the auction process is used to establish prices, whereby bids to sell power at a particular time are arranged in ascending order until there is sufficient power offered at a specific price to satisfy the power demand. All electricity is sold at the highest “market-clearing” price paid to generators that bid to provide electricity at or below the market-clearing price. RTOs typically max out the price of a bid at $1000 but can sometimes make exceptions for costs of electricity production. RTOs also employ forms of shortage pricing where electricity can peak above caps during stressful demand periods.

4 of the 7 U.S. RTOs utilize capacity markets to provide financial incentives for generation sources to maintain supply and add new investments into generation. (American Public Power Association). The term "capacity" refers to the responsibility of a utility company to always have enough power generation available to meet the needs of its customers. Peak demand will almost always occur during the hottest and coldest times of the year. To meet regular electricity demand and account for backup electricity, the amount of capacity that utilities must have its estimated peak demand plus reserve margins. RTOs determine this calculation in RTO-run capacity markets. Utilities determine calculations when operating outside RTO-run markets. There is limited technology currently to store electric energy, so RTOs must be communicating with generation sources to stand by during peak demand. Generation sources connected to regional transmission networks must always have fully operational equipment and personnel regardless of the amount of electricity it produces. Capacity payments cover these costs to secure reliable electricity delivery. Large customers that use lots of electricity also can agree to defer electricity back to the grid during peak demand response.

In capacity markets, generation capacity is set to produce electricity at least one year in advance (Penn State). For example, in the PJM Interconnection (PJM) RTO capacity markets, generators are expected to be able to produce electricity up to three years in advance. This timeline of electricity production availability varies in each RTO market. Three RTOs operate mandatory capacity markets, New York ISO (NYISO), PJM, and ISO-New England (ISO-NE).

All capacity used to meet reserve margins must be purchased through a capacity market auction operated by the RTO.

Ancillary services markets allow for RTOs to have diverse backup generation sources in cases of peak demand or high stress. “Reserves” refers to capacity that can be plugged into the grid within 60-, 30-, or 15-minute windows. “Regulation” refers to capacity that can change output on demand. Ancillary services vary and are very important for the stability and security of regional grid networks.

The origin of the electricity that consumers use varies. U.S. electricity markets have both wholesale and retail electricity components that are managed by RTOs. In wholesale markets, electricity traders and utilities are involved in the sale of electricity to consumers. Retail markets are more focused on the sales of electricity to consumers. Both markets can be traditionally regulated or competitive markets. Some parts of wholesale markets are traditionally regulated where vertically integrated utilities control all aspects of electricity flow to consumers. Vertically integrated utilities are responsible for the generation, transmission, and distribution systems that power consumers’ homes and appliances. Across the country there are also restructured, competitive, wholesale markets run by independent system operators (ISOs). ISOs utilize competitive market strategies, allowing independent power producers and non-utility generators to trade electricity. In these competitive markets, utilities provide retail electricity services to consumers and often own generation and transmission sources.

Retail markets are more regulated at the state level. In traditionally regulated retail electricity markets, consumers cannot choose the generation source for their power and must purchase from the utility in the given area. Traditionally regulated electricity markets are most popular in the Southeast, Northwest, and Western United States. In these states, the majority of renewable sources are utility-owned. This makes it difficult the implementation of comprehensive renewable energy projects in those states. Competitive retail markets let consumers choose between electricity suppliers. These electricity retail markets have allowed for competition between independent electricity providers in 24 states across the country. Out of these 24 states, 18 have adopted retail choice “which allows residential and/or industrial consumers to choose their own electricity provider and generation options, including renewable energy,” (EPA 2022). This policy enables flexibility in retail supply contracts as well as the location and scale of renewable sources.

Renewable energy options can be critically impacted by market structure as well as state and utility policies. In traditionally regulated markets with vertically integrated utilities, customers are limited to green products offered by their utility. Customers in competitive electricity markets can choose between electricity service providers. Both markets have distinct benefits and differences. Viable market strategies will be key for the nationwide adoption of renewable energy sources.

FERC Revisions to PUPRA 2020

The purpose of PURPA was to aid the U.S. in navigating an unpredictable energy market and facilitate the advancement of renewable energy facilities. In 2023, PURPA is still driving renewable development. As of 2017, “PURPA projects accounted for over 40% of the solar energy projects built in the United States” (Transformation Holdings). PURPA has been successful because it has forced electrical utility companies to purchase renewable sources when prices are lower than fossil fuels. This has led to vast changes in electric utility companies’ energy portfolios with increased diversification of renewable energy sources. With prices of renewables at an all-time low and other significant developments including the growth of wholesale and capacity markets, FERC recognized the vitality of updating PURPA legislation.

In 2020, FERC revised PURPA for modern applications. FERC granted state regulatory authorities more leeway to determine the avoided cost rates for sales of QF both within and outside of the organized electric markets (FERC 2020). FERC's revisions also gave states the ability to determine energy rates for QF contracts without having to include capacity rates. Lastly, FERC decreased the rebuttable presumption of non-discriminatory access to power markets from 20 megawatts to 5 megawatts for small power production facilities, excluding cogeneration (FERC 2020). FERC also finalized that QFs can qualify for legally enforceable obligation through demonstration of commercial feasibility and commitment to building under state-determined criteria.

PURPA legislation initiated the process for renewable implementation and recent changes have aimed to increase renewable production. However, accessibility to U.S. grid systems has become more complex with the emergence of ISOs and RTOs in the 1990s and early 2000s. ISOs and RTOs essentially run wholesale energy markets independently and according to their own political agendas. This can complicate the interconnection process for renewable generation sources and limit the effectiveness of economic investments dedicated to renewable projects. Chapter 3 will discuss the economic implications of a transition to 100% renewable generated electricity as well as the economic barriers that prevent the full realization of renewable benefits.

Chapter Three: Economic Impact of Renewables Implementation

Transmission and Distribution System Investments

As discussed in chapter 1, lack of critical investments into the physical structure of the U.S. electric grid system has put unnecessary financial stresses on taxpayers and the American economy. The U.S. electric grid system still primarily relies upon ACSR and ACSS wiring for transmission and distributions lines. These cables are extremely dated technology that frequently cause dissipation of electricity via released energy through heat. This loss of electricity is unnecessary and cost-burdening for taxpayers. The heat released during the transmission and delivery processes contributes climate change as well by increasing atmospheric temperatures. It also requires even further fossil fuels to be burned during the electricity generation process to account for lost electricity during transmission and distribution.

Adopting composite core conductors for transmission and distribution lines will limit the amount of heat that escapes into the atmosphere because composite core wiring has more efficient electricity conducting properties. Composite core conductors are also significantly cheaper to install into the existing grid system than ACSR and ACSS wiring. This is due to the low sag needed to support composite core conductors. ACSR and ACSS wiring require high sag, which means that transmission structures must be built higher and more frequently across a distance for functionality. Less materials will have to be used to build supporting transmission structures and less land will have to be cleared for the structures to be built. In a 2022 transmission construction project in the western U.S., Southwire Co. was required to build new transmission wiring while maintaining the same amount of electricity capacity. Charles Holcombe, manager of overhead systems and solutions at Southwire Co., stated that when design engineers installed composite core wiring, the distance between support structures was doubled to 1,200 miles (Utility Dive 2022). The installation of composite core conductor wiring needed half as many structures to be built for the new line with total project costs being less than 15% of what ACSR or ACSS project would cost (Utility Dive 2022).

Transmission and distribution lines across the country can be reconductored with composite core wiring. Rather than having to build new transmission and distribution lines, the wiring can be reconductored to increase capacity and reduce sag. When RTOs or utilities recognize that capacity needs to be increased across certain systems, new costly projects are no longer needed. When transmission lines need to be built across areas with challenging terrain, like waterbodies are marsh, the reduced sag factor from composite cores provide more flexibility for project planning. Once again, sag refers to the vertical difference between points of supporting structures and the lowest part of the conductor. The same crews that install ACSR and

ACSS are also fully capable of building composite core transmission systems. As such, the conversion to composite core wiring will be viable with the current workforce and will require minimal workforce development. Composite core wiring does not lose electricity from core magnetization. This is important as electricity will not be lost due to heat dissipation and will not contribute to rising atmospheric temperatures. Owners of renewable generation sources will be incentivized to sell electricity to the grid as they will not lose electricity in the transmission process. The switch to composite core conductors is clearly economically viable. New systems of wiring will last longer, require less maintenance, and need significantly less investment for the building of supporting structures. Lastly, core composite conductors will save taxpayers in electricity costs, increase electricity efficiency during peak demand, and will not contribute to climate change.

Economic Viability of Decentralization

The U.S. electric grid system evolved without overarching strategic planning. The grid expanded as the demand for electricity grew. Cities and towns with proximity to important American cities were the first to be connected to the emerging grid systems. Overtime, federal incentives propelled transmission companies to reach rural populations. Large electric generation and transmission companies consolidated. What has resulted from the sprawled evolution of the U.S. electric grid system is a centralized system with three major interconnection areas. RTOs and ISOs now are the leading managers of regional generation and transmission networks across the nation. RTOs and ISOs operate with centralized generation plants that must travel great distances through transmission lines, substations, and distribution lines to reach end-use customers. The makeup of centralized plants largely consists of fossil fuel sources: coal, natural gas, etc.

Centralized operations present several key difficulties. The first being, that centralized operations impede resiliency. When transmission lines are required to travel hundreds of miles to reach end-use customers, the transmission system is vulnerable to natural disasters and extreme weather events. The risk for transmission systems to be impacted by natural events is significantly greater than that of a decentralized grid where the supply is physically closer to the demand. Centralized power plants worked for RTOs and ISOs when fossil fuels were the only source of electricity because fossil fuel sources are not location dependent. Centralizing operations was convenient decades ago. However, with the emergence of renewable generation sources that are location dependent, grid systems must be decentralized.

Through the decentralization of regional grid networks with renewable implementation, electricity supply will be closer to end-use customers, resiliency and cybersecurity will be increased, and the grid will be decarbonized. Electricity can be supplied faster and more efficiently during peak demand or extreme weather events when the generation sources are closer to customers. As previously noted, outdated transmission and distribution lines that utilize ACSR and ACSS conductor wiring are susceptible to electricity losses and serious weather events. Decentralization of grid systems will save costs in electricity losses and will not require the construction of long-distance transmission and distribution lines.

Moving toward the decentralization of grid systems allows for customers to choose their electricity sources. Opting to use systems like distributed energy resources (DERs) empowers electricity consumers to make independent decisions about their generation sources. DERs refer to a range of small-scale electricity generation and storage devices typically linked to a decentralized grid. DERs provide diversification of economic options for customers who can buy or rent electricity supply from their localized grid system. Deploying DERs allow for customers to purchase decentralized electricity supply from renewable sources generated by neighbors and community members. Utilizing decentralized generation sources empowers communities to make independent electricity supply decisions that fit their specific needs. DERs also make it possible for communities to produce and distribute their own renewable electricity. Incorporating DERs into a decentralized system enables the democratization of electricity and empowers communities to become energy independent and resilient. Having multiple market options increases customer loyalty and retention, as well as more direct relationships with their electricity supply. Customers are becoming increasingly interested in having more control over their electricity decisions. The centralized grid system of the past does not provide flexible market options for customers and prohibits energy independence.

Centralized grid systems are more inherently prone to damaging effects from cyberattacks than decentralized systems. New decentralized systems are emerging such as blockchains and aggregated DERs that present viable cyber security solutions for resilience against hackers. Pete Tseronis, the moderator of a National Renewable Energy Laboratory (NREL) panel on the future of blockchain, defined blockchains as a "distributed digital records of actions agreed upon and performed by multiple parties," (McMahon 2022). Blockchains are verified through a vast number of users to validate transactions and add new blocks to the blockchain. This type of secured network is emerging as a feasible way to file important electricity contract agreements, customer information profiles, and other legal documents. NREL has been investigating the possibilities of utilizing blockchains for electricity market transactions for a few years. With the enhanced cybersecurity benefits of blockchain now being realized, it is very likely that soon blockchains will shape documentation moving forward.

New verification strategies in blockchain like the proof of stake process use significantly less electricity than the early forms of verification in blockchain. In contrast to the proof of work approach, the proof of stake mechanism involves miners utilizing their existing cryptocurrency holdings to acquire mining rights proportional to the number of coins they possess. When there is a block that requires validation, the blockchain system will randomly select a node to perform the task. The proof of stake process still requires some minute structural improvements for increased equity in access to verify blocks. However, this new form of digitally secure documentation will reduce blockchain mining by 99% in comparison to Bitcoin's proof of work process (Chow 22). Data aggregation from DERs could provide further opportunities for resiliency against cyberattacks and will be substantially commercially sustainable.

DER aggregation refers to the division of electricity supply into three independent markets including residential load, and commercial and industrial (Walton 2017). The DER aggregation process will combine and summarize individual data points and observations into a single representation. Aggregating can involve various mathematical or statistical operations such as averaging, summing, counting, or finding the maximum or minimum value. Utilizing DER aggregation will provide a more comprehensive and informative view of the data and make decentralized electricity distribution easy to manage. The decentralized distribution system consists of numerous nodes and intentionally lacks a central authority that could be vulnerable to strategic attacks (Energy Blockchain Network 2018). If one node were to be hacked, the system would be alerted and that node would be isolated, preventing further grid compromise. With a centralized system, it is much easier for hackers to disrupt the distribution system as all systems trace back to one generation source. As cyber security threats grow more serious and widespread, investment into upgrading decentralized systems with blockchain and DER aggregation will be critical for cyber security and resilience.

Investment into DERs, blockchains, and decentralized distribution networks will protect the U.S. electric grid from cyberattacks and extreme weather events. DER data aggregation and localized distribution systems will make strategic electricity distribution more efficient and easier to manage. DER aggregation blockchains will also increase resiliency against cyber-attacks by decentralizing the node network. Decentralizing the grid system with the incorporation of DERs will provide flexibility for renewable implementation that rely upon effective locations. The physical decentralization of the grid will facilitate the addition of renewable sources by providing flexibility on location effectiveness. Decentralization will allow customers to independently decide their electricity generation sources. Increasing economic options for customers and providing financial incentives for renewable implementation will increase customer relationships with their electricity supply and rapidly increase grid decarbonization. Installing localized distribution networks makes it easier for customers and communities to choose generation sources, store generated electricity, and sell electricity to the grid. The decentralization of the electric grid will increase cyber security and enhance energy independency. Next, the economic benefits of renewable generation sources implementation will be discussed on a macroeconomic level.

Limiting Curtailment

The combination of DER data aggregation and distributed networks with renewable generation source implementation has the capability to reduce curtailment in electricity markets. Curtailment refers to measures used to reduce electricity generation in order maintain the balance between supply and demand (Kury 2022). Curtailment is becoming a prevalent issue in

Southwestern and Western states that produce abundant solar electricity. When there are days that are extremely sunny, solar energy sources may produce more electricity than is demanded by the market that day. Grid operators will step in and reduce production to limit oversupply and financial losses. The price of generated electricity from solar and wind sources is significantly less expensive than fossil fuel generated electricity. Renewable sources also emit substantively less GHGs than fossil fuel sources.

The price of renewable generated electricity is at an all-time low and new technology like DER data aggregation, distributed networks, microgrids, and battery improvements will limit curtailment by distributing electricity more efficiently. The U.S. electric grid functions at 60 hertz, meaning that electricity flows back and forth 60 times per second (Kury 2022). This system ensures that electricity supply meets electricity demand. When the supply is lower than average, frequency will drop. When there is overproduction, the frequency will increase. Generation sources will be notified that they are oversupplying and producing below a targeted price and can disconnect from the grid. This is concerning as this process can lead to blackouts. The issue of curtailment and matching supply to demand presents viable opportunities for the implementation of new technologies to support renewable generation sources. Utilizing DER aggregation to localized distribution networks will enhance systematic recognition of electricity demand from separate markets including residential, commercial, and industrial. This will streamline efficiency between supply and demand and will allow for renewable sources to produce electricity continuously without having to disconnect from the grid with fear of financial losses from oversupply. This will rather provide producers of renewable electricity ana avenue to capitalize on these favorable weather conditions. Decentralizing grid operations with distributed networks directly improves transmission and delivery efficiency and reduces curtailment by providing pinpointed demand data.

Investment in microgrids with battery storage technology will facilitate the transition to renewable sources and limit curtailment. Microgrids are decentralized electric grid systems that operate with independent generation sources. Microgrids enhance energy independency and reduce the risk of blackouts by invigorating communities with their own generation sources and transmission and distribution networks. Battery storage technology can support the independence and resiliency of microgrids by providing ways for electricity to be preserved for peak demand or extreme weather events. Moreover, rapidly improving lithium-ion batteries will further enable the efficient storage of excess electricity generated from renewable sources. This will aid in reducing curtailment by allowing for renewable generation sources to produce the required supply for demand and store excess electricity for future use. Battery storage technology is still in its early stages; however, this technology will be instrumental for supporting renewable electricity generation.

National Workforce Benefits of A Renewable Energy Transition

Electrical plants using renewable energy sources present a key advantage over those continuing to use fossil fuel plants because they are more labor-intensive. Thus, more jobs will be created per dollar invested in renewable energy than traditional electricity generation technologies. According to the Wisconsin Energy Bureau,

> "Investment in locally available renewable energy generates more jobs, greater earnings, and higher output ... than a continued reliance on imported fossil fuels. Economic impacts are maximized when an indigenous resource or technology can replace an imported fuel at a reasonable price and when a large percentage of inputs can be purchased in the state," (NREL 2022).

For states and municipalities looking to increase electricity supply, it has long been common practice to import fossil fuels from out-of-state suppliers. This translates to exporting energy dollars and losing the potential to create local jobs. Instead states and municipalities can opt to develop localized renewable resources and distribution networks which will create a multitude of jobs through construction, operation, and maintenance. Investments in local renewable resource initiatives are sustainable long term because electricity is generated from sources that will last, unlike fossil fuel sources which are finite.

Investments in renewable technologies have ripple effects across local economies. Through a concept known as the 'multiplier effect,' wages and salaries earned by renewable energy industry employees generate additional income and jobs in the local economy, (NREL 2022). Additionally, when taxes are paid by renewable energy companies, local economies benefit which contributes to reductions for taxpayers in communities. Renewable generated electricity contributes higher tax revenue than generating electricity from fossil fuels. The California Energy Commission found that solar plants yielded twice as much tax revenue as traditional natural gas plants, (NREL 2022). Through different economic incentives, renewable implementation can reduce utility bills for individuals, companies, and communities.

Transitioning the U.S. electrical grid system to 100% renewable electricity will have significant economic benefits on the micro and macro levels. Renewables are the fastest-growing electricity source (IEA). In the United States, the renewables industry grew by 42% from 2010 to 2020, (Center for Climate and Energy Solutions 2022). Most of the increase has come from hydro, wind, and solar power. Renewables make up roughly 20% of electricity produced currently, but this is expected to jump to 35% by 2030, (Center for Climate and Energy Solutions 2022). The impact of this growth is reflected in job creation and the national economy.

The transition to renewables is boosting employment opportunities in the United States with green jobs rising in every sector, (United States Energy and Employment Report 2022). The fast growth of renewable industries is simultaneously creating rapid job growth. Renewable energy jobs 2021 accounted for 40% of total energy jobs in 2021, despite only comprising a modest sum of America's electricity mix. (World Economic Forum 2022). As the renewable industries continue to increase, renewable jobs will become the most popular employment opportunities in the energy industry.

There is a wide variety of job opportunities arising as renewable technologies advance. In the motor vehicles sector, the hybrid electric vehicles industry experienced the biggest spike in employment with over 23,000 new jobs, (World Economic Forum 2022). This contributed to an overall 25% jump in carbon-reducing motor vehicles in the United States. Other energy-efficiency technologies including heating, ventilation, and air conditioning added over 17,000 jobs in 2021, seeing an overall increase of 3.3%, (World Economic Forum 2022). Smart grids have been growing tremendously as well, outpacing all other green technologies. Smart grids are relatively new to the industry; however, their impact will be key in upgrading existing grid systems. Jobs in the smart grids grew by 4.9% in 2021 with batteries for electric vehicles and electricity storage growing by 4.4%, (World Economic Forum 2022). The job growth across these renewable energy technology industries is a key indicator that renewable sources have the potential to create thousands of employment opportunities across the country.

Becoming A Net Exporter of Renewable Technology

The U.S. is one of the leading global manufacturers of renewable energy systems, however, most of this production is exported to developing nations. This is due in part to the lack of viable fossil fuel reserves in many developing countries. There is also a lack of extensive, effective electricity grids, which gives a high potential for renewable energy technologies to be implemented. Electricity demand is growing at an all-time high in developing countries. Renewable technologies can aid nations in the mitigation of climate change related extreme weather events while strengthening resilience against cyber-attacks and volatile fossil fuel costs. Rising fossil fuel costs triggered by the war in Ukraine are disproportionately affecting developing nations relying on imports for their energy consumption, (Papathansiou 2022). Developing nations do not possess the financial ability to install and maintain large, new, electrical infrastructure. However, steeply declining costs in renewables can make investments in energy-efficient infrastructure more reasonable, especially as the prices of fossil fuels surge amid the war in Ukraine.

The U.S., being one of the leading manufacturers in renewable technologies can increase its production of renewables and help developing countries develop their sustainable energy future by increasing total exports of renewable technologies. The U.S. recently became a net exporter of energy resources in 2019 with exports increasing each year. While the majority of these exports are crude oil and natural gas, the U.S. has an opportunity to increase its exports of renewables as their prices continue to drop globally. Investment in the domestic production of renewable technologies will be crucial for the economic growth of the U.S. This investment will have significant long-term payoffs. Renewable resource implementation into the national electric grid will strengthen resiliency and reliability. Renewable resources are infinite, unlike fossil fuels which will not last forever. Therefore, the U.S. cannot rely upon fossil fuels as a method of electricity generation in the future.

Investing in the domestic production of renewable technologies will strengthen U.S. supply chains. This is important since the U.S. relies exclusively on Chinese imports for certain technologies such as solar panels (Sutton, Williams 2021). Now will be the time for the U.S. to invest as renewable technologies continue to develop and expand. The costs for renewable sources are currently decreasing, however, being reliant upon Chinese imports for these technologies is unsustainable and weakens the supply chains for these materials. By investing in the domestic production of renewable technologies, the U.S. national workforce will increase, and international labor will not have to be relied upon.

Renewable Plants are Cheaper to Build Than Fossil Fuel Plants

Russia's ongoing invasion of Ukraine has resulted in increasing costs for the construction of new coal and natural gas powerplants in the U.S. Russia's invasion of Ukraine has contributed to the burgeoning costs of fossil fuels. The surging costs of fossil fuel plants have opened new opportunities for the construction of renewable projects. New wind and solar projects cost roughly 40% less than coal or natural gas plants, (Baker 2022). The price of new onshore wind projects costs about $46 per megawatt hour while new solar plants cost $45 per megawatt hour. In comparison, new coal plants cost $74 per megawatt hour, and natural gas plants cost $81 per megawatt hour, (Baker 2022). The costs for building new renewable projects will cost the U.S. significantly less while also reducing carbon emissions by a wide margin. Additionally, renewable sources are infinite and sustainable for future electricity demand; unlike fossil fuel plants that are finite and prone to drastic increases in costs due to global conflicts.

While fossil fuel sources still power the wide majority of the country's electric grid, U.S. dependence on these sources is decreasing. Power sector coal demand has decreased in nearly every state since 2007. Between 2007 and 2020, the use of steam coal in the U.S. dropped by 61%, (EIA 2022). In 2020, national shutdowns reduced overall energy usage, accelerating the downturn of coal consumption. As electricity demand lowered, utilities and grid operators opted to move away from coal, the most expensive form of energy. This resulted in a 20% drop in coal generation, the largest single-year decline in coal usage, (Kirk 2022). However, in 2021, production shortfalls increased the prices of natural gas, thus allowing for coal usage to increase once more. Coal-powered electricity generation then increased by 17% in 2021. However, this recent surge was viewed by the EIA as temporary and coal usage has continued to decrease. In 2022, coal-powered electricity generation dropped from 23% to 20% and will continue decreasing as the prices of renewable sources are significantly cheaper. U.S. renewable energy sources could undercut between 75% to 91% of existing coal power plants, (Ambrose 2021). This means that replacing outdated coal power plants with new renewable sources will be cheaper.

According to TransitionZero, a not-for-profit climate analytics company, it is now cheaper to switch from coal sources to renewables than it is to switch from coal to natural gas. This is due to two main factors, the first being that renewables and clean energy technologies are becoming cheaper each year. Secondly, gas prices are currently very volatile with ongoing world conflicts like the Russia and Ukraine crisis. A common misconception is that switching from fossil fuels to renewables is inefficient and not cost-effective, however, “the carbon price needed to incentivize the switch from coal generation to renewable energy for storage has dipped to a negative price,” (Tao 2022). Switching from coal power plants to renewables will save construction costs.

Shifting to renewable plants will provide key social benefits for marginalized communities. The fossil fuel industry causes public health hazards, which result in the premature deaths of hundreds of thousands of individuals annually in the United States. Moreover, these dangers disproportionately affect Black, Brown, Indigenous, and underprivileged communities

(Green Peace 2021). Fossil fuel plants are strategically sited in marginalized communities because there will be less resistance to the hazardous effects it produces. Often, fossil fuel plants employ members of marginalized communities to work at the plants. These jobs present serious health risks. Renewable plants will not pollute the air in surrounding neighborhoods and municipalities. This will eliminate the extremely harmful health effects from air pollution in disadvantaged communities. As noted previously, renewable plants are more labor intensive than fossil fuels, thus implementing renewables will require more jobs to be filled. These jobs will be environmentally safe and pose no adverse health risks. By eliminating fossil fuel plants from disadvantaged communities, these populations will no longer be sources of disproportionate health defects and can experience safe working environments.

With the decentralization of the U.S. grid system and deployment of microgrids, grid systems can become independent and localized. This will enable all communities to generate and distribute their own clean energy. Decentralizing the electric grid will give communities autonomy over their electricity markets. Appropriating DER aggregated data will increase distribution efficiency and allow for communities to independently produce electricity and sell it to the grid. Increasing the democratization of electricity through renewable implementation will be essential for creating equitable economic solutions. Democratization of electricity will be reviewed in detail in chapter 4.

International markets for renewables continue to grow as well as the demand for electricity and grid systems from developing countries. The U.S. can expand the production of renewables to export to developing countries right now as the renewable sources remain low. Demand is going to continue growing rapidly over the next decade

Environmental and Social Costs

Various negative externalities associated with electricity generated from fossil fuel plants threaten human health and the environment. For clarity, negative externalities are the costs of doing business that are not directly included in the final cost or benefit of the service. Fossil fuel plants do not include the impact of GHG emissions or air pollution during the process of fossil fuel harvesting, electricity generation, and transmission and distribution. The environmental impacts of fossil fuel reliance are clear: ecosystem service and biodiversity deterioration, air pollution, contribution to rising temperatures and climate change. Vital ecosystem services like the carbon cycle mentioned in chapter 1 are extremely complex which makes it difficult to price estimate. Similarly, biodiversity and air quality are extremely intricate processes that have not been fully realized economically. However, it is very feasible to define negative effects on the environmental and human health economically.

According to the Center for Research on Energy and Clean Air, in 2018, economic and health costs derived from the air pollution of fossil fuel burning totaled $150 billion in losses (Mittelman 2020). These losses came in the form of work absences, years of life lost, and premature deaths all due to the lack of air quality. In 2018 the U.S. was one of the top three leading nations in premature deaths related to air pollution with 230,000 (Mittelman 2020). The burning of fossil fuels for electricity generation is unsustainable for the environment, human health, and the American economy. Transitioning to renewable sources for electricity generation will improve the American economy by reducing healthcare costs associated with air pollution. Higher air quality will result in less work absences which will increase workplace productivity and the economy.

Renewable Energy will substantively decrease GHG emissions and contribute to decreasing temperatures. This will reduce the rising of sea levels which are a concerning threat for coastal U.S. economies. By 2100, it is estimated that the U.S. must invest over $300 billion in critical coastal infrastructure to mitigate rising sea levels (Burgas, Gomez-Diaz, Garcia-Serrano, Gonzalez-Solis, Ramos 2021). Implementing renewable generation sources will be an important step toward reducing impacts of sea level rise. In addition to sea level mitigation, the decarbonization of the U.S. electric grid system will reduce the effects of ocean acidification. This will invigorate coastal communities that rely upon the ocean for food sources and other economic activities.

Decreasing the GHG emissions and atmospheric temperatures will impact the American economy on land as well. The agricultural sector and farmers will have normalized growing season schedules, optimizing agricultural output. As noted in chapter 1, the increased temperatures of early spring begin the process of evapotranspiration earlier. This has shortened the length of time in summer that soil can grow crops. Drier soil from desiccating western states has increased the spread of wildfires exponentially. This has caused insurmountable economic damages with neighborhoods, cities, and important resources being destroyed. Wildfires have been very costly for reconstruction investment needed afterwards. The increase of wildfires presents concerning risk for increase of healthcare costs as well. The damages on soil and earth from wildfires impacts the amount of land dedicated for agriculture and can burn entire crop yields. Opting to renewable generation sources will nearly eliminate rising temperatures and GHG emissions that facilitate increased wildfire spread which will effectively reinvigorate the agricultural sector.

Transitioning to renewable generation sources will eliminate the extremely damaging effects of fossil fuel harvesting and transportation. Oil spills and leaks are extremely harmful for the environment and the American economy. In 2008, the collapse of coal ash pond at a

Tennessee Valley Authority power plant smothered 300 acres in sludge; this resulted in an $825 million cleanup (Environment America 2009). Renewable generation sources currently require critical minerals that are environmentally degradational to mine. However, renewable technology is new and evolving fast. As the U.S. federal government invests into the U.S. electric grid with a renewable generation source implementation, the renewable industry's economies of scale are set to grow. Investing into renewable technology research and development will refine the materials needed. Overtime, the scaling of research development and planning will reduce negative environmental effects.

Chapter Four: Political Action in Electric Grids

Transforming the electric grid to use 100% renewable energy will be the most impactful way to reduce the effects of climate change in the U.S. Many states, as well as the federal government, are adopting 100% clean energy goals by varied deadlines in the coming decades. States and federal programs have released economic incentives to fund research and deploy renewable energy sources. However, the political infrastructure supporting the fossil fuel industries prevents effective renewable implementation and development. Fossil fuel corporations dominate the energy sector and are responsible for creating policies that support private interests instead of prioritizing societal and environmental goals. Current political institutions will need to be reorganized for effective renewable implementation. This will strengthen the use of economic resources and state and federal incentives to adopt renewable energy.

Issues with RTO Electricity Markets Management

Throughout most of the country, RTOs control the electric grid under FERC supervision. Many of these RTOs were formed in the 1990s and continue to have a “distinct intellectual lineage in the privatization and new governance movements of that time,” (Welton 2021). RTOs are structured like private industry groups where industry members vote and decide on the regulations for regional electricity markets and grid operation. While this system has been effective for grid reliance, this political arrangement has made it incredibly difficult for clean energy to progress. RTOs have not incorporated clean energy or energy conservation policies into grids and market regulations even when these implementations lower costs and enhance market functionality, (Welton 2021). Federal energy policies support the RTOs' decisions to continue promoting the usage of fossil fuels, namely though lavish direct subsidies. Oil Change International, a clean energy advocacy organization, estimates the total amount of U.S energy subsidies to be around $20.5 billion annually with $14.7 billion in the form of federal subsidies and $5.8 billion in state-level subsides, (Generation180 2022). 80% of these subsidies are delivered to oil and gas production in the form of deductions and tax exemptions “that result in massive, avoided costs for fossil fuel producers,” (Generation180 2022). U.S. energy subsidies support RTOs to prioritize the continuation of fossil fuel production and inhibit grid decarbonization goals.

Over the last 20 years, RTOs have gained influence across the country. However, the extent of RTO authority varies regionally. When FERC initially developed RTOs, the goal was to “ensure non-discriminatory access to privately owned and managed transmission infrastructure,” (Welton 2021). FERC was aware that RTOs may have to increase their responsibilities in monitoring electricity markets. At the beginning of their creation, this role was not clearly defined. Yet, overtime, RTOs grew to have a large role in regulating electricity markets. RTOs now manage markets for electricity trading and technical support services. This has led to RTOs creating eligibility and bidding rules for electricity markets. FERC has additionally increased the responsibilities of RTOs to manage transmission planning and cost allocation. This means that under each region that RTOs operate, there must be specific procedures for transmission grid expansion and coordination with utility members for cost allocation.

RTOs have also expanded their control over resource adequacy which was typically designated to state authorities. For example, in regions such as PJM, ISO-NE, and NYISO, capacity is centrally regulated. These regions have states that require the divestment of generation assets which can cause issues in the utility-scale planning for resource adequacy, (Welton 2021). In response to these issues, eastern RTOs have centralized capacity markets by assigning capacity obligations to all utilities in that region to meet end-use customers. Utilities are then required to purchase adequate capacity through auctions from different generation companies. Instead of state authorities planning capacities and deciding the resources receiving investment, RTO-regulated markets make administrative decisions. The “layering of capacity markets on top of energy markets has proven a controversial and unstable element in the eastern RTOs,” (Welton 2021). Due to the RTO administration in these regions, states have had less autonomy to implement renewable sources for electricity generation. RTOs effectively administer the generation source makeup of states within the governing region. The bias against renewable sources' participation in electricity markets is notable in how RTOs define ‘state support’. In the RTO definition of ‘state support,’ there is an overwhelming inclusion of state-led policies that promote clean energy, while other historical federal and state subsides supporting fossil fuel sources are not included. This intentional exclusion of fossil fuel-supported subsidies in the definition of ‘state support’ in RTO reforms allows for fossil fuels to continue being prioritized.

RTOs have been very slow to address existing electric issues such as demand response, electricity storage systems, and transmission policies. Certain RTOs have also been very misguided and aggressive against the implementation of renewables as this does not fit current models or goals. The implementation of renewables in ISO-NE and PJM, two markets with mandatory capacity markets, has been especially slow. These two RTOs have recently introduced capacity market reforms that make it incredibly difficult for renewables to compete in these markets. States in the ISO-NE and PJM regions will face many challenges trying to reach their renewable sources and grid decarbonization goals. The RTOs in these regions believe that resources receiving ‘state support’ creates price suppression and impede the market’s ability to support existing resources.

FERC approved RTO reforms to ISO-NE capacity markets in 2018 and finalized approvals for PJM capacity market reforms in 2020. FERC created further exclusions on market participation in PJM to additional resources receiving state support, these resources mainly being renewables. These new FERC additions to PJM markets will make renewable implementation difficult by limiting renewable participation in regional capacity markets. This makes it very expensive for states to incorporate renewables into their electricity generation and will prolong state goals to decarbonize grid systems.

RTO market reforms can be viewed as "protectionist maneuvers by incumbents—in particular, fossil-fuel generation owners—to prop up the fossil fuel industry against encroachment by [renewable] resources," (Welton 2021). The emergence of RTOs as policymakers has been economically ineffective. The ISO-NE and PJM regions have not indicated any need for expanding capacity markets. Between 2008 and 2017, the PJM region demands for capacity markets remained relatively flat, however during that period PJM added 15,000 megawatts of unneeded electricity generation—almost all coming from natural gas, (Welton 2021). These additions have exceeded regional capacity and have essentially invested in an unnecessary generation. The North American Electric Reliability Corporation (NERC) handles the standard-setting for target reserve margins for each region across the U.S. More specifically, NERC identifies the percentage of supply that each region should keep above peak demand to enhance reliability. In the summer 2018, NERC identified PJM's target reserve margin to be 16.1%, however, PJM's actual margin that summer was 32.8%, (Welton 2021). Regions with capacity markets across the U.S. have produced similar inefficient results, which has consequence consumers paying over $1 billion annually for unneeded fossil fuel investments.

RTOs have continued to discriminate against renewables with new policy implementation regarding 'fuel security'. Notable plans in recent years under former President Donald Trump and the Department of Energy have opted to subsidize coal and nuclear power as 'fuel secure' resources. However, these plans have not been enacted as FERC in 2018 did not recognize these fossil fuel sources as grid resiliency enhancing. These abstract and undefined concepts of 'fuel security' are still currently present in RTO agendas. Most recently, ISO-NE passed a short-term solution where ratepayers subsidize uneconomic fossil fuel plants by approximately $150 million per year to provide winter energy security, (Welton 2021). Despite serious inquiries from NERC, FERC's "procedural rules allowed the proposal to go into effect in August 2019 due to lack of a quorum to vote the proposal up or down," (Welton 2021). This recent policy passage has drawn concrete criticisms that RTO incumbents will continue to push their fossil fuel agenda around vague concepts of 'fuel security.' Without proper political oversight, RTOs will most likely be able to continue these current practices. This will exhaust taxpayers all while investing in fossil fuel systems that do not contribute to grid resiliency or efficient electricity storage.

While RTOs in ISO-NE and PJM have been particularly aggressive in the protection of fossil fuel generation and disbarment of renewables implementation, not all RTOs share these qualities across the country. MISO and SPP have been two of the leading RTOs in integrating wind into their electricity generation systems. California has also been a major leader in promoting comprehensive DER and storage integration. California is one of the first regions to not rely upon RTOs for transmission governance. This has proven effective in the implementation of renewables as well as capacity efficiency as the state does not have to adhere to the fossil fuel promotion of RTOs. Regional differences in RTO governance have contributed to imbalances in the national structural transmission and generation services across the country. Reducing RTO governance will be important to increasing renewable competition in capacity markets.

Political Restructuring of Electricity Markets

Chapter 3 presented the economic viability of decentralizing physical grid components including the generation sources and transmission as well as distribution networks. Localizing the authority of electricity markets empowers community energy independence. Without oversight from RTOs that promote fossil fuel agendas, communities can feasibly reach renewable energy installation targets. Invigorating local autonomy over electricity markets will increase economic efficiency as incentives created for renewable implementation can be fully utilized. Applying new technologies like DERs and smart grids to decentralized electric grid systems will increase local municipalities' ability to manage electricity generation and transmission. This will eliminate the economic losses that RTOs create when unsuccessfully attempting to mitigate supply and demand. As various battery technologies improve, electricity storage will be managed more effectively. This will limit curtailment and strengthen community resiliency.

Decentralizing political decision making of electricity markets will increase the democratization of electricity. State and federal incentives included under the Inflation Reduction Act of 2022 (IRA) are making it possible for communities to invest in renewable technology. The IRA legislation "is the most significant climate legislation in U.S. history" (EPA). This bill will accelerate renewable growth as well as the accessibility and equity of electricity and grid resources tax and production incentives. The Investment Tax Credit (ITC) and Production Tax Credit (PTC) allows taxpayers reduce a portion of the cost of renewable energy systems from their federal taxes (EPA). The Inflation Reduction Act will extend the Investment Tax Credit (ITC) of 30% and Production Tax Credit (PTC) of $0.0275/kWh (2023 value) until at least 2025, provided that projects with over 1 MW AC meet the prevailing wage and apprenticeship requirements. However, starting from January 1, 2025, the traditional PTC/ITC will be replaced by the Clean Electricity Production Tax Credit and the Clean

Electricity Investment Tax Credit for systems placed in service (EPA). Further bonus credits are available that aim to increase accessibility of renewable energy in disadvantaged communities.

Section 48(e) under the IRA aims to provide enhanced access to tax credits for clean energy, prioritizing disadvantaged communities and populations affected by environmental injustice. Environmental justice criteria must be met for eligible bonus ITC credits (EPA). Additionally, only solar and wind plants are eligible in 2023 and 2025. However, over time more renewable plants will be included under different tax credits. Providing a variety of tax credits for disadvantaged communities includes all Americans in the renewable energy future. Decentralization of the U.S. electric grid system allows for communities to explore different economic options for electricity generation. Scaling technologies like DERs, blockchain, and microgrids will enable people to more easily trade electricity in their communities and also to the grid.

Blockchain mining processes are currently very energy intensive. Large cryptocurrency companies like Bitcoin utilize mining processes to verify the authentication of transactions. The proof of work process is the predominant mining process being utilized currently. This process is responsible for contributing exorbitant amounts of carbon emissions due to the excessive amount of electricity needed to power the nodes in the blockchain system. Computers used in the mining processes for blockchain require high-processing software to ensure security against cyber threats. The electricity demand to support the proof of work mining processes are comparable to countries' total electricity demand. As blockchain markets continue to grow, it is imperative to find solutions to mitigate the electricity usage rates in mining processes. As mentioned in chapter 3, scaling the proof of stake process will provide a viable solution to diminishing electricity demand and emission rates. This technology is also fairly new, therefore the solutions for mitigating electricity demand and optimizing its usage are still being developed and refined.

IRA legislation has streamlined tax credit monetization through new direct pay and transfer options. The option of direct payment enables eligible tax-exempt organizations, including state, local, and tribal governments, rural electric cooperatives to directly convert particular tax credits into monetary funds (EPA). This will include a variety of renewable energy credits like the ITC and PTC. Entities that qualify for this provision have the choice to consider these tax credits as tax payments eligible for refunds. If these entities pay more than their tax liability for these credits, they can receive a direct payment from the IRS. Under the IRA, taxpayers who meet the eligibility criteria and are not tax-exempt entities can transfer some or all of specific tax credits, such as the ITC and PTC, to a third party without any pre-existing relationship. The IRA introduces direct pay and transfer options for tax credit monetization. Eligible tax-exempt entities can convert specific tax credits into monetary funds, while eligible taxpayers who are not tax-exempt entities can transfer credits to unrelated parties. This section of the IRA makes tax credit monetization more straightforward and efficient.

Providing direct monetary benefits of tax credits with flexible transfer options is a guiding step in the process of decentralizing energy authority. Involving communities and businesses incentivizes direct autonomy over generation and distribution options. Developing more incentives like tax credit monetization will require less authority from RTOs that block state created renewable tax incentives. Instead of incurring economic loses from ineffective and mismanaged RTO investment, states and municipalities can take full advantage of federal incentives and plan their own future.

As mentioned in chapter 1, the interconnection queue process is mismanaged and ineffective in connecting renewable generation sources to the grid. A significant challenge in the development process for most renewable energy developers is the lack of transparency regarding interconnection costs and timelines. Each year, the interconnection process grows longer with more renewable generation sources vying to be added. In the case of the PJM RTO, the interconnection queue has reached unparalleled levels. As the pipeline of renewable projects continues to grow, the PJM staff is struggling to cope with the overwhelming surge of requests. Reports of interconnection study results coming in over one year late has become common (Coller 2021). Delays in the development process generates uncertainty around which party bears the responsibility and cost implications of potential interconnection facility upgrades. Developers operating in PJM are now more frequently demanding PPA termination rights, which require buyers to take on a higher level of development risk, if necessary, interconnection or permitting approvals are not granted. In certain cases, buyers may need to provide developers with a PPA exit ramp, and it may be necessary to re-open PPA price negotiations to improve the chances of successfully executing the project. In an already highly competitive market, the backlog in PJM's interconnection process is exacerbating the complexity and uncertainty of PPA contracting.

The RTO governance of interconnection queues has proven to be substandard and incapable of handling the future implementation of renewable generation sources. The nature of centralized operations inherently hinders productivity. Localizing the electric grid system will be significantly more viable for processing interconnection studies. Renewable sources utilize natural forms of energy and are therefore location dependent. Decentralized operations can more effectively assess cost allocations for developers and process interconnection studies based on the specific needs of local communities and their energy demands. This could ultimately result in a more efficient and cost-effective process, allowing for better integration of renewable energy sources into the grid.

The notably slow pace of transmission line expansion is impeding the integration of renewable energy projects into the electric grid, hindering progress towards grid decarbonization. In 2020, total U.S. electric grid capacity was calculated to be 1,148 GW (University of Michigan 2020). Currently, "over 1,000 gigawatts worth of potential clean energy projects are waiting for approval," (Gates 2023). The lack of construction of new transmission lines has prevented the full realization of renewable energy projects. From 2013 to 2020, transmission lines have only expanded at 1% each year (Clifford 2023). This slow progress is glaring and impeding the effectiveness of the IRA legislation. In order to install all of the renewable projects waiting in interconnection queues, construction must expand 2.3% each year (Princeton University 2022). RTOs are struggling to coordinate transmission projects due to competing interests of stakeholders and project cost allocation debates.

There have been some gradual developments at the federal level concerning transmission infrastructure. The IRA approved a $5 billion budget for transmission line construction, however this not nearly enough (Clifford 2023). The "Building a Better Grid" initiative, led by the U.S. DOE, has been incorporated into the Bipartisan Infrastructure Law signed by President Joe Biden. The initiative aims to foster collaboration and investments towards the advancement of the country's power grid infrastructure. This initiative covers a wide variety of activities including a $2.5 billion transmission facilitation program, $10.5 billion Grid Resilience and Innovation Partnerships Program, and a $760 million Transmission Siting and Economic Development Grants Program (DOE). While these projects are indeed a step in the right direction, the effective management and utilization of these federal resources is lacking. It will be imperative to restructure RTO governance and delegate regional transmission planning to transmission-owning utilities with federal oversight.

Chapter Five: An Opportunity for Resilience and Sustainability

There are glaring weaknesses in the physical aspects of the grid in the transmission and distribution structures. The outdated technology supporting existing grid infrastructure is incapable of efficient delivery during peak demand and extreme weather events. The first subsection in this chapter will provide solutions for improving transmission and distribution technology.

The decentralization of the U.S. electric grid will be key for effectively managing electricity transmission and distribution. Decentralization will improve the efficiency of delivery and grid budgeting. The second subsection will highlight how emerging technologies such as DERs, blockchain, microgrids, and batteries will support decentralized networks. Additional benefits of such a system include the democratization of electricity and improvements in energy markets, which will also be explained in detail in the second subsection.

The fossil fuel generation sources that the electric grid utilizes are socially and environmentally degradational. The transition to renewable generation sources is necessary for effectively reducing GHG emissions and combatting climate change. Renewable generation sources will need to be implemented expediently. However, existing RTO governance prohibits the effective adoption of renewable energy sources. Solutions regarding the political restructuring of grid operations will be discussed in the third subsection.

Upgrading Transmission and Distribution Lines

The U.S. will have to improve the resiliency of its electric grid systems by investing in the physical reinvigoration of transmission and distribution systems, substations, and transformers. As climate change weather-related events continue to worsen due to a variety of factors, mainly GHG and carbon emissions, the outdated infrastructure for the U.S. electric grid systems will need to be improved. By 2040, over 100,000 miles of transmission lines will require replacement, (Bowie, Oumansour, Underwood, Yurkevicz 2020). Creating a new transmission network will be critical for meeting future electricity demands.

As mentioned previously, ACSR and ACSS wiring is not sustainable technology for transmission and distribution lines. ACSR and ACSS wiring is inefficient in its delivery as the wires are prone to electricity dissipation through the release of heat. Switching to composite core conductor wiring will be a crucial first step in transforming the physical components of the grid system. Composite core conductor wiring enables the transmission of higher voltages of electricity, allowing for a greater amount of electricity to be transported at any given time. This will be more effective for electricity delivery during peak demand and extreme weather events. The cost of installing composite core conductor wiring will be significantly cheaper than constructing ACSR and ACSS wiring. This is due to the low sag required for composite core conductor technology. About half as many supporting structures will be required for construction and existing crews that install ACSR and ACSS will be able to build the composite core conductor infrastructure.

The recent IRA has approved federal funding for the expansion of new transmission lines. However, the budget allocated for this construction is inadequate for the proposed expansion. Federal funding for new transmission and distribution lines will have to increase. The leadership and management of transmission expansion projects must also be improved for efficiency and cost-effectiveness. Decentralizing the authority of transmission expansion will be critical for project success. Centralized RTO administration cannot successfully handle transmission expansion responsibilities. The following subsection will discuss how proposed decentralization of the U.S. electric grid will substantially improve the transmission and distribution processes as well as the adoption of renewable generation sources.

The Benefits of Decentralization

The centralized, one-way, grid system that the U.S. currently relies upon is inefficient, with many problems inherent to its design. Electricity must travel long distances from central power plants, over transmission and distribution lines to consumers in cities and towns. Because the current electric grid is a one-way system, issues in one location can cause ripple effects down the line in other locations. These issues are compounded by transmission and distribution lines that are prone to disruptions due to their old age. Electricity demand is only going to increase across the country in the coming decades. There will simply be a need for updated and novel infrastructure to meet this demand.

The current unidirectional model is being replaced by a newer bidirectional model based on efficient distributed generation and utility-scale renewables. This model is significantly more flexible and relies less on centralized infrastructure. Decentralized electricity grids offer the advantage of transferring, storing, and harvesting electricity or heat in smaller units located closer to consumers. This localized generation and storage will improve efficiency by eliminating electricity dissipation that often occurs when electricity has to travel long distances over transmission and distribution lines. This dissipated electricity brings unnecessary costs to taxpayers and is also environmentally harmful. Installing localized grid systems where transmission and distribution systems travel short distances to meet consumers will reduce carbon emissions and improve efficiency.

Localizing electric grid systems across the U.S. can be effectively initiated through the utilization of DERs, blockchain, microgrids, and battery storage. Implementing DER technology locally will facilitate the full realization of small-scale electricity generation and distribution. DERs allow for customers to purchase decentralized electricity supply from renewable sources generated by neighbors and community members, making it possible for communities to produce and distribute their own renewable electricity. Building microgrids and battery storage devices will enhance local grid resiliency and sustainability.

DER data aggregation will empower communities' ability to make energy decisions independently. Organizing data on electricity supply and demand through this form of technology will increase transmission and distribution efficiency. By aggregating DER data, communities will have access to more accurate and timely information about their electricity usage, which can help them identify opportunities for energy efficiency and cost savings. This data can also be used to improve grid planning and operations, as well as inform energy policy decisions at the local and regional levels. Battery storage will play an important role in localized grid systems by storing excess energy generated by DERs during periods of low demand, and releasing that energy during periods of high demand. This can help balance the grid and reduce strain on renewable generation sites during peak demand hours. Combining battery storage with DER aggregation can improve the overall efficiency and reliability of a localized grid system.

Blockchain technology can enhance the security and transparency of energy market transactions and help ensure that customers receive fair compensation for any excess energy they generate and sell back to the grid. The decentralized nature of blockchain technology ensures that no single entity controls the flow of information or transactions. By using blockchain, customers can securely and efficiently trade energy with their neighbors and community members. All transactions can be traced and verified easily. Operating energy markets through blockchain will strengthen cyber security and resilience against cyber-attacks. Current centralized energy markets cannot provide the same level of security and data quality assurance as blockchain markets. The implementation of blockchain technology in energy markets has the potential to revolutionize the trading and distribution of energy, creating a more secure, transparent, and efficient system that benefits both customers and the overall energy grid.

Improving the democratization of energy is crucial for the future of energy markets. The aforementioned technologies will be essential for achieving this goal. However, these technologies are still in early development and require significant investment from the federal government to scale and increase efficiency. More specifically, blockchain technology and battery storage need to be developed. As previously discussed in chapter 4, blockchain technology is highly energy-intensive, and mining processes consume an exorbitant amount of energy. With increased investment and development, the energy used in these processes will decrease over time. Battery storage technology is a vital tool for establishing self-sufficiency in localized grid systems, reducing dependence on the centralized power grid, and enabling the integration of more renewable energy sources. As battery storage technology improves, decentralized grids can become fully autonomous.

Decentralizing the U.S. electric grid system will be beneficial for increasing electricity equity and access. The combined inefficiency and inflexibility of issues with transmission and distribution systems create increased energy burdens for low-income Americans. Energy burdens are considered high when they exceed 6% of household income. For Americans 150% below the poverty line, the average energy burden reaches 12% of household income, (Office of Energy Efficiency and Renewable Energy 2022). Improving energy efficiency across the country through upgrades to transmission and distribution systems will save low-income communities significantly in utility bills. Installing renewables as the sources that generate electricity in local, decentralized, grid systems will also improve the health and wellbeing of low-income communities.

Fossil fuel plants are often located in low-income areas where there is less protective legislation and lobbying. These fossil fuel plants can bring local jobs and increase revenues; however, this is outweighed by the detrimental health effects resulting from air pollution. As mentioned in chapter 3, the carbon emissions from coal plants in low-income communities cause disproportionate levels of asthma and other respiratory illnesses. Diesel backup generators installed in these areas also contributes to adverse health effects from air pollution. Microgrids inside these communities can very effectively address electricity storage concerns and strengthen community resiliency against climate change-induced weather events and cyber-attacks.

The decentralization of U.S. electric grid systems will require federal and state policy support as well as clear governance of electricity and capacity markets. There are existing state and federal policies and incentives for reaching certain grid decarbonization goals through renewable implementation, however, RTO governance halts the effectiveness of these policies and incentives. RTOs have collected extensive oversight and responsibilities since their birth in the 1990s. During the Trump administration, RTOs were able to gain more power in the electricity and capacity markets as fossil fuel sources, especially coal, were favored heavily. Because RTOs control electricity market legislation and capacity market targets, policy was created across the U.S. to make it easier for fossil fuel sources to compete in electricity markets and more difficult for renewables to compete. Capacity measures for regions are also handled by RTOs. These targets are often inefficiently measured, causing unnecessary tax burdens and heightened utility bills for Americans while also underestimating the needed electricity for cities and towns. Lapses in governance and lack of oversight from FERC allows for inadequate capacity margins for states under RTO management. Changes in the governance of RTOs must favor state authority. This will limit the ability of RTOs to push agendas biased against renewable implementation and allow for renewable competition in electricity markets. States will have the ability to choose their own electricity generation sources. ‘State-supported’ electricity sources can more efficiently utilize funding while contributing to state grid decarbonization targets.

Coordination between RTOs across the U.S. is difficult because the level of power varies regionally. In California for instance, RTOs do not have state governance, therefore it is easier for renewables implementation. However, in ISO-NE and PJM regions, RTOs lead governance in electricity and capacity markets. While it is key to decentralize the electric grid and install systems of local renewable generated electricity, there must be uniform regulations across all RTOs to ensure the competitive participation of renewables in markets. Allowing renewables to participate freely in markets, without regulation that prioritizes fossil fuel industry agendas, will more efficiently maximize ‘state-supported’ investments. ‘State-supported’ investments are being wasted in current regional capacity markets as recent RTO legislation was created to favor fossil fuel investments instead. This industry bias perpetuates carbon emissions from fossil fuel power plants and contributes to heightening climate change weather related events. The U.S. electric grid system is not currently structured to handle the adverse impacts of increasing climate change weather related events. The centralized electric grid also cannot manage high demand efficiently when such events occur. Small lapses in transmission and distribution lines can cause serious impacts down the line. This cycle contributes to the collapsing U.S. grid.

Policy Recommendation: Establishing RTO Regulation

RTO governance must be limited with a shift towards empowering local and state governance. As previously noted, RTOs favor fossil fuel industries and continue to construct policies to strengthen their foothold on capacity markets. This leads to the waste of ‘state-supported' investments into renewable sources as their participation in markets is limited and becomes more expensive. Under local and state governance, exclusive policies favoring fossil fuel industries will not have to continue. As the costs for renewable projects continue falling nationally, it will be vital for local and state governance to adopt renewable implementation as soon as possible. Regulating RTOs will hasten the interconnection of renewable projects to localized grid systems. In areas like ISO-NE and PJM, renewable projects will be able to emerge, contributing to national grid decarbonization targets. When states can construct their own localized grid systems with renewable electricity generation, they can also benefit from the job creation of these projects. Renewable projects are more labor intensive than fossil fuel plants, which will open more opportunities for regional energy industries. Renewable technologies are continuing to grow and expand. These technologies will be able to emerge more easily with limited RTO governance. Thus, employment opportunities will increase across the country as new renewable markets arise.

Limited RTO governance and increased state oversight presents valuable economic benefits. Recent political action under Trump's administration empowered fossil fuel industries and allowed for the misguided construction of additional fossil fuel power plants across the country. There is a clear governance lapse between RTOs and FERC which creates lapses in capacity markets and local economies. NERC will need to incorporate the responsibilities under current RTOs so that capacity targets can be adequately met. Improvements in the efficiency of capacity target management will relieve energy burdens for taxpayers and save costs of building unnecessary electricity generation sources.

There are several feasible ways in which RTOs can be amended. FERC can modify RTOs' authority of markets and revert responsibilities to more basic functions. This solution would effectively place more authority within FERC and reduce lapses in governance. While this would ultimately limit RTO governance, this solution may not truly improve efficiency in capacity markets and local economies. Alternatively, FERC may retain the current scope of RTO duties but impose more stringent oversight mechanisms to enhance public scrutiny and control. Within this solution, FERC may authorize states to have veto power over RTO decision making. FERC could mandate that RTOs involve state representatives in decision-making processes or deploy its own authority to regulate RTO activities. Congress may also increase FERC's regulatory mandate to further enhance oversight. Thirdly, another plausible strategy for reshaping the power dynamics in the electricity system would be for FERC or Congress to adopt measures that curtail the scope of utility power or conduct a thorough examination of the potential ramifications of corporate mergers on the system. A more profound solution could be implemented by FERC or Congress that would initiate a shift towards either public control or state ownership of the electricity grid, a model that has been adopted in several other countries.

Policy Recommendation: Transitioning to State Ownership of Electric Grids

The reorganization and democratization of electric grid systems in the U.S. could be viably achieved through state ownership models. State ownership can facilitate a transition away from the reliance on fossil fuel production and move towards a renewable energy future, which prioritizes the needs of communities over profits. As discussed in the two previous subsections privatized RTOs operate according to their own agenda which adversely impacts states' autonomy over energy markets. For states seeking to implement renewables rapidly, RTO governance presents key barriers.

FERC and Congress could decentralize electric grid authority in favor of state ownership of electric grid systems through new legislation. Transitioning to state ownership would allow for states to deploy their own policy incentives for the adoption of fully renewable generation sources. Additionally, this may prove more effective for the development of EV charging stations across states. State ownership of electric grid systems can result in improved coordination and integration of grid infrastructure, leading to increased efficiency and reduced costs in the long run. Transitioning away from privatized, RTO governance can promote innovation in electricity generation, transmission, and distribution technologies. This may make it easier for technologies like battery storage systems to scale and grow more efficient. State ownership can also ensure equitable access to electricity, particularly for low-income and marginalized communities.

Many countries in Europe have already transitioned or begun transitioning to public ownership of electric grid systems. In Germany, roughly two-thirds of people have municipal-owned electricity (Hobbs 2022). After 2005, Germany began transitioning from privatized electric grid systems to publicly owned electricity with increased public demand for renewable energy. In Munich, publicly owned energy companies have been supplying every household with renewable energy since 2016. By 2025, it is expected that publicly owned energy companies will supply all industries in the city with 100% renewable energy (Hall and Weghmann 2021). Germany has successfully utilized decentralized renewable generation sources across its country to supply its people. Germany's decentralization transformation has invigorated local economies. Over half of the installed capacity for renewable energy comes from private residents and farmers.

Before decentralizing their electric grid systems and transitioning to public ownership of electric grid systems, Germany's electric grid was very similar to the U.S. Germany had a centralized electric grid system, primarily relying upon fossil fuels for electricity generation.

However, as public demand for renewable energy implementation increased, Germany realized the social, environmental and economic benefits of transitioning to renewable energy sources. It is very possible for the U.S. to both decentralize and transition to state ownership of the electric grid system. The phase out of fossil fuels will be necessary in transforming the U.S. electric grid.

Policy Recommendation: Phasing Out Fossil Fuels

A critical first step in the transition to fully renewable generation sources would entail the halting of new permit issuance for fossil fuel production and infrastructure. This first step will need to be supplemented with a gradual reduction in government subsidies towards fossil fuels and a complete divestment of both public and private financial investments in fossil fuel production and distribution. Rather than providing financial assistance or bailouts to fossil fuel companies, resources should be directed towards supporting affected industry workers and communities through initiatives aimed at promoting economic diversification. The polluting fossil fuel industries should be subject to providing resources for the transition to renewable energy as these companies are responsible for social and environmental degradation. Additional resources will need to be directed at laying the foundation for an equitable transition to renewable sources of energy.

Pricing carbon emissions can accelerate the phase out of fossil fuels. Carbon pricing will provide new methods of revenues at the federal and state level. The revenues generated from carbon pricing can be strategically invested in infrastructure to facilitate renewable energy development. Moreover, carbon pricing can help raise awareness among consumers and businesses about the true cost of carbon emissions. Incorporating social and environmental justice initiatives will be key for securing an accessible and equitable clean energy future. This will lead to more informed decision-making and spur innovation in areas such as carbon capture and storage.

Federal funding for renewable energy research, development, and installation will need to be followed at the state level. Transitioning to a fully decentralized electric grid system will entail the expedition of the interconnection queue process where ready renewable energy sources are waiting. As mentioned earlier in this chapter, the interconnection queue process can quicken with the expansion of new transmission and distribution lines. The investment required to upgrade efficiency in transmission and distribution systems will need to be significantly greater than the funding included for new projects in the 2022 IRA legislation.

In conclusion, transitioning to fully renewable sources of energy will require a multifaceted approach that begins with halting new permits for fossil fuel production and infrastructure. A gradual reduction in government subsidies towards fossil fuels and a complete divestment of both public and private financial investments in fossil fuel production and distribution must follow. Incorporating social and environmental justice initiatives will be crucial for ensuring an equitable clean energy future. Pricing carbon emissions can accelerate the phasing-out of fossil fuels, and increase federal funding for renewable energy research and development. Upgrading the efficiency of transmission and distribution systems will require significant investment upfront but is necessary for the transition to a fully decentralized electric grid system. By following these steps, the U.S. can effectively transition to a decarbonized grid within a few decades.

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