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Energy Industry Study Report

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1. Literature Review

This paper documents a top-level exploration of the global energy industry and its ramifications for the United States' enduring interests and national security. Prior scholars at National Defense University conducted similar research and documented their results within publicly available reports. Current students examined reports from 2009 and 2018 to find gaps in the research and analyze trends within the energy industry. Previous reports conducted a point-in-time analysis of the energy industry and are therefore ripe for an update.

Over the past three years, the United States has taken steps consistent with many of the recommendations made in 2009 and 2018 (see Appendix A). Additionally, the strategic environment has evolved, requiring additional analysis and recommendations relevant to this industry. The strategic environment has changed drastically since 2018, which has increased the urgency to find solutions and the willingness of US political administrations to invest in solutions. Given the drastic changes in global affairs since 2018, this paper fills a critical gap in the body of knowledge by documenting the energy landscape in 2022 and analyzing it under the lens of the current strategic environment. Finally, the paper identifies current national-security implications and makes new resource-informed policy recommendations.

The methodology used by the team (see Appendix B) for the research conducted included:

- In-class guest lectures (see Appendix C1);
- Domestic field studies (see Appendix C2); and
- A literature review using National Defense University academic resources and the internet.

2. Strategic Environment

2.1. Global Energy Environment

The ongoing war in Europe highlights the role of energy in global stability. The worldwide response of oil and gas prices to the disruption in supply from Russia due to ongoing sanctions represents this effect and highlights that even local disruptions to supply can have global impacts in today's large and interdependent global economy. Furthermore, the environmental impact of energy choices increases tension between countries as the world collectively attempts to establish a fair and meaningful way to reduce greenhouse gases. The Paris Agreement established short- and long-term goals for 196 nations to reduce greenhouse gas emissions, with the final goal of net-zero emissions.[1] However, global temperature and emissions trendlines suggest a shift toward cleaner energy sources is needed to achieve net-zero emissions. The transition to clean energy threatens to devalue a critical resource for countries that are economically dependent on fossil fuels.

Another concern as the world transitions to clean energy is energy equity. In 2019, 760 million people worldwide lacked access to electricity, with many more lacking consistent and reliable access.[2] Developing nations face pressure to skip over affordable fossil fuels and invest directly in renewables. While the initial capital costs are higher, investments made in renewables will have a greater impact on developing countries because climate change disproportionately impacts them.[3] Furthermore, developing countries typically have renewable flows much greater than their demand, which could be a source of income in the future when energy storage becomes technologically feasible.

The United Nations chairs a special climate group with the goal of net-zero carbon emissions by 2050. A country must back its carbon commitment with credible action to become a member. Approximately seventy countries pledge to achieve net-zero emissions, including the most significant emitters: the United States, China, and the European Union.[4] These commitments are critical first steps to curtailing rising planetary temperatures.[5] The effort to partially meet these commitments will have a substantial impact and be better for the planet than not attempting to be net-zero.[6] An undertaking such as this impacts many parallel industrial sectors, and at times those efforts intersect and can cause an inflection if not appropriately managed. To this end, many entities in the US government have begun to develop strategies to meet these goals.

2.2. Great Power Competition

The great power competition among the United States, Russia, and China represents the primary national security focus of the United States and its allies. The great power competition is the global struggle for military, economic, and ideological supremacy. This competition encompasses military might and stretches to energy, public policy, healthcare, telecommunications, education, innovation, influence, and coalition-building.[7]

As the world transitions to renewable energy sources to combat global climate change, those outside the great power competition are watching to see which competitors can make an effective transition. This transition requires maintaining influence by establishing and meeting climate change pledges while remaining economically competitive. If a country can strategically reduce its dependence on fossil fuels, it will undoubtedly have a strategic advantage. China currently dominates the global renewable energy market and is rapidly expanding solar, wind, and hydroelectric capacity across the globe.[8] China's dominance in the renewable energy market has emerged primarily from being first to market in manufacturing and production, particularly in the wind turbine and solar panel markets.

Additionally, China is currently one of the world's most prominent developers of hydroelectricity, which accounts for roughly twenty percent of China's domestic electricity generation. China's technological expertise, manufacturing superiority in the renewable energy industry, and strong financial position have placed it in a unique position to successfully support and finance renewable-energy infrastructure projects across the globe and promote Chinese interests abroad.[9] China's technological advantage enables it to move ahead of its global competitors by offering renewable energy infrastructure investment in developing nations. To compete with China, the United States must seek to drive technological innovation through public and private enterprises. To remain relevant, the United States must regain that competitive advantage in technological innovation.

In February 2022, the US Department of Energy (DOE) released the first-ever comprehensive strategy to secure America's clean-energy supply chain.[10] The strategy outlines robust and long-term initiatives focusing on energy independence. Moreover, observers recognize that a well-executed transition to clean energy will lead to economic opportunity for the United States in line with the US enduring interests of "expanding economic prosperity and opportunity" identified in the *Interim National Security Strategic Guidance*.[11]

On November 15, 2021, President Biden signed the Infrastructure Investment and Jobs Act of 2021, which should cost taxpayers more than $300 billion (about $920 per person in the United States) on climate and energy-related matters alone.[12] The United States will use these funds to upgrade power infrastructure to support clean-energy goals, create jobs in clean energy, develop a network of electric vehicle (EV) chargers, harden energy infrastructure against weather events, and tackle legacy pollution.[13]

On the other hand, Russia is not taking the same steps as China and the United States. Russia is economically dependent upon fossil fuels and is fighting against the reduction of fossil fuels to combat climate change.[14] Russia opposes any reductions to the use of fossil fuels, including taxes on producers and consumers, claiming that these initiatives prevent Russia from being competitive in the global market. Despite this resistance, Russia still intends to be net-zero by 2060. The plan is to move away from oil and coal and towards natural gas, repair infrastructure, and focus on reforestation.[15]

Russia is the world's third-largest oil producer, and the second-largest natural-gas producer, supplying much of Europe's natural gas.[16] The recent invasion of Ukraine has strained relations with Europe and put future reliance on Russian natural gas in jeopardy. Russia is also an Arctic power and, in 2007, took action to plant a flag under the North Pole to symbolize intent to dominate the region.[17] Over the past few years, Russia has been steadily increasing its military and commercial presence in the Arctic by developing new bases and refurbishing old ones. Additionally, Russia has constructed new icebreakers and submarines, giving it a distinct military advantage. The Arctic has an estimated thirteen percent of the world's undiscovered oil resources, about thirty percent of natural-gas reserves, and an estimated twenty percent of the natural-gas liquid resources.[18] Thus far, these resources have been out of reach. However, scientists expect the Northern Sea Route to be fully navigable by 2040, allowing access to these previously untapped oil and natural gas reserves.[19]

3. Industry Analysis

3.1. Firms Reviewed

1. Tesla, Inc.
2. SunPower Corporation
3. General Electric Company
4. Lithium Americas Corp.
5. ExxonMobil Chemical Company
6. NextEra Energy, Inc.

3.2. Structure, Conduct, & Performance

Several energy-related markets make up the energy industry. It includes large- and medium-sized companies competing to provide energy and energy storage solutions for homes, businesses, and transportation. Firms produce energy via various means from renewable sources such as wind farms, solar arrays, and nuclear fission. Regardless of the energy source, many firms have the same goal to provide residential and commercial electricity. Other firms focus on cleaner transportation solutions that involve EVs, battery storage, and charging infrastructure. One common ground is the belief that major advances in high-capacity battery storage will change the energy mix used in the United States and abroad. High-capacity battery storage will smooth the variability inherent in renewable sources of energy production, allowing consumers to receive electricity when the sun is not shining and the wind is not blowing.

The current presidential administration seeks to influence the structure of the energy industry through multiple executive orders pushing firms more aggressively towards renewable energy.[20] However, legacy tax incentives for renewable energy projects, dating back to 1992, struggle to achieve approval for the minimum number of years required to complete a project and receive the incentive. Firms take incentives into account when making profitability predictions, and many choose not to invest in renewable energy sources that lack planned incentives through the estimated life of the project.[21] Moreover, tax incentives used to increase domestic fossil fuel production are transitioning out before the United States is ready to transition to renewables and when a secure domestic energy supply is crucial.[22]

The conduct of the industry varies between the firms that produce power, those that provide battery storage, and those that provide the physical materials to enable power generation. Power-generation firms compete in geographically segregated markets supplying energy to customers near the generating source. Power generation is a highly regulated market. Firms in the other two markets have a global reach. Battery suppliers provide solutions for both EVs and grid storage for conditioning the supply variability of renewable energy sources. These firms sell their products in the retail market for vehicles and private and public storage batteries. Many of these firms are vertically integrated into other markets, source the raw materials, or engage in recycling. Firms either compete based on quality and features or cost and price. Firms that provide the physical materials for renewable power generation, like wind turbines and solar panels, compete with quality and features and are able to have a higher price for better quality and features. While traditional power-generation methods use fossil fuels which compete based upon price.

The performance inside of each market within the larger industry varies depending on the business model of the firms within the market as well as consumer trends. In general, successful, large firms are vertically integrated, providing the means by which they generate energy or energy-related products. Large firms expand their operations through various funding sources, including private capital, internal research and development funds, pass-through costs, and exploitation of government credits and subsidies. Within the S&P 500, the energy sector outperformed the other ten sectors in 2021 and continued into 2022.[23] The energy sector (within the S&P 500) is mostly oil and gas stocks. As of January of 2022, the energy sector netted an 18.4% return compared to the S&P 500 at −7%.[24] However, the energy sector earned the worst returns during the pandemic when transportation was at a standstill.[25] Renewable stocks, included with other sectors, have underperformed the market in recent years.

3.3. Porter's Five Forces

Analysis of Porter's Five Forces business model reveals the energy industry, as a whole, is unlikely to outperform the market over the long term.[26] Increasing demands for energy entice entrants to the market. However, when they arrive, they realize (1) there are high barriers to entry in terms of capital costs; (2) that competition exists mostly on price, forcing market prices lower; and (3) that the market is highly regulated. Additionally, consumers tend not to have brand loyalty, nor do they care about the energy sources, caring more about the cost and availability when demanded, giving buyers more power than expected in an environment approaching energy scarcity.

There is strong competition across the spectrum of the industry, with more expected in the renewable energy area as the United States transitions away from fossil fuels. This is true because the individual markets within the energy industry are primarily oligopolistic, with only a few sellers for products that have no noticeable differentiation. These sellers compete based on price and drive prices lower, enabling only high-volume sellers the opportunity to be profitable.

Despite this, the threat of new entrants remains high as buyers tend to have little brand loyalty. Additionally, except for companies that provide power to consumers, most others in the industry are providing a commodity which can be substituted for another equivalent commodity with little afterthought. With that being said, high capital costs and long-term agreements are industry standards that create some barriers to entry. There is an inherent threat of substitutes between fossil- and renewable-energy sources. Furthermore, government regulation impacts the ability to substitute between these two major sources.

Increasing energy demands suggest the bargaining power of suppliers should be higher than that of customers. However, tax incentives, disincentives, and substitutes make this a less-than-straightforward analysis. As more consumers and municipalities shift to renewable energy sources, fossil-fuel suppliers will lose bargaining power. As fossil-fuel firms leave the market, this portion of the industry may turn into a monopoly requiring those who are unable to shift to renewables to pay higher prices for plentiful resources. The renewable sector is likely to experience opposite impacts. The power of suppliers will increase as more consumers seek out resources, but new entrants to the market will likely also increase, creating a new balance. On a positive note, to consumers, increased competition among the suppliers of wind turbines and solar panels should drive down costs.

The analysis of the five competitive forces for the future of renewables depends heavily on government intervention in the market. The United States is currently heavily incentivizing companies and individuals to install sources of renewable energy generation. This support is helping to drive down the initial capital costs of renewable projects for companies through economies of scale. This has been key to allowing renewable energy technologies such as solar and wind to become cost-effective.[27] If the US government continues to subsidize renewable energy over fossil fuels, then renewable firms will likely remain profitable. However, a reduction in renewable incentives will slow the adoption of these technologies, and the industry will remain fossil-fuel-based for the foreseeable future.

3.4 Current Energy Landscape

To fully complete an industry analysis, this report considered not only companies within the industry, but also the various energy options available. This analysis considered fossil fuels, solar, hydropower, nuclear, geothermal, space, wind, lithium, and biomass (see Appendix D). For each of the energy options, consideration was given to three categories: affordability, reliability, and resiliency. Using these factors, a score was given to each of the energy options to determine the overall desirability of currently available energy options. This is a point-in-time analysis intended to inform decisions makers of potential limitations as the United States seeks a diverse energy mix.

Energy Type	Affordability (USD/MWhr)[28]	Reliability (Capacity Factor)[29]	Resiliency (EFORd)[30]
Fossil Fuels (NG Combined Cycle)	High ($39.54)	Medium (54.5%)	Medium (~4%)
Solar	High ($32.85)	Low (24.6%)	High (<2%)
Hydro	High ($37.87)	Medium (37.1%)	Medium (~5%)
Nuclear	High ($38.42)	High (92.7%)	High (~1%)
Geothermal	Medium ($45.11)	High (71%)	Medium (~5%)
Space	*	*	*
Wind	High ($36.00)	Medium (34.6%)	High (<2%)
Lithium	Low ($101.01)	Low (4.6%)	**
Biomass	High ($39.84)	Medium (61.5%)	Medium (~4%)

* No deployed non-experimental assets for evaluation.
** Negligible amount in service / not yet developed to commercial levels

4. Stakeholder Interests

Energy is critical to every aspect of life; both short- and long-term energy choices impact individuals and businesses in terms of economics and health. As such, there are multiple stakeholders competing for influence with respect to regulations, laws, policies, and public opinion. Finding the "right" energy mix is a complex problem.

4.1. Political Interests

Within the United States, the energy industry is highly regulated. These regulations are in place for the overall safety not only of plant workers, users, and neighbors but also from a broader, environmental perspective. On January 20, 2021, the United States rejoined the Paris Agreement, pledging to reach net-zero emissions by 2050.[31] With that, statutes and regulations were created at the national, state, and local level. The specific language within these statutes and regulations is highly contested by representatives of companies, environmental groups, and others. Legislation that requires specific compliance measures can quickly make an industry insolvent or make products too expensive for the customer to absorb the cost increase. The changing global energy landscape will also impact geopolitics. Secure access to fossil fuels plays a significant role in international politics today, and as the world transitions more towards renewable-energy generation, the influence of fossil fuels in international affairs will shrink. As renewable-energy generation technologies such as wind and solar have their own resource needs, such as rare earth metals, access to those resources will replace fossil fuels as a driver of geopolitics.

4.2. Social Interests

In most countries, every aspect of life relies on the use of energy. Therefore, the need for an affordable, reliable, and resilient power supply is critical.

In the United States, there are energy equity and justice programs at all levels of government to ensure a "fair and just distribution of benefits in the energy system," regardless of social status or other identifiers.[32] These initiatives focus on designing systems and upgrades that will reach disadvantaged communities as well as ensuring affordable access to energy. As the United States considers its transition to renewables, energy equity must be a consideration.

Another social aspect impacting the transition to renewables is the current source of heating and cooking in households. Many families rely on gas for these basic functions. A drastic move away from fossil fuels could make these basic functions either unavailable or unaffordable for these households.

At the commercial community level, access to a reliable and resilient source of energy is the most important factor. Ensuring uninterrupted access to energy allows hospitals to function, grocery stores to keep food at safe refrigeration levels, and gas stations to distribute energy resources.

At the national level, EV charging infrastructure is a key initiative. According to the Environmental Protection Agency, in 2020, transportation was responsible for 27.2% of greenhouse gas emissions.[33] EVs are a promising way to reduce this burden on the climate. However, the use of EVs is not possible on a large scale without the infrastructure allowing families to abandon gas vehicles and embrace EVs. Presently 89% of households in the United States with an EV also have another non-EV vehicle.[34] Furthermore, 66% of households with an EV drive their non-EV more miles per year.[35] These figures will likely change as both charging infrastructure and range improve.

4.3. Economic Interests

Dr. Zahid Asghar, a university-level scholar and professor of applied economics, explained the relationship between energy and economics: "Energy is one of the most important inputs for economic development. From a physical viewpoint, the use of energy drives economic productivity and industrial growth and is central to the operation of any modern economy."[36] From a policy perspective, energy conservation policies significantly impact energy consumption and energy growth in energy-dependent countries.[37] Energy dependency can mean two different things. The first refers to requiring energy for personal and commercial needs—and the United States is undoubtedly energy-dependent in that sense. The second refers to reliance on outside sources (external to the United States) for energy needs. The United States is currently not energy-dependent in this latter sense. However, the transition to renewables threatens to change the state of this dependency. Currently, the United States exports more energy than it imports, and the United States is aware that maintaining some amount of energy independence, especially from its great power competitors, is important.[38] The current administration is focused on supply chains and jobs that will enable the United States to maintain this independence as the United States transitions to renewable energy sources.

4.4 Security Interests

The US government recognizes the need to secure our electric infrastructure. The electric-power system is vital to the nation's energy security, supporting national defense, emergency services, critical infrastructure, and the economy. Preventing exploitation and attacks by foreign threats is critical.

The DOE has a vital role in developing recommendations and identifying opportunities. These actions institutionalize change, increase awareness, and strengthen protections against high-risk, electric-equipment transactions by foreign adversaries, all while providing additional certainty to the utility industry and the public. The US government must balance national security and economic considerations while consulting with various stakeholders from electric utilities, academia, research laboratories, government agencies, and other stakeholders on various aspects of the electric infrastructure.[39] Private-industry partners throughout the country have a critical economic role to play. A secure, resilient supply chain will be critical to harness emissions outcomes and capturing the economic opportunity inherent in the energy sector transition to achieve future climate goals. Industry partners have a crucial role in identifying vulnerabilities and risks to the energy-sector industrial base, addressing them throughout every transition stage.[40]

Oil remains a crucial energy-security concern for the United States and its allies from a national-security perspective. The DOE's role in energy security has expanded in the last few years, specifically by Presidential Policy Directive 21, Emergency Support Function 12, and the Fixing America's Surface Transportation (FAST) Act of 2015.[41] The following principles illustrate a twenty-first-century framework for energy security:

1. Development of flexible, transparent, and competitive energy markets, including gas markets;
2. Diversification of energy fuels, diversification of sources and routes, and encouragement of indigenous sources of energy supply;
3. Reducing our greenhouse gas emissions, and accelerating the transition to a low-carbon economy, as a critical contribution to enduring energy security;
4. Enhancing energy efficiency in demand and supply and demand-response management;

5. Promoting deployment of clean and sustainable energy technologies and continued investment in research and innovation;
6. Improving energy systems resilience by promoting infrastructure modernization and supply and demand policies that help withstand systemic shocks and cyberattacks; and
7. Putting in place emergency-response systems, including reserves and fuel substitution for importing countries, in case of significant energy disruptions.

The growing importance of electricity to energy and national security, today's robust global oil markets, the developing global gas market, and a range of energy-security threats, trends, and changes, constitute a new broad and complex energy-security mission for the US government and DOE. To effectively ensure this expanded definition of energy security for the United States, policymakers must consider various factors from both domestic and international perspectives. These include ensuring domestic access to energy, securing the electric grid, encouraging the development of global markets, and supporting alliances and partnerships that strengthen energy security.[42]

5. US Enduring Interests & National Security Implications

The United States is committed to managing the critical nexus among energy, economic statecraft, and US national security while advocating for US companies. The United States will continue to pursue its enduring interests by acting on multiple fronts, including the following climate and energy-related initiatives:[43]

1. Invest in climate resilience and green energy at home and abroad, leading a global effort to reduce carbon pollution;
2. Open markets and reduce barriers to energy trade and development by promoting open, transparent, and market-based energy sectors to advance US economic interests;

3. Promote US energy resources, technologies, and services to sustain US economic growth and job creation;
4. Ensure the energy security of the United States, its partners, and allies by supporting the diversification of energy sources, supplies, and routes;
5. Promote access to reliable energy, foster economic growth, and promote prosperity; and
6. Mitigate climate change and address its impacts across all sectors by partnering with countries to reduce emissions, protect critical ecosystems, transition to renewable energy, and promote the flow of capital toward climate-positive investments.

The following events threaten US national security:[44]

1. The United States, allies, and partners lack reliable access to affordable energy;
2. Closed energy markets shut out US companies;
3. Competition for energy leads to conflicts;
4. Poor governance prevents market-based energy solutions; and
5. Terrorists and rogue regimes exploit energy resources to fund violence or destabilizing behavior.

6. Operational Energy & Microgrids

At the US Department of Defense (DoD) level, increased global instability has led to initiatives that will allow maximum flexibility to meet the energy needs of the department. To that end, DoD's Operational Energy office seeks to "enhance military capability, readiness, and resilience for the warfighter, while mitigating risk and cost in the supply and use of energy in operations and training."[45] Addressing both the increased demand for energy and the changed character of requirements will enable the department to continue to ensure the effectiveness of the US military in an era of great power rivalry. Over the past thirty years, conflicts involving the

United States have been asymmetrical; the United States has enjoyed a significant advantage in military capability and global logistical support. This has led to less focus on logistical considerations for US military weapons systems in favor of maximizing effectiveness and lethality. However, in the near future, the United States may encounter an adversary with an equally advanced military, and in this case, every dependency and vulnerability will be of consequence. Specifically, a dependency on stockpiles of fossil fuels to meet military energy needs represents a critical vulnerability. A renewed focus on operational energy within the DoD will help mitigate these factors and ensure agile and resilient logistics to support US missions in even the most contested environments.[46]

One means of addressing the changed character of required support is through microgrids. Microgrids can be used in both civilian and military environments and provide a redundant and portable power supply.

The US electrical grid connects millions of homes, businesses, and other buildings to central power sources, allowing them to power electronics, appliances, and heating and cooling systems. Electrical-grid interconnectedness means that every repair, outage, or planned maintenance to any part of the grid affects all users. A microgrid can fill the gaps where the larger electrical grid leaves off.

Microgrids operate as localized energy grids separate from the larger electrical grid. They can operate when main electrical grids are not operational and build resilience, helping to stop outages and aid in overall system recovery and response. They support an efficient and highly flexible electrical grid by integrating the ever-growing distributed resources of renewable energies such as solar, geothermal, and wind. The efficiency of the entire electrical-delivery system is helped by using local energy sources, ultimately helping reduce energy loss in transmission and distribution. The DOE has a vast portfolio of activities that focus on developing and implementing microgrids further to improve the reliability and resiliency of the grid. Microgrids can help communities better prepare for future weather events and keep the United States moving toward a clean-energy future.[47]

Microgrids may have helped save lives with the devastating impact of Winter Storm Uri, which claimed the lives of more than one hundred people and left four million people without power or heat for days throughout Texas. A lack of appropriate infrastructure investment and insufficient planning exacerbated and prolonged this natural disaster. Backup generators and uninterruptable power supplies are insufficient when facing natural disasters and prolonged emergencies. These backup systems cannot maintain critical lifesaving systems for an extended period. Texas hospitals were overwhelmed with patients and lacked sufficient power to provide critical services.[48]

One of the future DoD applications of microgrids includes the Tactical Microgrid Standard (TMS) capability. TMS provides standardization and interoperability requirements needed for successful mobile-power systems. It has shown proven benefits to enhance fuel savings and increase functionality. It is also user-friendly. TMS systems are relatively simple to deploy, are efficient, and provide resilient generation and distribution.[49] Despite promising future applications, TMS is not presently operational for use in a contingency environment. Though, DoD is fully engaged with national laboratories and industry representatives to make this a reality in the near future.[50] Specifically, the United States Army Corps of Engineers is leading a consortium to develop this standard.[51]

Another DoD application of microgrids can be seen at Tyndall Air Force Base in Bay County, Florida, where a first-of-its-kind, renewable microgrid is being constructed as a cooperative pilot project between Gulf Power and Florida Power & Light.[52] It will comprise a 150 kW solar array and a 450 kW, 2.5-hour battery with a ten-year lifespan and support three critical buildings on base. Microgrid technology is suited to uniquely address the needs for resiliency in the wake of extreme weather events such as wildfires and hurricanes.[53]

7. Future Trends

There are multiple global trends that directly and indirectly impact the energy industry. Population growth, aging populations, climate change, regional conflicts, resource scarcity, and changes in globalization are just a few. Some of these trends, like a growing and aging population, work in concert with each other, demanding more energy. Others, like resource scarcity and climate change, pull in opposite directions, creating better access to resources but with a smaller environmental impact. Each of these trends creates a demand on the energy industry. There is a need for a diversification of energy resources and strategic planning to navigate the globalized nature of energy.

The United Nations projects that the global population will grow from 7.71 billion in 2019 to 9.74 billion in 2050.[54] Although the global population continues to grow, the annual rate has dropped from a peak of over 2% in the late 1960s to about 1% in 2019.[55] This drop in the growth rate is primarily attributable to a reduction in the birth rate, which in conjunction with lengthening lifespans, will drive an increase in the average age of the population over time.[56] The number of persons over the age of eighty is projected to triple by 2050.[57] This will mean a smaller percentage of the population will be able to contribute to the workforce and an increase in those that require assistance to survive in their later years. This expanded assistance will require services and materials that will require ever-increasing energy to manufacture and use.

This increasing energy use for the older population will accentuate the fact that energy usage has consistently grown at a rate greater than that of the population for all of history.[58] As the population grows, there is a greater need for food and fresh water. Producing fresh water from saltwater or even brackish water is highly energy-intensive.[59] Water scarcity is already an issue that impacts the health and well-being of people and also puts power generation at risk.[60] This risk comes from critically low water levels at hydroelectric sources and insufficient water inventory to cool plants that rely on thermal means for electrical generation.[61]

There are four general areas for technological improvement related to energy production and use: generation, transmission, transportation, and end-use. Most experts agree that the limits of chemistry, thermodynamics, and technology are being reached regarding efficiency gains in end-use scenarios.[62] In electrical transmission, there have been advancements in high-voltage, direct current (HVDC) transmission lines that have several advantages over traditional alternating-current lines.[63] The problem is the sheer number of cables and amount of equipment that would have to be replaced to change to HVDC, with the United States alone having over 200,000 miles of cable.[64] The increased use of microgrids can be a stepping-stone to overcoming this problem.

The areas with the most significant promise are in power generation. Some techniques that represent opportunities are hydropower, nuclear, and space. For hydropower, the potential is not with the typical hydroelectric power generation using dams; it is with wave action. Several companies are investing in technology to harness the energy present in the never-ending movement of the world's oceans.[65] This technology has the advantage of not being impacted by drought, does not take acres of usable land, and is available twenty-four hours a day. Again, when talking about nuclear power, the potential is not with typical, large, multi-megawatt reactors. Here, the discussion is on micro-reactors using a fuel called TRISO (TRi-structural ISOtropic particle fuel), which has numerous benefits that simplify these reactors' operation, maintenance, and security.[66] In terms of space, the key component is that of power beaming. This technology would allow energy transfer from one location to another without a capital-intensive infrastructure.[67] This would allow for the expansion of the power grid into areas that would be prohibitively expensive or dangerous using current techniques. It would also allow for replacing the grid with microgrids, increasing domestic resiliency. Both the micro-reactors and the power beaming translate directly to national security by supporting the operational energy needs of deployed units.

A final area of technology that needs additional focus is carbon sequestration. While the previous technologies all deal with the future of energy, carbon sequestration deals with its past. Carbon sequestration is the ability to remove carbon from the atmosphere, reducing the concentration of greenhouse gases in the atmosphere.[68] This also reduces the amount of carbon dioxide trapped in the ocean, reducing its acidification.[69] This technology is needed because even the most aggressive estimates do not result in achieving less than a two-degree rise in temperatures by 2050 by reducing emissions alone.[70]

These technologies support the critical need to expedite, allowing for the creation of a national energy portfolio, using diverse energy sources to support energy independence. The negative impact of a system that allows energy to be used as a weapon of war reaches far beyond the physical battlefield. Russian oil and gas are highly ingrained in the European market.[71] As a result, Russia is using access to those fuels as a bargaining chip, demanding payment in rubles.[72] In response, Poland and Bulgaria will turn to other sources of energy, including gas storage, new pipelines, and imports from other countries.[73] Paying in rubles would support not only the

Russian economy but mitigate some of the damage from the crash of the ruble from sanctions. It could also divide the rest of the world politically into those countries that continue to support Ukrainian independence and those that can no longer afford to support Ukraine. See Appendix E for additional information on the Ukrainian crisis and US energy policy and interests.

8. Key Takeaways & Fully Resourced Policy Recommendations

The Eisenhower School last published an analysis of the energy industry in 2018. Since then, the international security environment has grown more complex. The following events are recent examples of global instability that have added to the complexity: the COVID-19 pandemic, the US military withdrawal from Afghanistan, the collapse of the Afghanistan government, and the Russian invasion of Ukraine. This discord is exacerbated by trends like population growth, increasing energy demands from industrializing developing countries, and climate change. Each of these trends will challenge the ability of the United States to achieve its national-security goals. The analysis of the energy industry provided in this paper yields several key takeaways about the importance of the industry to US national security.

8.1. Key Takeaway #1

Energy is vital to national security, and the United States is vulnerable to attack from multiple angles. US adversaries will exploit energy resources as a source of competition and targets. Although only nine percent of US gross domestic product (GDP) comes directly from the energy industry, the industry has an inordinate impact on GDP because all other industries use energy.[74] Further, electricity in the United States is delivered through a complex network of aging infrastructure which introduces vulnerabilities that adversaries could take advantage of in a time of conflict. Moreover, the aging infrastructure is also susceptible to damage during increasingly common extreme weather events caused by climate change.

8.2. Key Takeaway #2

The energy industry presents both threats and opportunities to climate change. There is a growing global consensus and mounting empirical data pointing to the threat posed by climate change. While not the only contributor to global emissions, the energy industry is the largest source, responsible for 76% of the human-caused emissions.[75] The United States needs to diversify its energy-generation capabilities to reduce those emissions. The US energy industry has made some progress in reducing emissions through the transition from coal to natural gas and the increased use of renewable energy sources such as wind and solar. Renewable energy represents the next generation of global energy production, and an efficient transition of the US energy industry to renewable energy provides an opportunity for both future US energy independence and a strong competitive position in global energy markets.

8.3. Key Takeaway #3

The US military is not at a point where it can pivot away from fossil fuels entirely. Despite fossil fuels being a large source of greenhouse-gas emissions, the United States cannot transition many of its assets to renewable energy sources are they are not yet technologically capable of meeting the military requirements. The military's operational energy needs, such as naval ships, jet aircraft, and ground combat vehicles, need the energy density provided by fossil fuels. DoD currently has no viable substitute for fossil fuels. However, DoD continues to pursue new technologies, such as microgrids, that will enable it to further reduce emissions while still achieving its operational goals.[76]

8.4. Analysis

The United States must act to protect its vital energy infrastructure. Efforts to increase the resiliency of that infrastructure in the face of increasingly frequent, severe weather disruptions are ongoing. The United States' attempts to diversify its energy-generation capabilities have also revealed supply-chain vulnerabilities, both in components and raw materials. The United States must address these vulnerabilities to build and sustain a larger mix of renewable-energy assets within the national electrical-generation portfolio.

In order to assess the United States' ability to meet its national-security goals within the energy industry, a SWOT analysis (strengths, weaknesses, opportunities, and threats) is useful. The United States benefits from a strong position in the global economy and a skilled labor force that possesses a high level of technical ability to field and operate complicated energy-generation assets. The United States must contend with relative weaknesses in both an aging electrical generation and distribution system and limited organic access to many of the critical materials necessary for pivoting toward renewable-energy generation. Opportunities exist within the vibrant science and technology community within the United States and having areas of the country well suited to many types of renewable-energy generation. Threats to US energy security include existing supply-chain vulnerabilities and disruptions to global supply due to international conflict.

The United States can leverage its strengths and mitigate its weaknesses to meet its national-security goals and strengthen the national innovation and defense-industrial base by implementing the following five core policy recommendations. These recommendations are intended to enhance the affordability, reliability, and resiliency of the US energy sector. Funding for these initiatives could be sourced from a carbon tax described in the first recommendation as well as through long-term savings from revolutionizing the energy industry in the United States. Fossil-fuel emissions are the main contributor to climate change, which in turn drives more frequent and damaging natural disasters. The United States is estimated to have lost over $1.79

trillion to natural disasters since 1980, and over $450 billion of that impact has occurred since 2017.[77] Successfully reducing US carbon emissions may slow the growth in frequency of damaging climate change impacts and save the nation from paying for recovery efforts; in effect, enacting the below recommendations represent an investment against rising future loss.

8.5. Recommendation 1: Incentives

Continue tax incentives for capital costs of renewable energy sources to push for a greater mix of renewable-energy generation. The United States has successfully increased the amount of renewable energy generation in the United States through tax incentives on solar, wind, and battery-storage installations. Day-to-day usage costs for renewable sources are now competitive with fossil-fuel generation; though, renewable-energy projects still have higher initial capital costs.[78] Tax incentives for renewable-energy capital projects need to be attractive to consumers and make these projects affordable. Recent high levels of inflation and the interest rate hikes designed to combat the high inflation add complexity to the affordability challenge. These factors should be considered alongside any tax incentives.

The United States should also explore the possibility of a carbon tax to incentivize the transition toward renewable energy generation. Economic theory uses the concept of an externality to describe a situation when there is either harm or benefit to society that the market laws of supply and demand fail to capture completely.[79] The harmful effects of the emissions from fossil fuels represent a negative externality, as the impacts of climate change are not included in the market price of energy derived from fossil fuels. Creating a tax on carbon emissions would allow market forces to more appropriately capture the true cost of continued fossil-fuel use and incentivize both individual consumers and companies to adjust their behaviors accordingly.[80] Any proceeds from such a tax could then be applied to resource initiatives aimed at accelerating US clean energy goals.

8.6. Recommendation 2: Microgrids

Increase the installation and use of microgrids to improve resiliency around sites key to national security. While currently only a tiny part of the overall US generation capacity, microgrids dramatically increase the resilience of the US electrical system where they are used. Microgrids provide resilient power and allow the United States to respond more rapidly to natural disasters and attacks. Microgrids, such as the one being installed at Tyndall Air Force Base, will allow for continued operations following a man-made or natural disaster.[81] Additionally, large-scale use of microgrids as redundant backup systems, or stand-alone systems, will deter adversaries from grid attacks during a conflict because a grid attack will have less of an impact. Currently, military installations draw power from the commercial grid. As such, an adversary strike on the US national power grid would severely degrade military readiness across a large area. US adversaries are undoubtedly aware of this vulnerability, and the United States should take action to remove this temptation. The use of microgrids will ensure that military installations continue to function regardless of the status of the commercial power system; this should deter adversaries from targeting the commercial power grid.

8.7. Recommendation 3: Modernization

Invest in modernizing energy infrastructure. The existing US energy infrastructure is aging and has vulnerabilities both to physical and cyber-attacks. Additionally, the lack of significant energy-storage capacity in the US electrical grid increases the transition challenge to renewable energy. Efficient use of renewable energy requires storage so that energy generation can occur when available and separate from the time demanded. The development of storage capabilities and more resilient infrastructure will help offset the inherent challenges with the unpredictable generation from renewable sources. The Infrastructure Investment and Jobs Act, signed into law by President Biden in 2021, provides $21 billion in federal funding to increase the resiliency of the national power grid and includes funding to increase the amount of storage available.[82] While the funding provided is a good first step towards modernization, additional funding will be needed to modernize the US electrical grid fully.

8.8. Recommendation 4: Research & Development

Increase investment in energy-related research and development efforts to target basic research and commercialization. The United States has one of the best science and technology enterprises globally; with respect to the energy industry, the United States has achieved technological success by encouraging private industry to partner with national laboratories.[83] Future technological breakthroughs in advanced solar cells, new high-capacity batteries, and fusion or space solar power are critical enablers to the energy industry achieving the US dual goals of increasing generation capacity and reducing emissions. The United States should target increased funding specifically for energy-related research to bring these technologies to maturation and fielding ahead of our great power rivals.

8.9. Recommendation 5: Efficiency

Focus on increasing efficiency, both in operational energy and energy generation and distribution. The US military has operational energy needs currently dependent on fossil fuels. Jet aviation is one of the largest fuel consumers in the US military. Even modest increases in fuel efficiency can add up to considerable savings in emissions.[84] Similarly, a significant portion (potentially forty percent) of the energy in fossil fuels, such as coal or oil, is lost to heat when generating power. Approximately five percent of the electricity transmitted throughout the electrical distribution system in the United States is lost as well.[85] Ongoing efforts to increase generation efficiency, such as using combined-cycle natural-gas plants, should continue, and the United States should seek additional opportunities for efficiency.

9. Conclusion

The world population is growing rapidly and driving an even faster increase in energy demand. Climate change presents a real and increasing threat to global stability, economic activity, and access to resources. The energy industry in the United States faces a dual imperative: it must provide more energy to meet growing demand and do so in an economically competitive way that reduces global emissions to combat climate change. The United States has a vital national interest in curtailing emissions, meeting domestic energy demands to sustain economic growth, and securing affordable energy sources. Recent US efforts to boost renewable generation and shore up vulnerable supply chains are steps in the right direction. The energy supply-chain disruptions due to the global pandemic and Russia's invasion of Ukraine indicate that the United States will not be able to rely on importing fossil fuels and the raw materials needed to transition to renewable energy. The United States must sustain its focus on transforming the energy industry to meet its national-security goals of stability, security, economic prosperity, and combatting climate change. If the United States fails to make the necessary changes, it will not only miss an economic opportunity to lead the coming energy revolution but will also have to contend with a steadily worsening global-security situation while being deeply vulnerable to disruptions to global energy supply chains. The recommendations offered in this paper provide lines of effort that will help the United States continue to move toward these goals.

Appendix A: 2009 and 2018 Policy Recommendations

2009 Energy Industry Study Report Recommendations:[86]

1. Appoint an energy leader to produce and execute a strategic plan;
2. Diversify energy produced and used;
3. Take a global leadership role in energy;
4. Increase investments in energy innovation; and
5. Reduce energy consumption.

2018 Energy Industry Study Report Recommendations:[87]

1. Set conditions to profit from energy exports economically
2. Protect nuclear power as a geopolitical tool
3. Establish policies to make renewables more viable for large-scale use

Appendix B: Teams

B1. Author Team (Alphabetical by Last Name)

1. Colonel Rafat Albatran, Royal Jordanian Air Force
2. Captain Wayne Andrews, US Navy
3. Colonel Leobardo Avila, Mexican Air Force
4. Ms. Molly Bach, Industry Fellow, KBR
5. Ms. May Baptista, US Department of State
6. Commander James Davis, US Navy
7. Lieutenant Colonel Patrick Farrell, US Army
8. Commander Peter Gaal, US Navy
9. Lieutenant Colonel Matthew Hoffman, US Marine Corps Reserve
10. Ms. Heidi Ingraham, US Department of the Air Force
11. Lieutenant Colonel Jonathan Keen, US Space Force
12. Captain Toriano Murphy, US Navy
13. Lieutenant Colonel Joshua Persing, US Air Force
14. Lieutenant Colonel Jaime Ramirez, US Air National Guard
15. Colonel David J. Shattls, US Air National Guard
16. Lieutenant Colonel Marie F. Slack, US Army

17. Colonel Ionel Vlasie, Romanian Army

B2. Faculty Team

1. Dr. Alexandria Huerta, US Agency for International Development
2. Colonel Thomas McCarthy, US Air Force

Appendix C: Industry Field Studies & Outreach

C1. Energy Lecture Series

1. Andrew Moyseowicz, Senior Smart Grid International Trade Specialist, US Department of Commerce, International Trade Administration.
2. Anne Ahrendsen, Energy Storage Trade Specialist, US Department of Commerce, International Trade Administration.
3. Anthony J. Gannon, PhD, Associate Professor in the Department of Mechanical and Aerospace Engineering, Naval Post Graduate School.
4. Anthony Pedroni, National Vice President, Development, NextEra Energy Resources.
5. Chris Herman, International Trade Specialist, Renewable Energy, US Department of Commerce, International Trade Administration.
6. Cora Dickson, Senior Renewable Energy Trade Specialist, US Department of Commerce, International Trade Administration.
7. Erik Limpaecher, Leader, Energy Systems Group, MIT Lincoln Laboratory.
8. Jeff Waksman, PhD, Program Manager, Strategic Capabilities Office, Office of the Secretary of Defense.
9. John D. Jennings, Government Partnership Advisor, Advanced Research Projects Agency—Energy.
10. Mary C. Harris, Co-Chair, City of Alexandria's Energy and Climate Change Action Plan Task Force.
11. Nikos Tsafos, James R. Schlesinger Chair for Energy and Geopolitics with the Energy Security and Climate Change Program at the Center for Strategic and International Studies.
12. Oliver Fritz, Chief of Staff and Director for Operational Energy in the Office of the Deputy Assistant Secretary of Defense for Environment and Energy Resilience.
13. P. Mason Carpenter, Colonel (USAF Ret.), Innovation Project Transition Engineer for the Office of the Secretary of Defense.
14. Paul Jaffe, PhD, Researcher and Electronics Engineer, Naval Center for Space Technology at the US Naval Research Laboratory.
15. Thomas Shearer, Colonel (USAF Ret.), Intelligence Surveillance Reconnaissance Directorate, Headquarters, US Space Force.
16. Victoria Yue, Senior Climate Trade Policy Specialist, US Department of Commerce, International Trade Administration.
17. Wesley Henderson, PhD, Battery Research Scientist, US Army Research Laboratory.

C2. Domestic Field Studies*

1. Bayfront Park, Florida Power & Light, Miami, FL
2. US Department of Energy, Emergency Command Center, Washington, DC

3. Dominion Energy Headquarters, Richmond, VA
4. Dominion Energy Power Station, Emporia, VA
5. Edison Electric Institute, Washington, DC
6. Florida International University, Engineering Campus, Miami, FL
7. Florida Power & Light, Physical Distribution Center, Riviera Beach, FL
8. Lawrence Livermore Labs, Livermore, CA
9. Montgomery County Recycling Center, Derwood, MD
10. Naval Postgraduate School, Monterey, CA
11. NextEra Energy Headquarters, Juno Beach, FL
12. Schweitzer Engineering Laboratories, Mobile Microgrid, Washington, DC
13. Turkey Point Nuclear Generating Station, Homestead, FL

* Note: Due to COVID-19 and budget restrictions, no international travel was conducted for this study.

Appendix D: Current Energy Landscape

D1. Current Energy Sources

To complete the industry analysis this report considered the various energy options available. This analysis considered fossil fuels, solar, hydropower, nuclear, geothermal, space, wind, lithium, and biomass. Included within this appendix are descriptions of each of these currently available energy sources. For each of the energy options, consideration was given to three categories: affordability, reliability, and resiliency. The definitions for these categories are included in this appendix. The results of the analysis are in the main body of the report.

D2. Fossil Fuels

Fossil fuels have powered worldwide economic expansion for over 150 years. The use of fossil fuels has consistently grown over the last century and today provides approximately eighty percent of the world's energy. The burning of fossil fuels releases stored carbon and other greenhouse gases into the atmosphere. An excess buildup of these greenhouse gases has caused dramatic alterations to the Earth's climate.[88] Before climate change was a concern, the global shift towards fossil fuels was due to the energy density of fossil fuels. Fossil fuels merge energy density with ease of transport, inspiring novel technologies in electricity and transportation. It is not feasible for the world to stop extracting and using fossil fuels instantly. The global economy, human health, and individual livelihoods currently depend heavily on oil, coal, and gas. However, over time, the world must replace fossil fuels with low-carbon renewable energy sources.

D3. Solar

The solar power industry in the United States has seen massive growth since 2000. In the last decade alone, solar has seen an average annual growth rate of 33%.[89] Solar power accounted for 3.3% of the total US power generation in 2020, making it the fastest-growing electricity source.[90] Solar power is the fastest-growing sector of the green energy market because its power source is plentiful, the equipment is reliable, and it is becoming more affordable than ever before because of government subsidies. However, available daylight limits solar-power generation. Therefore, producers must combine solar grids with battery storage. Solar energy is an attractive power source in the continental United States and Hawaii due to the amount of solar radiation the country receives and is an excellent option to incorporate into the diversification of our nation's power grid. The adoption of solar energy becomes less practical as one ventures further from the equator as these areas face limited solar collection hours and lower solar intensity.

D4. Hydropower

Hydropower was most likely the first form of energy harnessed by humankind. The advent of turbine technology by the 1700s resulted in the use of mechanical power to support Industrial Revolution era goals, such as processing cotton and other textiles and factory mechanical processes. The late 1800s saw the first uses of waterpower to produce electricity, with rapid advancements in the United States and Europe. The first half of the twenith century continued such rapid advances, with expansive projects such as the Hoover and Grand Coulee Dams producing forty percent of all US electricity in 1940.[91]

Hydropower projects have a wide range of costs, primarily based on the size and complexity of the project. However, it can be a very affordable method of generating electricity. The significant upfront costs of building substantial civil-engineering projects such as the Hoover Dam are generally amortized over long periods, approaching a century in this case. The maintenance, equipment, and operations costs are generally less than other forms of electricity generation for the amount of electricity produced. Hydropower currently accounts for two-thirds of all renewable electricity generated globally and has the potential to reach an additional 50 gigawatts of electricity generation by 2050 if adequately developed.

D5. Nuclear

Nuclear energy comes from the nucleus of a uranium atom. All nuclear power plants use nuclear fission, where a reactor splits particles to create energy.[92] The resulting reaction releases a large quantity of energy in the form of heat and radiation. This process is a nuclear chain reaction, and uranium is the fuel most widely used by nuclear plants.[93] Even though this metal is common to find in rocks worldwide, uranium is considered a nonrenewable energy source.[94] Nuclear power plants heat water to produce steam. After that process, plants use steam to spin large turbines that generate electricity.

As a security measure, most nuclear reactors have concrete domes protecting the reactors, which are essential to contain accidental radiation releases.[95] Furthermore, not all nuclear power plants have cooling towers.[96] As a result, some nuclear power plants use various water sources from lakes, rivers, or oceans for cooling. However, one of the principal concerns about using nuclear energy is the creation of radioactive waste. These radioactive materials from the fission process can remain radioactive and dangerous to human health for long periods.[97]

D6. Geothermal

The first evidence of geothermal use in America dates back ten thousand years, with settlements near hot springs. The springs provided shallow pools for warmth and vitality. Fast forward to 2022, and geothermal resources can be tapped more than ten miles below the Earth’s surface to extract energy.[98] According to the US Energy Information Administration, geothermal energy is hot water or steam (300–700°F) extracted from geothermal reservoirs in the Earth’s crust.[99] It comes from the heat trapped deep beneath the surface of the Earth and can be used to generate renewable electricity. It accounted for two percent of US renewable energy consumption in 2020. The United States leads the world in geothermal electricity generation at 16 terawatt-hours, followed by Indonesia, which produced roughly 14 terawatt-hours. There are two types of electricity-generation systems other than natural hot water springs and reservoirs: power plants and heat pumps.

Geothermal energy is the most reliable renewable energy. Unlike solar and wind power, which rely on constant sunshine or consistent, stable blowing wind, geothermal energy is available twenty-four hours a day, seven days a week, and 365 days a year. Geothermal generators can also operate at an availability rate of over ninety percent of what the plant produces.[100] They can produce more electricity over time than power plants using coal, natural gas, nuclear power, or hydropower.[101]

Additionally, Geothermal energy is sustainable. It will never be depleted as long as the Earth exists. It has been tested and proven over time in numerous locations. Initial concerns highlighted the challenges of pumping out the Earth's underground water. Innovative technologies can reinject wastewater back into the ground through a well after use, ultimately prolonging the reservoir's life.[102]

D7. Space

Space-based solar power is the concept of collecting solar energy in space by satellites and directing it to return to Earth at a specific location. The DOE estimates that more space-based solar power reaches the world in one hour than humans use in one year. Space-based solar energy can supply a steady, uninterrupted power transmission through rain, clouds, and other common atmospheric conditions. While traveling an extreme distance, this power can safely travel at intensities no greater than the midday sun. This energy generation method has been in conceptual planning since the 1970s, but requirements to have a several-kilometer-wide satellite in space to receive and project the power to Earth has hindered significant advancements in this type of green-energy technology.

Solar laser satellites and microwave solar satellites can provide space-based solar power. Both require a receiver in space to capture the energy and direct it to Earth. The current estimation for startup costs ranges from $500 million to $1 billion.[103] Total production cost is estimated in the tens of billions and requires as many as one hundred launches into space, with some needed space-based assembly. Some argue that it may not be economically viable even with these estimated costs. These hurdles come from technological limitations of wireless power transmission combined with rotating satellites and fixtures.

D8. Wind

Wind power was the world's second-largest renewable energy source for power generation (behind hydropower). With 743 gigawatts of global capacity, wind power produced more than 6% of global electricity in 2020, with 707.4 gigawatts of the 743 gigawatts being produced onshore.[104] Within the United States, only 8.4% of electricity comes from wind power.

Onshore US turbines must be within the guidelines of several regulations. The Bureau of Land Management (BLM) outlines the rules and regulations for onshore wind turbines. Each state has different zoning areas that allow the development of wind farms which BLM determines. Developers also must follow EPA noise standards and Federal Aviation Administration (FAA) height standards and regulations. The FAA regulations have hindered the height of onshore turbines. For example, suppose a developer wants to install a turbine taller than 499 feet. In that case, the FAA has additional steps developers must take for approval. Some developers find the extra steps are not worth it.

D90. Lithium

Lithium is a reactive alkali metal and is the lead element in the group of metals known as the lithium family. Lithium is a good conductor of heat and electricity and is reactive with air and water. The reactive nature makes it dangerous to handle (it is highly corrosive and challenging to extinguish if it catches fire). However, those same reactive qualities make it a great candidate for use in a battery. Lithium is also the least reactive element in this family. Lithium is very light and has a high energy density, making lithium an ideal candidate for products that depend on lightweight battery technology.

Could one use other elements? Maybe. For applications allowing lower energy density, sodium and potassium are available. China is currently investing in both sources of lithium-ion alternatives. Applications for these replacements might be in things like battery storage of solar power with battery packs that remain in place. Lithium does not occur freely in nature. Its reactive nature causes it to bond to other elements and it appears naturally in various mineral deposits. Most lithium comes from brine deposits, followed by hard rock and clay. The lithium hydroxide found in the hard-rock deposits is the most valuable and expensive to produce. In addition to the direct mining of lithium hydroxide, one can further refine lithium carbonate into lithium hydroxide. However, no company has successfully mined lithium from clay. The Thacker Pass project by Lithium Americas will be the first project to do so.

Around eighty percent of the total lithium production worldwide originates from Australia, Chile, and Argentina. Five companies dominate lithium production: SQM, Albemarle, FMC, Tianqi Lithium, and Jiangxi Ganfeng Lithium. Chilean and Argentine deposits appear in brine. Australia's deposits appear in hard rock. China's production is from both hard rock and brine. Australia produces a concentrated spodumene (a pyroxene mineral consisting of lithium aluminium inosilicate) transported to China for upgrading into specialty lithium chemicals (primarily lithium hydroxide). China controls more than half of the world's lithium processing and purification operations and has three-quarters of the world's lithium-ion battery factories.[105] In the United States, Lithium Americas is preparing to open the world's first clay lithium mine. That mine will provide the United States with an extraction and refining capability of up to 80,000 tons per year. However, this is an industry first. Much depends on Lithium Americas's feasibility assessment.

There is a massive demand for lithium due to the rapid growth in the production of EVs that use lithium-ion batteries. Experts expect the worldwide lithium battery market to grow by 4,000% by 2040.[106] The US industrial base must be able to respond to this massive increase in market demand, or else it is likely to benefit well-resourced competitors in Asia and Europe. The price of lithium is rising, up 280% since January 2021, and creating a domestic supply of lithium has become the modern version of oil security.[107] However, the United States is far behind, with only one domestic lithium mine operating: the Silver Peak Mine in Clayton Valley, Nevada.[108]

Almost every major automaker has announced a transition to electric cars. Tesla delivered nearly a million vehicles in 2021, and a handful of new electric car companies like Rivian and Lucid are rolling out new models off the line.[109] In an unprecedented move, most major world automakers have announced long-term milestones for their transition from all gas fleets to all-electric fleets. For example, General Motors has announced that it will produce only EVs from 2035. Ford Motor Company has already reorganized its entire company into two divisions, one producing legacy gasoline vehicles and one focused on future EV production. These plans depend heavily on the ability of these companies to drive the production of charging networks to support an EV fleet. Only Tesla has made significant progress in its charging network.

D10. Biomass

Biomass is an organic (plant- or animal-based) renewable energy source that has been around since prehistoric times when hunter-gatherers used to make wood fires to cook their food and warm themselves. According to the International Energy Agency, biomass is "the most important source of energy today."[110] Various and abundant sources produce biomass, commonly referred to as feedstocks, including "wood and wood processing wastes—firewood, wood pellets, and wood chips, lumber, and furniture mill sawdust and waste, and black liquor from pulp and paper mills; agricultural crops and waste materials—corn, soybeans, sugar cane, switchgrass, woody plants, and algae, and crop and food processing residues; biogenic materials in municipal solid waste—paper, cotton, and wool products, and food, yard, and wood wastes; animal manure and human sewage."[111] And all these feedstocks can be relatively easily transformed into usable energy "through various processes, including direct combustion (burning) to produce heat; thermochemical conversion to produce solid, gaseous, and liquid fuels; chemical conversion to produce liquid fuels; biological conversion to produce liquid and gaseous fuels."[112]

From a carbon dioxide (CO_2) emission perspective, biomass is "a carbon-neutral source of energy"[113] since "biomass combustion is assumed to be balanced by the uptake of carbon when the feedstock is grown, resulting in zero net emissions over some period of time."[114] However, this assumption seems to "ignore entirely emissions from combustion, and measure only emissions from the supply chain (from harvesting, processing the wood and transporting it)."[115] Moreover, when "biomass is burnt in the presence of oxygen, it produces carbon dioxide—and, in general (depending on the type of feedstock and efficiency of the power plant), at a higher rate per unit of electricity generated than coal, and much higher than gas."[116] In fact, it is very complicated to calculate the overall carbon impact of biomass, and it "needs to take into account a wide range of factors that affect the balance between carbon in biomass and in the atmosphere."[117] These factors include but are not limited to: "the impacts of any initial land clearance to grow trees (in the case of plantations); any indirect land-use effects; any losses of soil carbon during harvesting; supply-chain emissions from the energy consumed in harvesting, processing and transporting biomass; and the time delay until replacement trees are large enough to absorb carbon at the same rate as the harvested trees."[118] For example, on the one hand, "burning municipal solid waste (MSW), or garbage, in waste-to-energy plants could result in less waste buried in landfills"[119] that would typically generate more CO_2 and methane.

On the other hand, burning MSW to produce bioenergy releases chemicals and substances into the air that "can be hazardous to people and the environment if they are not properly controlled."[120] Moreover, the residue from waste-to-energy plants can contain high concentrations of various metals that were present in the original waste."[121] A similar case, but with some minor differences, is with biogas mainly composed of methane and CO_2 and produced through biomass decomposition or from burning biomass. Burning biogas to produce energy releases CO_2, "but because methane is a stronger greenhouse gas than CO_2, the overall greenhouse effect is lower."[122] Also, "ethanol and gasoline-ethanol blends burn cleaner and have higher octane ratings than pure gasoline, but they have higher evaporative emissions and contribute to the formation of harmful, ground-level ozone and smog."[123] Similarly, biodiesel combustion "produces fewer sulfur oxides, less particulate matter, less carbon monoxide, and fewer unburned and other hydrocarbons, but it does produce more nitrogen oxide than petroleum diesel."[124] Consequently, the carbon impact of biomass "will depend critically on the feedstocks used" and on the advance of bioenergy technologies.[125] These two factors will ultimately determine whether the use of biomass is carbon-neutral or carbon-negative.

Practically speaking, biomass is a reliable source of energy mainly because it is not intermittent or variable like other sources of renewable energy (e.g., solar stops when the sun goes down; wind fluctuates with the speed of wind). Hence, biomass energy plants can either run continuously or easily be turned on or off to produce baseload power and meet energy demands without disruption. Also, it is "a sustainable alternative to fossil fuels because it can be produced from renewable sources that can be continuously replenished."[126] Moreover, unlike other renewable energy sources (solar and wind), it can be efficiently and cost-effectively (in fact, in the case of raw materials at no cost) stored in large amounts. However, biomass also has several downsides concerning costs, efficiency, and environmental impacts that can vary depending on the fuel used and how it is collected.

D11. Definitions

Affordability: There is no universal definition of *affordability*. The Michigan Public Service Commission developed a definition in April 2022 to submit as an industry-standard: "A household has the resources to meet their home energy needs for heating, cooling, and other uses in a healthy, sustainable and energy efficient manner without compromising a household's ability to meet other basic needs."[127] To compare affordability, this report uses the levelized cost of energy (LCOE), which is a measure of the average net present cost of electricity generation for a generating plant over its lifetime.[128]

Reliability: *Reliability*, according to the DOE, is "the ability of the system or its components to withstand instability, uncontrolled events, cascading failures, or unanticipated loss of system components."[129] For the purpose of this analysis, this report uses *capacity factor* as the measure of reliability. Capacity factor is "the ratio of the electrical energy produced by a generating unit for the period of time considered to the electrical energy that could have been produced at continuous full power operation during the same period."[130]

Energy Resilience: The US Code defines *energy resilience* to mean "the ability to avoid, prepare for, minimize, adapt to, and recover from anticipated and unanticipated energy disruptions in order to ensure energy availability and reliability sufficient to provide for mission assurance and readiness, including mission essential operations related to readiness, and to execute or rapidly reestablish mission essential requirements."[131] To compare resilience, this report uses Demand Equivalent Forced Outage (EFORd), which is the probability that a unit will not meet its demand periods for generating requirements (the lower the EFORd, the better).[132]

Appendix E: Ukraine

The energy industry in the United States can have a significant but indirect impact on the conflict in Ukraine. Ukraine has significant energy-production capability, especially nuclear power. The conflict has disrupted much of it, with concerns over nuclear safety, electrical-grid transmission, and support. Conventional production and transportation have decreased significantly.

Factors directly impacting the energy industry from the conflict are wide and varied. The price of oil has risen to over $100 a barrel.[133] American oil companies have, almost without exception, stopped exploration and business deals with Russian companies, with the expectation that this will result in billions in losses. The increased profit margin on barrels of oil will at least partially offset these losses.

The wind-generation industry in Ukraine has lost about two-thirds of its electricity generation capacity, with a significant portion located in contested regions either destroyed or disconnected from the grid.[134] Lithium reserves located in the central region of Ukraine are not at long-term risk, mining is still in the nascent stage, and there is limited impact on the global market. Solar power has expanded rapidly in the past couple of years. While still small compared to the rest of Europe, the glide path towards renewable energy will almost certainly be stopped. If government policies remain the same as pre-conflict, there is a significant opportunity for US firms to participate in both utility-scale and residential photovoltaic construction.

The initial round of sanctions will impact the energy sector directly, while the initial round of assistance was almost exclusively in the armaments, defense, and humanitarian areas. However, the expected renewed focus on renewable energy, coupled with the desire for energy independence, will drive spending by global governments. Expected winners include renewable research and development, energy industry cybersecurity in transmission and generation, public support for renewable and energy dependence, additional/continued tax incentives and rebates for renewable and domestic fossil fuels, government support and legal frameworks for mining of strategic materials, such as lithium, vital to electricity management, storage, and generation.

US policy must focus on providing grid reliability and resilience through grants and security assistance bills to get the Ukrainian electrical system back to pre-conflict as quickly as possible. Tariff and tax incentives need to be used in the medium term to encourage US power-generation companies to provide a speedy post-conflict rebuild. In the long-term, US fossil fuels companies and strategic mining and minerals firms need support through the Defense Production Act to promote energy independence for the United States and Europe. Support will also help them to secure extraction rights to Ukrainian raw materials.

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