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NATIONAL SECURITY IN AN ERA OF CLIMATE CRISIS & ENERGY TRANSITION

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ENERGY INDUSTRY STUDY SEMINAR 2021

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Executive Summary. Energy drives economies and sustains societies around the world. Modern events—the deadly tsunami hit to Japan's Fukushima nuclear plant, Puerto Rico's electrical devastation from Hurricane Maria, cyber-attacks on Ukrainian electrical grids and the US Colonial Pipeline, and the notorious Texas freeze of 2021—demonstrate the dramatic impact of energy disruptions. In every sense, energy empowers states to be competitive and influential. This paper describes the strategic environment surrounding the global energy sector, discusses the current state and outlook of energy industries globally, considers the Energy Trilemma and National Security nexus, and examines the global threat of climate change, including related policies and implications.

In a time of Great Power Competition, the role of energy becomes increasingly intertwined with geopolitics. The world's superpowers are in diplomatic and technological competition for energy resources. Russia's increased activities in the Arctic region, growing Russia-China energy ties, China's Belt and Road Initiative projects, and China's expanding influence in Africa provide vivid evidence of the race. Given the increased volatility of the strategic security environment, the protection of critical energy infrastructure is no less important than territorial defense. Countries without reliable and resilient access to energy resources continue to be vulnerable and threatened.

Nations are coming together to address the threat of climate change via the Paris Agreement and related goals. The escalating climate crisis should drive a global energy transition from fossil fuels to renewable and clean sources of energy to reduce emissions, but countries' varying energy situations and national security create divergent paths. As such, despite ambitions, these goals are currently not achievable without a significant change in global energy source production and consumption, the pace of energy transition, and investment now to meet goals in 2030 and 2050. **The countries of the world must prepare for a new global energy environment due to climate change while pursuing their respective national security objectives. As principal champion of the long-standing rules-based international order, the United States must lead in this global challenge through a complex process of global energy and climate diplomacy.**

The United States must hasten global cooperation on climate change and energy transition, given that domestic and international actions to mitigate and adapt to significant climate change effects remain inadequate. The United States is relatively well postured given its diverse energy base, strong market policies, and trade institutions, as well as strong innovation, financial, infrastructure, human capital, education, and industrial bases. Although it is unclear what the impact of the energy transition will be on total emissions, it will mitigate the worst of climate change outcomes by limiting emissions. This report proposes policy recommendations for the United States to best lead in the complex national security environment. Policies that reduce fossil fuel emissions or encourage the transition to a low-carbon economy also help US energy security by supporting the sustainability of energy resources.

First, the US must implement carbon pricing to allow low carbon-emitting energy sources to compete with high carbon-emitting fossil fuels. This policy requires the US to update environmental regulations to establish more comprehensive clean energy standards and enact either a carbon tax or a cap-and-trade system. **Second**, the US must increase energy education, research, and development. Establishing an understanding of the impact that energy has on our security and prosperity and investing in our innovation systems is critical to developing low-

carbon technologies. **Third,** the US must ensure a "just" energy transition to avoid adverse impacts on vulnerable populations such as developing nations and displaced US workers. Initiatives that prevent job losses, reduce US dependence on minerals mined where human rights violations are prevalent, and assist developing countries in decarbonizing while economically prospering are vital. **Fourth,** the US must re-establish itself as a leader in climate change through preeminent multilateral engagements to encourage and enforce international commitments to decarbonization. The initiative begins with reorienting the US's substantial diplomatic and development apparatus to prioritize climate diplomacy and setting the example by implementing aggressive domestic decarbonization policies.

This is a significant time for energy as countries around the world focus on their climate-impacted energy futures. US government and industrial partnerships must earnestly and urgently execute a sustainable energy security strategy that leverages international networks and relationships for current and future generations.

Research Methodology. This report is the culmination of five months of extensive study of the energy industry by the 2021 Energy Industry Study Seminar at the Dwight D. Eisenhower School for National Security and Resource Strategy from January to May 2021. The studies included extensive seminar instruction and virtual visits from industry, academic, and government experts. This report discusses the current conditions in key energy industries and articulates the analyses conducted on the United States, China, Russia, Japan, and Puerto Rico. The methodology used includes Porter's Diamond Theory of National Advantage, the National Innovation System, and National Industrial System models. The term-long study and the analyses drive specific policy recommendations the United States should consider to help ensure long-term energy security.

I. Introduction

Energy is the foundation of the world's modern economy and fuels prosperity and opportunity worldwide. Energy plays an essential role in the national security of all countries; however, the energy landscape is different for each country. Some countries enjoy affordable and reliable energy. Other nations rely heavily on imports to meet their needs—many struggle to meet the needs of populations without access to basic, modern energy services. The portfolios of energy sources used to meet varied energy consumption needs also differ across the world.

To the United States, energy is a key geopolitical and geo-economic asset that cuts across all its national security interests. It is vital to domestic markets, the national economy, foreign policy, international trade, and the environment. Energy is a critical enabler of US society. Domestically, homeland defense networks depend on diversified sources of energy to safeguard the American people. Abroad, the US Department of Defense (DoD) relies on power to execute mission-essential functions. The United States also enjoys the geopolitical benefits of being a leader in the global energy market. Internationally, US allies and partners face a diverse set of energy security challenges that directly affect US energy security. Some do not possess domestic energy sources. Others face significant vulnerabilities like erratic energy providers.

Modern global energy practices generated a common threat to all countries in the form of climate change. Wide-ranging national security implications of climate change include energy risks. Extreme weather events can affect energy production and transportation, and temperature changes impact energy demands and electrical loads. In addition, sea-level rise can affect coastal and riverine energy infrastructure. Disruptions to energy supply and consequential tensions and conflicts in one part of the world may cascade elsewhere.

The escalating climate crisis is driving a global energy transition from fossil fuels to renewable and clean sources of energy to reduce emissions, but countries' varying energy situations create divergent paths. To address climate change fairly and justly, world leaders must recognize that each country will differently address their diplomatic, economic, energy resiliency and security, environmental, and military priorities. Some countries are increasingly moving toward cleaner energy while others, for various reasons, continue to rely on coal-fired power. However, the climate crisis demands the abilities of all countries, both developed and developing, to mitigate the consequences of the rising energy demand. Climate change cannot be effectively addressed by any nation alone. Climate and energy diplomacy are needed.

The US position in the world's energy security and the transition has numerous, worldwide, significant implications. The web of cross-border energy networks presents an already challenging arena. However, the complex and volatile security environment engendered by the continued rise of China and the resurgence of Russia increases the complexity. The US role in efforts to combat climate change will be a critical aspect of diplomacy in the years ahead. US leaders need to navigate the energy transition while simultaneously dealing with Russian aggression and US-China competition across the spectrum of power and influence. Climate change and the associated energy transition are strategically crucial to the United States, a global power with strategic interests worldwide. How the energy transition unfolds will dramatically affect US national security.

The climate crisis and energy transition also present the United States with a leadership opportunity through international engagement and cooperation. The United States can collaborate to pursue shared energy security goals and, as a potential frontrunner in clean energy, lead by example. Leading the world is how the US traditionally ensures its domestic peace, security, and prosperity. **The countries of the world must prepare for a new global energy**

environment due to climate change while pursuing their respective national security objectives. As principal champion of the long-standing rules-based international order, the United States must lead in this global challenge through a complex process of global energy and climate diplomacy.

This paper outlines the strategic environment and key stakeholders, including climate change policy and implications; defines the energy sector and nexus relationships; outlines and examines current industry conditions and outlooks of key energy sources; analyzes the US, China, Russia, Japan, and Puerto Rico's energy systems using Porter's Diamond, the National Innovation and National Industrial Systems; and provides policy recommendations for the US to best lead in this complex national security environment.

II. Energy Sector Overview

Energy Sector Defined

The vast **energy sector** is composed of millions of different international and national energy and energy-related industries throughout the global value and supply chains. The value chain includes exploration and extraction of the fuel source, and then the production, power generation, transmission, and distribution of the fuel. Industry subsectors are also broad and include fossil fuel industries of oil, petroleum, natural gas, and coal; electric power; nuclear power; renewable energy and fuels like hydro, wind, solar, geothermal, and biomass; as well as battery storage, smart grids, and energy efficiency activities.

The total world energy supply from 1990-2018 was primarily composed of fossil fuels (Appendix A, Figure 1). More than 80 percent of the world's energy is currently obtained from fossil fuels, and this trend is expected to continue through 2050, with almost 70 percent of global energy coming from fossil fuels (Appendix A, Figure 2).[1] Global consumption follows similar current and projected trends through 2050 (Appendix A, Figures 3-4). Global consumption has increased nearly every year over the past 50 years, with many countries' consumption increasing as incomes rise and populations grow.[2] As populations increase and developing countries' economies expand, demands for energy, electricity, industrial products, and transportation also increase. Although experts continually re-evaluate these forecasts and some project different scenarios, unless there is a significant global societal change in energy production and consumption in the next ten years, these trends will continue.

The world's largest energy consumers per capita include the US, Saudi Arabia, Qatar, Canada, Iceland, and Norway.[3] Further, the average person in these countries consumes as much as 100 times more than the average person in some of the poorest countries.[4] Figures 5 and 6 (Appendix A) outline global consumption from 2010-2050 by region and sector for Organization for Economic Cooperation and Development (OECD) countries and non-OECD countries. Energy consumption projections in Asia and non-OECD nations increase to 2050, with distinct growth in the industrial and transportation sectors. When evaluating by energy source, the US Energy Information Administration (EIA) projects renewable energy consumption to increase to 2050, natural gas consumption to remain steady, and petroleum and coal use to decline slightly (Appendix A, Figure 7).

The Energy Trilemma and National Security Nexus. The World Energy Council defines a healthy energy system as "secure, equitable, and environmentally sustainable."[5] A carefully managed balance between these competing demands and dimensions is defined as the *World Energy Trilemma* (Appendix A, Figure 8.*)*[6] The International Energy Agency (IEA)

defines **energy security** as "the uninterrupted availability of energy sources at an affordable price."[7] As the IEA highlights, international and national energy security has short and long-term aspects, including the ability to meet immediate supply and demand balances and respond to any changes as well as plan, support, and meet long-term investments for economic, political, social, and environmental developments and needs. The World Energy Council further outlines energy security in the effectiveness of nations in their respective management of domestic and external sources and the resiliency of the energy infrastructure throughout the value and supply chain.[8]

Consistent with globally integrated world markets, energy security does not require or mean energy independence. Although national energy self-sufficiency supports national security, including protection against vulnerabilities to supply changes, disruptions, or changes in prices, nations do not need to be independent. No country is energy independent – and the US has never have been. In fact, diversification of sources and supplies bolsters national energy security. Energy security improves "by being integrated into a global energy market, allowing more optionality, interconnectedness, competition, supply diversity, and interdependence."[9] Global interdependencies assist with global market efficiencies, strengthening international and national energy security, reliability, and resilience.

Continuing with the *Energy Trilemma*, **energy equity** is a nation's ability to provide reliable, affordable, and abundant universal access to energy.[10] Uneven supply of energy among countries creates national security vulnerabilities. These vulnerabilities are exacerbated by political instability; price and quantity manipulation of supply; competition, conflicts, or attacks on supply and consumption infrastructure; natural disasters; importer or exporter interests; and increasing demand and pace of industrialization, especially in China and India. Any energy disruption—the coronavirus pandemic, electric power blackouts, and natural disasters as in Puerto Rico, Japan, and Texas—can cost lives and trillions of dollars. Furthermore, climate change creates additional threats to energy and national security, especially in sectors that heavily rely on oil, namely militaries.

Lastly, **environmental sustainability** represents a country's energy system transition toward mitigating and avoiding environmental and climate change impacts through improved generation productivity and efficiency, transmission and distribution, decarbonization, and air quality.[11] The state of a nation's energy transition varies and depends on international, regional, national, and local factors and is further discussed in Section V. As nations transition their respective energy systems, international and national environmental sustainability will improve. However, energy transition itself may cause further stability or instability, with the potential for conflict.

The *Energy Trilemma* dimensions must be carefully managed, balanced, and mutually supported by public- and private-sector policies, regulations, and investments. Moreover, it is paramount that these dimensions are managed within the strategic international and national security nexus for long-term sustainment. A century ago, "energy security became a decisive factor in international relations…it is about relations among nations, how they interact with each other, and how energy impacts their overall national security."[12] "Underlying everything else is the fundamental need of countries—and the world—for reliable and resilient energy with which to power economic growth."[13]

III. Stakeholder Interests, the Strategic Environment, and Climate Context

Key International Stakeholders & National Security Interests

Interdependent international and national relationships create opportunities for both cooperation and competition across a broad range of interests, with energy security and environmental sustainability being no exception. For example, the US cooperates through energy trades with Canada, the Middle East, and the European Union (EU). Also, the US and Japan recently agreed to partner "to address climate change and promote green, sustainable global growth and recovery" through clean energy technologies and relevant sectors.[14] Energy cooperation with allies and partners reinforces the international world order, fosters healthy markets, and promotes shared interests. Competition between allies and partners also fosters healthy markets (e.g., US and Middle East oil and gas exports) and innovation, while competition with adversaries may lead to conflict, sanctions, or punitive trade policies, as seen with recent US actions against Russia, China, and Iran.

Each nation faces different energy challenges. As a world leader in the supply and consumption of energy, the US has diversified production across numerous energy sources including oil, natural gas, coal, wind, solar, hydropower, geothermal, and nuclear power, though 70 percent of consumption is currently from petroleum and natural gas. Most energy end-use is for the transportation and industrial sectors (Appendix A, Figures 9-10). Renewable energy accounted for 11 percent of US consumption in 2019, primarily from biomass, hydroelectricity, wind, and solar (Appendix A, Figure 11). The US is one of the world's largest energy importers and exporters, supporting economic prosperity. However, consumption and the type of fuel consumption must change to meet global climate goals.

Adversaries that have energy and climate agendas contrary to US interests threaten US national security. Considering Great Power Competition (GPC) geopolitical dynamics, Russia and China present two vastly divergent perspectives on climate change. **China** is the world's largest energy consumer and emitter of greenhouse gasses and is actively pursuing energy diversification through expanded renewable energy, nuclear, and traditional fossil fuels. Through international investments such as the Belt and Road Initiative (BRI), China also aims to secure critical minerals and resources worldwide. By taking advantage of its status as a developing country and becoming an early leader in emerging renewable energy, China fortifies long-term economic prospects, avoids international confrontation over climate and energy policy, and uses progress on carbon reduction as a political wedge between the US and its European allies.[15] On the other hand, **Russia** maintains relevance through substantial oil and gas resources and military prowess. Global warming allows Russia to expand access to arctic trade routes and therefore incentivizes Russia to stymie global norm-setting on emission reduction and clean energy. Moreover, Russia has no intention of weaning itself off its carbon-intensive economy and is more likely to expand its domestic use and exportation of oil and coal.

The **EU** and member countries are among the world's leaders in renewable energy investments, though they are still reliant on US, Russian, and Middle East fossil fuel imports as well other nations. The European Green Deal outlines the strategy for combating climate change and environmental degradation through measures to "transform the Union into a modern, resource-efficient and competitive economy, where there are not net emissions of greenhouse gases by 2050; economic growth is decoupled from resource use; and no person or place is left behind."[16] Geopolitically and militarily, country commitment to the EU and the North Atlantic

Treaty Organization (NATO) is not as strong as in the past; however, economically, the EU remains one of the three largest global trading players with the US and China.[17]

The **Middle East** is one of the world's most important energy sources and is key to global economic and energy security and stability. The energy sector, in particular oil and natural gas, comprises about 40 percent of the gross domestic product as a critical trade export for some Arab nations. The region faces counter-interests from countries worldwide seeking lower carbon and renewable sources. Iran's continued engagements with China and Russia, participation in energy black markets and illegal oil transport, and pursuit of nuclear weapons further complicates the geopolitical environment and contribute to regional instability.

Energy security and climate change are expected to complicate security, governance, and migration policies in **developing nations** across the globe, potentially undermining US security interests in critical regions. Although these nations vary on the development continuum, they all actively seek improved energy access, security, reliability, and resilience. As such, while some developing countries may make modest contributions to emissions reductions and many have committed to carbon neutrality by 2050, they do not intend on decelerating development trajectories due to climate issues created by rich nations. India is implementing significant renewables infrastructure, while many African nations' abilities will be dependent on low-cost renewable technology. Latin American nations are active in international forums and collectively committed to 70 percent renewable energy by 2030. Fragile states such as North Korea will be particularly challenged.[18] Following the collapse of the Soviet Union, North Korea has faced challenges meeting its energy demands without Soviet-subsidized oil.[19] The global community continues to impose economic sanctions on North Korea because of its nuclear weapons program, restricting access to raw materials that further stresses its energy security. As a major exporter of coal, continued sanctions will hinder North Korea's ability to engage in an energy transition and likely lead to greater instability.

Though the relationship between energy, climate change, and **violent extremism** is not linear, climate-induced water and food insecurity coupled with poor governance, energy insecurity, and poverty provide opportunities for terrorist organizations to exert influence over vulnerable populations. Thus, climate impacts on energy-insecure nations that already cultivate anti-US sentiment may lead to increased terrorism and extremism. Africa's Lake Chad Basin region serves as an example of decades of resource depletion due to climate change that fueled insecurity and poverty. Violent extremism proliferated in surrounding countries such as Cameroon, Chad, Niger, and Nigeria, exacerbating existing ethnic and religious tensions.[20]

Strategic Security Environment

Great Power Competition. The international rules-based order US leadership helped establish in the wake of the Second World War led to enduring stability among western nations and sustained economic prosperity.[21] China progressively challenged that order throughout its steady rise[22] to make the system more accepting of its authoritarian model,[23] position itself as a counter-balance to American power,[24] and ultimately support its national interests.[25] Russia's rapprochement with China further exacerbates the erosion of international institutions and paves the way for a multipolar world.[26] Meanwhile, America's most valued alliances – such as the United Nations (UN) and NATO – show signs of weakening.[27] If that decay persists, it will hinder American capacity to shore up support among like-minded allies.[28] The establishment of

tomorrow's global paradigm and the ideals that underpin acceptable behavior are at the heart of this great power competition.[29]

While the threat Russia poses is often characterized as urgent and near-term,[30] China is more concerning due to its greater potential to alter the world order. Like the Cold War, US competition with China is expected to endure for decades.[31] Unlike the Cold War, cooperation also permeates this relationship due to the interrelated Chinese, US, and world economies. Beyond economics, this relationship includes energy, climate change, nuclear proliferation, societal well-being, and global pandemics, which underscore the need for international cooperation for future generations. The US approach to any major policy issue with China or Russia, including climate change, needs to be calibrated within a broad array of international and national security interests.

To effectively lead on the world stage, the US must leverage the full range of diplomatic, informational, military, and economic instruments of power across many arenas.[32] The energy industry has a fundamental role to play. There are opportunities – and arguably a necessity – to cooperate with China to pave the way for a global response to climate change and set global emissions standards for the future. There will be many areas for competition, such as with the technological innovations needed to drive energy transitions. And various forms of intense competition could potentially spill into conflicts, such as diplomatic confrontations over international institutions and the rules that govern national behavior, values, political and social ideology, or international trade and commerce for national and global power.

Climate Change, Energy Transition, Policy, and National Security Implications

Carbon Emissions and Future Projections. Carbon dioxide's growing concentration in the atmosphere threatens the environment, economy, and national and international security. Three-quarters of global greenhouse gas (GHG) and carbon dioxide (CO_2) emissions are from coal, oil, and gas, mostly for electricity generation and transportation. [33] Globally, industry accounts for 24 percent of GHG emissions, transportation for 16 percent, and commercial and residential buildings for 17.5 percent, while agriculture accounts for 18 percent of emissions.[34] Within the US in 2019, transportation generated 29 percent of GHG emissions, electricity 25 percent, industry 23 percent, commercial and residential buildings 13 percent, and agriculture 10 percent.[35] These industries are critical to the global economy, infrastructure, and way of life; addressing their carbon emissions is vital.[36]

Climate change is expected to profoundly impact critical aspects of life around the world, including water, transportation, wildlife, agriculture, ecosystems, and human health. These combined climate and energy impacts may especially endanger the health and safety of inhabitants in regions with existing security issues like ethnic tensions or corrupt governance. Despite a recent flurry of net-zero commitments by countries, collective global efforts are lacking.

There is a large gap between countries' stated climate pledges and plans, various national fossil fuel production plans, and what is required to meet the Paris Agreement goals (Appendix A, Figures 12-13). Even the most optimistic assessment of current net-zero pledges does not meet the goal to limit global warming to 2°C. [37] The emissions gap in 2030 is estimated at 12-15 Gigatons (Gt) CO_2 emissions (CO_2 e) to limit global warming to 2°C and 29-32 Gt CO_2 e to meet the 1.5°C target, which is equal to the carbon emissions of the six largest emitters combined.[38] Meeting these global targets requires an acceleration in structural changes to world energy

production and consumption.[39] This has been recognized, and the upcoming 2021 United Nations Climate Change Conference is intended to accelerate action towards the climate goals.

Reaching a goal of global net-zero reductions by 2050 will require unprecedented actions by governments, energy companies, investors, and citizens over the next decade. For example, to meet a 40 percent reduction in emissions by 2030 requires low-emissions sources to provide 75 percent of global electricity generation, up from less than 40 percent, and for more than 50 percent of passenger cars sold worldwide in 2030 to be electric, up from 2.5 percent.[40] To put the world on track to meet Paris Agreement objectives, global investment in energy transformation needs to reach $110 trillion US dollars (USD) through 2050.[41] This includes doubling the current annual investment in new renewable installed capacity. However, global investment in clean energy has been flat since 2016 and declined 20 percent in 2020 due to COVID-19 economic impacts.[42] Without a dramatic transition from the forecasted energy production and consumption and a corresponding massive increase in needed investment, the world will remain far from its carbon emission and climate change targets.

Energy Transition, Progress, and Issues. As discussed above, the US and the world must achieve significant reductions in GHG emissions to limit global warming to well below 2°C and avoid the worst impacts of climate change. While the task is daunting, the transition to low and zero-carbon energy sources has already begun with notable successes in some areas. However, as global energy demand continues to rise, it is uncertain whether the transition will result in an overall reduction in GHG emissions or merely limit future increases. This section considers the benefits and costs of the energy transition. Later in the report, energy transition case studies of the US, China, Russia, Japan, and Puerto Rico show how each face unique opportunities and challenges in the energy transition.

The most significant and, perhaps, obvious impact of the energy transition would be avoiding the worst outcomes of climate change. Climate scientists expect global mean temperatures to rise by 2-4°C by the end of the century without a successful decarbonization effort. The economic costs of this level of warming would be staggering, with negative changes in labor supply, agricultural production, and increased mortality. The US alone will lose between 0.5-2.0 percent of potential annual gross domestic product (GDP) over the last twenty years of the century.[43] (Appendix A, Figure 14) Clearly, the long-term global economic potential would benefit from transitioning to global net-zero emissions to limit future warming.

In addition to avoiding the worst climate outcomes, the energy transition also provides opportunities for economic growth. Innovation and increased production scale have dramatically reduced the costs of renewable energy sources such as wind and solar. According to the International Renewable Energy Agency (IRENA), solar photovoltaic (PV) module prices have fallen by around 90 percent since 2009, and wind turbine prices have fallen by 55-60 percent since 2010.[44] By 2019, newly deployed solar PV generation costs were cheaper than the least expensive new fossil fuel-fired option for most locations.[45] Renewable generation also saves on operating costs, leading to additional savings societies can direct toward other priorities.

Energy transition also means labor transition, and clean energy is the driver of job growth in the energy industry. For example, in the US, more than three times as many people work in clean energy than fossil fuel extraction and production. It has become increasingly important to rural areas where they have grown more quickly than in cities. Indeed, clean energy industries make up more than 10 percent of private-sector employment in rural areas of the midwestern

US.[46] Worldwide, clean energy employment increased by 57 percent between 2012 and 2019 to 11.46 million.[47] (Appendix A, Figure 15)

The demand for energy increases as the global population increases and societies pursue a higher quality of life. Societies demand energy that is available, reliable, and affordable. For many, fossil fuels are the only viable option to meet these requirements. As a result, fossil fuels account for more than 80 percent of global energy production.[48] Nevertheless, to achieve the Paris Agreement's climate goal of limiting global warming to below 2°C, the global community must reduce its dependency on fossil fuels and replace them with renewable energy sources. The fundamental challenge of this energy transition is determining how the global community will meet the ever-increasing demand for energy while also reducing greenhouse gas emissions that contribute to global warming.

Despite the progress of many participating countries towards reducing emissions, they collectively failed to stop the growth in global emissions requiring increased reductions than anticipated.[49] Consequently, the transition must accelerate, which may have negative economic impacts on world energy markets that can lead to geopolitical and socioeconomic instability.

Moreover, the time lost to global inaction to mitigation climate change has a cost. Global hesitance to conduct energy transitions earlier has made it more difficult to meet emission reduction goals. A recent study suggests that each additional year of delay in implementing mitigation increases impact exponentially.[50] This hesitance is explained in part by human behavior described as temporal discounting, in which persons place greater value on rewards that happen sooner than later.[51] Thus, society is less likely to assign the proper significance to the need to act today to create energy transitions since the most serious effects of climate change will not be seen until future generations. By comparison, from the first research in 1973, it took just 16 years for the world to discuss, agree, and put in place a solution to reverse the depletion of the world's ozone layer caused by chlorofluorocarbons.[52] Satellite animation of the changing atmosphere over the Antarctic appeared to depict an "ozone hole" that became a strong visualization and metaphor that convened a sense of urgency based on an imminent threat.

The transition to new energy sources globally requires significant industrial, commercial, residential, and transportation infrastructure changes. The transition will require trillions of dollars in capital investment over the next century to finance both new sources of energy and to adjust existing infrastructure. No one source will fund this energy transition. It will take a collective effort that includes government incentives and subsidies for renewable energy along with significant private investment.[53] Countries have different priorities, economies, resources, wealth, cultures, and governance. Thus, the global transformation will occur at different paces and with different energy mixes as individual societies make different choices and trade-offs.

In the international context, climate and energy justice is the concept that developed nations should financially support developing countries that are most likely to suffer the worst effects of climate change. (Appendix A, Figure 16) The responsibility derives from the notion that these developing nations have benefited far less from the carbon-intensive industrialization of the past two centuries.[54] Consequently, developing nations will be unable to prosper and potentially become unstable if the international community forces them to forgo fossil fuels before industrialization without providing alternatives. The foundational premise is that developed countries are responsible for causing climate change because of industrialization; therefore, they are morally responsible for assisting underdeveloped countries denied similar economic advancement.

A similar concept has emerged domestically. Climate change will have the greatest impact on people least responsible for causing it. The impact leads to differing social, economic, public health, and other adverse impacts on underprivileged populations. Further, the premise includes the principle that energy transitions should be just (e.g., workers in the fossil fuel industry should not bear the economic cost of energy transition that necessitates the downscaling and eventual replacement of their industries and jobs). Thus, US climate and energy policy must consider its effect on reducing global warming and how well it enables developing nations and disadvantaged portions of US society to conduct energy transitions.

United Nations Efforts and Paris Agreement. According to a recent UN Intergovernmental Panel on Climate Change (UNFCCC) report, the sheer scale of the climate-change challenge has no precedent in all of human history.[55] The UNFCCC, governed by the so-called "Conference of Parties" or COP, lends its name to annual meetings to review international progress on mitigating climate change.[56] The landmark Paris Agreement was adopted by world leaders at the 2015 COP meetings in Paris.[57] It reaffirms a goal previously agreed upon in earlier international climate treaties of preventing the global average temperature from rising more than 2°C above pre-industrial levels and sets a goal of global carbon neutrality by 2050. The Agreement requires all countries to make binding emissions-reduction pledges known as nationally determined contributions (NDCs). It contains procedures for evaluating the success of individual national efforts every five years, but there are no formal enforcement mechanisms.[58]

US Climate Policy. In 2015, President Barack Obama joined the Paris Agreement under his executive authority without submitting to the formal treaty ratification process in the Senate. After coming into office in 2017, President Donald Trump announced the US withdrawal from the Paris Agreement. Withdrawing may not have substantially impacted efforts to reduce US emissions, which were already trending down due to state and local regulations and the widespread substitution of less carbon-intensive natural gas for coal in electric power generation; however, it weakened the global perception of the US as a leader in climate diplomacy.[59]

In 2021, despite a need to remain focused on COVID-19, race relations, and political extremism,[60] President Joe Biden, acknowledging the magnitude and imminence of global warming, made mitigating and adapting to climate change a core component of his administration's early policy initiatives.[61] President Biden pledged to make combatting climate change "an essential element of US foreign policy and national security"[62] and fortified this message by rejoining the Paris Agreement on his first day in office. In doing so, he forcefully stated his vision of the US as a world leader in the fight against climate change. His administration has since announced plans to cut US emissions by 50 percent of the 2005 baseline by 2030, decarbonize the electric power industry by 2035, and achieve net-zero emissions by 2050.[63] These goals are ambitious, and some observers already dismiss them as unrealistic.[64] Given the fluctuations in US climate policy, the success of the Biden administration's climate diplomacy will in many ways depend on its ability to implement its policies to reduce US emissions.

US National Security Implications. President Biden's climate policy initiatives are reaffirmed in the subsequent Interim National Security Strategic Guidance.[65] Climate change is a significant threat to US national security interests as rising global temperatures increase geopolitical and geo-economic instability.[66] A changing climate limits prosperity and stability, which causes increased international conflict. Fragile states that struggle to govern and provide for their populations adequately are most at risk. Direct impacts such as extreme weather events often damage infrastructure, which developing nations struggle to rebuild. These impacts cause

secondary effects that exacerbate instability. As already observed in Northern Africa and South Asia, climate change increases water scarcity, prompting nations to compete for adequate water supplies for drinking, agriculture, manufacturing, and energy production.[67] Water scarcity causing food insecurity is particularly concerning, as other climate impacts can promote the spread of invasive species and decrease biodiversity that will further threaten food production. These combined climate impacts may lead to mass human migration and humanitarian crises. To avoid these effects, persons in developing nations must have access to opportunities to adapt to the impacts of climate change and embrace low-carbon development to avoid future environmental damage.[68] Even countries capable of recovering from extreme weather events and adapting to changed ecosystems may struggle to provide the water, food, and energy necessary to fuel economic growth. Global competition for resources will surge, and US adversaries will seek to capitalize on instability.

IV. Current Global Energy Industry Conditions and Outlook

This paper discusses oil, natural gas, coal, nuclear, hydroelectricity, solar, wind, and waste-to-energy, and associated essential minerals, but biomass, biofuels, hydrogen, and geothermal energy also play meaningful roles in global energy. Each energy source industry is discussed globally and domestically.

Oil Industry

Industry Conditions. Oil accounts for the greatest share of any category of energy consumption, making up one-third of the world's total consumption.[69] Overall, oil consumption increased for thirty-five straight years (through 2019) with a decline in developed countries and an increase in developing. BP's 2020 statistical review of world energy showed oil consumption dropped by .6 percent, from the previous year, amongst countries in the OECD despite the US leading the world in consumption and China having the fastest consumption growth.[70] In 2019, Iran was the only country with a double-digit increase in demand at 11 percent, in contrast to countries like Iceland, Venezuela, and Pakistan, which all had double-digit decreases in demand.[71] The US, Russia, and Saudi Arabia are the highest oil-producing companies in the world, comprising 40.5 percent of the world's oil production, while the Organization of the Petroleum Exporting Countries (OPEC) countries produced 38.2 percent.[72] OPEC possesses 70 percent of the world proved conventional crude oil reserves, but Venezuela has the highest levels of conventional reserves, followed by Saudi Arabia.[73] The US, Japan, and China are the top importers of oil, respectively, while Indo-Pacific nations make up three of the top five importers and five of the top ten.

Demand growth for gasoline and diesel between 2019 and 2025 is set to weaken in countries around the world as energy transition trends increase. The world's oil production capacity is expected to rise by 5.9 million barrels per day (mb/d) by 2025, which more than covers growth in demand.[74] The US leads the way as the largest source of new supply, followed by Brazil, Guyana, Iraq, and the United Arab Emirates (UAE), who also had impressive gains.[75] While countries like Colombia, the United Kingdom (UK), Russia, Egypt, Nigeria, and Angola have the biggest declines, OPEC crude oil capacity has risen by 1.2 mb/d to 34.1 mb/d despite sanctions wiping out production from countries like Iran and Venezuela.[76] In 2019, the US Gulf Coast became the largest seaborne crude oil export hub outside the Middle East, supplying 2.6 mb/d to world markets, overtaking Black Sea and Nigerian ports.[77] The US Gulf Coast will solidify its position as the largest seaborne export hub outside the Middle East, but as US growth

plateaus, Middle East producers will step up to supply the required incremental barrels.[78] Asia, specifically in China and India, is expected to account for 77 percent of oil demand growth through 2025 because all major Asia economies are dependent on imports.[79] At the same time, oil production in the region is expecting to decline, which is expected to cause import requirements to surpass 31 mb/d.[80]

Challenges. One of the more difficult challenges for the world's largest oil companies, known as big oil or supermajors, is maintaining the global power balance while maneuvering a fast-paced energy transition that has a push for renewables and reducing emissions while meeting a great demand for oil and gas.[81] For example, the emerging urbanization in developing Asia companies continues to drive significant demand for perceivably cheaper fossil fuel imports to power their increasing energy demands. For many oil and gas companies operating carbon capture, utilization, and storage (CCUS) represents a natural extension of core capabilities such as managing reservoirs and pipelines, but to date, it remains unclear whether this can become a business that will deliver attractive returns.[82] Refined oil outputs, such as feedstocks, are another demand that pose significant challenges. A lot of attention has been placed on reducing oil consumption for energy purposes, but over thirteen other types of petroleum products made up 29 percent of total petroleum consumption in 2020.[83] The chief executive officers (CEOs) of these companies are challenged to adapt to a low-carbon era and determine which direction to go in to evolve their companies.

The increase in Asian oil demand creates a condition where oil import voyage duration will increase and inherently limit flexibility when dealing with emergencies.[84] The region will have to address this issue individually and collectively to enhance oil supply and security, especially with China's increasingly aggressive actions in the South China Sea. Overall, international trade and globalization make exporting oil susceptible to chokepoints. The most notable chokepoints that affect the market are the Strait of Hormuz and the Strait of Malacca.[85] The areas neighboring the Arabian Peninsula are among the most sensitive to the world economy's functioning. This region is exposed to numerous geopolitical threats, and the peace in the area is easily destabilized. The region is especially risky for shipping and oil transportation, which impacts the economic performance of many countries in the area. The North Africa region is also vulnerable to further economic chaos from social unrest. Large areas of North Africa were subject to political, social, and economic disorder as occurred during the Arab Spring in 2011.

Market Outlook. The COVID-19 pandemic gave oil and gas companies a glimpse of what a world with reduced oil and gas demands looks like, and it is inevitable, big oil must adjust to the energy transition. The writing was on the wall before the pandemic as the return to shareholders lagged the Standard & Poor's (S&P) 500 by seven percentage points for the last fifteen years.[86] They are also receiving pressure, not from just environmentalists but also investors and analysts, to standardize reporting of greenhouse gas emissions produced by operations, cut capital spending, and focus new investments on stable renewable jobs.[87] The economics of the global energy transition are now posing a viable threat to oil and gas production in the longer term as solar and wind power expand in supply and electronic vehicles and battery technology drive demand changes.[88] Remaining stagnant is no longer an option; the oil and gas companies must make changes to be competitive. The results have led to the divesting of assets so companies can concentrate their oil and gas production to the countries where oil and gas are cheapest and easiest to produce and deliver significant cash flow and profit at the lowest possible cost and carbon footprint.[89]

An analysis by McKinsey and Company identified three models of strategic responses among oil and gas players: the resource specialist, the integrated energy player, and the low-carbon pure play.[90] Resource specialists are betting on a future that promises a material need for hydrocarbons for another 30 to 50 years and will focus on offering investors high yield potential or top-line growth. This is the common approach of most American oil and gas companies as they focus on CCUS technology and other ways of greening their operations.[91] National Oil Companies (NOCs), such as the hydrocarbon-producing Middle East and North Africa (MENA) states, along with other rentier countries like Russia, which are dependent on fossil fuel revenues, are likely to fall in this resource specialist category. Integrated energy players are looking to retain their profitable core while also capturing some of the large global opportunities now emerging in low-carbon markets, including renewable power, bioenergy, next-generation mobility, energy services, and hydrogen. This is the common approach taken by larger European oil and gas companies as they have adopted aggressive climate reduction goals and are diversifying through large investments in renewable energy generation.[92] Low-carbon pure plays are betting heavily on building future-proof, low-carbon businesses while divesting themselves of legacy, high-carbon portfolios. Orsted and Neste are the most notable businesses taking this approach as Orsted (Danish) has stated the goal of becoming the first offshore wind major, and Neste (Finnish) has shifted from oil refining to processing biofuels.[93] Digitalization is expected to play a key role in effective energy transition strategies in 2021 as companies identify ways to increase efficiency by enabling remote operations and driving human-machine collaboration, setting near-term emissions targets, using standardized and credible reporting, and tracking accountability across the hierarchy.[94]

Government Issues. Pandemic-related public stimulus policies promise to provide considerable new investment in green technologies as seen by the European Green Deal and the Just Transition Mechanism. The Biden administration has proposed recent legislation that also provides incentives to green projects, particularly wind and solar. There is not an equal amount of effort from the government to support CCUS efforts. The US government needs to support current and future CCUS projects through a whole-of-government approach with collaboration among federal, local, and state officials to secure government and private funding, as well as enhanced regulatory and legal frameworks that can establish public-private initiatives to facilitate growth or tackle other broad societal issues.[95] Other legislation by the administration, specifically a ban on any new fracking and on federal lands, will deliver a blow to the market, but it is not as significant as some anticipated. The ban does not prevent new fracking if a permit was already secured. The biggest consequence of the ban will be the need to increase imports potentially produced with greater carbon emissions than if produced in the US.[96] Developed countries must encourage and support cooperatives worldwide, including both developed and emerging countries, joint projects including third countries, on innovation policy, rulemaking, standardization, and providing a wide variety of solutions toward decarbonization, for example, regulatory reform (Hydrogen filling stations, grid rules, gasoline cars, procurement). There needs to be an international effort to create taxes on companies and tariffs on countries that do not put enough effort to fulfill the international requirements for cleaner energy. This effort must be balanced with other methods to maintain market stability, such as maintaining flexible policies and a presence in the chock points.

Natural Gas Industry

Industry Conditions. Natural gas is the fastest growing and cleanest burning fossil fuel, contributing to "almost one-third of total energy demand growth through the last decade, more than any other fuel."[97] It is used in power generation, industrial applications, and transportation. Just five countries hold over 61 percent of the world's natural gas reserves.[98] Russia leads, with 19 percent of the world's total reserves, followed by Iran, Qatar, Turkmenistan, and the US.[99] Natural gas production has continued to grow, reaching a new record in 2019, with US production accounting for almost two-thirds of this increase.[100] The US and Russia are by far the world's largest natural gas-producing countries.[101] In 2019, the US produced 23 percent of the world's natural gas, while Russia accounted for 17 percent.[102] Since 2010, 80 percent of the industry's growth has been concentrated in three regions: "the United States, where the shale gas revolution is in full swing; China, where economic expansion and air quality concerns have underpinned rapid growth; and the Middle East, where gas is a gateway to economic diversification from oil."[103]

The US Natural Gas Industry. Over the last 15 years, fracking and horizontal drilling technologies enabled the US to access huge underground energy reserves and emerge as a major liquified natural gas (LNG) supplier. For the first time in almost 60 years, the US became a natural gas net exporter in 2017.[104] US LNG export capacity increased from less than 1 billion cubic feet per day (Bcf/d) in 2016 to nearly 9 Bcf/d at the end of 2019.[105] The natural gas industry provided approximately 634,000 US jobs in 2019 (which included energy extraction, processing, transportation, storage, and end uses for electricity and transportation).[106] By comparison, the oil sector boasted 822,000, while the coal sector is declining with 186,000 (Appendix B).[107]

Pipeline vs. Liquefied Natural Gas. Although natural gas is often the hydrocarbon of choice due to its relatively cleaner combustion, availability and cost ultimately affect which form of energy is consumed. The natural gas market is becoming increasingly globalized. Pipelines transport natural gas from the production or extraction site to refineries and, ultimately, consumers. There are 1,308 operational gas pipelines worldwide.[108] Where pipelines are not feasible, face unyielding chokepoints, or do not exist, producing regions can sell to markets by liquefying natural gas. Often LNG is a better option for islands, mountainous countries, regions fragmented by geopolitics, or areas with security-of-supply concerns.[109] LNG offers a geographically flexible alternative to static pipelines. The key difference between pipeline natural gas (PNG) and LNG is really "the flexibility of the product being offered."[110] In 2019, 43 countries imported LNG.[111] The availability of shale gas and the rising supplies of LNG are driving global markets.[112] The LNG market also offers the "opportunity for redirection to any customer prepared to pay the highest price."[113] Floating storage and regasification unit technology allows LNG suppliers to more quickly respond to changes in gas demand.[114] Moving gas is perhaps the most straightforward part of the equation. The economics and geopolitics of international gas markets are far more complicated.

Market Outlook. Energy experts forecast Russia, Qatar, and the US will strengthen their capability and capacity during the next ten years, solidifying themselves as the three major players in the global natural gas market.[115] Qatar plans to be a significant player in the global natural gas market through expansion projects that will increase its gas production by 50 percent. Qatar's natural gas production expansion is based on the anticipated rise in demand across the world over the next several decades.[116] Russia will triple its export capacity in the next ten years through new pipelines such as Nord Stream 2, Turk Stream, and the Power of Siberia line to

China.[117] In terms of LNG, the Yamal LNG project in the Arctic will set Russia as a top natural gas exporter in the world.[118] Lastly, the US has many new projects in the planning, review, and construction process. Once complete, these projects are projected to add five times the production capacity, allowing the US to remain a major player in the world's natural gas and foreign energy markets long dominated by adversaries.[119] Other countries such as Australia, Norway, and Canada will remain important players at a regional level. None of the new entrants in the natural gas market are expected to compete with Russia, Qatar, and the US—the trio known as the Bear, the Camel, and the Eagle in the oil market—due to their strength in reach, size, and growth.

In the next ten years, China and Europe will be the largest gas importers, followed by Japan.[120] The performance in rising markets is dependent on various government pricing policies. This includes tariffs and trade wars, and increased legislation towards renewables and electric vehicles (EV). For example, when China's imposition of import duties on US LNG, "as a result of the bilateral trade war," diverted much of the US LNG from China to the EU.[121] China will see an increase in demand for natural gas due to its switching plan from coal to gas. China has undertaken a transition policy from relying on coal to natural gas. In recent years, in China, vast quantities of LNG are imported to mitigate the pollution problems afflicting Chinese cities.[122] The Fukushima nuclear reactor disaster caused the immediate closure of all nuclear facilities in Japan. This increased demand, making Japan the largest Asian importer of LNG.[123]

The EU also plays a key role in the global gas market, "with 55 percent share in the global net PNG) imports and 20 percent share in the global LNG imports.[124] Overall, European gas production, excluding Norway, is expected to fall by 40 percent in the next five years.[125] The steady decline in domestic gas production, coupled with growing energy demand means increased EU dependency on gas imports. Russia supplies nearly 40 percent of the EU's natural gas, but the US is steadily gaining more market share. Since 2016, EU imports of American LNG "jumped from zero to nearly 3 billion cubic meters -- and that figure keeps climbing."[126]

Covid-19 caused a significant disruption. Although LNG managed to remain steady, global gas demand decreased by 1 percent.[127] However, in 2020, gas was markedly less impacted by the pandemic than oil or coal demand.[128] By multiple accounts, most of the gas demand lost in 2020 due to the pandemic is expected to be recovered in 2021 and beyond.[129] In 2021 alone, global gas demand is projected to increase by 2.8 percent.[130]

While clean energy sources continue to grow as part of the world's low-carbon transition, natural gas is widely expected to remain a relied-upon fuel source for several decades to come – functioning as a transition energy source between fossil fuels and renewables. It is inaccurate to assess the future demand or production for natural gas worldwide; natural gas is a versatile fuel and uses vary by region. In some markets and industries, increased use of natural gas can deliver environmental benefits (i.e., switching coal-to-gas). In other markets and industries, decreased use of natural gas is a logical step to decarbonization.

Challenges. Despite optimistic gas demand predictions, LNG recovery is "subject to uncertainties regarding industrial rebound or fuel price competitiveness."[131] The pandemic caused a global oversupply, meaning LNG remains a buyer's market in 2021. To keep the advantage "shifting back into the sellers' court," industry leaders must promote liquefaction projects.[132] The industry also faces climate-related challenges. Due to the carbon dioxide released upon combustion, natural gas contributes to the greenhouse gas problem and is not considered zero-emission.[133] To sustain growth in the long term, low-carbon gas technologies, including biomethane and CCUS, need to be significantly scaled up.[134] "Sustained collaboration

between industry participants, national governments, intergovernmental agencies and financial institutions can open up new avenues for growth while assisting the energy transition."[135]

There are also an increasing number of voluntary government and industry commitments to eliminate flaring and manage methane emissions which is a positive trend that needs to continue and accelerate.[136] Several field trials demonstrated viable technologies to lessen flaring, but the root issue of flaring involves business models. "If there is inadequate provision for productive use of the gas at the project planning stage, including the necessary gas infrastructure, then finding a technology fix later on is much more difficult."[137]

Government Issues. Geopolitical correlations make gas markets an extraordinary blend of national security interests and profit-driven activities; these politics present a challenge. As global gas trade increases so does the interconnection of gas markets; "demand or supply shock in one region may now have repercussions in others."[138] Moreover, suppliers can use resources for strategic and political objectives, and dependence by consumers on natural gas imports increases their strategic vulnerability. One example of this challenge is the political storm surrounding the Nord Stream 2 natural gas pipeline under construction from Russia to Germany.

Gas infrastructure investment is vital for long-term growth, "particularly in countries with potential reserves and those…with a high dependence on coal."[139] Investments need support from technological innovation to raise efficiency and keep prices low.[140] Accommodating government policies and third-party access to infrastructure for non-state players are needed to facilitate LNG growth in China, Malaysia, South Korea, Singapore, Thailand, Pakistan.[141] Government policies worldwide can help with sanctioning liquefaction projects.

Climate & Opportunity. The natural gas industry has many opportunities in the current global energy transition. The promotion of natural gas as part of the global energy transition stems from its cleaner emissions profile than other hydrocarbon fuels. Although still a fossil fuel, natural gas has cleaner combustion than oil or coal. The use of gas turbines generates about half of the CO2 emissions compared to coal-fired power plants.[142] Leading experts expect carbon-capture technology to heavily influence the natural gas industry.[143] "Natural gas can potentially play two important roles in an accelerated transition to a low carbon energy system."[144] One as a bridge fuel to help countries cut emissions in the short term while preparing to transition or transitioning to more zero-emission renewables.[145] The other, in combination with CCUS, as a source of near-zero carbon power.[146] In countries with advanced energy portfolios, natural gas is also good for augmenting renewable energy intermittency and interruptions; when there is a shortage of sun and wind energy, natural gas is a viable source of energy to cover the gaps. Hydrogen production from natural gas also presents an opportunity for future power generation. "Hydrogen can be produced using diverse, domestic resources…using a wide range of processes."[147]

Coal Industry

Industry Conditions. The coal industry centers around the mining and sale of, in descending order of carbon content: anthracite, bituminous, sub-bituminous, and lignite coal for electricity and heat production, also known as thermal or steam coal, and metallurgical or industrial coal for steel and cement production. All types of coal are fossil fuels from organisms buried and compressed over millions of years, so the supply is considered a nonrenewable resource.[148] Global coal consumption peaked in 2013-2014 with nearly 8,000 million short tons (MMst) a year for a $669 billion/year market.[149] While the top line of global consumption has dropped slightly, decreased use in the US and Europe is countered by increased demand in China

and Indonesia. The Asian Pacific now accounts for over 80 percent of coal consumption, with China, India, Japan, and Korea owning the lion's share of imports. China is the world's top consumer with 3,693 MMst - approximately half of the global share in 2019 – and sans the COVID-19 anomaly, is on track for a 4 percent growth per annum. Comparatively, the US produced 706.3 MMst, consumed 586.5 MMst, and exported 93 MMst of coal in 2019. The domestic electric power sector used almost 92 percent of US coal, which equates to approximately 20 percent of the nation's electricity production. Coal's role as an electricity generation fuel in the US is in a noticeable decline over the last decade due in part to the availability and affordability of natural gas, as well as growing regulations against burning without expensive carbon capture technology.[150] The global coal market is predominantly defined by an oligopoly of a few large companies, especially BHP in Australia, Coal India, Peabody in the US, and Rio Tinto in the UK, due to the significant capital required to operate mines, costly equipment, transportation, access to mines, and massive barriers to entry for competitors due to the above-listed factors and governments with increasing disfavor for coal.[151]

Challenges. The overwhelming dilemma of coal as an energy source is contrasting its low cost and simplicity to burn and turn into electricity versus its proven negative environmental consequences. Coal's role in the industrial revolution of the West is undeniable, and it altered the course of history through the 18th and 19th centuries.[152] However, of the common fossil fuels, coal by far the dirtiest (e.g., anthracite coal emits 228.6 pounds of carbon dioxide per million British thermal units, whereas natural gas is 117 of the same).[153] In turn, the energy density value of coal is negated in long-term negative externalities to the environment due to the contribution of greenhouse gases and environmental pollution. As lesser-developed nations in the Asian Pacific region begin to hit their stride economically through the use of coal-fired power plants, developed nations lack credibility in directing these nations to use cleaner fuels because they benefited from coal during their own economic expansion. The technology to use coal for energy generation is known and readily available, so as developing nations pull more and more of their population out of poverty, other wanting nations find difficulty in saying "no" to coal.[154] While coal is clearly declining in the US, pockets of industry and culture remain vigilant in keeping it alive as long as market forces and regulations permit them to profit.[155]

Market Outlook. The growth of coal consumption in the Asian Pacific continues to be the hinge in the global outlook. Beyond the major players already mentioned, Vietnam, Malaysia, Thailand, Philippines, Pakistan, and Bangladesh are all presenting growth forecasts with increased coal consumption through 2025. The US market is heading downhill quickly, but the global aggregate will likely be unaffected or increase due to significant population deltas in the developing Asian nations and thus complicate attaining net-zero GHG emission goals.[156]

Government Issues. Global coal consumption is intertwined in international treaties like the Paris Agreement with the intent to reach a global peak of greenhouse gas emissions as soon as possible to begin an immediate reduction to net-zero in the long term. While no specific global law is coal-specific, concepts such as carbon pricing could find no easier target. However, carbon pricing on an international scale, such as the mechanisms in the Kyoto Protocols, becomes rather divisive in regard to who receives the taxes, so individual countries have a cleaner pathway to applying them internally.[157] A myriad of environmental laws and regulations dictate the US coal industry. The Clean Air Act (CAA), National Environmental Policy Act (NEPA), Solid Waste Disposal Act (SWDA), Federal Water Pollution Control Act (now Clean Water Act (CWA)), Resource Conservation and Recovery Act (RCRA), Solid Waste Disposal Act, Toxic Substances Control Act (TSCA), Safe Drinking Water Act (SDWA), Marine

Protection, Research and Sanctuaries Act ("Ocean Dumping Act"), Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, also known as "Superfund"), and Maximum Achievable Control Technology Act (MACT) all factor into the management of coal production and consumption.

Climate Change. The coal industry creates a scenario analogous to the tragedy of the commons, the economic dilemma of individuals neglecting the collective well-being of Earth's ecosystem for personal gain. Each company ultimately seeks profit, which in this case, contributes to long-term, negative externalities due to the proven, environmentally harmful consequences burning coal imparts on local and global ecosystems. Coal companies will not autonomously stop seeking profits; such actions present a conflict of interest to themselves and their shareholders. External forces are required to compel coal stakeholders to incorporate cleaner technologies or to leave the market.[158] The ultimate desire of *developed* nations to see *developing* nations forgo a coal phase requires a comprehensive incentive structure, which likely means providing tailored resources and support.

Nuclear Energy Industry and Small Modular Reactors (SMR)

Industry Conditions. The US developed the first nuclear reactor in 1942 and has operated commercial nuclear power plants since 1958.[159] Until the 1980s, nuclear electricity generation capacity in the US rose steadily before plateauing for the last three decades. Currently, 94 commercial nuclear reactors operate in the US at 56 power plants spread across 28 states. These power plants provide approximately 20 percent of US electricity generation capacity. However, US nuclear energy infrastructure is aging, and many reactors are reaching the end of their service lives.

The average age of US nuclear reactors is 39 years, with 21 nuclear reactors currently undergoing decommissioning.[160] When the Tennessee Valley Association's Watts Bar Unit 2 came online in 2016, it was the first nuclear new reactor to begin operations since 1996. Only two nuclear reactors are under construction in the US at this time, Vogtle Units 3 and 4, and are expected to come online by 2022.

Challenges. With no new projects in development, nuclear-generating capacity in the US is expected to decline over the coming decades. Meanwhile, China and Russia are actively exporting traditional nuclear power plants. The long-term decline in US nuclear reactor construction is the result of numerous factors. Principally, the cost of new nuclear projects (many billions of dollars with a history of cost and schedule overruns) is often not economical for most companies and jurisdictions. For example, South Carolina halted the construction of two reactors in 2017 after nine billion dollars and numerous delays presented no clear path to financial success. Nuclear energy is not cost competitive and has not experienced the same generational cost declines of renewables and other electrical generation technologies. A 2019 IEA report showed that the levelized cost of a new nuclear reactor in the US was much higher than most other renewable and non-renewable electricity.[161] Factors such as these make it hard to find investors willing to invest the significant up-front capital to build nuclear projects. Additionally, public perceptions and fears of nuclear power have dampened the appetite for expanding nuclear capacity. Nuclear accidents in the last four decades, such as Chernobyl, Three-Mile Island, and Fukushima, imprinted a significant negative connotation on nuclear power; large societal barriers must be overcome to realize any large-scale nuclear development.

Market Outlook. One promising emerging technology with the potential to overcome the shortfalls of traditional nuclear reactors is SMR. SMRs are advanced nuclear reactors that

generate substantially less energy and are much more scalable than a traditional large commercial reactor —various designs under development range in size from tens of megawatts up to hundreds of megawatts.

SMRs have numerous advantages.[162] As their name suggests, they are modular, both in terms of construction and deployment. Their smaller size allows them to be built in a factory and shipped to the site, with limited required on-site preparation, unlike traditional nuclear reactors. The units can be bundled together to provide scaled power based on the customer's needs. The smaller size also lowers capital investment costs, alleviating one of the main barriers to the broader deployment of nuclear energy. Compared to building a traditional large-scale nuclear reactor, SMR construction and costs may be measured in years and millions of dollars instead of decades and billions of dollars. SMRs can also deploy almost anywhere there is a need. They require much less land use than a typical reactor (acres versus square miles) and do not require access to an abundant water source for cooling.[163] They are designed with passive safety features to prevent accidents and can be buried underground to address additional safety, security, and nonproliferation concerns. Most SMR, also require little to no refueling, with some designs expected to last up to 20 years.

According to the International Atomic Energy Administration (IAEA), there are about 50 SMR designs and concepts being developed around the world. SMRs were first operationalized by Japan and China in the late 1990s. Russia deployed a more modern design in 2019 in the form of a floating nuclear power plant (Akademik Lomonoso) to supply power in the Arctic city of Pevek. Currently, two SMRs are in advanced stages of construction in Argentina and China.[164]

There are also numerous companies developing SMR designs in the US; NuScale is farthest along. They obtained a standard design approval from the US Nuclear Regulatory Commission in September 2020, allowing NuScale customers to proceed with plans to develop SMR power plants.[165] Utah Associated Municipal Power Systems (UAMPS), a consortium of community-owned power systems throughout the west, contracted with NuScale to build the first domestic SMR power plant on Department of Energy land at its Idaho National Laboratory.[166] Although attractive and developing SMR technology solves many of the problems of traditional large-scale nuclear, widespread deployment is still likely over a decade away. The first US SMR is expected to begin initially generating power in 2029, with full operation the following year. Additionally, the UAMPS plant is expected to cost $6.1 billion over 40 years, including inflation, financing, and decommissioning, resulting in an estimated levelized energy cost of $55 per megawatt hour(MWh).[167] According to US Energy Information Administration's 2026 estimates, this places the NuScale plant on par with the levelized cost of hydroelectric generation but still higher than onshore solar and wind plants.[168] However, the total capitalized cost of the 12-module, 924 megawatts electric (MWe) UAMPS plant design is estimated to be only 38 percent of a new gigawatt nuclear reactor (or about $4 billion less).[169]

Climate. As one of the safest, cleanest, and most reliable sources of energy, nuclear power may play an important part in the energy transition. In addition, some SMR advantages also make the technology more attractive than wind and solar. Whereas wind and solar provide intermittent power, nuclear energy provides a continuous and consistent baseload making them well suited to complement more intermittent renewable power generation sources. This, in addition to being low maintenance and easily deployable, makes SMR a particularly advantageous low-carbon energy technology for developing countries and small island nations. They also do not require the minerals and rare earth elements necessary to produce renewables

and other green technologies, and many of the modular benefits mean SMR may become cost-competitive with wind and solar as the technology develops over time.

Government Issues. Pending Congressional appropriations, the Department of Energy (DoE) expects to invest $3.2 billion in the Advanced Reactor Demonstration Program over the next seven years. This is significant but is less impressive when compared to the $20 billion in annual subsidies for the oil and gas industry. Moreover, with China and Russia having already deployed or in the final stages of deploying SMRs, the lengthy US regulatory approval process is hampering US competitiveness.

Opportunities. SMRs may also be a key tool for developing countries, and the US is competing with designs developed by Chinese and Russian state-owned enterprises. To this effect, the International Development Finance Corporation (DFC) recently signed a letter of intent to support NuScale's development of a 2.5 gigawatts (GW) project in South Africa.[170] This should be just the start of similar activity to export and finance SMR technology. An executive order signed in 2020 directed the Secretaries of State, Defense, Commerce, and Energy along with the NASA Administrator to develop a common technology roadmap for SMR through 2030.[171]

Hydroelectric Power Industry

Background. Hydropower is one of the oldest forms of energy generation and is currently the largest source of renewable energy in the world, with an installed capacity of over 1126 GW.[172] Overall, water accounts for one-fifth of the world's electricity, with more than sixty countries getting over half of their electricity from hydropower.[173] Until 2019, it was the largest source of total annual US renewable electricity generation but has since declined due to the emergence of solar and wind.[174] There are about 1,450 conventional and 40 pumped-storage hydropower plants operating in the US; the majority of the power is produced at large dams on major rivers, built before the mid-1970s by federal government agencies.[175] There are two types of hydropower facilities, traditional, which include run-of-the-river systems and storage systems, and pumped-storage hydropower facilities (PSH), usually located on or near a water source because the source of hydroelectric power is water.[176] The volume of the water flow and the change in elevation from one point to another determine the amount of available energy in moving water; therefore, the greater the water flow and the higher the head, the more electricity a hydropower plant can produce. PSH is the most dominant form of energy storage on the electric grid today.[177]

Industry Conditions. Hydropower is an attractive renewable option because it is an energy supply without the direct emission of CO_2 and with an unbeatable energy pay-back during its technical lifetime.[178] It is one of the most efficient energy sources because its production can be easily adapted to the demand. As an organic energy source, it creates jobs and financial resources in remote areas and has the potential for recreational and tourism activities.[179] Hydropower reliance on the water cycle makes its power vulnerable to seasonal variations in precipitation and long-term changes in precipitation patterns, such as droughts.[180] Climate change is expected to have a major impact on the development of hydropower energy because of the effects on the entire hydrological cycle of precipitation, runoff, and evaporation, making it more difficult to predict stream flow through traditional methods.[181] In tropical and midlatitude rivers, water sources are already flowing less or drying up. The streamflow of a third of the world's large rivers from 1948 to 2004, with six percent less freshwater flowing into the Pacific and three percent less making it to the Indian Ocean.[182] Shrinking rivers in countries like Kenya,

the Philippines, and Venezuela have created resiliency issues due to reduced or shut down power generation in existing dams when their reservoirs dropped below critical levels resulting, in periodic blackouts and electricity rationing.[183]

Challenges. Criticisms and hesitations of hydropower stem from environmental and social issues surrounding its construction projects. This is prevalent in developing countries such as China, Ethiopia, Brazil, and Turkey, where governments ignore these concerns and initiate projects that displace populations.[184] The Three Gorges dam in China had several environmental and social consequences. Its construction led to the displacement of 1.5 million people, and faulty construction led to the submersion of numerous factories, mines, and waste dumps in the region that eventually polluted the Yangtze river.[185] In addition, studies have shown that the construction of hydropower dams threatens freshwater biodiversity in South America, Southeast Asia, and Africa due to a 20 percent reduction in large free-flowing rivers, the habitat of freshwater species.[186] These environmental and social impacts are the reason many put off the energy source, citing the tradeoffs are not worth the social and ecological price.

Market Outlook. Hydropower saw an immediate increase in projects across the world, notably in Europe, following Fukushima, but in recent years those projects slowed.[187] That growth is expected to increase once again due to the ambitious energy transition and the flexibility of hydropower. Solar and wind are the surging renewables, but they are variable sources of energy, whereas the flexibility of hydropower energy enables it to store and supply electricity generated by other sources, providing an essential link for aiding the integration of different renewable supplies within the grid.[188] Recent innovation prioritizes hydropower moving from large dam projects to run-of-the-river plants that utilize the natural flow of rivers and small turbine generators to produce energy.[189] These plants have an operational life of twenty-five years but cannot store energy and, unlike dams, are considered to be unpredictable due to weather considerations such as low rivers in the summer or frozen in the winter.[190] Nonetheless, these types of projects are expanding, and hydropower capacity has seen a net growth of 1688 megawatts (MW) over the last decade by increases at existing facilities, new hydropower in conduits and canals, and by powering non-powered dams (NPD).[191] The market is attempting to leverage technology from the industrial internet of things to increase the efficiency of hydropower by increasing digitalization which can result in the reduction of carbon emissions by seventeen metric tons while increasing output by one percent; yielding savings in operations cost up to five billion dollars.[192]

US Government Issues. Federal and state government policies over the last three years will significantly affect the hydropower market. Specifically, America's Water Infrastructure Act (AWIA) has worked with Federal Energy Regulatory Commission (FERC) to transform the licensing process to make it more efficient and transparent to further incentivize hydroelectric projects. FERC now has more flexibility on licensing terms, extensions, and wait time to begin projects. Revised policy on license terms that defaults to forty years regardless of the investment required to keep the facility operational, thus reducing administration costs and offers licenses more time to recoup costs of investments made in projects.[193] FERC was also directed to introduce an expedited licensing process for NPDs and closed-loop PSH projects that resulted in the publishing of two reports in 2019 providing information that supports the development of federal NPDs and closed-loop PSH due to this mandate.[194] The US Environmental Protection Agency's (EPA) proposed rules on the Section 401 water quality certification process aim to improve the efficiency of the federal hydropower authorization process. FERC's proposal to modernize PURPA might affect the ability of new small hydropower projects to secure power

purchase agreements. States are committing to increasingly ambitious renewable or clean energy mandates and energy storage targets that could help spur investment in new hydropower and PSH.[195]

Solar Power Industry

Industry Conditions and Factors. Global solar PV capacity additions are expected to continue to grow through 2022, representing a stable and higher than previously predicted growth from 2017 in all segments (utility-scale, commercial/industrial, residential, and off-grid). Global total capacity is anticipated to grow from approximately 98GW in 2017 to 150GW in 2022.[196] Outlooks across the US, China, India, Brazil, EU, and other key markets out through 2025 look to expand solar PV capacity, albeit at different rates depending on COVID-19 economic recovery and government subsidies and incentives, and commissioning deadlines.[197] As China's subsidies for distributed PV closed and the country transitioned to competitive auctions in 2020, investment shifted from commercial PV applications (which accounted for 50 percent of PV growth in 2018) to utility-scale applications, while residential applications continue to grow. PV deployment will continue to accelerate in other key markets such as the US, Europe, and India (Appendix A, Figure 17).[198] Figure 18 (Appendix A) provides a comparison of projected capacity increases globally depending on smooth policy transition in China to boost investor confidence, speedy US and European recovery for distributed PV, rapid implementations of energy auctions and grid connections for solar PV in India, Latin America, the Middle East, and Africa, and favorable adoption of policies in the Association of Southeast Asian Nations (ASEAN (largely untapped market)).[199]

In addition to PV, global concentrating solar power (CSP) capacity increased by 35 percent or 600MW in 2019, surpassing the 10-year average of ~24 percent. Growth through 2030 is forecasted to come from China, Morocco, South Africa, and some emerging economies.[200] Spain and the US currently lead in CSP capacity, but China is expected by most to become the new global leader of CSP by 2030. CSP should become more cost-competitive as thermal storage systems (i.e., use of molten nitrates) advance.[201] Figure 19 (Appendix A) shows the current growth of CSP over the past decade, and Figure 20 (Appendix A) shows the projected growth through 2030.[202]

In the US, the solar industry generates tens of billions of dollars of economic value and employs more than 242,000 people.[203] In 2018, solar generation accounted for ~1.5 percent of US total electricity generation and is predicted to grow the fastest of all renewable sources through 2050. California, a solar-heavy grid, has already experienced times where half of the demand on the grid was met by solar PV.[204] Figure 21 (Appendix A) provides a comparison of utility-scale PV projects between 2007 and 2019.

Industry Supply Chain. Mineral commodities such as cadmium, gallium, germanium, indium, selenium, tellurium, aluminum, copper, nickel, steel, and zinc are key components of PV panels, some of which are limited in global supply and processing capabilities.[205] Access to skilled, technical labor remains a critical resource in the R&D, design, construction, and servicing of both PV and CSP infrastructure. Global growth in the manufacturing of solar-grade polysilicon, PV cells, and PV modules outpaced US capacity in the past two decades, resulting in an 80 percent loss of global market share for the US.[206] The production of polysilicon, wafers and ingots, and cells and modules now resides overseas, mostly in Asia. However, the National Renewable Energy Laboratory (NREL) estimates that the PV demand growth on international and domestic markets for all components of PVs represents significant growth opportunity

particularly for upstream industries in the US, which includes steel, aluminum, inverters, flat glass, ethylene vinyl acetate (EVA) encapsulant, and Tedlar backsheets. These upstream supplies are also produced in Asia to a large extent, but the US also produces domestically in the upstream areas and even exports EVA and Tedlar.[207] The US mostly relies on imports of aluminum and PV inverters in the upstream activities.[208] Battery manufacturing supply chains also rely on imports to a great extent.

Challenges. Solar sources diversify energy supply bolstering national security. However, solar brings challenges such as reliance upon foreign actors for supply chain materials and processing. As previously discussed, China possesses a major share of global rare earth minerals processing capabilities. Solar PV and batteries for storage rely on heavily imported supply chains, which poses a challenge to energy security.[209] CSP requires suitable geography, adequate land, and a large initial capital investment which create barriers to entry.[210] Like other renewable sources, the government-business environment of favorable renewable energy policy paired with an incentivized private industry and an informed public enabled solar energy to approach cost parity with fossil fuels much faster than predicted.[211] As found by a Carnegie Mellon University study found that solar-plus-storage could deliver that cost parity with equal security to natural gas.[212] Looking forward, the Biden administration's $2.3T infrastructure plan and recommitment to the Paris agreement signals strong government-business opportunities for investing in solar energy as part of the US energy transition.[213] However, potential shifts in the government-business environment, as well as differences across states and even some areas within states, pose a challenge for effective solar implementation.

Government Issues. A US domestic challenge is to balance the incentives, subsidies, and tax credits that promote the advancement of solar energy while addressing the energy trilemma. Government policy and investments in concert with private industry investments should continue to bolster solar PV and CSP supply chain resiliency. Trump administration tariffs cost the US an estimated 62,000 jobs and nearly $20B in private investment in the solar industry.[214] China now leads the world in rare earth metal mining and processing, a critical portion of the value chain. The Biden administration looks to focus on energy portfolio diversification to bolster energy security with an emphasis on increasing renewables overall. In relation to utility-scale solar, the US innovation ecosystem remains strong, placing the US second only to China in total PV deployment.[215]

Climate Change. A key role for the solar industry with respect to climate change is to ensure close government-business coordination on policy and regulation efforts that fosters a healthy domestic competitive environment, strengthens factor inputs to keep US companies competitive in global markets, increases the US energy portfolio diversification, and increases supply chain resiliency. Similar to other renewable sources, investments in the solar value chain coupled with continued domestic deployment moves the US closer to Paris Accord commitments and increases energy security, energy equity, and environmental sustainability of the US energy system.

Wind Power Industry

Industry Conditions. Wind power is one of the fastest-growing, low-cost renewable energy solutions that is now competitive with many other power generation technologies in many parts of the world.[216] According to the IRENA, globally, installed on and offshore wind power capacity has increased by a factor of almost 75 in the past two decades.[217] Today, global cumulative wind power capacity is up to 743 GW, adding 90 GW in 2020, which is more than a

53 percent growth compared to 2019.[218] In the US, the EIA estimates that "total annual US electricity generation from wind energy increased from about 6 billion kilowatt-hours (kWh) in 2000 to about 338 billion kWh in 2020."[219] Currently, the US can draw clean power from over 67,000 wind turbines installed across 44 states.[220] After hydropower, wind is now the top renewable source of electricity generation and should be at the forefront of infrastructure development priorities considering the accelerating energy transition. As a renewable and environmentally responsible energy source, wind power must be an important part of diverse energy system portfolios to ensure energy security, reliability, and sustainability.

Challenges. Wind represents a non-dispatchable energy source, meaning it only generates electricity when it is actively engaging a turbine system, and it cannot change output based on demand due to its intermittent nature.[221] Additionally, wind energy can have adverse environmental impacts such as disrupting wildlife patterns as well as noise and visual pollution for populations living near wind farms. Wind farms can also impact radar, sonar, and radio frequencies, impacting national security depending on military activities and other vital services near turbines or wind facilities.

Market Outlook. Despite wind power growth, many countries have yet to realize even a fraction of wind power potential across their inland and coastal areas. Global wind energy is expected to grow on average by 4 percent each between 2021-2025.[222] With its diverse geography, the US has a vast number of geographical areas with high potential to generate wind energy, particularly the Great Plains and offshore coastal areas. The extent of wind activity and frequency, combined with access to suitable open spaces are two main variables considered for future projects (Figure 22, Appendix A). The DoE estimates that potential onshore US wind power resources are capable of "yielding about nine times the nation's power needs" and offshore wind "could meet nearly twice the nation's electricity demand."[223] Estimates from the DoE's 2015 Wind Vision Report indicate wind has the potential to provide 20 percent of US electricity by 2030, and 35 percent of US electricity by 2050.[224] Electricity generation from wind power currently accounts for 8.4 percent of the nation's total production, a majority of that capacity emerging over the past decade.[225] Wind power is an essential part of the US portfolio of energy solutions due to the many long-term economic benefits including, the potential for increased innovation, manufacturing, and overall growth in several supporting industries. A recent study by Wood Mackenzie, a leading energy research and consultancy firm, indicates the global supply chain for wind turbines could reach $600 billion by 2028.[226] Moreover, the DoE's Wind Vision Report estimates the wind energy industry will create more than 600,000 jobs in manufacturing, installation, maintenance, and supporting services by 2050.[227] Growth potential in domestic and global markets represents an opportunity for the US to scale up its manufacturing and diversify its supply chains to be a major exporter of wind turbine technology and equipment well into the future.

Government Issues. Wind power growth over the next five years will continue to be driven by government policy, including feed-in tariffs, production tax credits, individual tax credits, and Green Certificates or technology-neutral auctions and tenders.[228] The Energy Act of 2020 represents positive steps toward wind power development in the US with the authorization of critical DoE research, development, demonstration, and commercial application (RDD&CA) activities "including research for onshore, offshore, distributed wind energy systems, advanced manufacturing, grid integration, and wind system recycling programs."[229] Individual states also have extensive policies, regulations, and programs driving the wind power market. The most influential are RPS which exist in 30 US states, Washington DC, and three additional territories.

RPS require that a specified percentage of electricity sold by a utility company comes from renewable resources. Although RPS targets vary widely, they continue to play an integral role in state efforts to diversify energy portfolios, reduce emissions, and expand economic development (Figure 23, Appendix A).

Climate Change. Given climate change realities, the US must set a vision that leads federal, state, and local governments to incorporate wind power as a renewable energy source. Without security and sustainability in its overall energy system, the US risks being left behind by allies and competitors. Balancing the US energy portfolio with increased renewable sources such as wind power is an important step to fulfilling international commitments and the moral obligation to leave the economy and environment better positioned for future generations.

Waste-to-Energy Industry

Industry Conditions. Waste-To-Energy (WTE) is a burgeoning market that connects the markets of waste management and energy production. The bottom line is WTE is the conversion of waste materials into usable electricity, heat, and fuel. According to The World Bank, 2016 witnessed the world's cities produce approximately 2.01 billion tons of solid waste. With increasing urbanization and population growth, their forecasters are expecting a 70 percent increase from 2016 to 3.4 billion tons in 2050.[230] In the US specifically, MarketLine identified 261.2 million tons of solid waste managed in 2018 for a value of $14.4 billion, with an expected 1.5 percent growth to 265.1 million tons in 2023 with a value of $16.1 billion. The US thus accounts for approximately 16.8 percent of the global waste management industry. The EPA reports a similar number in the same year, spread across the population for approximately 4.9 pounds per person per day, but also acknowledges that almost 94 million tons were recycled or composted.[231] Unfortunately, almost 150 million tons were sent to landfills. North America also handles approximately 61 cubic kilometers of wastewater, but only 4 percent is currently harnessed for value midstream of treatment. [232]

Challenges. Firms and municipalities are generally finding new WTE facilities too burdensome with capital and regulation; landfills are easier and cheaper to build. The US is accustomed to having a large land mass to work with, and out-of-sight-out-of-mind landfills rarely break the noise level of discussion. In economic terms, the average US citizen does not bear the negative externalities imposed on the world's market by their waste. A truck appears and hauls their trash away. However, the laws of physics and mass balance cannot be ignored from the perspective of the earth's ecosystem. Americans think they are recycling, but those materials are simply shipped to lesser-developed nations willing to deposit them in the ocean.[233]

Market Outlook. The US represents 4 percent of the world's population but accounts for 12 percent of global municipal solid waste, making the US the most wasteful country per capita in the world. Even for low economic growth forecasts, the EIA shows US energy consumption nearing 80 quadrillion British thermal units (BTUs) in 2050; accelerated economic growth will go well over 90 quadrillion BTUs in the same timeframe.[234] As fossil fuel-based electricity decreases more and more due to pollution and government regulation, WTE should surface as opportunities to account for a portion of an organizations' renewable energy portfolio. Porter declares that these demand conditions aid competitive advantage, so thus the summation of waste production and energy results in a strong argument for the US to seek growth and innovation in the WTE market. The DoE currently estimates there are 3,400 wastewater treatment plants (WWTPs) in the US with flows greater than 1 million gallons a day that could support anaerobic digesters, but only 1,300 are currently utilizing such. Nearly two-thirds of the WWTPs in the US

are throwing away "free" electricity if they would just harness the biogas from their waste streams. The DoE estimates that if all WWTPs conducive to combined heat and power were actually capturing their energy, the US could produce 241 GW from wastewater alone.[235] 150 million tons of the 260 million tons of produced Municipal solid waste (MSW) in the US goes to landfill every year that could be producing energy. There are only 75 functioning MSW incinerators currently in the US. Improving technologies in incineration, anaerobic digestion, pyrolysis, and efficiencies in electricity production from other sources are adding to the potential for WTE infrastructure to provide returns on invested capital greater than the weighted average cost of capital (ROIC/WACC). Economic feasibility studies are demonstrating as waste streams increase in energy potential and infrastructure and technology decrease in cost, ROIC/WACC potential in the WTE market will attract more players (either profit-seeking or municipal services) to enter the market.[236]

Government Issues. A myriad of environmental laws and regulations dictate the waste, energy, and WTE markets. The Clean Air Act (CAA), National Environmental Policy Act (NEPA), Solid Waste Disposal Act (SWDA), Federal Water Pollution Control Act (now Clean Water Act (CWA)), Resource Conservation and Recovery Act (RCRA), Solid Waste Disposal Act, Toxic Substances Control Act (TSCA), Safe Drinking Water Act (SDWA), Marine Protection, Research and Sanctuaries Act ("Ocean Dumping Act"), Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, also known as "Superfund"), and Maximum Achievable Control Technology Act (MACT) all factor into the management of waste, the production of energy, and everything in between for WTE. The government could foster the WTE industry with increased resources for education on waste and WTE potential, a Carbon Tax on fossil fuels but discount on WTE facilities that would otherwise just send trash to landfill or ocean to incentivize WTE, infrastructure funding for anaerobic digesters on all WWTPs, and R&D funding increase to the NIS to improve WTE tech.

Climate Change. As long as humans inefficiently dispose of waste in landfills, oceans, and open ground, that waste will decompose and emit greenhouse gases. These gases, especially methane and its Global Warming Potential (GWP) of 28-36 times that of carbon dioxide, could be harnessed by WTE technology and converted into energy.[237]

Critical Minerals

Background. Minerals are critical for renewable energy technologies. Lithium, cobalt, and nickel give batteries greater charging performance and higher energy density.[238] Copper is essential for the increasing use of electricity.[239] Rare earth elements such as neodymium are required for magnets vital for wind turbines and electric vehicles.[240] Although these technologies use different materials, all use a higher mineral intensity than fossil fuel electricity generation. An electric vehicle uses approximately five times as much mineral as an internal combustion vehicle.[241] An onshore wind plant requires eight times the quantity of minerals as a gas-fired plant of the same capacity.[242] Thus, a renewable energy transition will lead to a significant increase in mineral demand, by some accounts nearly 500 percent by 2050,[243] because of how these technologies produce and store electricity. (Figure 24, Appendix A)

Industry Conditions. From the 1960s to the 1980s, the US held the lead in the global production of rare earth minerals. Since then, processing and manufacturing of the global supply of rare earths shifted almost entirely overseas, in part due to lower labor costs and lower environmental standards. The US is now dependent on these foreign sources of critical materials.[244] Of the 35 minerals or mineral material groups identified as critical by the Secretary

of the Interior, the US is 100 percent import-reliant for 14 and is more than 50 percent import-reliant for most of the other 21.[245] Moreover, the production of many of these minerals is more geographically concentrated than that of oil or natural gas. For lithium, cobalt, and various rare earths, the top three producers control well over three-quarters of global output.[246] In some cases, a single country is responsible for around half of global production.[247]

The concentration of refining and processing operations is also high. For example, China has the world's largest lithium and rare earth material reserves.[248] However, China does not derive its natural resource advantage solely from owning resources; instead, China controls the supply chain and processing. China recognizes the value of those minerals and has invested heavily in those markets. It dominates the global processing of nickel, cobalt, and graphite - critical components of vehicle battery electrodes - despite mining very little. China also controls the processing of almost all the world's lithium, and Chinese chemical companies accounted for eighty percent of the world's total output of raw materials for advanced batteries.[249]

Recycling is the most important strategy to reduce primary demand for critical minerals (Figure 25, Appendix A). Lithium-ion batteries can be recycled through two main processes: chemical solutions to leach minerals from materials or high temperatures processes to separate materials using chemical reactions.[250] Currently, only the most valuable materials like cobalt and nickel are economically feasible to recycle. Harder to recycle minerals such as lithium and manganese may become economically justified as demand for them rises or new technologies make their recovery less expensive. Recycling is also not without social and environmental impacts. In particular, the recycling of rare earths from end-of-life products involves similar chemical techniques used for initial raw material processing, making the industry attractive to the same groups that control the raw material processing industries (i.e., China).[251]

Market Outlook. As battery technology develops and batteries become more efficient, their size can be reduced, relevant to their capacity. Thus, reductions in battery size present the simplest way to reduce material consumption. Emerging battery technologies not available commercially may also affect material requirements in the future and reduce demand for the more valuable minerals. For instance, technologies that use sodium instead of lithium could be used for future battery storage. Though scientifically feasible, several factors limit mass production, such as high development costs limited production capacity.[252] However, these limits will continue to degrade as the development advances and more capital is pushed into the innovation system due to rising interest globally in climate change mitigation.

A critical area of US government activity is the Energy Resources Governance Initiative (ERGI) which seeks to establish sustainable supply chains for the essential minerals. Through ERGI, the US and its partners (Australia, Botswana, Canada, and Peru) seek to disseminate and encourage best practices for industry and government. ERGI also supports industry and foreign government partner efforts to "green" mining operation and increase recycling of key minerals and metals.[253] While ERGI so far has provided approximately $10.5 million in technical assistance to developing countries, the Biden administration may need to increase this level of engagement to counter the strong influence China already exerts on producer states.

Challenges. Competition for the limited natural resources required for the development and production of batteries and renewable infrastructure such as lithium, cobalt, copper, and others, will continue to be political and economic issues since many of those resources originate from outside the US Notably, much of the production capacity and infrastructure for battery systems resides in China, and other countries outside the US As demand in the US continues to accelerate along with the overall economic and political competition with China, the globalized

supply chain for the production of energy storage systems and renewable infrastructure could present problems should economic or political tensions between the nations grow. Many rare earth minerals and other critical commodities such as nickel, cobalt, and graphite make current battery supply chains very narrow and vulnerable to disruption. Figure 26 (Appendix A) depicts the countries of origin for minerals required in the production of Li-Ion batteries. The limited sources and the fact that those sources lie outside the US presents a significant challenge and risk to US battery and renewable technology manufacturers. That leaves the US dependent on China and other trading partners for much of its battery supply, a risky proposition not just for the industry but also for the military, which is planning to electrify more of its vehicles and equipment.[254] China has built a dominant position in new energy technologies, and critical minerals will be a political and economic hotspot for years to come.

Because these resources are often mined and extracted in developing countries, the use of critical commodities and minerals brings with it ethical and moral issues. The Democratic Republic of Congo (DRC) has a long history of human rights abuses and unsafe working conditions in its cobalt mines that local governments have done little to correct.[255] The continued demand for these rare earth minerals in counties like the DRC will exacerbate these types of problems. Cultural differences between the developed and developing countries are significant and often drive what advanced nations consider to be injustices. Developing populations may depend on child labor unsafe work in rare earth industries to sustain even low basic standards of living, making them resistant to reform and change and further complicating the situation. Additionally, if the US and US companies pull back from these nations due to ethical issues, China will step up to fill the void, spreading its influence and control of markets and commodities critical to the mitigation of climate change and overall global energy resilience.

The US Electrical Grid

The current US national grid is out-of-date, and ill-prepared to meet the energy demands of the current or next century. Innovation must be applied to modernizing the grid because this key piece of infrastructure serves as a primary enabler of national security, economic power, and innovation. As the nation transitions its energy generation from fossil fuels to renewables, it is the grid that will serve as the conduit for transmitting that power to where it is needed. Further, advances in generation types and locations, along with new types of storage and additional demands placed on the system by electric vehicles, will all compound the issue of the nation's currently outdated grid.

Informed policy analysis and recommendations depend on a shared understanding of terminology and history. Before examining the history of the electrical grid, definitions must be established. In this paper, the grid refers to "…the backbone of the power system – a collection of power plants and transmission lines that ensure delivery of electricity across the continent at the flick of a switch."[256] In 2003, this interconnected system [and more broadly electrification in general] was ranked by "…the National Academy of Engineering, a division of the National Academy of Sciences…as the single greatest engineering achievement of the twentieth century…"[257] The grid is indeed an engineering marvel, but it is not a singular entity as Figures 27-28 (Appendix A) demonstrate. Rather, the US grid is part of the larger North American grid, which itself is comprised of four major and several smaller interconnections "…functioning predominately independently of one another with limited exchanges of power between them."[258]

Challenges. The basic structure of today's electrical grid dates to the late 1800s and still faces many of the same challenges today as when it was first built. "Then, as now, system

operators had to ensure that the amount of electricity generated at any given moment closely matched demand, deliver[ed] the quantity needed in an instant, and maintain[ed] steady frequency and voltage on all parts of the system."[259] Beyond the operational challenges of the grid's design, governance continues to be complex. "Each state has its own utility laws. Then there are eight regional reliability councils that work with the North American Electric Reliability Corporation, which is overseen by the Federal Energy Regulatory Commission."[260] The complexity and bureaucracy associated with electricity generation, transmission, distribution, and sale have been echoed by many industry experts when discussing reluctance to make changes to their operations or undertake new projects.

Strengths. For all its flaws, the US electrical grid is directly tied to the economic might of the nation. Electricity powers industry, heats and cools private homes, and fuels innovation by lighting classrooms and dormitory rooms at the nation's network of colleges and universities. "Electricity – not oil – is the heart of the US energy economy. With electricity, America controls its own destiny."[261] Internal to the electricity industry, the grid enhances economic competition "…because [it] allows multiple generators and power plants to provide electricity to consumers, [and] different generators compete with each other to provide electricity at the cheapest price."[262] The US macroeconomic tendency toward market capitalism with the promotion of competition has helped to balance supply and demand in the electricity market with the positive externality of fueling innovation, providing the foundation for national security, and enabling domestic industry to lead the world. From an economic perspective (beyond just the raw engineering marvel), it is clear the US power grid is an impressive achievement.

National Security. The electrical grid is vital to US national security and is therefore also a key vulnerability. The grid supplies electricity to Department of Defense installations and operating locations for other federal agencies and organizations who also play important roles in the nation's security. Economic power is key to national security, and the grid supports industry and commerce. Because of its importance to the nation, the grid is a clear center of gravity any enemy would target across the spectrum of conflict. "The threat landscape facing the energy and electricity sectors is increasingly serious…and the power grid remains a popular target of foreign adversaries."[263] Beyond the physical infrastructure comprising the grid, its cyber-enabled and internet-connected components must also be protected. Cyber security was not a concern in the late 1800s and most of the 1900s, but today's connected world makes any link to the internet a vulnerability. As more systems connect to the grid – from smart meters to electric vehicles to artificial intelligence-enabled distribution and monitoring systems – increased attention must be paid to cyber hardening to keep the grid secure from malign domestic and foreign actors.

National Innovation System. The US electrical grid represents the epitome of innovation – when initially created, it was a novel, value-adding solution to the problem of safely and reliably transporting electricity around geographic regions and the nation at large. Further, the grid continues to fuel and be fueled by the US national innovation system. The national innovation system is the loosely coordinated process by which the business, regulatory, and policy environments combine along with the promotion of science and technology, economic principles, and other social institutions to foster innovative practices, organizations, and technologies.[264] The US without its electrical grid would be a fractious, inefficient place where innovation would struggle greatly.

Cyber Threat to the Energy Sector

Cyberspace is a major sphere of contention in the GPC with China and Russia.[265] As asserted in the US National Cyber Security Strategy, the ability to protect against cyber-attacks is essential to ensuring the reliability of energy infrastructure, military operations, and the functioning of American life in general.[266] However, those who oversee and manage America's energy infrastructure – including electric grid operators, refineries, and distribution companies – are increasingly under attack in cyberspace, which poses glaring risks to energy reliability. For example, hackers working for Russia's Foreign Intelligence Service (SVR) have been targeting energy organizations in the US and Europe since 2011.[267] Under pseudonyms like Energetic Bear and Dragonfly, they infiltrate entities like grid operators and nuclear power plants through their information management systems. They then surveille their activities undetected and establish controls that can be used to manipulate their operations. The 2016 Russian attack on Ukraine's power distributors is a prime example of how attacks can target energy infrastructure by manipulating the supervisory control and data acquisition (SCADA) systems, cast hundreds of thousands into darkness, and make one country susceptible to the political leverage of another. The recent DarkSide attack on Colonial Pipeline that temporarily shut down half of the supply of gasoline to the US Eastern coast is another example of a less politically motivated attack by non-state actors.

Cyber Solutions. Today's cyber solutions implicate the broader private sector and US government. Unfortunately, the solutions required to deal with the cyber challenges are much broader than the energy industry itself because hackers breach organizational systems using similar methods, regardless of whether they are attacking private sector firms, civilian government institutions, or the military. The recent Russian SolarWinds attack, for example, compromised hundreds of diverse organizations by infiltrating software management updates conducted by a widely used US company, SolarWinds. The attack resulted in the theft of highly sensitive information from across major US firms, military contractors, and government entities like Homeland Security, Energy and the Pentagon.[268] The FERC's emergency response plans for managing power outages were also compromised, giving vital information to Russia in the event it wanted to implement another Ukraine-like attack in the US[269] Furthermore, these attacks are being carried out from within US borders, thereby avoiding detection from intelligence agencies that are prohibited from surveilling internally. The energy industry is thus connected to the broader cyberspace issues to which the government and other industries are tied, and therefore cannot be expected to go it alone in finding solutions. To the contrary, actors across energy sectors will need to actively collaborate with other industries – including the insurance industry -- and the US government to establish mechanisms that bolder resiliency. Although fool-proof resiliency is an unrealistic goal, serious progress needs to be made in responding quickly to attacks in real-time, finding ways to monitor the internal cyber landscape while respecting privacy laws, fluid government-private sector cooperation, and ensuring adequate cyber professionals to meet national demand.

Cyber Vulnerabilities. Tomorrow's cyber vulnerabilities are established today. Solutions for dealing with today's cyber-attacks will not be enough to address long-term energy security because the innovations that provide the means for tomorrow's attacks are currently being created. Emerging Information Technologies (IT) – such as 5G, quantum computing, and artificial intelligence (AI) – are evolving and will offer new pathways in cyberspace. The US response will therefore require juggling the challenges of today's attacks while laying the innovative groundwork to outpace adversaries – China in particular – in the IT competitions over

the coming decades. In addition, the shift towards the so-called Internet-of-Things (IOT) -- including smart homes, grids, and cities – will create even greater connectedness of systems that could open even more vulnerabilities for cyber-attacks.

US Government Architecture to Foster Coordination. The US government has a vital role to play as a catalyst. However, as past experience has shown, such as with the intelligence-sharing failures prior to 9/11, the special interests of different agencies and departments can work against a cohesive approach. The Cyber Solarium Commission, which was established by Congress to recommend solutions to minimize cyber vulnerabilities, proposed a new government architecture to improve coordination and facilitate information sharing. The Biden administration subsequently began implementing some of Cyber Solarium's recommendations, such as the establishment of a new National Cyber Director (NCD) position under the Executive Office of the President. The NCD has the mandate to strengthen government and industry cooperation and works closely with the newly created Deputy National Security Advisor (NSA) for Cyber and Emerging Technologies, which is responsible for coordinating cybersecurity efforts across the federal government. Two key entities that the Deputy NSA brings together are 1) the Cybersecurity and Infrastructure Security Agency (CISA), which falls under the Department of Homeland Security (DHS) and is charged with defending US networks, and 2) the US Cyber Command which is responsible for US offensive operations. The new institutional arrangement is just getting established, and although time will tell as to its effectiveness, it marks a step in the right direction.

Human Capital. "Factor conditions" are identified under Porter's Diamond as an essential component of promoting national competitiveness, particularly with regards to the investments required to establish a cutting-edge workforce.[270] During the course of numerous discussions with senior leaders across the private sector and government, the current number of cyber experts isn't sufficient to meet the national demands.[271] According to the Cyber Solarium Commission, there are more than 30,000 vacant government cyber positions and more than 500,000 in the private sector.[272] Regarding emerging technologies, China is currently producing four times as many science, technology, engineering, and mathematics (STEM) graduates as the US.[273] Chinese students constitute by far the largest international cadre in US universities, and these students are much more likely to return home than in 2000.[274] While the US remains a magnet for international talent due to its superior universities and technology companies, dramatically expanding the human capital base in cyber and IT should remain a rallying point between the US government and private industries.

Supply Chain. Reliable "supporting industries" comprise another aspect of Porter's Diamond for competitive advantage.[275] which is a major weakness for cyber security across US industries. As the CyberWinds case demonstrates, when software management providers cut costs by skimping on security in order to benefit their bottom line, every industry is made vulnerable.[276] Furthermore, the challenges of the future 5G system will orbit around how the applications for 5G are utilized and will perhaps offer similar vulnerabilities as information software does today.[277] As many such software and applications are produced outside of the US, the challenge will be to enforce standards in foreign entities that supply software and applications to the US.

V. Country Analyses, Porter's Diamond, National Innovation & Industrial Systems

This section outlines country analyses for the United States, China, Russia, Japan, and Puerto Rico using Porter's Diamond Theory of National Advantage, the National Innovation

System, and National Industrial System models. The Porter Diamond (Figure 29, Appendix A) is designed to help understand the competitive advantage that nations or groups possess due to certain factors available to them and to explain how governments can act as catalysts to improve a country's position in a globally competitive economic environment.[278] The National Innovation and Industrial Systems models further outline how innovation is supported through education, training, and knowledge; regional and industry clusters; and other supporting institutions, including macroeconomic environment, market conditions, and country performance.

The United States. The analysis of the US will begin by applying Porter's Diamond Model and then taking those outputs and linking them to the national innovation system and national industrial model. This section of the paper shows how and why the US is competitively advantaged as compared to other nations around the world. Finally, this analysis sets the foundation for an evaluation of current policies and recommendations for new policies, which will be presented in the following sections.

Government. The US government sets the conditions for national competitive advantage via regulations and policy. The US federal, state, and local governments institute macroeconomic energy policy through programs and incentives (such as tax credits, tariffs, grants, and loans) that encourage energy investment, adoption, procurement, and research with the private and public sectors. While considerable debate surrounds the value and costs associated with government regulation, the US is the sixth-best globally for ease of doing business.[279] Such a business-friendly environment allows market forces to direct capital flows where they will be most efficiently utilized and allow companies to be profitable. The government also influences national competitiveness through direct and indirect contributions to the research, development, and deployment of basic sciences and advanced technologies. The US has a long history of supporting such R&D efforts across the entire spectrum of technological, organizational, process, and policy innovations. However, the US government's role in R&D varies according to political priorities, and such discontinuity can at times hinder progress.

Chance. The US strength in global energy markets is partly due to the fortuitous combination of natural resources (oil, natural gas, coal, wind, geothermal, hydro, wood, solar, etc.) and human ingenuity (innovative inventors such as Edison, Tesla, and Musk) being in America instead of any other country. Chance enabled US-based inventions, resources, and ideas to lead the world and set the path for others to follow.

Strategy, Structure, and Rivalry. International and domestic competition in the energy sector is driven by market forces and government regulation, or lack thereof. As such, competition is fierce and dependent on supply, demand, and innovation associated with reliability and flexibility enhancements. Access to new markets – determined by external forces (nations, trading blocks, conflict, etc.) – further impacts the ability of US-based firms and individuals to be competitive. Energy underpins the global economy, and energy markets can benefit or hinder US global economic competitiveness in the energy sector. Industry's energy dependence presents a risk to the US economy, as recently demonstrated by the hacking of the Colonial Pipeline in the southeastern portion of the nation, so thoughtful actions must be taken to ensure energy security.

Factor Conditions. Technical innovation, skilled labor, and financial capital all contribute to the deployment and operational success of the US in international energy competition. The US supports innovation, and its developments in energy exploration, development, generation, and distribution have been exported around the world. Skilled

engineers and tradespeople are necessary to keep the system operating smoothly, and adequate capital keeps it all funded. The nation must endeavor to remain in a leadership position by focusing policies on attracting the best-skilled people globally while also encouraging private sector risk-taking regarding innovative energy technologies.

Demand Conditions. The US is the largest economy in the world,[280] and it is fueled by energy and electricity. Domestic demand is generated by home use, industry, government, and other commercial enterprises. Further, domestic energy demand is driven by international demand for goods and services produced in the US. International energy demand is largely dictated by the health of the global economy and the associated demand for goods, services, and transportation of each. As the world's superpower, the US must shoulder the responsibility of setting and enforcing the international economic rule of law to ensure a level playing field for all nations and industries. Such "enlightened self-interest" will directly benefit US firms as well as resulting in positive externalities for companies around the world.

Related and Supporting Industries. The energy sector is directly supported by the domestic and international production, distribution, and trade of raw and refined resources, electricity generation equipment and technologies, and supporting infrastructure elements (generators, transformers, wires, refinery components, ships, etc.). Indirectly, the energy sector is related to all US and global industries because it is the "fuel" interconnecting and enabling all businesses to operate, transport, and provide their goods and services. US-based multinational corporations oversee all aspects of the global energy trade and have direct interests in developing supporting industries as well. The government should incentivize continued economic development while promoting domestic locations for corporate headquarters, research facilities, and other capital savings and investments.

This Porter's Diamond analysis demonstrates numerous US advantages in the global energy competition. The nation is an energy supplier and is innovative. The US's reliable and resilient domestic power generation and distribution system fuels domestic industry, service providers, and educational institutions, enables national security, and promotes innovation at home and abroad. The US is ranked as the world's most powerful country, and a portion of that determination is based on economic strength and influence.[281]

National Innovation System. The national innovation system is the loosely coordinated process by which the business, regulatory, and policy environments combine along with the promotion of science and technology, economic principles, and other social institutions to foster innovative practices, organizations, and technologies.[282] The US has been and continues to be an innovative nation.[283] While it may not be the world's leader, the country is near the top of the rankings, and its process, product, organizational, and technological innovations have spread globally. As related to global power, influence plays a big role, and the ability of the US to export people, ideas, and products is significant. The products of the US economy and educational system continue to fuel and be fueled by the US national innovation system, which is in turn powered by the energy sector. Further, the strength of the US rests in its people and its ideals. The quest for liberty and innovation are not uniquely US traits, but they are perhaps best cultivated in this "land of opportunity" and must continue to be promoted and supported. Indeed, the US without its energy sector would be an inefficient place where innovators and their innovations would struggle greatly.

The Porter Diamond Model is helpful in analyzing the various elements of national advantage which comprise its aggregate value and contribute to innovation on a national scale. Government regulations and macroeconomic policies pave the way for the nation's continued

development, expansion, and global leadership in a competitive environment. Like many things throughout history, chance likely played a role in the discovery and commercialization of the many facets of the energy sector in the US fossil fuels, nuclear reactors, and the transport and trade of energy-related commodities and technology enable national competitiveness beyond the energy market; indeed, the resilient and reliable generation and trade of energy and its supporting elements are foundational to businesses in all industries. In this respect, energy enables firms to develop and implement strategies and structures which make them competitive domestically and internationally, resulting in globally dominant firms being headquartered in the US. The supporting factor conditions (technology innovation, labor, capital) are present in abundance in the US and enhance and are enhanced by leadership in the energy sector. Domestic and international market demand conditions require innovations enabled by the steady supply and trade of energy – raw and refined fuels, technology, and supporting services. The ability of the US to anticipate and react to shifting demand signals is demonstrative of its underlying innovative framework. Finally, energy's related and supporting industries directly contribute to innovations in all areas that can be shared, marketed, and sold around the world.

The US energy sector provides a unique example of the mutually supportive nature of the national innovation system and technological developments, policy and regulatory guidance, and business operations. In this case, the US sets the benchmark in combining the three sides of the innovation success triangle – business, regulatory, and policy environments – most effectively to win the global innovation race.[284] The race is not a short one; it is more of an ultra-marathon that is just getting started. The US must continually develop each leg of the innovation success triangle to ensure continual progress, which is required to maintain the nation's leadership in the ongoing great power competition.

National Industrial Model. The energy sector supports and is supported by the national innovation system, and the same is also true regarding the national industrial model. The US national industrial model balances "…national security, economic competitiveness, and advanced technology…to ensure long-term competitiveness and economic resilience."[285] Of note, a study of G20 countries found that the US ranks second in terms of industrial competitiveness of overall renewable energy industries, largely due to advanced energy technology, abundant resources, market scale, and environmental pressure. The elements of national competitive advantage detailed in Porter's Diamond model, which contribute to and are enhanced by innovation, are all also directly supportive of US industry. Innovation and industry are two sides to the same coin; some of the crucial links the energy sector provides to the national industrial model are: 1) foundational support to all industries across the nation (Related & Supporting Industries); 2) contributions to enhance competition in all domestic and international industries (Strategy, Structure, & Rivalry); and 3) support to the national security apparatus (Government). Simply, US industry could not exist in its current form without many and varied benefits of the energy sector. It is so intertwined with the nation's global competitiveness it is almost impossible to separate the two.

Operational Energy for the Department of Defense. In addition to being central to US competitiveness, innovation, and industrial operations, the energy sector plays a vital role in building and supporting the strength of the nation's military. From electricity on domestic and overseas bases to ship, aircraft, and land-based vehicle fuels, energy enables global power projection and force support across the full spectrum of conflict. Global engagement and continuing operations would be impossible without the steady and robust energy supply. "The [US Department of Defense] defines *operational energy* as the energy required for training,

moving, and sustaining military forces and weapons platforms for military operations."[286] Powering the US military is a huge expense; in Fiscal Year (FY) 2017, over 85 million barrels of fuel costing approximately $8.2 billion were required to support global operations.[287]

US Department of Defense attention to operational energy consumption is important fiscally, logistically, and environmentally. In FY17, energy expenditures ($8.2B) represented 1.4 percent of the total budget ($590.5B),[288] so even a small reduction in fuel use can result in significant cost savings which can be passed along to the US Treasury or an increase in weapon system development, acquisition, or maintenance. Increases in operational efficiency can reduce the logistics requirements placed on the services. As a significant planning factor, logistics support can limit operational effectiveness and responsive power projection. More efficient weapons systems provide more flexibility, additional options, and increased lethality to planners, commanders, and tactical warfighters. Finally, as a major consumer of fossil fuels, the DoD is also a major contributor to greenhouse gas emissions. "In 2017, the Pentagon's greenhouse gas emissions totaled over 59 million metric tons of carbon dioxide equivalent," …which would have made it the 55th largest greenhouse gas emitter if it were a country.[289] In addition to its own impact on the environment, the DoD is also concerned with how climate change may contribute to environmental changes impacting the global security environment. Energy and its financial and logistical costs, as well as its impact on the environment, will continue to of concern to DoD planners for decades to come. It must be a prime consideration in the development of future weapon systems, construction of new facilities, and planning of operations if forces are to be effectively and efficiently employed in global operations.

China's Energy Sector. Beginning with reforms in the late 1970s, China embarked on a period of rapid economic growth that continues to this day. Unlike in other leading economies such as the US, EU, and Japan, government industrial policy continues to play a major role in the Chinese system, where state-owned enterprises (SOEs) account for roughly 40 percent of GDP.[290] This model of state capitalism or so-called "socialist market economy with Chinese characteristics" has proven successful for China.[291] Forty years after re-opening to foreign investment, it now boasts the world's second-largest economy and vies with the US for global political influence.

China's manufacturing-based economy is the world's largest consumer of energy. Energy security remains a major concern for the Chinese economy, which relies on imports for a significant and growing share of its energy mix.[292] China is the world's largest importer of coal, oil, and natural gas.[293] While the share of renewables and nuclear power in its energy mix has grown steadily in recent years, China remains heavily reliant on coal to power its industrial economy.[294] Figures 30-31 (Appendix A) offer a glimpse into China's energy mix. China is the world's largest emitter of greenhouse gases by a wide margin, outstripping the US, EU, and Japan combined.[295]

Chinese policymakers have sought to gradually reduce reliance on fossil fuels in favor of nuclear and renewables. The Chinese Communist Party's latest five-year economic plan, issued in March 2021, codifies the goals of peaking carbon emissions by 2030 and carbon neutrality by 2060, as announced by President Xi Jinping in 2020.[296] China is poised to continue to lead the world in total clean energy investment and generation through the next decade. Nevertheless, as noted above, clean energy is a relatively small share of total primary energy consumption. Hydroelectricity is China's top source of clean energy, accounting for about 8 percent. Other sources, including wind, solar, and nuclear, make up about 7 percent of the energy mix.[297]

While China's clean energy transition, if successful, would help the world meet the greenhouse gas emissions reduction goals set in the Paris Agreement, the effort should be understood in the context of the Chinese government's broader goal to provide increasing volumes of secure and affordable energy to ensure continued economic growth and rising standards of living for the Chinese people.[298] This includes diversifying sources of oil and natural gas imports as well as continuing to rely on its large domestic coal reserves. In the eyes of China's leadership, energy security is a more immediate threat than climate change.

Porter's Diamond Analysis. For at least the past 15 years, China has focused on the development of renewable energy with the encouragement and backing of government resources. From a national competitiveness perspective, they have pulled ahead of other countries and are continuing to widen the gap.

Government. The "Medium and Long-Term Development Planning of Renewable Energy," issued in 2007, declared that China's installed capacity of wind power and solar power would reach 30 GW and 1.8 GW, respectively, by 2020.[299] In 2012, the Chinese National Energy Administration's "Twelfth Five-Year Plan" increased these goals to 100 GW of wind capacity and 21 GW of solar capacity by 2015.[300] By the end of 2020, China had installed 281.5 GW of wind generation capacity and 253.4 GW of solar generation capacity, far exceeding its stated goals.[301] Unlike the US, China is able to quickly mobilize all necessary **industrial system** resources to meet its goals. It is not always easy to discern how much direct government backing Chinese companies receive, but it is clear that China has and will continue to promote these firms. It is estimated that between 2010 and 2012, the Chinese government subsidized $42B worth of loans to support the production of solar panels, a key factor in their price decline and resulting dominance of the industry.[302] This year, China again committed to increasing its financial support of the renewables industrial system for the development of wind and solar companies through subsidies and state-back loans.[303] However, China's actions must be viewed from the perspective of economic security and longevity of the current government. While taking serious steps towards renewables, China continues to rely primarily on coal and exports coal power plants to developing countries. China's shift towards renewables builds on their inherent low-cost production advantage to provide the world's need for solar panels and wind turbines. Domestically, it also stems from growing discontent with pollution and air quality.

Chance. China controls about 35% of global reserves of rare earth minerals, a required input for renewable energy technology. They extract these at a higher rate than other countries, accounting for the production of 70% of these minerals. China has built on this natural advantage to buy or control rare earth mines around the world, and now mines 80% of rare earth minerals used globally and is responsible for the refining of 95%. This gives China a big advantage in the race to renewables.[304] As the world's most populous country, China has a built-in labor advantage that has helped propel it to become a production powerhouse. China has relied on this huge pool of workers to create a vast industrial sector that can undercut competitor prices, including in the renewables market.

Factor Conditions. Human capital is perhaps the most important production factor to consider. China's meteoric economic growth over the last thirty years was fueled, in part, by its large population and low dependency ratio. In recent years, this demographic dividend has diminished. Decades of low birth rates, encouraged by urbanization and the "one child policy," have turned China into the most rapidly aging country in the world. The dependency ratio is now forecast to become an ever-greater drag on economic growth, with the ratio of the old-age-dependent population to the working-age population rising from 17% today to 36% in 2060.[305]

The Chinese government hopes that greater investment in industrial automation, including artificial intelligence, will make up for its shrinking labor force, but the success of that bet is uncertain. The Chinese government hopes that greater investment in industrial automation, including artificial intelligence, will make up for its shrinking labor force, but the success of that bet is uncertain. Allegations of forced labor in China's green technology supply chain and threatened western sanctions also threaten further undermine its low-cost labor advantage.[306] On the positive side of the ledger, China continues to outpace all other countries in terms of education in the so-called STEM fields of science, technology, engineering, and math. According to a recent World Economic Forum report, China has twice as many recent graduates in these critical fields as a percentage of its population as the United States.[307] China hopes this investment in STEM education will yield innovations in the energy space and other major industries.

China's **national innovation system** is well-positioned to support its dominance of the global renewables sector. Government support for the NIS stands out for its centrally coordinated innovation planning and its massive commitment to increasing R&D funding. The Council on Foreign Relations described "Made in China 2025," released in 2015, as a state-led industrial policy that seeks to make China dominant in global high-tech manufacturing, including clean energy technology.[308] Such government-led programs guarantee a domestic market for Chinese firms while protecting them from international competition as they develop expertise and economies of scale. China's national investment in R&D has increased dramatically over the last thirty years. Even as its economy has expanded rapidly, the share of GDP devoted to R&D has increased from 0.56 percent in 1996 to 2.18 percent of GDP in 2018.[309] Before the COVID-19 pandemic, China was already expected to overtake the US as the world's top R&D investor, and it almost certainly did.[310] While this data includes both public and private sector investment, the control the Chinese government exercises over large state-owned enterprises and the private sector ensures research will be directed towards the Chinese Communist Party's (CCP) national security and economic development priorities, such as clean energy.

Demand Conditions. China has also set the demand conditions at a national level to advance its domestic renewables market. It now has the most installed wind and solar generation of any country by far. Combined, these sources provide almost three times more power than what the US, the next largest, has installed.[311] Over the last decade, China has become the world's leading investor in renewable energy, accounting for 23 percent of global renewables investment in 2019 and deploying almost three times the capacity of any other nation.[312] In December 2020, President Xi announced that China will boost its installed capacity of wind and solar power to more than 1,200 GW and would increase the share of non-fossil fuels in energy consumption to around 25 percent by 2030, up from a previous commitment of 20 percent. The Chinese government also ordered grid companies to increase the amount of power purchased from clean sources from 28.2 percent in 2020 to 40 percent by 2030.[313] These demand conditions imposed by the government will continue to advance wind and solar technology.

Related and Supporting Industries. China's rapid growth in renewables has coincided with state-led dominance of related and supporting industries. China has leveraged its industrial capacity and sheltered domestic market to become the world leader in the production and export of technologies essential to the clean energy transition. China controls the majority of worldwide critical minerals and rare earth elements necessary for the production of renewable technologies.[314] As of 2019, Chinese companies produced 70 percent of global solar photovoltaics and accounted for nearly 75 percent of lithium-ion battery manufacturing

capacity.[315] China also controls most of the global supply chain for the so-called "rare earth minerals" that are needed to manufacture these products. As of 2019, China outstripped all other countries in the production of rare earths and accounted for over 80 percent of US imports.[316]

Strategy, Structure, and Rivalry. In doing so, Chinese companies now dominate the wind and solar industries. Six of the top ten wind turbine suppliers and eight of the top ten manufacturers of solar photovoltaic modules are Chinese companies.[317] Rivalry is an important factor to advance an industry. Having so many top companies competing against each other within China makes them even more competitive on the global stage. Also, Chinese companies have a competitive advantage using Government-sponsored intellectual property theft. It is alleged that in 2012, as Chinese solar producers were beginning to compete on the global stage, Chinese hackers acquired solar panel technological innovations that had taken German and American companies years to develop.[318] These technologies were then provided to Chinese companies to quickly bring similar products to market. These sorts of Government-supported actions distort the competitive marketplace by removing the otherwise high barriers to entry.

Russia's Energy Sector.

Government. The government's highest priorities under President Putin do not appear to be about achieving rapid economic growth but rather about maintaining power by building loyalty through oil and gas revenues. Putin maintains tight controls over national oil and gas companies through a highly centralized political system and ensures the state provides jobs, services, and adequate subsidies to help maintain political support and consolidated power. In short, Russia's abundant energy resources as a tool of political influence with no genuine internal competition does not facilitate the country's energy sector development. Most private companies are owned or operated by government officials, which creates conflicts of interest that fuel corruption. Not surprisingly, Russia ranked first in the crony-capitalism index of 2016,[319] which results in the pilfering of profits from natural resources and limits investments in the country's future. Russia has no carbon pricing mechanism, giving companies little incentive to pay higher prices for clean energy. Russia's political alliance with China aims to undercut American power and the current rules-based international system. Energy cooperation with China, such as the $400 billion Siberia pipeline for the export of natural gas to northern China, reinforces this alliance.

Chance. The country's high dependency on fossil fuel revenues means its economic strength is largely determined by oil and gas prices. The 2008-2009 drop in oil prices plunged the country into a deep recession, and the 2014-2016 financial crisis was the result of its currency devaluation and significant drops in oil prices. The 2019 economic downturn due to high inflation and US sanctions was exacerbated by the COVID-19 pandemic, which conspired with dropping oil prices to send the country into another major recession.[320] While Russia's Ministry of Finance manages a sovereign wealth fund to help smooth out periods of price shocks, the revenues from oil and gas are the primary means for funding national programs and maintaining support among the population. In 2017, civil unrest led to protests against widespread corruption, putting into question the long-term viability of Putin's regime.

Strategy, Structure, and Rivalry. The weak rule of law and poor track record around the enforcement of property rights has ultimately hurt the country's ability to attract foreign investment. Extreme corruption further undermines forces of a market economy and creates incentives for firms to collude with the political establishment. Furthermore, US sanctions have denied major state-controlled oil and gas companies – like Rosneft, Novatek, and Gazprom –

from accessing international financial markets, which further hinders their energy industry's finance options. Since the Stalin era, Russia has viewed arctic exploitation as their path to becoming an energy dominance and nationalization. Their energy transition strategy is to be among the last among the low-cost oil-producing countries in the market. The Kremlin projects a 30-year future for natural gas as a mobile, clean alternative to coal. Natural gas has more recently has been at the center of the country's economic and geological future based on the new pipelines established to China, Turkey, and Germany to increase their global market share of LNG exports. Russia views the climate change in the Arctic region as an opportunity to expand revenues coming from the Northern Sea Route, which is estimated to be capable of moving up to 80 metric tons of cargo a year by 2024.[321] Russia also faces political competition with OPEC countries as evidenced by their succumbing to pressures to reduce oil production levels, which ultimately hurts is Russia's resource-based economy.

Factor Conditions. In terms of human capital, the chaos of the 1990s affected optimism and thus fertility, leaving Russia today with a "plunging" aging population trend, characterized by a negative population growth rate of -0.16 percent.[322] It has a weak base of human capital for innovation, which means it would have to rely on attracting talent from the outside and reform its education system if it would like to become a serious actor of next-generation energy innovations. For example, while Russia remains strong in traditional sciences like math and physics, its university system separates its higher-level research from the university system, thereby undercutting opportunities to nurture future innovators during their formidable academic years. [323] However, any efforts to increase technology transfers or even modernize the existing infrastructure will be inhibited by the sanctions that followed the annexation of Crimea, which includes a ban for international companies to export certain technologies. This barrier, along with an aging population that is not built for innovation, can diminish Russia's competitiveness in European and Asian markets over time.

Demand Conditions. In terms of home-market demand, the region is energy-rich, which creates conditions for natural gas to remain far cheaper than renewables. Like most rentier nations, Russia's public sector employment is larger than its private sector, which foments a climate of dependency throughout the country on the jobs and social benefits that come from the fossil fuel industry. This weakens local demand for policies that would promote diversification and alternative forms of energy. Externally, Russia is the world's second-largest exporter of fossil fuels, with Europe being its number one importer. However, Europe's current pivot to renewables and clean energy has forced Russia to pivot to the emerging markets in the East. Urbanization is steadily increasing in the heavily populated Asian countries, which are sparking demand for cheap and affordable energy. Although those countries are investing in renewable infrastructure, the current demand will sustain Russia's growth objectives for the medium-term. Russia still views Europe as a viable export customer despite the reduced energy demands, as seen with the agreement for the Nord Stream 2 pipeline project. Russia's GDP is estimated to fall by .5 percent between 2030-2050 due to the climate policies of import countries, which will reinforce market barriers for other energy-intensive exports such as metals, chemicals, and fertilizers.[324] Russia is also engaged in nuclear energy technology as a source of additional revenue. It has projects in India, China, and Iran and has signed nuclear power development agreements with Belarus, Finland, and Hungary. This bolsters Russian influence as it constructs nuclear power plants, provides enriched uranium, and provides post-construction maintenance without sharing technologies.

Related and Supporting Industries. Russia has an opportunity to leverage its existing infrastructure to become a leader in hydrogen production; however, the industry lacks the incentives due to government prioritization and investment causing them to lag potential competitors like Saudi Arabia, Chile, and Australia. Russia's private energy and metals companies are beginning to green their operations due to pressure from international investors, despite the national will to encourage energy transition. Internal energy majors are looking to monetize hydrogen production, but that is difficult because Russia has no carbon pricing mechanism, forcing the energy majors to focus on building an export business without government support.[325] Russia's export-oriented economy and external enemy policies have formed the **National Industrial Model.** It has become focused on those industries that allow Russia to make money from exporting energy resources (oil, gas, and nuclear technologies) and enhance military capabilities to remain competitive in this sphere. Russia has developed oil and gas, mining, processing precious stones and metals, aircraft building, aerospace production, weapons and military, and steel production industries. Underinvestment and international rather than domestic policy priorities constrain the development of other industries. The social sphere is one of Russia's weaknesses and could be ultimately a potential threat for Putin's regime.

National Innovation System. Russia's overall prospects for innovation into new technologies are limited, although the nation does have a strong base of an educated population and long-term prospects for revenue streams from oil and gas that could be invested. The "shadow economy" undermines the rule of law and the prospects for a market economy that would promote the kind of fair competition that is conducive to innovation. It is furthermore a tough environment for foreign investment and sanctions put limits on access to finance for the leading oil and gas companies to invest like those in the US and EU. Promoting technology transfers from other countries like Ukraine would be smart to jumpstart progress, as would greater long-term investments in R&D. If a new, rational government were to assume leadership, sea change ideas such as privatization and diversification would perhaps have a chance, but under the current leadership, those prospects are virtually nil.

Japan's Energy Sector.

Government. Today, Japan boasts the third-largest economy in the world, after the US and China.[326] Over the last decade, Japan made significant progress in implementing policies and processes to establish an efficient, resilient, and sustainable energy system to support domestic and international growth. After several recent natural disasters, rebuilding a safe and reliable energy system to support economic growth and prosperity has become a major focus area. In 2019, Japan was the fifth-largest energy consumer, importing nearly 94 percent of its primary energy supply.[327] Due to its geography and lack of overall natural resources, Japan relies heavily on imports of oil, natural gas, and coal to sustain its energy requirements. Although the ascent of nuclear power stalled due to the 2011 Fukushima Daiichi nuclear disaster, Japan continues to shift its focus toward safety standards to bring capability back online. However, favorability for nuclear power is mixed across government and the general population. There is also growing emphasis on renewable energy sources such as solar and wind to meet zero-emissions and carbon-neutral targets by 2050. Energy policy and security are essential for Japan to remain a competitive nation, which it currently ranks 5th in the world out of 141 economies according to the 2019 Global Competitiveness Report published by the World Economic Forum.[328]
Japan's high dependency on imports for natural resources such as oil, natural gas, and coal means a certain degree of vulnerability in energy security. The fluctuation, volatility, and

availability of product in these markets could present significant issues for Japan's energy sector. Japan's energy security is contingent on diversifying fossil fuel supply chains while considering current and future requirements. A critical import, oil accounts for around 40 percent of Japan's energy supply, but more than 80 percent of the imported oil supply comes from a politically unstable Middle East.[329] Energy diversity also depends on Japan's willingness and ability to incorporate renewable energy capacity such as wind, solar, geothermal, and nuclear in the coming years. Natural disasters and weather events have wreaked havoc on Japan's energy system. How well Japan modernizes, diversifies, and hardens energy infrastructure will prepare Japan for future unexpected events.

Strategy, Structure, and Rivalry. Japanese firms are postured well for strategic competition across a broad array of international markets. Government and industry work closely together to pursue policies aimed at global technological and market leadership. Japan has a history of a highly innovative and groundbreaking industrial model from electronics to automobile manufacturing. Through solid public and private sector investment, Japan encourages consistent growth and development across the budding energy sector. These investments are leveraging electronics, software, and digital platform expertise with a focus on artificial intelligence and machine learning.[330]

Factor Conditions. Japan's domestic labor force consists of both a highly educated and skilled labor population to capitalize on innovation, design, development, and manufacturing. However, according to the World Economic Forum, Japan's workforce population is declining and may fall around 20 percent by 2040.[331] The advancement of artificial intelligence, automation, and robotics capability may limit the loss of long-term workforce capacity. Additionally, R&D spending in Japan is among the highest globally, which contributes to innovative manufacturing processes. As of 2018, Japan ranks 2nd in the world for R&D investments and plans to spend $275 billion in the energy sector alone in the next decade.[332] Government investment and forward-looking economic policies leverage a traditionally driven and high-performing culture. Japan's innovation ecosystem is steadily growing, supported by robust public and private capital investments. Although still small compared to the US's Silicon Valley, the startup ecosystem has transformed over the past decade through regulatory shifts, corporate transformations, and technological breakthroughs, opening up vast new opportunities.[333]

Supporting Industries. Japan evolved a **national innovation ecosystem** that promotes the accumulation and transfer of knowledge in the university-industry-government relationship to meet industrial and economic challenges. Japan prioritizes R&D in science and technology (S&T) to drive domestic innovation, global competitive advantage, and national economic growth. The inputs (Knowledge Creation and Basic and Long-term Research), the outputs (Products, Markets, and Social Services), and the interaction fields (Humans, Technologies, Funds, Regional Clusters, Industry-Academia Collaborations, Intellectual Property, Standards, and Regulation or Deregulation) characterize the system.[334] It should be noted that Prime Minister Suga and the Liberal Democratic Party have exhibited waning support for the top science advisory board to government, the Science Council of Japan, especially in military matters, therefore exposing a potential gap between Japan's innovation ecosystem and national security.[335]

Although the country looks to increase renewables, oil and gas imports will continue to play a significant role in Japan's total energy production mix, and Japan will be the third-largest contributor to crude oil refining capacity in Asia from 2018 to 2023.[336] Japan's refining

capability and strong chemical processing sector lend favorably to hydrocarbon energy production. The nuclear industry benefits from domestic companies specializing in reactor manufacturing, such as Toshiba, Hitachi, and Mitsubishi. Additionally, Japan leads globally with expertise in nuclear plant construction, equipment, nuclear fuel production, and recycling, and technical skill, making Japan globally competitive in nuclear technology.[337] Japan contributes significantly to the solar PV value chain through polysilicon, wafer and ingot, cell and module manufacturing, and PV installation services. In upstream solar supply, Japan competes globally in steel production (the world's third-largest producer), inverter manufacturing, and ethylene vinyl acetate (EVA) encapsulant production.[338] Other leading industries for Japan provide synergy to the energy sector through skilled labor, R&D, and funding. Such industries include the manufacturing of precision and high-tech goods (e.g., hybrid vehicles, robotics), semiconductors, electronics, automobiles, biochemistry, mining, and petroleum exploration. Additionally, Japanese industries and academic institutions partner with international companies (such as General Electric for nuclear generation) to increase supply chain resiliency.[339]

Demand Conditions. Since 1945, Japan implemented industrial policy through three distinct phases of the directly regulated private sector (1945-1960), support for strategic industries through hard measures (1960-1973), and support for strategic industry through soft measures (1973-1990), which led to remarkable economic growth.[340] Today, Japan does not maintain an **industrial policy**, but much like the US, it prioritizes investments to improve factor conditions such as R&D, innovation, tax incentives, subsidies, and other policies and regulations. For example, the Green Growth Strategy of December 2020 aims to address factors that enable Japanese companies to compete globally on a level playing field, such as carbon border adjustments, robust economic mechanisms, regulatory reform, and other market-based tools. As an island country with limited natural resources, Japan faces fundamental energy security and resiliency challenges.

As a highly industrialized nation, meeting energy demands to support a robust population and industry remains vital to economic success. At the 2019 G20 summit, Japan reiterated a long-term target of reducing greenhouse gas emissions by 80 percent from current levels and to "achieve net-zero emissions as early as possible during the second half of the 21st century".[341] Japan presented the "Green Growth Strategy in line with Carbon Neutrality in 2050" in December of 2020. Government climate goals and policies have increased demand for all low-carbon and renewable solutions, with Japan's share of renewable energy generation expected to increase from 19 percent in 2019 to 24 percent in 2030. On April 22, the Leaders Summit on Climate, hosted by the US, Prime Minister Suga declared that "Japan aims to reduce its greenhouse gas emissions by 46 percent in fiscal year 2030 from its fiscal year 2013 levels, setting an ambitious target which is aligned with the long-term goal of net-zero by 2050."[342] In particular, nuclear energy must play a role in achieving 2030 and 2050 goals, requiring an increase from 4 percent of total energy in 2019 to 11 percent in 2030. This increase in nuclear production requires an increase from 9 to at least 30 operational nuclear reactors.[343] Japan faces the opportunity to increase nuclear demand exportability in competition with Russia and China. The new strategy has also led to Japan's Road Map for Fuel Ammonia, which calls for 3 million tons of imports by 2030 and 30 million tons by 2050, leading to Japanese private company investments along the entire supply chain. Japan looks to export this tech to the region, exporting 100 million tons per year to the region by 2050.[344] Similarly, Japan's goals for hydrogen to replace combustion engines presents challenges, mainly in a ten-fold cost when compared with the emission-producing counterparts. The government invested USD$19 trillion

to support R&D investments to make hydrogen more viable, and Toyota recently established the Japan Hydrogen Association to promote investments in Japan's hydrogen supply chain.[345]

With reliance on energy imports, the slow transition to renewable and low-carbon sources, and the need to balance energy security, energy equity, and environmental sustainability, Japan will continue to operate and maintain coal, oil, and natural gas energy generation industries and thus maintain demand for hydrocarbon-based energy industries. Maintaining the hydrocarbon sectors also enables Japan's ability to respond to mobility and surge requirements.

Commonwealth of Puerto Rico. Puerto Rico presents an excellent case study on the energy dilemmas and issues that occur within small island ecosystems. Limited capital investment, aging infrastructure, and devastating natural disasters are the biggest problems affecting Puerto Rico's energy industry. The island's energy industry is in a phase of rebuilding after the natural disasters of 2017 and 2018, as well as privatization and restructuring of the previously held public utility.

Industry Overview. The 2020 GDP of Puerto Rico was $104 billion dollars, ranking 39th out of 56 US states and territories. The majority of GDP production in Puerto Rico comes from a heavy industrial manufacturing and pharmaceutical industry on the island. During the late 20th century, the island's energy industry made several significant investments in electricity generating infrastructure to support the growing manufacturing and pharmaceutical industries. However, the tax incentives that drove industrial development and subsequent electrical demand on the island have since expired, causing many manufacturing industries to depart. As a result, approximately half of the island's electrical generating capacity built to support a large industrial base sits idle and inoperable. This also leaves a very small margin of excess capacity available to the grid during times of increased demand, leaving parts of the island vulnerable to blackouts. Hurricane Maria in September 2017 destroyed PREPA's distribution network, creating long-term blackouts across the island.[346] Island-wide outages occurred on September 20, 2016, due to a fire at one of PREPA's plants—Central Aguirre resulting in all of Puerto Rico being without power for three days. In 2012, 14,000 residents were left without power following Tropical Storm Isaac. Hurricanes Irma and Maria caused significant damage to an antiquated, fragile power system that was already struggling to provide Puerto Rico with reliable and affordable power, as evidenced by reliability and safety metrics that stand well below US industry standards.[347] These natural disasters introduce a significant amount of **chance** into the island's energy industry that often comes with extraordinary consequences. Additionally, changes in the global climate have increased the frequency of these devastating storms.

Additionally, most of the electrical generation capacity resides on the southern portion of the island, while most of the demand resides on the northern portion, requiring long transmission lines to be built from south to north and through often rough terrain, making them susceptible to damage. On occasion, entire areas of the island are left without power when an animal, such as a cat or an iguana or a fallen tree causes damage to the system. Energy reliability and resilience are continuing key issues for the island of Puerto Rico. The industry desires to upgrade and harden the electrical grid and infrastructure, but limited amounts of investment capital make it difficult for Puerto Rico to make required upgrades. The majority of Puerto Rico's electricity is generated using oil and natural gas fired power plants. Puerto Rico also has 21 reservoirs that produce hydroelectric energy.[348] In 2019, the Puerto Rican government passed legislation requiring the

closure of coal fired power plants by 2028 and achieving 100 percent renewable energy by 2050.[349]

Strategy, Structure, and Rivalry. The Puerto Rico Electric Power Authority (PREPA) is the government owned utility that manages the generation, transmission, and distribution of electrical power across the island.[350] The authority is governed by a board of directors appointed by the governor with the advice and consent of the Senate. Since 2014, PREPA is also subject to the Puerto Rico Energy Commission, another government agency whose board of directors is also appointed by the governor.[351] Additionally, PREPA is the only entity authorized to conduct business in Puerto Rico, making it a government monopoly, until on January 22, 2018, when the governor of Puerto Rico announced that all assets of the company would be sold in a general privatization of PREPA.[352] PREPA has historically faced significant financial, operational, and reliability challenges.[353] Macroeconomic trends, including declining population and a stagnant economy, coupled with declining customer demand, have negatively impacted PREPA's revenues over the past ten years.[354] PREPA's fiscal situation is exacerbated by unsustainable debt obligations, which, coupled with its operational challenges, resulted in PREPA filing for bankruptcy protection via voluntary petition under Title III of the Puerto Rico Oversight, Management, and Economic Stability Act (PROMESA) to better position the utility to implement a comprehensive transformation and debt restructuring.

Factor Conditions and Supporting Industries. Volatility in fossil fuel prices in past years further adversely impacted affordability on the island given the system's dependence on fossil fuels and also introduce another high-impact source of **chance** into the industry. Figure 32 (Appendix A) shows the breakdown of base rate composition for PREPA showing fuel costs and purchased power making up almost 75 percent of the total rate. Like Japan and other island nations, the island does not have access internally to most of the resources required to maintain its energy industry. Additionally, the high cost of upgrading existing infrastructure and large amounts of investment capital required to deploy new technologies make the island's energy slow to evolve.

There are four labor unions that represent the workers from the authority. The utility experiences no shortages in labor in support of normal day-to-day operations but relies heavily on outside assistance in the rebuilding from natural disasters. ConEdison of New York and the Army Corps of Engineers, among many others, contributed significant amounts of manpower and resources during the recoveries from hurricanes Irma and Maria. Additionally, the growth of renewable deployment and the potential deployment of small nuclear reactors will require transitions and growth in the industry's workforce. Furthermore, the island maintains little to no organic capability to produce energy infrastructure assets and supplies, relying exclusively on imports from the US mainland.

Demand Conditions. The island maintains a flat load curve due to the relatively small fluctuations in temperature both throughout the day and seasonally. This requires the coupling of battery storage systems required as a part of any installation of intermittently producing renewable generation sources such as wind or solar to capture the energy produced by those sources at their peak and deliver power at the time and place of demand.

Many leaders within the island's energy industry have identified SMR as a desirable potential solution to some of the island's energy generation problems. The small footprint, enhanced safety features, and greater flexibility of SMR when coupled with other renewables make it an attractive option for the island's energy grid. Additionally, several public surveys identified that public acceptance of SMR and nuclear generation, in general, would likely be

high. An electrical grid that is more reliable, resilient, and that generates electricity at a lower consumer price would drive public acceptance of nuclear technology deployment. However, SMR technology is still in development and may not be coming to market quickly enough to meet Puerto Rico's needs in the short term.

VI. Comparative Analysis of Strengths, Weaknesses, Opportunities, and Threats (SWOT)

The industry and country evaluations provide the basis of a high-level SWOT analysis for the US, China, Russia, Japan, and Puerto Rico. Each faces unique challenges and requires tailored approaches toward climate change and energy transitions to safeguard national and economic security and maintain a balance of the energy trilemma. Each entity is postured differently with respect to climate challenges and energy transitions considering their own energy strategies and policies. The following brief synopsis is accompanied by an analysis overview found in Appendix B.

Overall. Three cross-cutting ideas stand out across the analysis. The first is government influence. The US and Japan foster competition and innovation through government policies, investments, and open economies but must tediously garner support for energy solutions such as nuclear and renewables. The US also faces the challenge of alignment between federal, state, and local levels. China and Russia, on the other hand, exert central control and direct specific developments regarding industry and supply chains. As a sub-national entity, Puerto Rico exhibits strong policy goals to set conditions for future development but faces challenges in funding and execution of those goals. Government policy, strategy, and investments of each country manifest in internal strengths and weaknesses as well as external opportunities and threats to other nations.

The second key point is the consideration of energy imports and exports. The US and Russia both export fossil fuels as a major source of GDP and therefore would benefit greatly from CCUS and other innovations to keep fossil fuel exports contributing toward GDP. China, Japan, and Puerto Rico rely heavily on imports and stand to benefit greatly from renewable and nuclear energy growth. Additionally, each country benefits from increased energy development when they are major stakeholders in energy-specific supply chains. Therefore, imports and exports, specifically through supply chain diversification, threads the chart in all areas.

Finally, alliances and partnerships will continue to provide both opportunities and threats. Energy supply chain diversification with like-minded partners, for example, could increase US, ally, and partner energy security but also negatively impact China and Russia exports. Thus, we will continue to see openings for both cooperation and competition amongst partners and adversaries as national competitiveness in the energy domain bleeds over into great power competition.

Strengths. Each of the four countries has strengths in structural characteristics and in enacted policies towards achieving strategic objectives. The US and Japan carry the strengths of democratic systems, open markets, innovative ecosystems, and legislation and policy aimed at promoting energy security, portfolio diversification, and global competitiveness. China and Russia, conversely, can claim as a strength their centrally controlled, stable governments capable of picking winners and losers and directing investments in domestic value chains. All four countries possess nuclear expertise and technology; however, China and Russia enjoy higher exports in this area as the US and Japan grapple with public support. The US, Japan, and China enacted policies to achieve success in renewable industries and renewable energy diversification, while Russia boasts a strong Arctic strategy in line with economic goals in oil

and gas exports. Highly skilled labor is an advantage to Japan, the US, and China to varying degrees. Finally, Puerto Rico possesses the strengths of published policy goals regarding emissions and renewable energy sources (largest wind generation and second-largest solar PV generation in the Caribbean).

Weaknesses. Demographics and skilled labor present challenges for all countries, each with a unique mix of population growth/decline and aging statistics, immigration policy gaps, and skilled labor availability for growing industries. Per capita, energy consumption remains high for the US and is growing for China. The US relies heavily on foreign supply chains for rare earth element processing and key parts for renewable generation, while Japan and China rely heavily on energy imports. US government divisiveness could also be considered a weakness in national competitiveness due to changing federal direction on climate and energy policy, as well as differing policies and enforcement at the federal, state, and local levels. Russia and China (although to a decreasing extent) do not foster innovative ecosystems and rely on external innovation. China also faces major environmental challenges due to industrial contamination of water sources and air which could hinder increased metal processing efforts should social pressure increase to address these factors. Russia's strategic aims surrounding fossil fuels as a primary fuel source fail to stimulate competitive growth in the renewables sector, thus taking away from Russia's competitiveness in renewables. The US and Japan face cultural and self-imposed regulations creating high barriers to entry for nuclear power. Japan also exerts strict trade regulations and high taxes that serve to stymie foreign investment. Puerto Rico faces a declining population, lack of skilled labor, debt, lack of resilient energy infrastructure, and lack of natural resources.

Opportunities. The US, China, and Japan stand to capitalize on all aspects of energy industry value chains and subsequent GDP growth with the energy transition. Russia does as well, but mainly in critical minerals since their strategic aims center around oil and gas industries. The US and Japan may also benefit from further development of domestic critical supply chains or energy supply chain partnerships with like-minded nations, both of which would reduce dependency on China and Russia. The US and Russia share an opportunity to advance CCUS and other technology that would keep fossil fuel energy sources as viable exports to both developing countries as well as those with emission and climate goals, especially considering future carbon taxes. China could expand market control or expand special economic exclusion zones in order to compete more effectively in energy markets or attract foreign investment. Russia could bolster Arctic activities to support energy exploration. Japan could expand nuclear export efforts to compete with Russia and China more effectively. Finally, Puerto Rico could seek grants and aid to rebuild its energy infrastructure for resiliency and energy transition demands, as well as seize the opportunity to increase energy independence using SMR technology. US, China, Russia, and Japan share several similar opportunities. The Arctic presents an opportunity to access additional oil and gas reserves. Carbon capture technology provides each country a benefit either as an import or export, extending energy security through a transition to renewable diversification. Geopolitical influence surely will manifest as new partnerships form in the supply, trade, and development of energy resources. Robotics, artificial intelligence, computing advances, and automation reduce energy industry hazards while increasing the efficiency and effectiveness of energy systems. Finally, global leadership and standards regarding climate and energy equate to influence and benefits, by which each country stands to gain.

Threats. The external factor of rising global energy consumption threatens energy supply chains for all countries as demand spurs competition for energy resources, critical materials, rare earth minerals, manufacturing capabilities, and finished products. Russia faces external challenges from other low-cost producing oil and gas nations as its fossil fuel exports remain critical to GDP growth. Cyber threats lurk as a concern for global energy infrastructure. Market volatility for differing sectors, particularly oil and gas, impacts each nation differently depending on whether it is a net energy importer or exporter. Global energy supply chain alliances, political sanctions, and global perception may threaten both China's and Russia's energy exports. Japan and Puerto Rico face similar direct threats from climate change itself in terms of rising sea levels and increased potential for hurricanes and typhoons. Natural disasters also disrupt supply regionally and globally. Carbon pricing, while advancing renewable portfolios, threatens each country differently depending on diversification of sources and the import-export balance of fossil fuels.

Key SWOT Takeaways:

- Growing global energy consumption, climate change, and energy transition, while universally impacting all countries in this analysis, do not do so uniformly. Increased global consumption, for example, may provide an opportunity for China to expand energy exports but hamper the US in its increased reliance on foreign supply chains. Warming temperatures and a melting arctic may threaten Japan's infrastructure but provide Russia with an opportunity for expanded oil and gas access.
- Each country will seek to posture to maximize advantages, seize opportunities, minimize weaknesses, and bolster against threats while simultaneously weighing actions in the context of national security, economic security, energy security, energy equity, and environmental sustainability.
- Energy resources, value and supply chains, partnerships, interdependencies, exports, costs, and government policies provide opportunities for nations to exert geopolitical influence.
- Government structure, economic structure, and national policies can provide both advantages and weaknesses. Whereas the US and Japan exhibit democratic systems with free-market economies that spawn innovation and competition, China exploits an authoritarian government structure with a centrally influenced social market economy that more directly intervenes in industrial policy.
- Government policy, taxes, incentives, and subsidies are used to secure national, economic, and energy security goals.
- Energy transition must be purposeful for the US to ensure energy security while working to bolster energy equity and environmental sustainability. Too quick of a transition to renewable and low-emission solutions without considering energy security (sources, cyber protection, infrastructure upgrades, reliability, skilled labor, etc.) could result in additional weaknesses and threats for the US.
- The US, Japan, and China have an opportunity to seize on energy transition momentum to better national, economic, and energy security, energy equity, and environmental sustainability. Russia can capitalize on a slow transition that results in steady or increased reliance on oil and gas.
- CCUS innovation will prolong GDP growth for countries reliant on fossil fuel exports.

VII. Policy Recommendations

As outlined above, the United States has a lead energy supplier and consumer role and is again taking a lead role in combating climate change. The country is relatively well postured given its diverse energy base, strong market policies, and trade institutions, as well as strong innovation, financial, infrastructure, human capital, education, and industrial bases. However, the US's ability to lead and respond globally may be hindered in a resource-constrained environment, especially as the nation continues to recover from the pandemic, addresses ongoing social inequity and injustice issues, and faces uncertainty with the growing national debt.

1. Establish the True Cost of Carbon

Situation. "It is light as air, yet it weighs tons. It is vital to life, but it is considered an accelerant in the world's ongoing environmental tragedy. It costs nothing to make, yet paying for it will equal tens of billions of dollars a year. What is it? It is carbon."[355] Some renewable energy sources have a lower levelized cost of energy than some fossil fuels. Nevertheless, establishing the cost of carbon will level the playing field for domestic energy producers and consumers, enabling lower carbon-emitting, but potentially more expensive, industries to better compete with those employing higher emitting technologies. Further, if common carbon pricing was extended globally, it would be considerably more difficult for developed nations to export their pollution to less developed parts of the world and help the US to hold other nations accountable to their climate targets.

Policy Recommendations. The US must implement a carbon pricing scheme. To contain and reduce human-generated carbon emissions, the US must start by updating environmental regulations to include clean energy standards. Regulations governing water and air pollution must specify allowable carbon emissions from all sources – industry, transportation, energy generation, and along all points upstream, midstream, and downstream in the supply and value chains.

Updates to carbon emission standards must then be complemented with an incentive (or penalty) structure for adherence to the rules. Most effective options to ensure regulatory compliance would be a "cap & trade" program or a tax on carbon. Either could be effective, but cap & trade would require the establishment of a completely new market with associated rules and oversight. On the other hand, "[a] carbon tax provides great clarity about the price of emissions [as compared to a cap-and-trade system] …[a]nd the US already has a well-developed tax collection system, which works smoothly for collecting excise taxes on many fossil fuels."[356] This would likely also require a carbon border adjustment tax to account for carbon emissions on imported goods.

Execution. If implemented, the policy recommendations above are likely to result in changes to the US economy vis-à-vis industry, education, innovation, and government action. Low carbon-emitted energy sources will increase in demand as the levelized cost continues to fall (Figure 33, Appendix A) and operate while high emitting sources will all but be eliminated from the nation's electricity generation portfolio. People in impacted industries will have to be retrained to ensure they have the means to support themselves and their families. The nation's electrical grid will have to be modernized to support the increase in distributed renewable energy generation and transmission. These various costs will have to be paid by both industry (via rate increases on consumers) and government (from collections of the carbon tax).

Feasibility. While the specifics of updated environmental regulations associated with clean energy standards would likely face partisan debate and a multitude of special interests,

common ground can be found and enacted into law. Clean and safe water and air should not be partisan because everyone, regardless of race, orientation, or state of residence benefits equally. However, the same cannot be said about the implementation of a carbon tax. A statement "…signed by 3,589 economists – including three living former chairs of the Federal Reserve, 27 Novel laureates and 15 former chairs of the Council of Economic Advisers" support a carbon tax as an effective means to reduce carbon emissions.[357] The exact amount of the tax levy should be expected to encourage lively debate, especially considering the extent of future carbon-caused damage can only be estimated. International organizations and forums such as the international organization for standardization (ISO) and the UN Climate Change Summit provide potential venues for non-partisan recommendations for the true cost of carbon and associated taxation.

2. Increase Energy Education, Research and Development

Situation. "Education is the most powerful weapon which you can use to change the world." – Nelson Mandela.[358] However, a world with its ecosystem in such peril that the existence of human life itself is threatened makes all other studies besides the energy-water-food nexus seem trivial. The trends in global climate change demand more education and resources for R&D in the study of the flow of energy in the one and only ecosystem this world has to offer.

Policy Recommendations. Akin to viewing Earth's ecosystem as "the commons" in Hardin's essay, all individual actions result in some consequence to the ecosystem regardless of geographic or political boundaries. In turn, all inhabitants (individuals, states, countries, etc.) should be educated in understanding how the commons exist, work towards decreasing their negative impacts on the commons, and seek to lift their neighbors to a higher quality of life. Within the sphere of US control, the government should mandate an energy-water-food-waste nexus curriculum in the Every Student Succeeds Act (ESSA), increase budgetary appropriations to the elements of the NIS involved in energy R&D, and reward industry for any contribution to disruptive technology advancing the state of the art of cleaner energy.

Execution. The ESSA, successor to the No Child Left Behind Act and reauthorizer of the Elementary and Secondary Education Act, is Federal law for public education in K–12th grade.[359] ESSA directs the states to institute an academic standard of their own choosing. The current standards implemented by most states are the Common Core State Standards, which are divided into English Language & Literacy Arts and Mathematics.[360] While obvious connections to science exist in both, energy is not listed in either, and only appears directly in science-specific standards like the Next Generation Science Standards[361] and the National Science Teaching Association Standards[362]. The critical nature of the subject demands an amendment to the ESSA. Increasing appropriations, while easier said than done, is as simple as prioritizing energy R&D over other discretionary budget items. Incentivizing industry could come in the form of tax breaks and publicity.

Feasibility. Amending ESSA would stir political debate over the appropriate role of the Federal government in education policy, but the states should comprehend that the singular ecosystem demands a common standard and curriculum. Further friction will be found amongst educators and policymakers in how to implement the energy curriculum in an already-booked school year, but once again, the situation demands it happen. Resourcing the amendment should be negligible. Any change to appropriations will obviously turn straight to politics, but this is what legislators do, and the subject demands cooperation amongst all parties with the extreme alternative resulting in the destruction of the global environment and human inhabitation of the earth. Tax breaks for innovative companies will also be a political discussion, but common sense

should dictate that small decrements in tax revenue now are a negligible price to pay for fostering a more sustainable environment for future economic development and national security. The US is a world superpower, and others listen when its elected representatives speak, so celebrating technological successes in cleaning the commons should be free.

3. Ensure a Just Energy Transition

Situation. The social aspects of mitigating climate change focus on how the transition to renewable energy affects carbon-intensive industries and the people relying upon these industries for energy security, energy equity, and environmental sustainability. As described above, fossil fuels provide over eighty percent of the world's energy and are the largest contributor to global warming. Thus, transitioning necessitates the downscaling or eventual replacement of fossil fuel industries and the promotion of renewable and low-carbon energy sources. The energy transition risks creating significant ethical and social problems as it advantages some industries and populations over others. Developing nations and the vulnerable portions of US society are especially at risk as the transition will impact them the most.

Policy Recommendations. US policymakers should take the following initiatives to promote a just energy transition to mitigate the adverse impact of energy transitions on vulnerable populations. First, the US should promote the development and adoption of CCUS technologies. CCUS technologies are processes that capture carbon emissions and either reuse or store them, preventing release into the atmosphere. This technology can significantly assist nations in reaching net-zero emission goals by removing carbon produced by burning fossil fuels at point sources such as power plants or industrial faculties or directly from the atmosphere. Large-scale CCUS implementation is essential to offsetting emissions from sectors in which reaching zero emissions is not economically feasible. Like renewable energy industries, CCUS implementation would facilitate a just transition by creating new jobs for displaced fossil fuel workers. Importantly, CCUS would also avoid job losses in fossil fuel industries by reducing these industries' carbon emissions, allowing them to remain a viable source of low-carbon energy during the transition.[363]

Second, the US must reduce its dependence on critical minerals used for advanced batteries and renewable infrastructure. The transition to renewable energy sources will require vastly more rare earth and other minerals to provide clean electricity and storage capacity. These minerals are often extracted in developing countries where corrupt governance and human rights violations such as child labor are prevalent. The continued demand for these critical minerals in developing nations will exacerbate these problems. A just transition requires the US to reduce incentives for developing nations to compromise human rights to satisfy global mineral demand. Specific initiatives should include creating technologies less reliant on rare earth minerals, creating a national battery recycling program, and funding "green" mining operations.

Third, the US must assist developing nations in decarbonizing their energy industries. Developing nations will not limit economic development to meet climate goals. Thus, climate impacts will intensify as these developing nations consume more energy as their populations grow and quality of life improves. If the international community forces them to reduce fossil fuel consumption without providing alternatives, developing nations risk being unable to prosper and becoming unstable. Current US policy facilitates just transitions in developing nations with financing to protect ecosystems and carbon sinks and invest in promoting renewable energy sources.[364] Current policy is an essential beginning to addressing a just transition. There is opportunity to do more still. As one of the largest emitters of GHGs and a primary global

provider of security, finance, and energy, the US must lead the international community. The US should commit to an immediate and significant reduction in coal used as an energy source, encourage additional investment in renewable energy, and finance sustainable land use.

Execution. A just transition policy must commit to a "people first" clean economy. Affected communities will be more receptive to energy transition policy initiatives to shape the development and implement solutions. For example, federal initiatives to securitize or forgive debt on fossil fuel plants are economically beneficial for communities to replace those plants with cheaper renewable energy generation or small modular nuclear reactors. Moreover, securitization or debt forgiveness can be conditioned on worker retraining, earlier retirement, relocation, and total funding of healthcare and pensions – further placing people at the forefront.

Feasibility. The cost of climate change's harmful effects is extraordinary (approximately two percent of GDP by some estimates), but the cost of failing to act will be greater. US investment in green innovation and infrastructure risk mischaracterization as wasteful spending and government overreach. Thus, it is critical US policy be cost-effective and that the benefits are visible to communities and directly improve constituents' lives. Though political parties demonstrate divergent climate positions, many climate and energy issues receive broad support among constituents across political ideologies, which increases the potential for political consensus.[365] A federal approach is difficult and costly. However, subsidizing R&D, providing tax incentives for technology adoption, and opening global markets as previously described will incentivize the private sector to increase innovation in critical technologies like CCUS. Some states are moving faster than the federal government with regulations and incentives. Federal policy can be modeled after state rules to garner political support from politicians favoring state-based solutions. Internationally, the COP26 summit in Glasgow in November 2021 will bring nations together to address progress towards the Paris Agreement's goals. It provides both the forum for international debate and discussion and an international platform for the US to launch policy initiatives and sway opinion.

4. Re-establish US Leadership on Climate Change

Situation. The Biden administration's pronouncements in support of the Paris Agreement climate goals and aggressive decarbonization of the US economy will buoy its climate diplomacy efforts. However, the US history of vacillation on climate policy gives pause to international partners who wonder if it will honor its commitments.[366] Adopting the following policy recommendations will improve US credibility and enhance the effectiveness of its climate diplomacy.

Policy Recommendations. The US should leverage its diplomatic and market power to encourage and enforce national commitments to decarbonization. This begins with reorienting its substantial diplomatic and development apparatus to prioritize climate diplomacy. Clean energy expertise must become commonplace at the State Department and not limited to its Bureau of Energy Resources (ENR). This will entail obtaining new funding for hiring and training personnel.

Climate change is one of the promising areas for US-China cooperation. As the world's largest emitter of greenhouse gases, ensuring China follows through or ideally exceeds President Xi Jinping's commitment to decarbonize by 2060 is essential to limiting global warming to near 1.5°C. The US should look to deepen cooperation in this area despite considerable frictions elsewhere. The US must also hold other countries accountable for meeting their Paris Agreement NDCs and for supporting clean energy investment in developing countries. This means difficult

conversations with not only China but also partners such as Korea and Japan about curtailing development financing for coal-fired power plants. While engagement should emphasize carrots, sticks such as limited trade sanctions should be on the table.

The US also must lead the diplomatic effort to finance the energy transition in developing countries. This includes increasing its commitment to the Green Climate Fund and ensuring other wealthy countries also meet their Paris Agreement obligations to raise $100 billion annually for climate finance. The US should also use its leadership positions in the World Bank and International Monetary Fund to encourage those institutions to finance ambitious clean energy transition programs in developing countries.[367]

In assisting developing countries, a major priority should be to counter Chinese investment in fossil fuel, particularly coal-fired energy programs under its BRI. Despite its recent pledge to "green" the BRI, non-hydroelectric renewables make up only 11 percent of Chinese overseas power generation capacity compared with 40 percent for coal.[368] With operating lifetimes of up to forty years, every new coal-fired undermines the Paris Agreement's emissions reduction goals. The US and its partners must offer developing countries viable alternatives to fossil fuels, which are perceived as cheaper and more reliable. The Japan-US-Mekong Power Partnership and USAID's Power Africa program may be models for this kind of engagement.

US Secretary of State Antony Blinken said recently, "It's difficult to imagine the US winning the long-term strategic competition with China if we cannot lead the renewable energy revolution."[369] To meet this challenge, the US should commit itself to lead the world in developing clean energy technologies such as grid-scale batteries and CCUS. Such innovation will also lay the foundations of national power through the end of the century. To that end, the US should increase its investments in basic science research focusing on clean energy technology. At 0.6 percent of GDP, federal government R&D investment is at its lowest point since 1955.[370] Congress should significantly increase funding for basic scientific research to exceed 1.5 percent of GDP by 2025. The Biden administration should direct this essential research at the National Labs and the Department of Energy. To encourage more significant private sector investment, Congress should also offer more generous tax treatment for research into clean energy technologies, including human capital investment and training.

Execution. While the climate crisis is a multigenerational challenge, immediate multilateral action is needed to hold global warming at near 1.5°C to avoid the worst impacts of climate change. Despite its ambivalent record on climate policy, US climate diplomacy is well-positioned to influence positive global climate action. Doing so will require subordinating some short-term national interests and supporting developing countries to affect a global energy transition as quickly as possible. US credibility and the success of its climate diplomacy rely on substantial near-term progress in implementing aggressive domestic decarbonization policies.

Feasibility. The additional outlays called for here to increase US capacity for climate diplomacy and support renewable energy R&D are relatively small fractions of the Federal budget and could be implemented without major tradeoffs. The most significant obstacle to the success of US climate leadership is the lack of national commitment to achieving the administration's aggressive domestic decarbonization goals. With Congress polarized on the question of climate change and public opinion toward global warming essentially frozen since 2016, it is possible the US will fail to marshal the resources for its own clean energy transition, let alone assist other countries.[371] Without legislation to provide dramatically increased funding for clean energy infrastructure and stricter regulation of emissions, the administration's domestic climate change agenda will fail alongside its climate diplomacy ambitions.

Note: Appendix C contains a collection of policy recommendations from individual research by seminar members through the term. These are not directly tied to the four recommendations discussed above but may be of interest to readers of this report.

VIII. Conclusion.

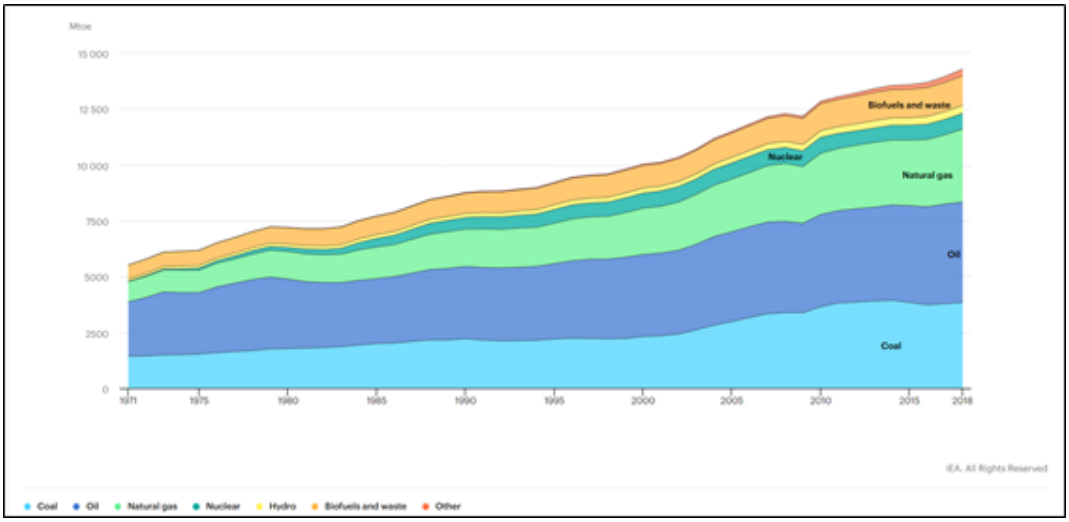
This is a significant time for energy as countries around the world focus on their climate-impacted energy futures. A renewed focus on the environment and the implications of climate change are collectively driving fresh dialogue, negotiations, partnerships, agreements, and policy actions. The conjunction of major events such as the pandemic accelerated international desires to evolve the way energy impacts the environment, recognizing the potential for rapid and radical change in a short period. Inevitable climate change complicates the complex energy environment for the foreseeable future. Climate challenges and uncertainties create urgency.

Countries must prepare for a new global energy environment, and the US must lead. The preceding analysis described the current strategic environment and provided an overview of the global energy industry. It also detailed the status of key sources of energy while highlighting specific challenges of the electric grid, critical minerals, cybersecurity, and the energy transition. The discussion on the national competitiveness of various countries, including the US and Great Power Competitors, provided analysis as a basis for US policy recommendations.

US government intervention and clear policy initiatives are required to guide private industry and markets nationally and internationally. The US requires strong and protected networks to uphold reliable energy for the American public. Globally, US allies and partners face an assorted arrangement of energy security challenges that clearly influence US energy policy. How the US approaches the energy transition process will have long-lasting implications around the world. The US cannot lead this change alone; it must prioritize energy and climate issues near the top of an evolving, collective agenda with allies and partners. Establishing a comprehensive and implementable energy strategy that includes leveraging networks, relationships, and agreements to accomplish meaningful progress is imperative for future generations.

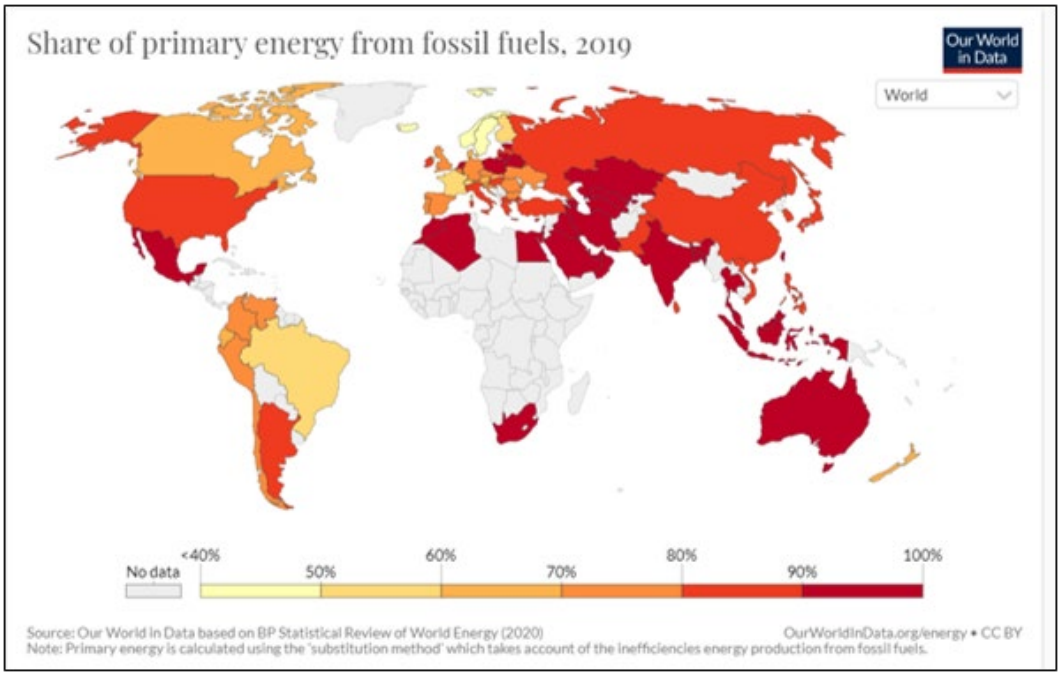
APPENDIX A: SUPPORTING FIGURES

Figure 1: Total Energy Supply by Source, World 1990-2018



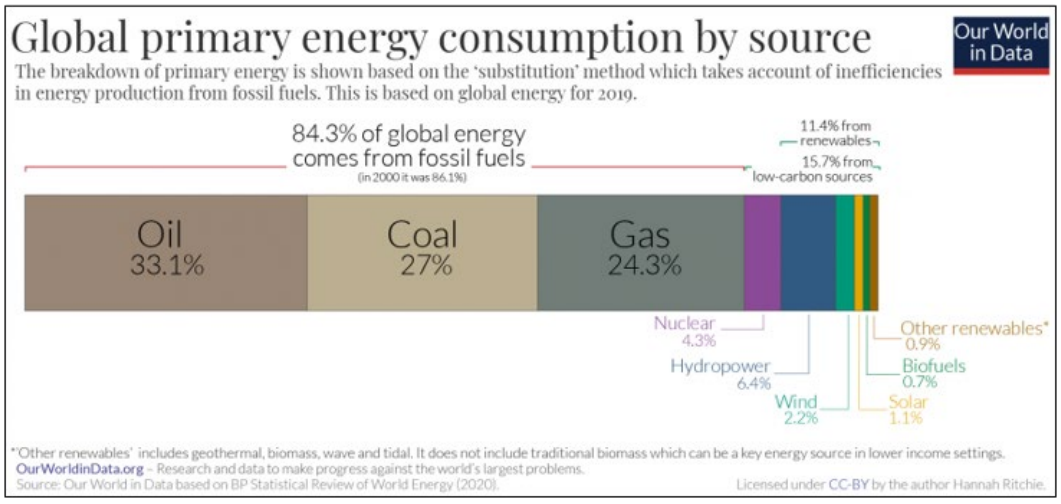
Source: International Energy Agency website, *World Total Energy Supply by Source 1990-2018*, Sep 4, 2020, https://www.iea.org/data-and-statistics/charts/world-total-energy-supply-by-source-1971-2018.

Figure 2: Share of Primary Energy From Fossil Fuels, 2019



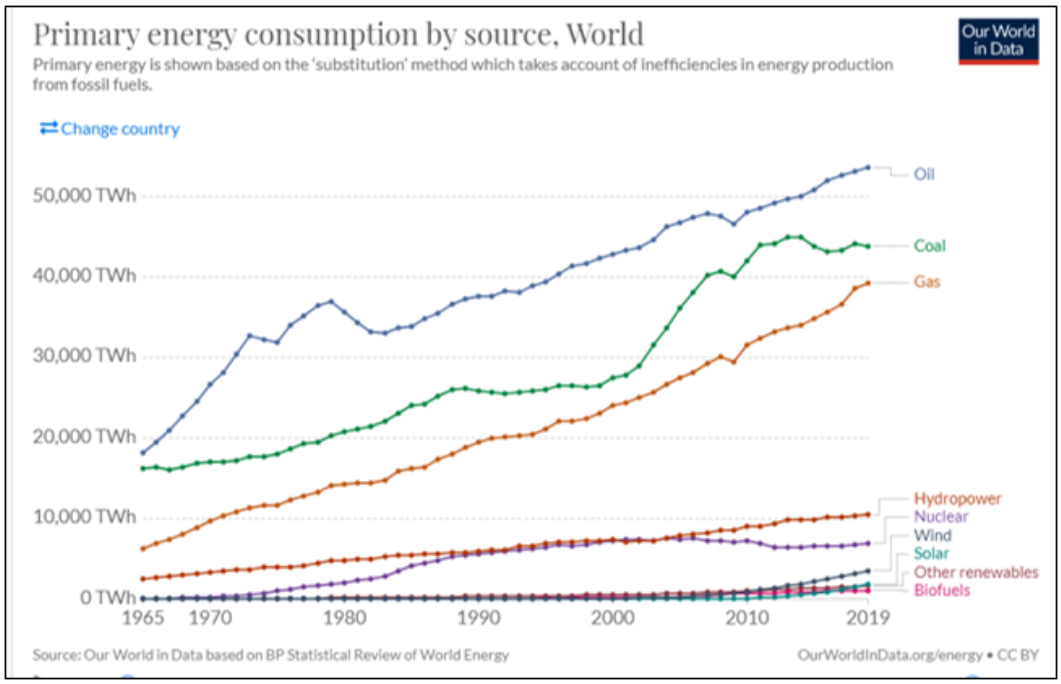
Source: Hannah Ritchie and Max Roser, Our World in Data website, *Fossil Fuels*, https://ourworldindata.org/fossil-fuels.

Figure 3: Global Primary Energy Consumption By Source



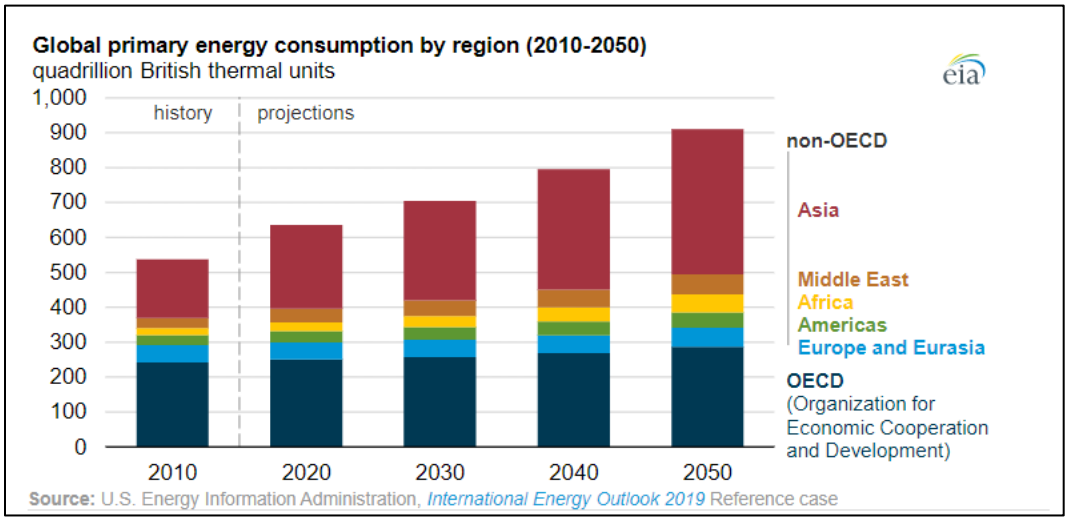
Source: Hannah Ritchie, Our World in Data website, *Overview of Global Energy*, https://ourworldindata.org/energy-overview.

Figure 4: Global Primary Energy Consumption By Source



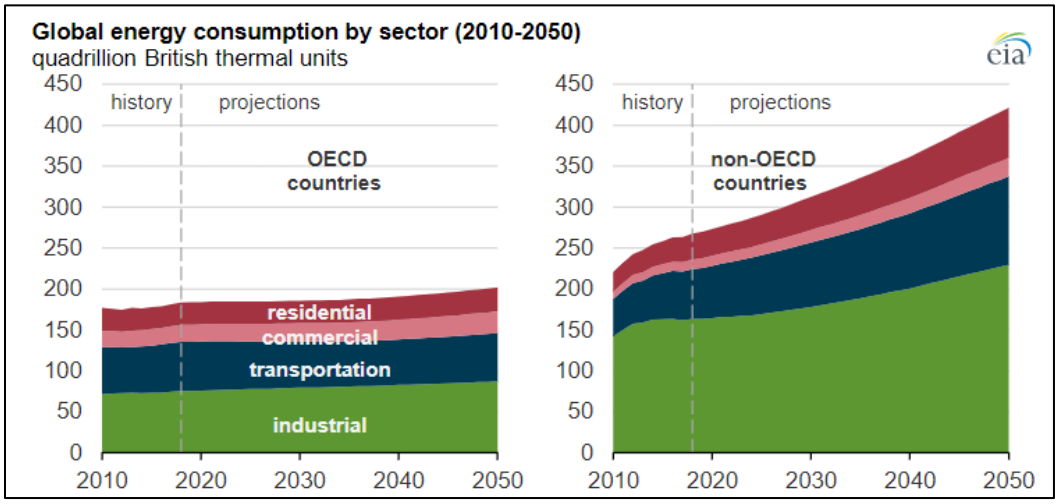
Source: Our World in Data website, *Global energy consumption by source*, https://ourworldindata.org/grapher/primary-sub-energy-source?country=~OWID_WRL.

Figure 5: Global Primary Energy Consumption By Region, 2010-2050



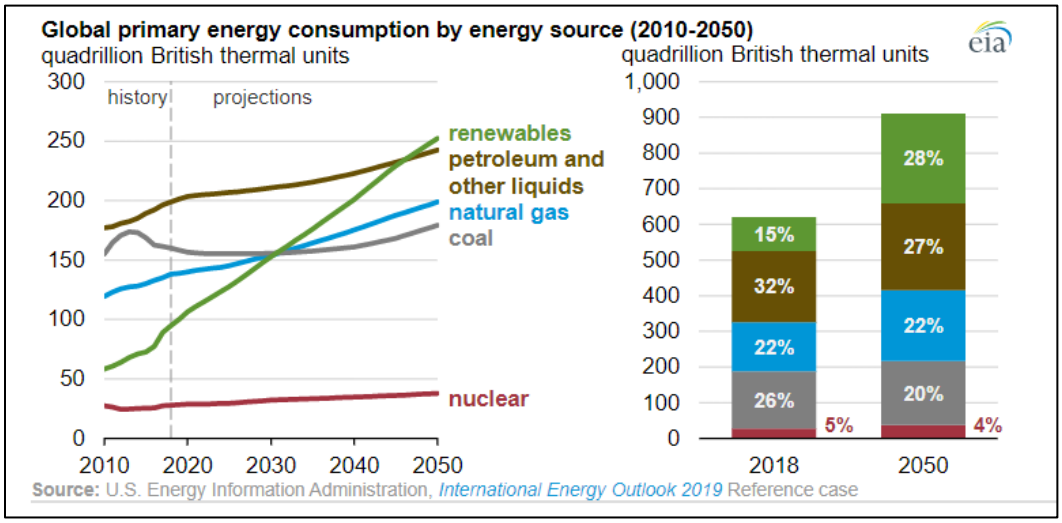
Source: Ari Kahan, U.S. Energy Information Agency website, *EIA projects nearly 50% increase in world energy usage by 2050, led by growth in Asia*, January 3, 2020, https://www.eia.gov/todayinenergy/detail.php?id=42342.

Figure 6: Global Energy Consumption By Sector, 2010-2050



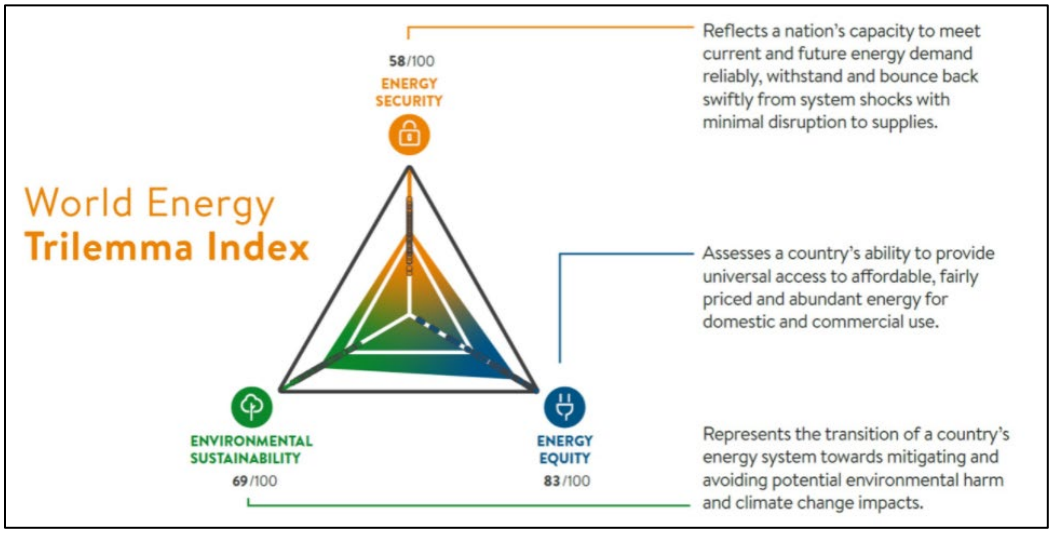
Source: Ari Kahan, U.S. Energy Information Agency website, *EIA projects nearly 50% increase in world energy usage by 2050, led by growth in Asia*, January 3, 2020, https://www.eia.gov/todayinenergy/detail.php?id=42342.

Figure 7: Global Primary Energy Consumption By Energy Source



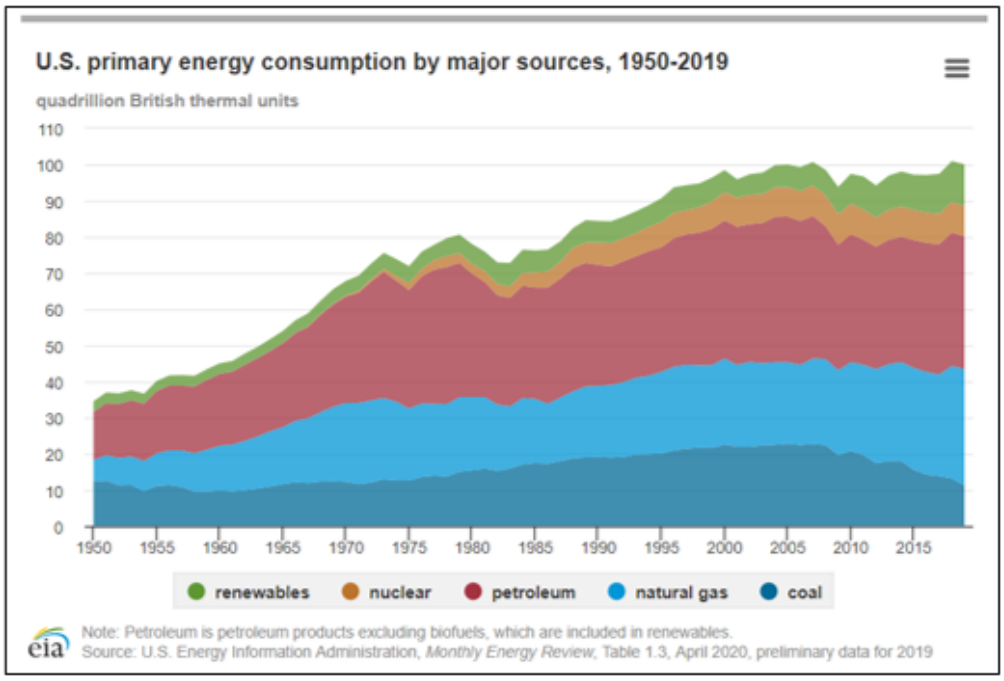
Source: Ari Kahan, U.S. Energy Information Agency website, *EIA projects nearly 50% increase in world energy usage by 2050, led by growth in Asia*, January 3, 2020, https://www.eia.gov/todayinenergy/detail.php?id=42342.

Figure 8: World Energy Trilemma



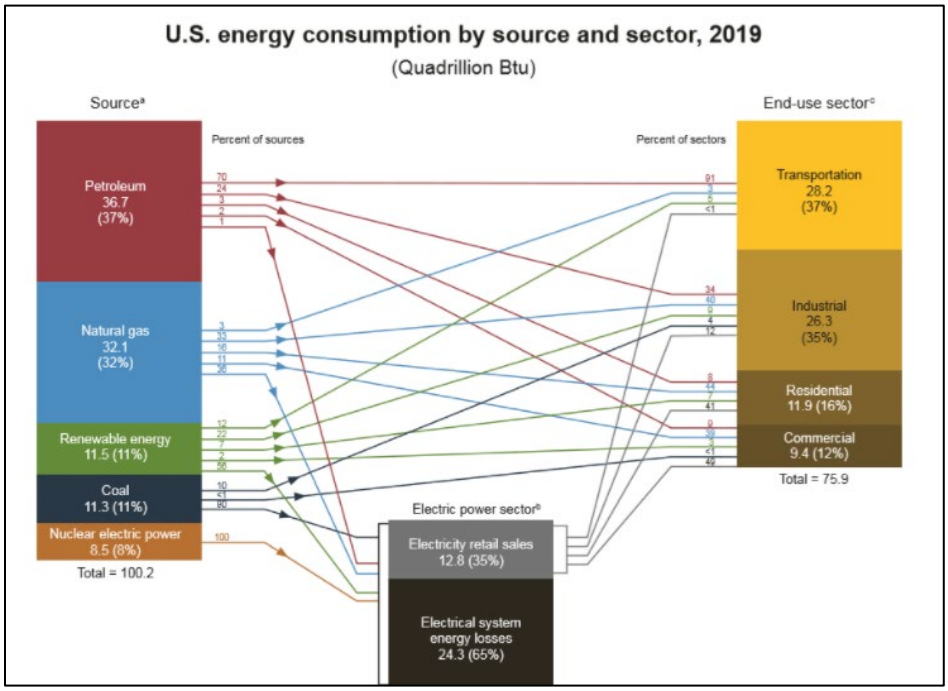
Source: World Energy Council website, *World Energy Trilemma Index*, https://www.worldenergy.org/transition-toolkit/world-energy-trilemma-index.

Figure 9: U.S. Primary Energy Consumption By Major Sources, 1950-2019



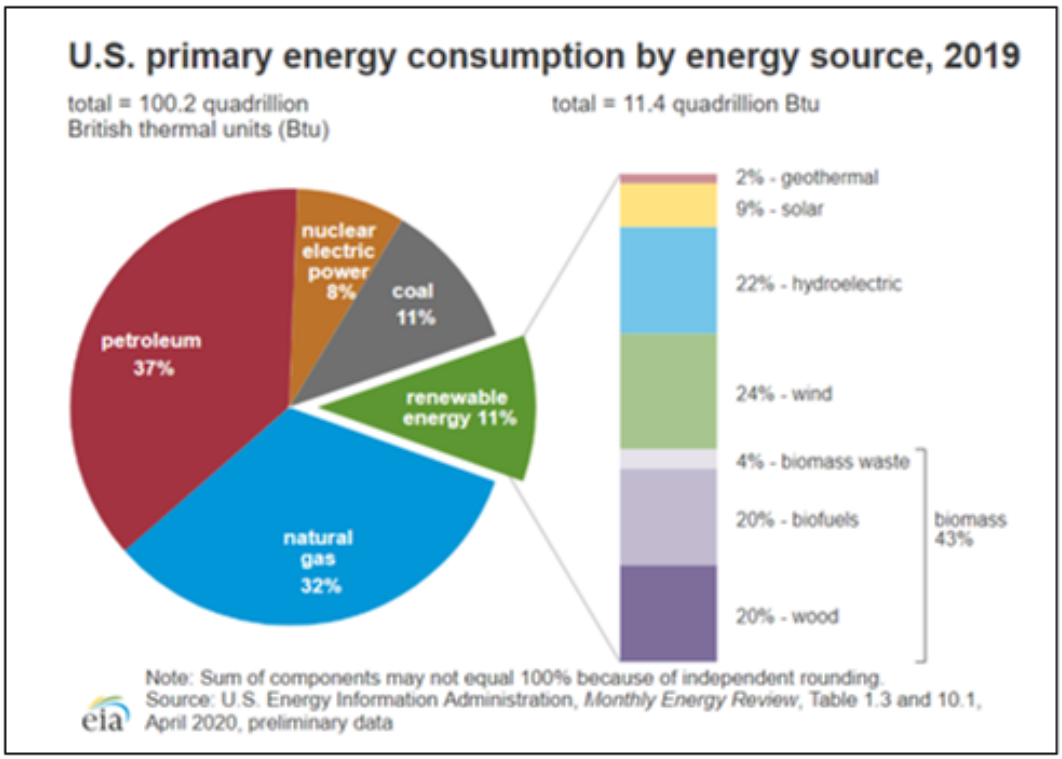
Source: U.S. Energy Information Agency website, U.S. energy facts explained, https://www.eia.gov/energyexplained/us-energy-facts/.

Figure 10: U.S. Primary Energy Consumption By Source & Sector, 2019



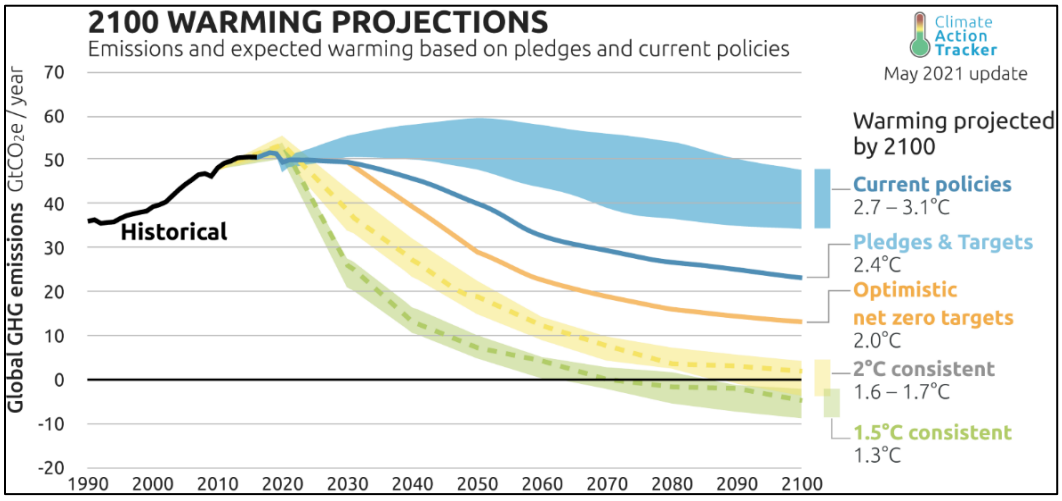
Source: U.S. Energy Information Agency website, U.S. energy facts explained, https://www.eia.gov/energyexplained/us-energy-facts/.

Figure 11: U.S Primary Energy Consumption By Energy Source, 2019



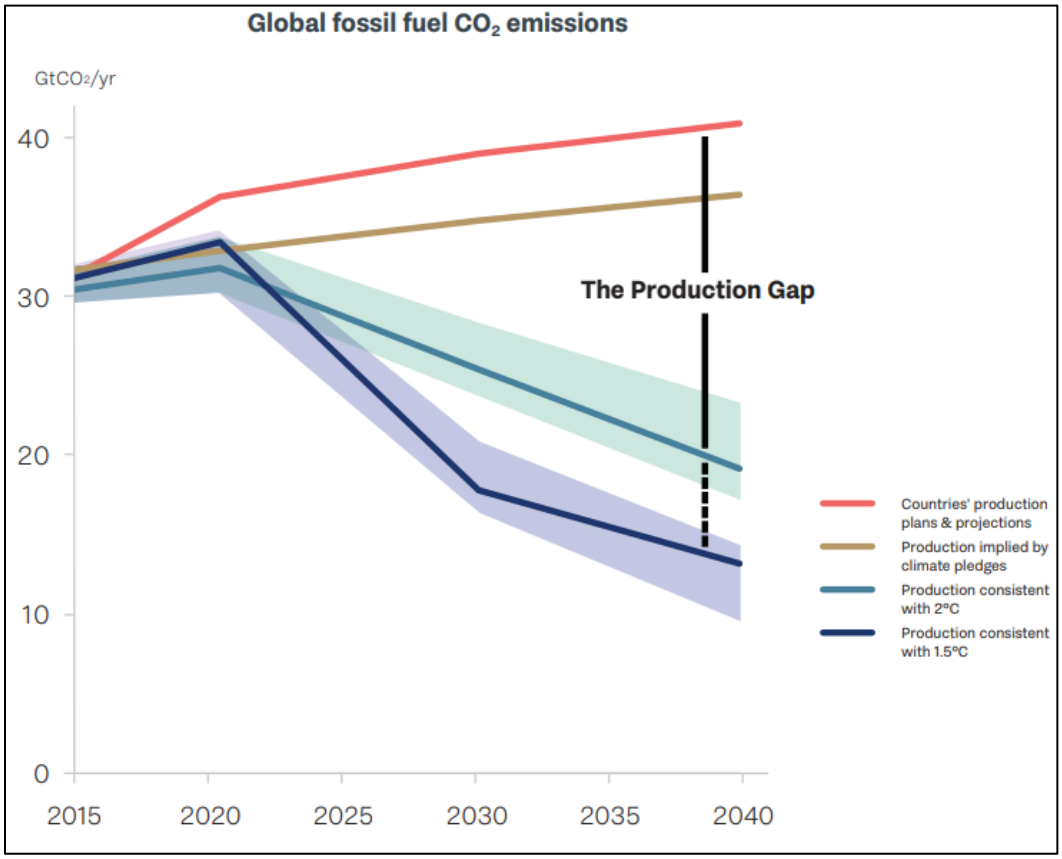
Source: U.S. Energy Information Agency website, U.S. energy facts explained, https://www.eia.gov/energyexplained/us-energy-facts/.

Figure 12: Global Warming Projections, 2100



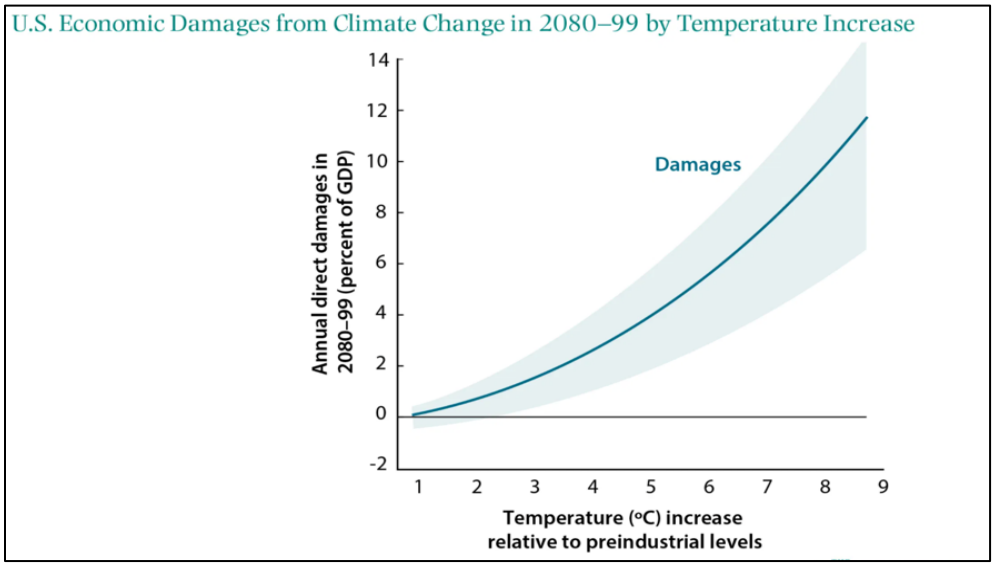
Source: Climate Action Tracker website, https://climateactiontracker.org/global/temperatures/.

Figure 13: Global Fossil Fuel Carbon Dioxide Emissions Gap



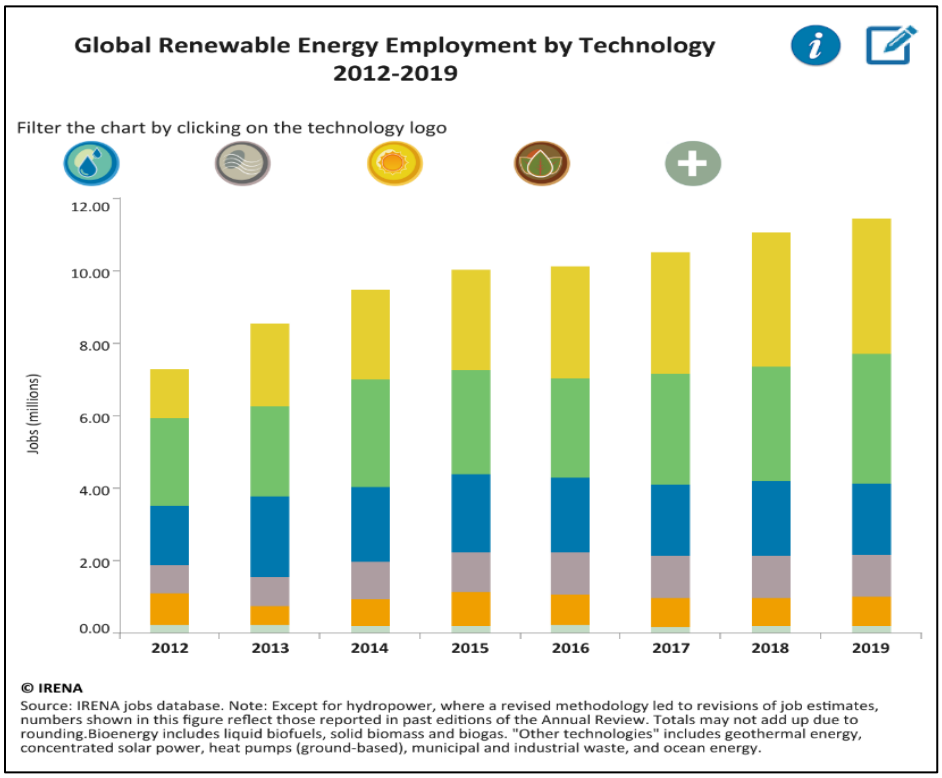
Source: SEI, IISD, ODI, E3G, and UNEP, (2020), The Production Gap Report: 2020 Special Report. http://productiongap.org/2020report. Page 14.

Figure 14: U.S. Economic Damages From Climate Change



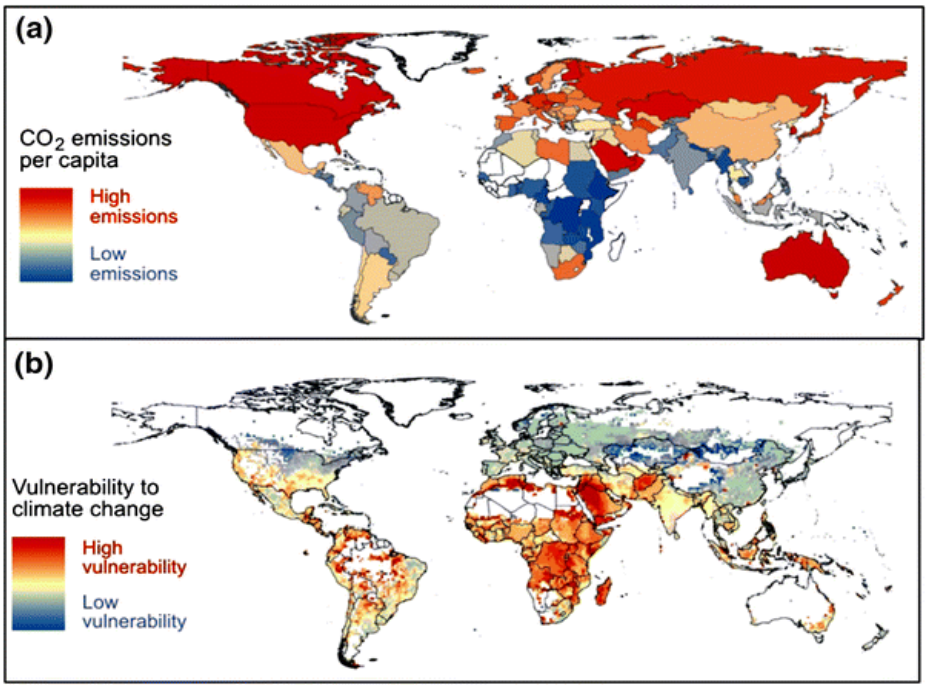
Source: The Hamilton Project, "Ten Facts About the Economics of Climate Change and Climate Policy," Stanford Institute for Economic Policy Research, pg. 7. https://www.hamiltonproject.org/assets/files/Environmental_Facts_WEB.pdf

Figure 15: Global Renewable Energy Employment By Technology



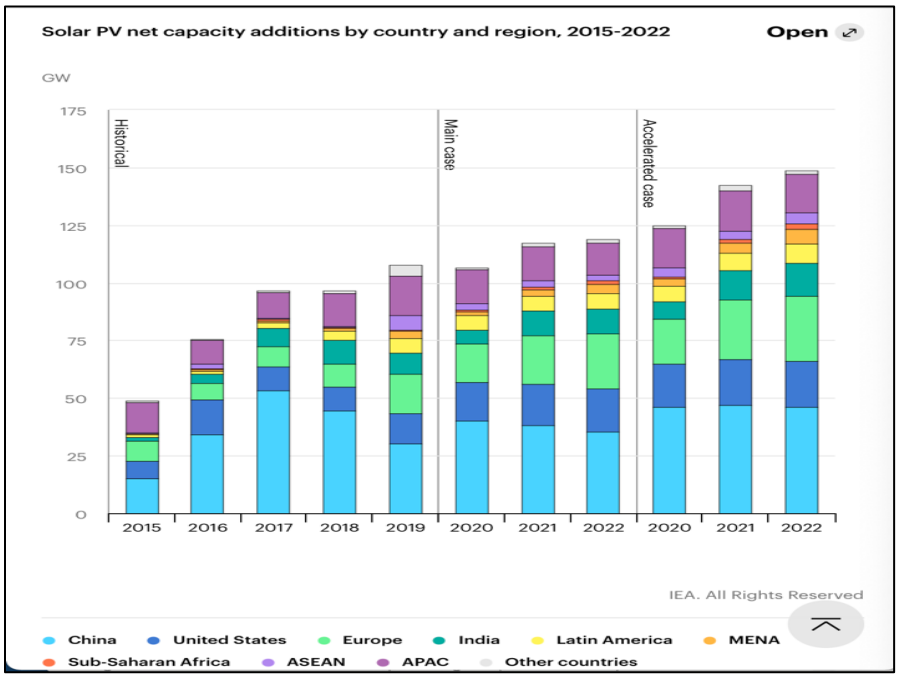
Source: IRENA Jobs Database, https://www.irena.org/statistics.

Figure 16: Emissions and Vulnerability to Climate Change



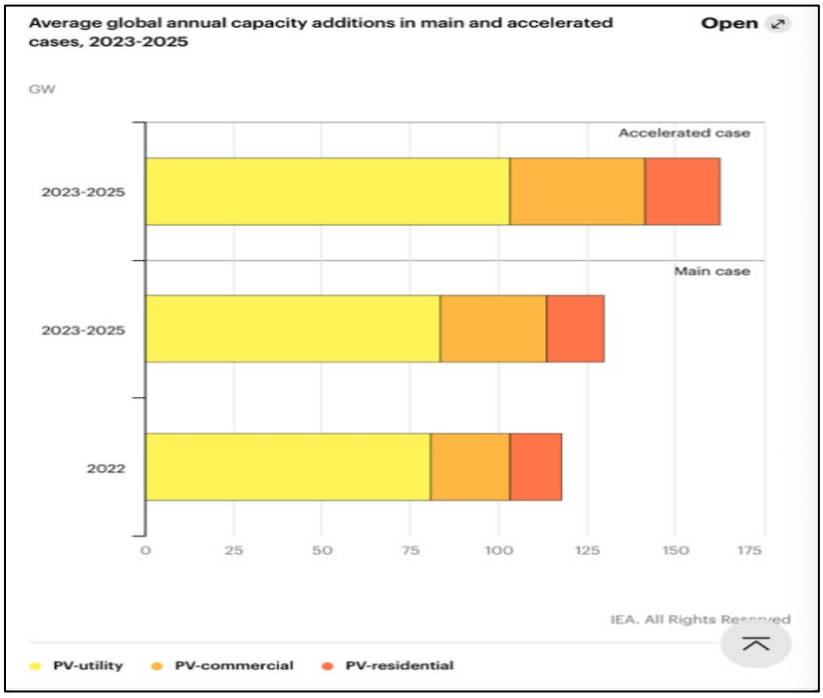
Source: Samson J, Berteaux D and McGill BJ, Humphries MM, "Geographic disparities and moral hazards in the predicted impacts of climate change on human populations," Global Ecology and Biogeography, February 17, 2011.

Figure 17: Solar PV Net Capacity Additions by Country / Region



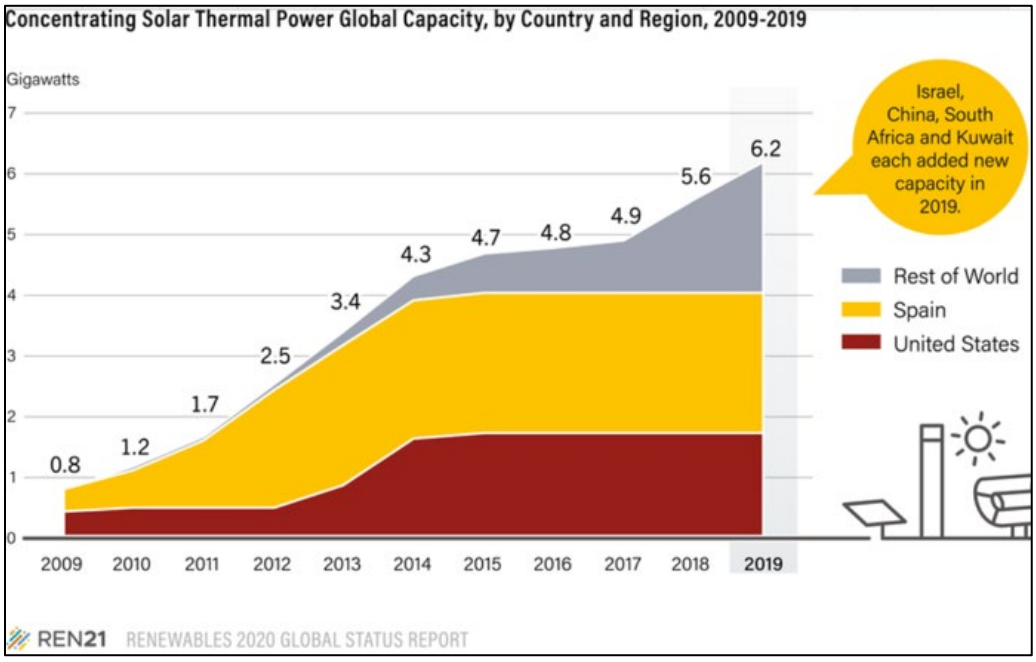
Source: IEA, "Renewables 2020: Analysis and forecast to 2025", Nov 2020, g 137.

Figure 18: Average Global Annual Capacity Additions Outlook



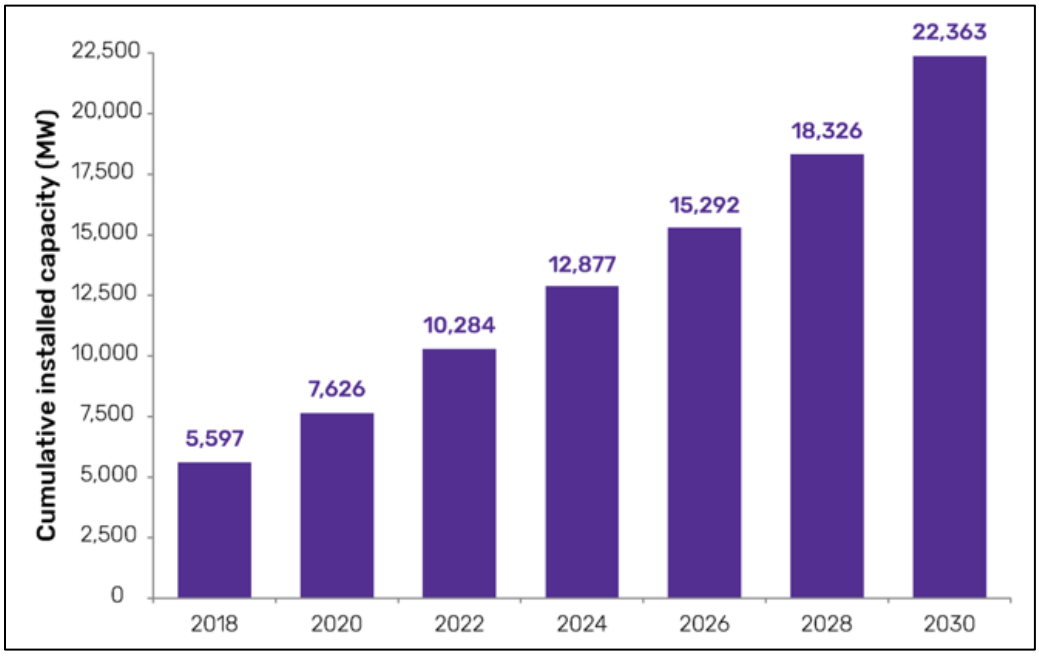
Source: IEA "Renewables 2020: Analysis and forecast to 2025", Nov 2020, Pg 138.

Figure 19: CSP Global Capacity 2009-2018



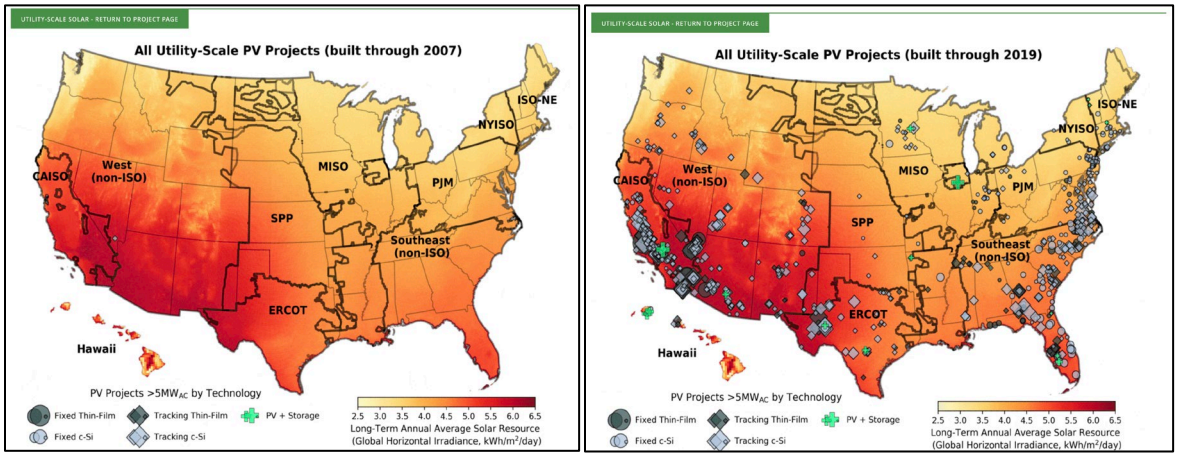
Source: REVE, "Concentrated Solar Power Capacity Grew 11% in 2019 to 6.2GW," Wind Energy and Electric Vehicle Magazine, July 2020. https://www.evwind.es/2020/07/06/concentrated-solar-power-capacity-grew-11-in-2019-to-6-2-gw/75588

Figure 20: Anticipated Global Concentrated Solar Power Capacity



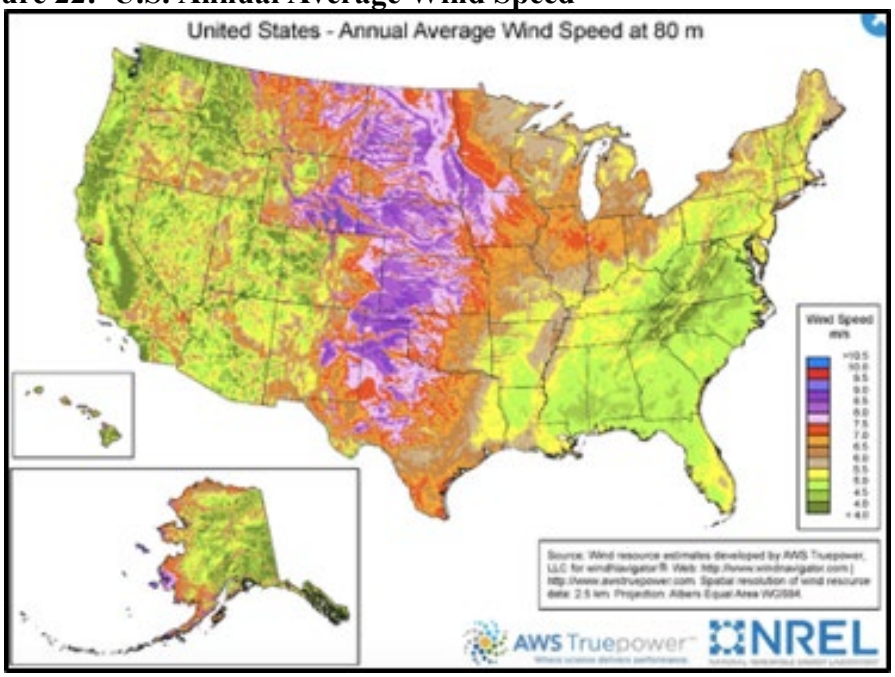
Source: REVE, "Concentrated Solar Power Capacity Grew 11% in 2019 to 6.2GW," Wind Energy and Electric Vehicle Magazine, July 2020. https://helioscsp.com/concentrated-solar-power-capacity-grew-11-in-2019-to-6-2-gw/

Figure 21: Comparison of All Utility Scale PV Projects in the U.S. (2007-2019)



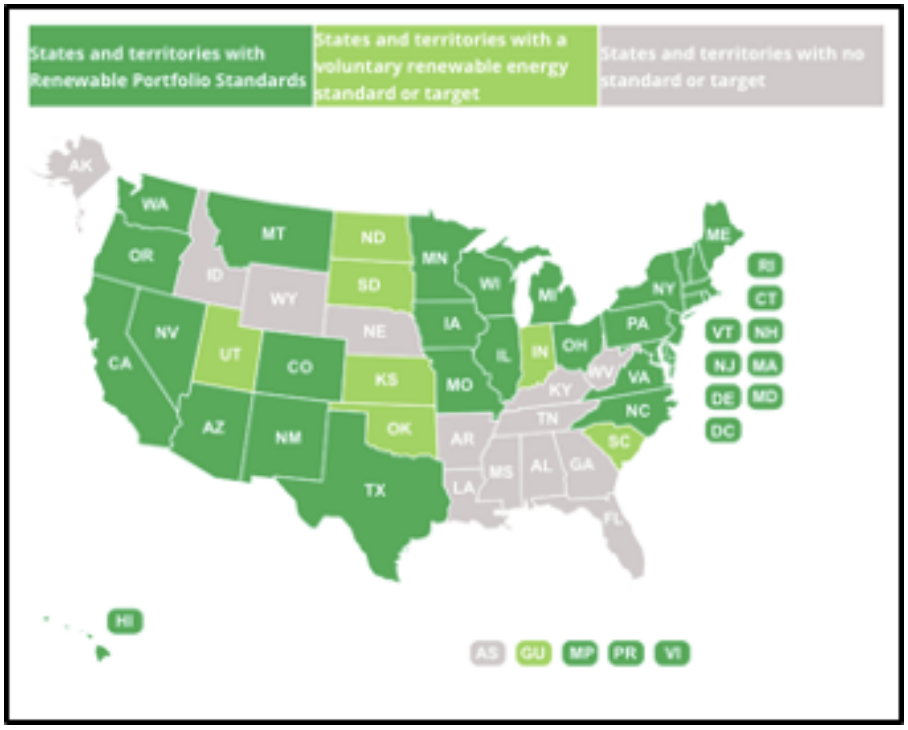
Source: Bolinger, Mark; Seel, Joachiml; and Robson, Dana. "Utility-Scale Solar," Lawrence-Berkley Laboratory, Pg 12. https://emp.lbl.gov/sites/default/files/lbnl_utility_scale_solar_2019_edition_final.pdf

Figure 22: U.S. Annual Average Wind Speed



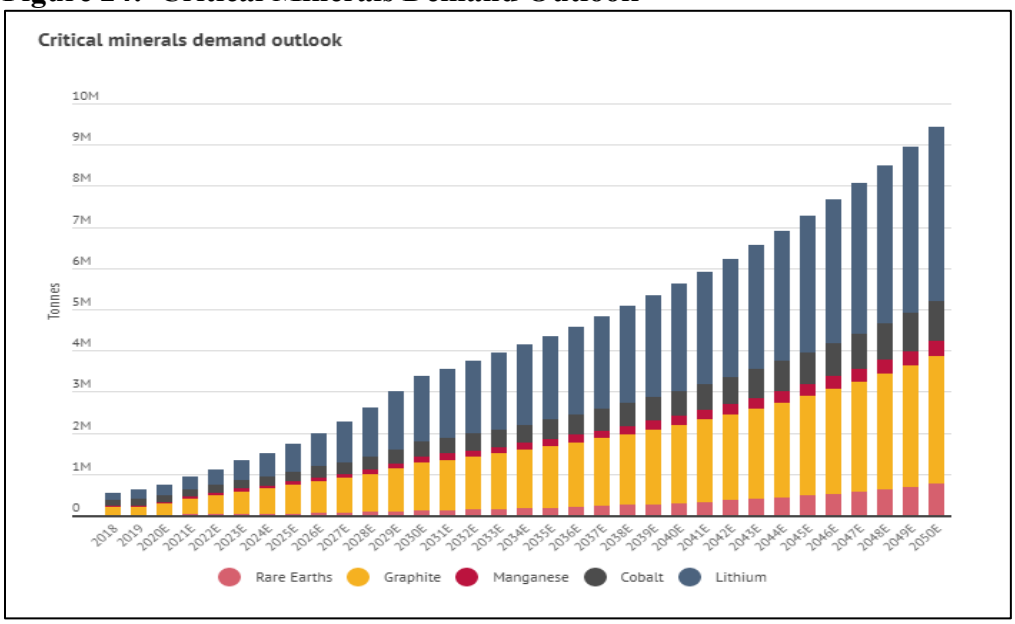
Source: U.S. Energy Information Administration website, "Wind Explained," accessed April 3, 2021, https://www.eia.gov/energyexplained/wind/where-wind-power-is-harnessed.php.

Figure 23: Renewable Portfolio Standards or Voluntary Targets



Source: Laura Shields, "State Renewable Portfolio Standards and Goals," National Conference of State Legislatures website, accessed April 7, 2021, https://www.ncsl.org/research/energy/renewable-portfolio-standards.aspx.

Figure 24: Critical Minerals Demand Outlook



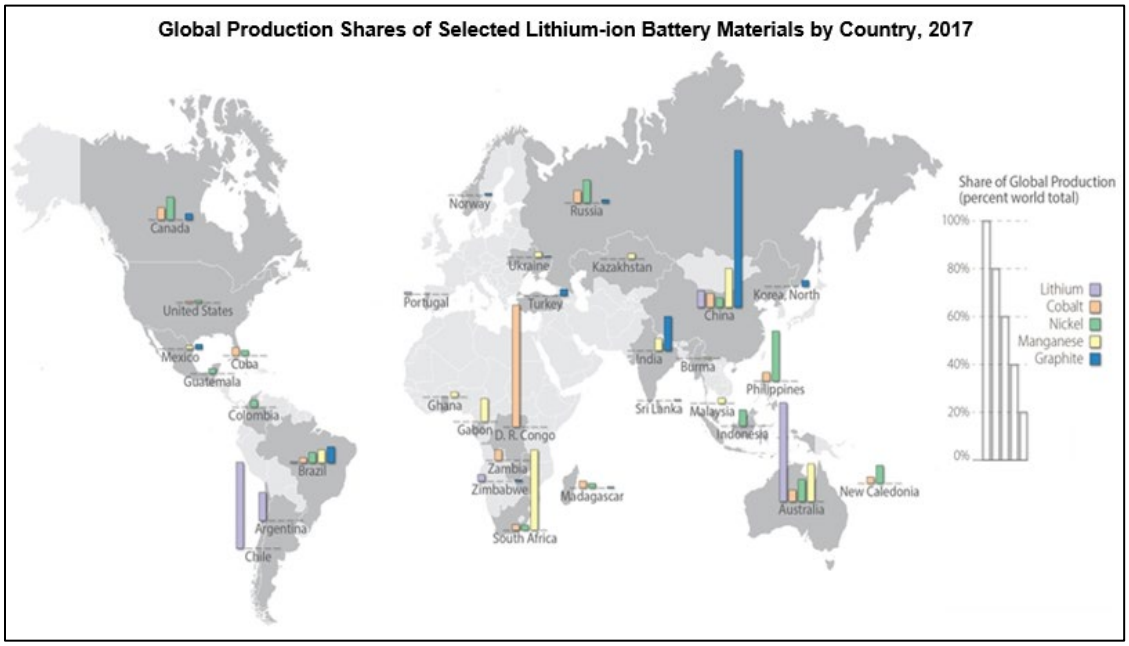
Source: Catherine Birch & Soni Kumari, "The minerals critical for new energy, new technologies, the future," https://bluenotes.anz.com/posts/2020/08/anz-research-critical-minerals-exports-renewable-energy-technolo

Figure 25: Summary of Challenges to Reducing Demand

	Importance to renewable energy	Materials efficiency or substitution	Current recyclability
Aluminium	High – used for wind, PV & batteries	With some loss of performance (steel, plastic)	~70-80% recycled
Cadmium	Low – CdTe small share of PV market	Efficiency increasing, can shift to other PV types	~77% recycled
Cobalt	Medium – Li-ion dominant battery technology	Efficiency increasing, can shift with loss of performance (LFP)	90% recycled
Copper	High – used for wind, PV & batteries	Difficult to substitute in most applications	~34-95% recycled
Dysprosium	High – used for wind & batteries	Can shift to other magnet or motor types, or non-PMG wind	Not currently recycled
Gallium	Low – CIGS small share of PV market	Efficiency increasing, can shift to other PV types	Not currently recycled
Indium	Low – CIGS small share of PV market	Efficiency increasing, can shift to other PV types except flexible	Not currently recycled
Lithium	Medium – Li-ion dominant battery technology	Efficiency increasing, but used for all Li-ion and Li-S	~10% recycled
Manganese	Medium – Li-ion dominant battery technology	Efficiency increasing, can shift to other battery types (LFP, NCA)	Very limited recycling
Neodymium	High – used for wind & batteries	Can shift to other magnet or motor types, or non-PMG wind	Not currently recycled
Nickel	Medium – Li-ion dominant battery technology	Efficiency increasing, can shift with loss of performance (LFP)	90% recycled
Silver	Medium – cSi large share of PV market	Efficiency increasing, copper possible but not commercialised	Not currently recycled
Selenium	Low – CIGS small share of PV market	Efficiency increasing, can shift to other PV types	Not currently recycled
Tellurium	Low – CdTe small share of PV market	Efficiency increasing, can shift to other PV types	~77% recycled

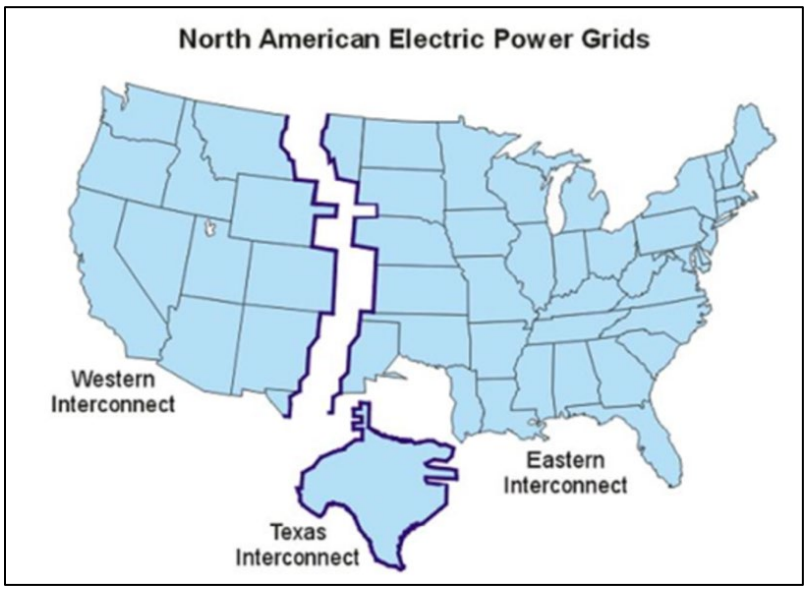
Source: Dominish, E., Florin, N. and Teske, S., "Responsible Minerals Sourcing for Renewable Energy," The Institute for Sustainable Futures, 2019, University of Technology Sydney, Pg 16. https://www.earthworks.org/cms/assets/uploads/2019/04/MCEC_UTS_Report_lowres-1.pdf

Figure 26: Global Production Shares of Selected Lithium-ion Batter Minerals By Country



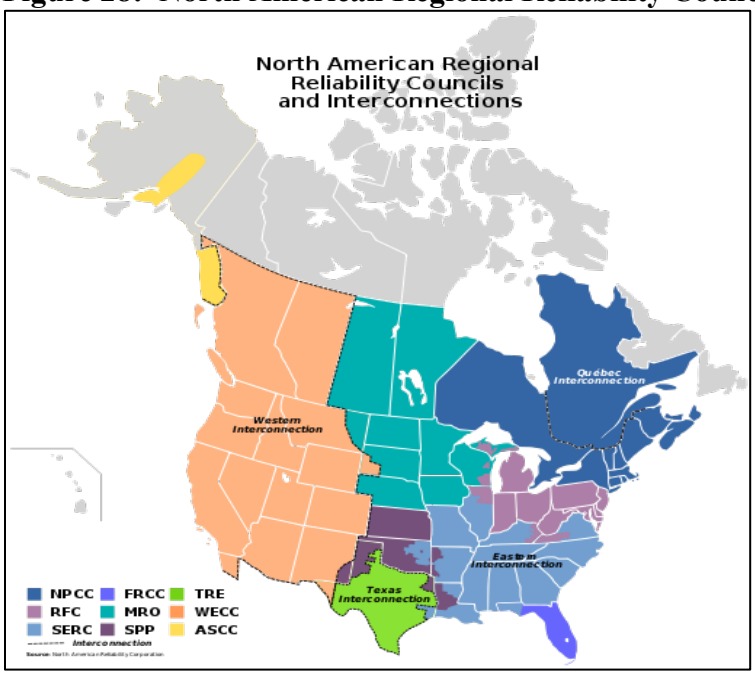
Source: McLellan, B. C., Corder, G. D. and Ali, S. H., 2013. "Sustainability of rare earths—an overview of the state of knowledge," Minerals 3(3): Pgs 304-317, https://www.researchgate.net/publication/277470366_Sustainability_of_Rare_Earths-An_Overview_of_the_State_of_Knowledge

Figure 27: North American Electric Power Grids



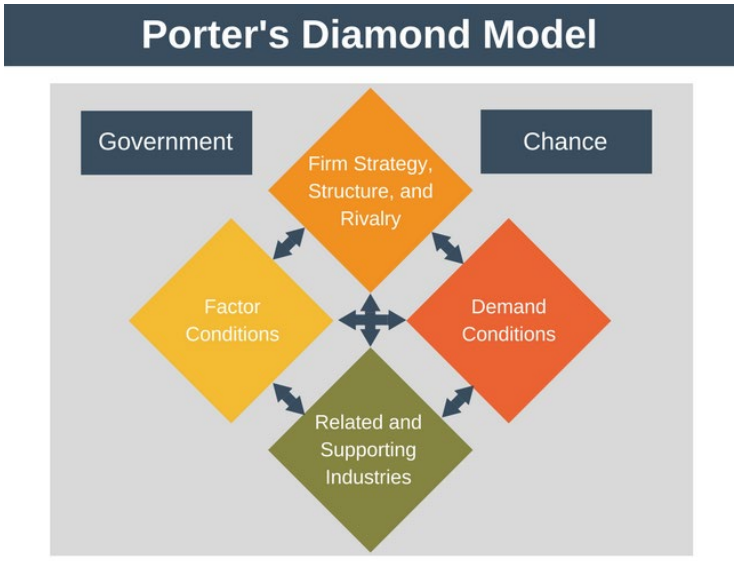
Source: "U.S. Electricity Grid & Markets," United States Environmental Protection Agency website, last modified 26 June 2020, https://www.epa.gov/greenpower/us-electricity-grid-markets

Figure 28: North American Regional Reliability Councils and Interconnections



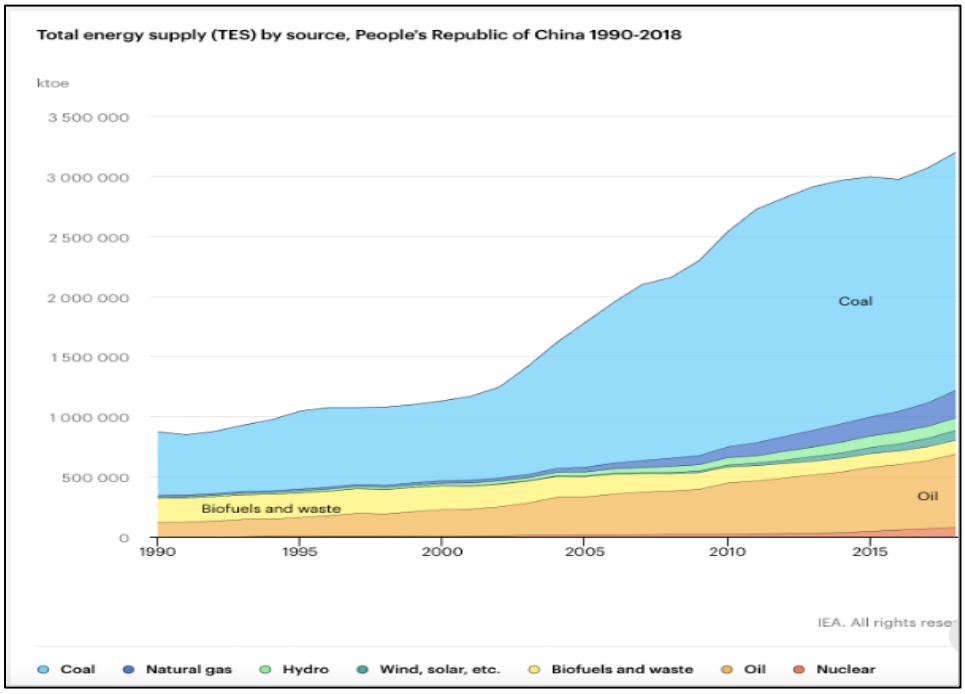
Source: North American Electric Reliability Cooperation website, "ERO Enterprise | Regional Entities," https://www.nerc.com/AboutNERC/keyplayers/Pages/default.aspx

Figure 29: Porter's Diamond Model



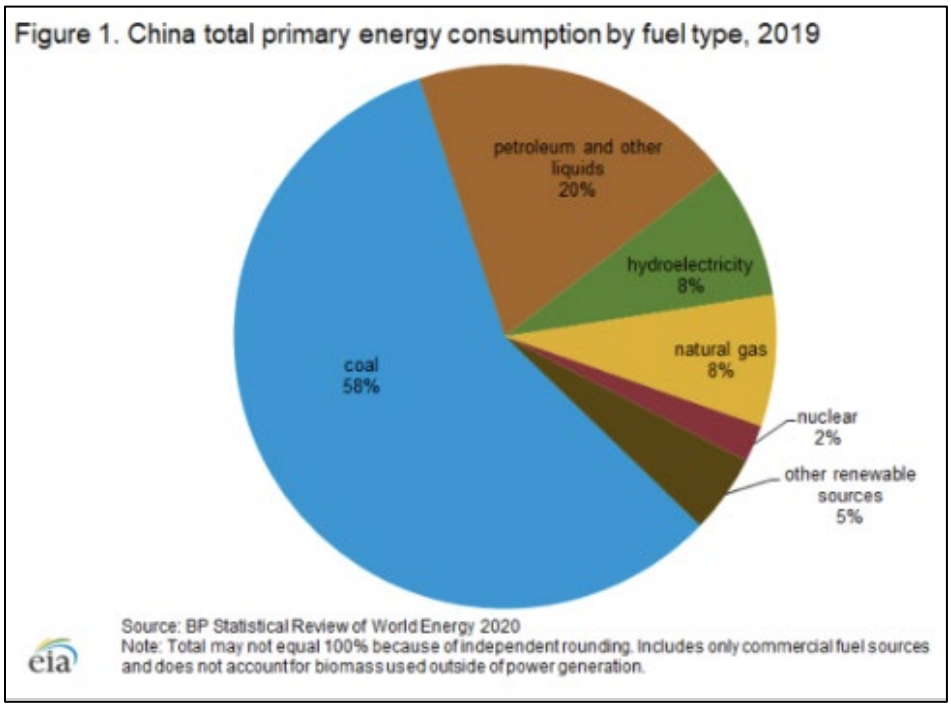
Source: Expert Program Management, https://expertprogrammanagement.com/2018/04/porter-diamond-model/

Figure 30: Total Energy Supply By Source, China 1990-2018



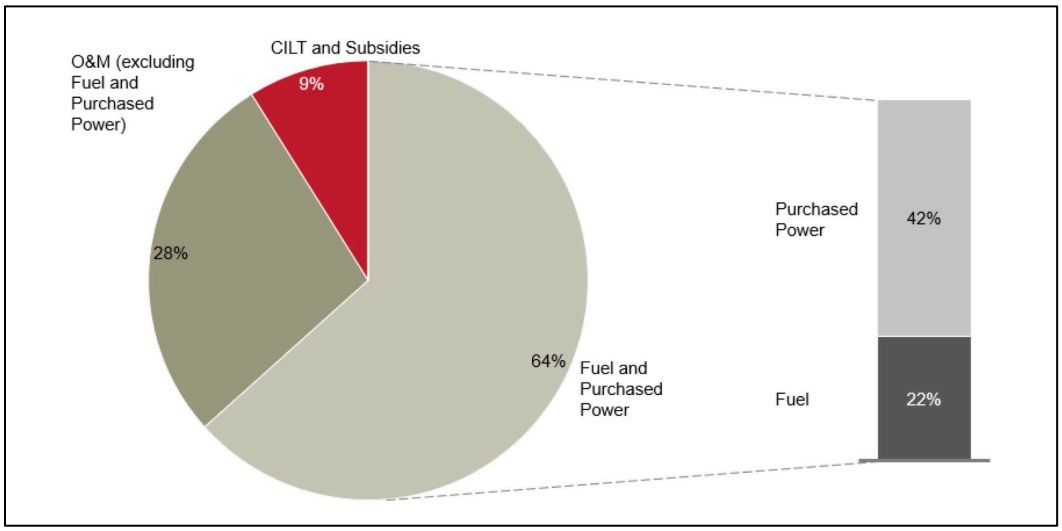
Source: IEA website. "China - Countries & Regions." Accessed May 9, 2021. https://www.iea.org/countries/China.

Figure 31: China Total Primary Energy Consumption By Fuel Type, 2019



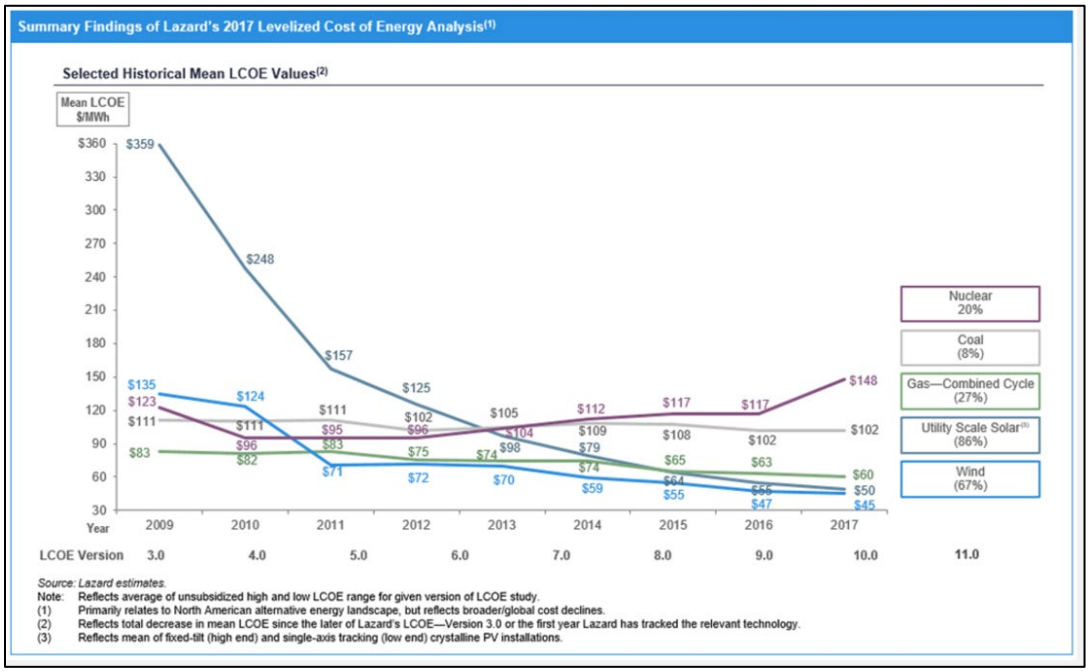
Source: EIA website, "China," accessed May 9, 2021. https://www.eia.gov/international/analysis/country/CHN.

Figure 32: Puerto Rico Electric Power Authority Projected Rate Composition for FY 2021



Source: Autoridad de Energia Electrica, "2020 Fiscal Plan for PREPA," Pg 39. https://aafaf.pr.gov/wp-content/uploads/2020-PREPA-Fiscal-Plan-as-Certified-by-FOMB-on-June-29-2020.pdf,

Figure 33: Levelized Cost of Electricity for Select Renewables



Source: LAZARD website, "Levelized Cost of Energy Analysis – 11.0," Nov 2017, https://www.lazard.com/perspective/levelized-cost-of-energy-2017/

ENERGY8

Porter's Diamond & National Innovation/Industrial System– U.S.

Factor Conditions/ Macro/Regs/Education

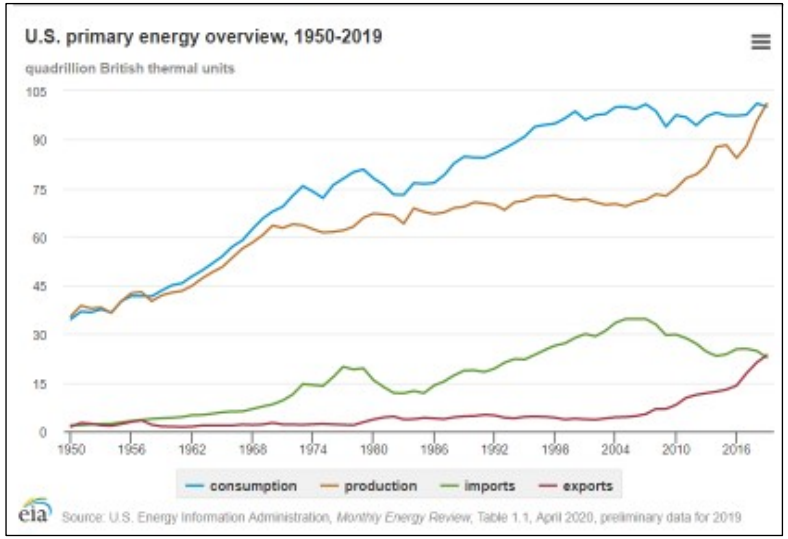
- Technological innovation
- Skilled labor
- Financial capital
- Government regulation
- Open, free markets

Strategy, Structure, Rivalry

- International and domestic competition
- Free & regulated markets support/hinder efficient energy trade
- National trade alliances (e.g. OPEC) influence prices paid by consumers prices & producer costs
- Market access determined by national agreements, trading blocks, conflict

Demand Conditions

- Largest economy; requires & supplies energy, products, & services globally
- Home use, industry, government
- Health of global economy & associated demand for goods, services, and transport



Related and Supporting Industries

- Domestic & international production, distribution, & trade of raw & refined resources
- Electricity generation equipment & tech
- Indirectly related to all US and global industries
- Gov't/military oil and gas reliance

Chance

- Natural resources (nc fracking) & technology

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ENERGY8 Porter's Diamond & National Innovation/Industrial System– China

Factor Conditions/ Macro/Regs/Education

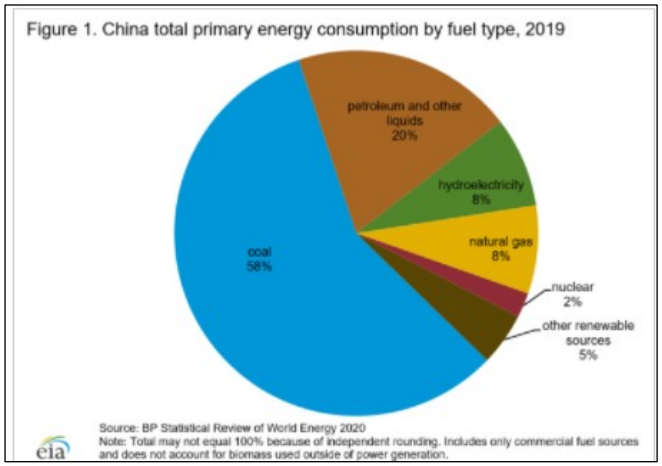
- Energy security remains major concern
- Quick mobilization of all necessary resources to meet goals
- Increasing financial support for wind & solar companies via subsidies and state back loans

Strategy, Structure, Rivalry

- Government support to national champions
- Chinese companies dominate wind &solar industries (but also exports coal plants)
- Six of top ten wind turbine suppliers and eight of top ten manufacturers of solar PV modules are Chinese companies

Demand Conditions

- World's largest consumer of energy & largest importer coal, oil, gas
- China has most installed wind &solar
- Plan to increase share of non-fossil fuels consumption to ~25% by 2030 (Today: ~5%)
- Ordered grid companies to increase power purchased from clean sources from 28.2% in 2020 to 40% by 2030



Related and Supporting Industries

- China controls majority of worldwide critical minerals and rare earth elements necessary for renewable technologies

Chance

- Large population & long-term government vision
- Control of rare earth minerals

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ENERGY8

Porter's Diamond & National Innovation/Industrial System – Russia

Factor Conditions/ Macro/Regs/Education

- Second highest oil producer
- Corruption, sanctions, aging population, insufficient R&D, rising prices for goods
- Brain drain
- Heavily gov't regulated economy
- Military-oriented national innovation system

Strategy, Structure, Rivalry

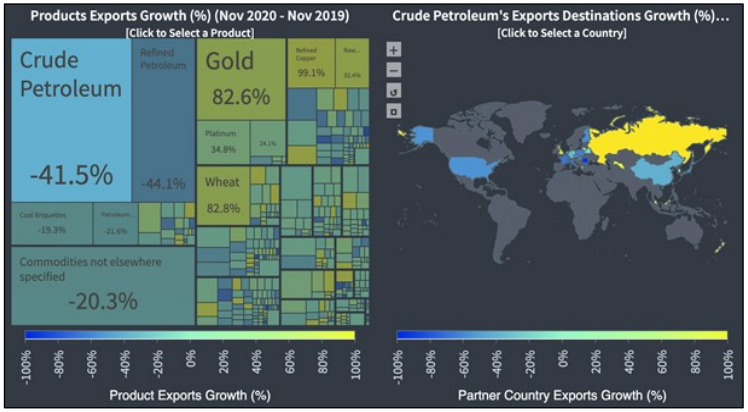
- "All in" on oil/gas exports
- Pivot East
- Nordstream
- Saudi Arabia/OPEC/US Rivalry

Related and Supporting Industries

- Largest oil/gas reserves in world
- Oil/gas infrastructure can be leveraged for hydrogen exports

Demand Conditions

- Renewable surge may hurt future demand for oil/gas
- Increase in EVs will replace combustion engine vehicles
- Anticipated future drop in OECD energy demand
- American boom in shale exports



Chance

- Break-up of USSR
- Dependence on fossil fuels
- COVID-19 hydrocarbon demand impacts

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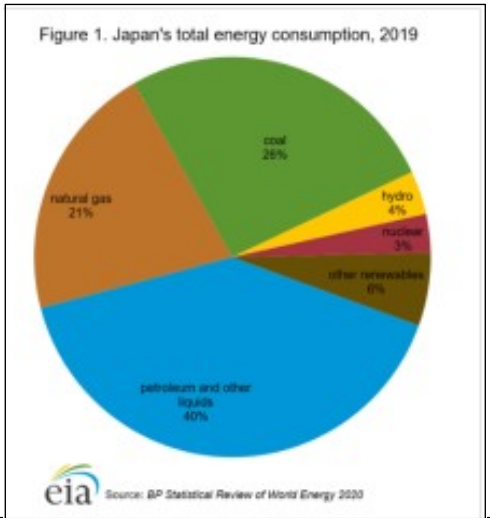
ENERGY8

Porter's Diamond & National Innovation/Industrial System – Japan

Factor Conditions/Macro/Regs/Education

- Highly educated/skilled labor force
- Declining labor force, 20% by 2040
- AI/robotics/automation offsets
- R&D spending 2nd globally
  - Manufacturing innovation
  - $275B in energy by 2030
- Forward-looking economic policies
- Healthy startup ecosystem



Strategy, Structure, Rivalry

- Global tech & market leadership
- Solid public-private policy & investment
- Energy policy & security directly tied to economic competitiveness

Related and Supporting Industries

- National innovation & partnerships
- Strong refining / chemical sectors
- Global expertise – reactor, equip, construction, fuel recycling, labor
- Solar PV value chain integration
- Other labor & processes – automotive, robotics semiconductor, mining, petroleum

Demand Conditions

- 3rd largest economy
- Climate and energy policies
- Support for Nuclear
- Hydrocarbons and CCUS
- Ammonia and Hydrogen R&D
- Economic – imports and exports
- Economy vs. Environment

Chance

- Strength of post-WWII rebuilding
- Focus on innovation & technology
- Aging population

ENERGY8

Porter's Diamond & National Innovation/Industrial System – Puerto Rico

Factor Conditions/ Macro/Regs/Education

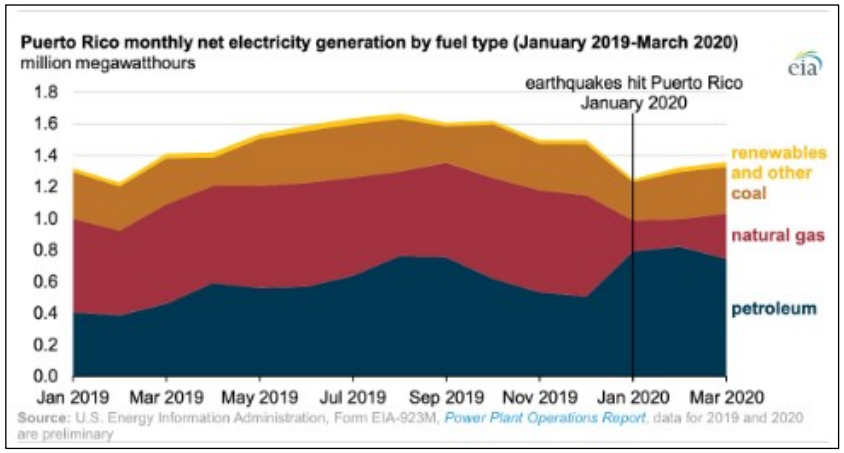
- Limited investment and resources, aging infrastructure
- Natural disasters & multiple hurricanes have devastated
- Declining population,stagnant economy, declining customer demand
- All coal-fired plants to close by 2028, 100% renewable by 2050

Strategy, Structure, Rivalry

- PR Electric Power Authority (PREPA) gov't-owned utility manages generation, transmission, & distribution
  - PREPA - significant financial, operational, and reliability issues
  - Privatizing, but gov't monopoly until 2018

Demand Conditions

- Most electrical from oil & natural gas
- Most electrical generation in south, with demand in north
- Flat load curve,coupled w/ battery storage for wind & solar
- SMR potential, but under development & may not need PR's short-term needs



Related and Supporting Industries

- Heavy industrial manufact & pharma
  - Previous tax incentivesfor infrastructure expired; ½ capacityis idle/inoperable

Chance

- Natural disasters (hurricanes)

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ENERGY8

SWOT Comparative Country Analysis

	U.S.	China	Russia	Japan	Puerto Rico
STRENGTHS	• **Government policy** • **Public/Private investment** • **Strong innovation ecosystem** • **Strong private sector** • Mixed, large economy	• **Directive governance/SOEs** • **Policy+ Strat** → BRI, MIC'25 • **Rare earth processing** • **Mnfctr'gcapability / labor** • Social marketJrg economy • **Nuclear tech exporter**	• **Strong vertical gov't system** • **Arctic strategy/position** • Dependent Europe • Oil and gas Infrastructure • **Energy rich resources** • **Nuclear tech exporter**	• **Government policy** • **Strong innovation ecosys** • **Hi-tech mnfctr'g/labor** • **Nuclear tech expertise** • Free market, large economy	• **Strong renewable policy goals -- 100% by 2050** • **Largest Wind & 2nd largest Solar PV in Caribbean**
WEAKNESSES	• **High energy consumption** • Manufacturing capability/labor • **Fed/state/loc gov't divisiveness** • **Supply chain dependency** • **Legacy infrastructure**	• High **energy consumption** • **Govm't market intervention** • **Reliance fossil fuel imports** • Environmental constraints • Innovation value chain	• **Fossil fuels dependency** • **Policies-- political vs econ** • **Low incentives to innovate** • No incentives to stop FF use • Overall Infrastructure	• Strict trade regs / high taxes • **Reliance fossil fuel imports** • **Supply chain dependency** • **Barriers to nuclear**	• **Limited gov't policy** • **Limited natural resources & no proven oil/gas reserves** • **Resilient infrastructure** • Limited skilled labor
OPPORTUNITIES	• Expanding EV & RE markets • Nuclear/CCUS innovation • **Supply chain diversification** • **Leadership and standards** • **Arctic development**	• **Supply chain domination** • **Renewable/R&D** • **Energy independence** • **Leadership and standards**	• Arctic development • **Closer ties with China** • **Exports oil/gas to developing countries** • **CCUS innovation**	• **Renewable value chain** • Nuclear export • **R&D in AI, robotics** • Mineral exploration export • Leadership and Standards	• **Rebuilding infrastructure** • Cultural acceptance of nuclear, particularly SMR • Export of SMR tech • **Economic recovery 2021**
THREATS	• **Demand/resource scarcity** • Global carbon pricing (FF export) • Commodity price volatility • **Cyber** threats	• **Demand/resource scarcity** • Volatility in oil/gas • Global diversification supply chains away from China • **Cyber** threats	• **Low-cost oil producers** • **Global GHG goals isolates** • Volatility in oil/gas • **Energy alliances/sanctions**	• **Demand/resource scarcity** • **Natural disasters, rising sea** • Volatility in oil/gas • **Cyber** threats	• **Demand/resource scarcity** • **Natural disasters, rising sea** • Volatility in oil/gas • **Cyber** threats

"Central to this agenda is building an equitable, clean, and resilient energy future, which is urgently required to head off the existential risk posed by the climate crisis. Doing so is essential to spark innovation, grow high-paying jobs, and ensure U.S. competitiveness in the decades to come." -- Interim National Security Guidance, Mar-2021

ENERGY8 SWOT Comparative Country Analysis - Expanded

	U.S.	China	Russia	Japan	Puerto Rico
STRENGTHS	• Rising **investment in renewable** & energy efficiency • Established infrastructure • **Technology innovation** leadership • **Government policy** favorable to energy diversification, incl renewables • **Strong Private sector** • **Free Market**	• **Abundant renewable energy** resources and value chain • Large energy market and increasing • **Vertical, directive governance** • **SOEs** • Successful **policies**, articulated **strategy** (BRI, Made in China, etc.) • Nuclear power tech exporter	• **Energy rich resources** • Arctic Strategy / position • Renewable capable • **Strong vertical gov't system** • Europe's dependence • Oil and gas Infrastructure to produce & export • **Nuclear power tech exporter**	• Work Ethic, Contribution • **Educated / Skilled Workforce** • Strong economic & energy Policy • Strong **gov't-industry innovation** system • **Hi-tech industries** cross-breed • Nuclear power tech expertise • Renewable energy potential Free Market	• **Low-energy use, renewables** • **Strong industry sector: drugs**, electronics, petrochem, foods, textiles • Private investment in manufacturing • **Policy** -- 40% renewable electricity by 2025, 60% by 2040, & 100% by 2050 • **Largest Wind & 2nd largest Solar PV in Caribbean**
WEAKNESSES	• High **energy consumption** • Employee attrition, loss of skilled labor • **Legacy infrastructure** • Limited manufacturing capability • **Renewable supply chain dependency** • Governmental polices inconsistencies - tariffs, subsidies/tax/incentive structure • Long gov't acquisition bureaucracy	• Aging population • High **energy consumption** • **Heavy reliance on fossil fuels & imports** • Gradual tightening of ecological/environmental constraints • Insufficient system flexibility • **Imperfect, gov't-controlled market** • Limited technology innovation due to SOE	• Decreasing population • **SOE does not incentivize tech** • **Heavily dependent on fossil fuels** • No incentives to decrease fossil fuel consumption • **Policies dictated by political needs** vs economic requirements • Aging infrastructure	• Birth rate low, top aging population • Cost of living in major cities / overcrowding • Strict trade regs / high taxes deter foreign investment • **Energy import FF dependent** • **Cultural disapproval & regulatory barriers to nuclear** • **Renewable supply chain dependency**	• Limited educated, skilled workforce • High national debt due to economic recession • **Limited natural resources & no proven oil/gas reserves** • Declining population • ¾ energy consumed from petroleum • **Lack of resilient energy infrastructure** • **Limited govt policy to promote energy transition and resiliency**

ENERGY8

SWOT Comparative Analysis – Expanded

	U.S.	China	Russia	Japan	Puerto Rico
OPPORTUNITIES	• Seize on energy transition momentum • **Policy/Strategy aligned with tax incentive / subsidies** • Expanding EV market • Land for solar/wind expansion • Nuclear advancement & innovation • **Decrease China reliance for renewable/battery; build domestic/intn'l supply chain** • **Grid updates & transformation** • **CCUS for FF exports**	• Seize on energy transition momentum • Economic globalization • **Huge investments in sustainable, renewable energy R&D** • Transition to freemarket energy, orexpand gov't control over energy to bolster exports &GDP • Continued **policies** and articulated **strategy** (BRI, Made in China, etc.)	• Northern Sea Route • Artic development • Infrastructure for hydrogen • **Closer cooperation with China** • Expand nuclear tech exports • **Potential to increase exports oil/gas to developing countries** • **CCUS innovation** globally to support Russia exports	• Seize on energy transition momentum • Income, new businesses/markets • Mineral exploration tech export • **Strong investment for renewable value chain** • Restore nuclear acceptance • Nuclear tech export in competition w/China & Russia • Growth in solar PV • **R&D in AI, automation, robotics** • Geothermal	• Seize on energy transition momentum • **Rebuilding infrastructure for energy transition / climate Δ** • Cultural acceptance of nuclear, particularly **SMR** • Export of SMR tech • Economic recovery 2021 • Renewable capacity
THREATS	• **Growing demand & resource competition** • Climate policy and carbon pricing hurts oil/gas (& GDP), but helps renewables • Commodity price volatility, outsourced critical supply chains • **Cyber** threats • DoD heavy reliance on	• **Growing demand & resource competition** • Volatility in oil/gas risks to energy security • Lack of technology development to fully utilize renewables • Global diversification of supply chains detracts from China's GDP • Lack of local consumption • **Cyber** threats	• Low-cost oil producing countries • **Global effort to reach GHG goals can isolate Russia** • Global warming could cost Russia ~$84B by 2050 • **Energy alliances and sanctions work against energy exports**	• **Growing demand & resource competition** • **Climate change, natural disasters, rising sea levels** • **Dependence on imports for energy well into future** • Volatility in oil/gas risks to energy security • **Cyber** threats	• **Climate change, natural disasters, rising sea levels** • **Dependence on imports for energy well into future** • Inefficient policy for energy transition, modernization, diversification

APPENDIX C: US POLICY RECOMMENDATIONS

The Seminar identified and described in the body of this paper four broad policy recommendations critical to enhancing the US energy transition and mitigating the climate crisis. The Seminar formed the recommendations from a comprehensive analysis of the energy industry. Additional industry-specific policy recommendations derived from a five-month long industry study and students' individual research efforts regarding energy transition and related national security aspects are detailed below.

Oil. Oil remains an essential energy source for global security and prosperity. Lowering the cost of oil and reducing its impact on global warming is vital to the industry's future during the global energy transition from fossil fuels to renewable energy sources. This is particularly important for renewable energy sectors that are not yet economically feasible, like air and sea transportation. The US should take the following initiatives in furtherance of these goals: increase innovation and investment in carbon capture utilization and storage (CCUS) and other decarbonization technologies; be more flexible in its policy toward the oil markets to stabilize the price in the US and the world; increase diplomatic efforts to stabilize the oil market, like ending the oil price war between Russia and Saudi Arabia; increase its energy diversity; and continue providing security at the choke points like the Strait of Hormuz, South China Sea, and North Africa to stabilize the world energy markets.

Oil Transport. While crude oil enables economic activities worldwide as a major energy source, its global transport constantly faces topographical and geopolitical risks. Climate change can affect the security environment surrounding oil transport. First, melting Arctic ice could allow crude oil to be transported by sea through the Northern Sea Route (NSR). For example, it may be possible to export Brent crude oil from the North Sea oil field to Asia. NSR reduces time and distance between East Asia and Europe 40% shorter than via the Suez Canal.[372] As countries transition from fossil fuels to renewables, the economies of countries that depend on crude oil production can deteriorate. Therefore, it is necessary to encourage countries highly dependent on crude oil for industrial diversification and innovation to alleviate the geopolitical risk of crude oil transportation. Additionally, the Indian Ocean and the South China Sea, which connect the Strait of Hormuz and the Strait of Malacca, are vital strategic points. Since the securing of crude oil has a significant impact on national security, the United States should constantly mitigate the topographical and geopolitical risks and secure sea lanes for energy security with its allies and partners in the Great Power Competition. As China strives to seize critical terrains in shipping crude oil as part of the Belt and Road Initiative (BRI), the United States needs to work with its allies and partners to prevent China from securing and monopolizing sea lanes.

Coal. Coal faces similar challenges as other fossil fuels. Its low cost and simplicity to burn as an energy source to generate electricity make switching to cleaner, low-carbon energy sources less appealing. The US should take the following initiatives to hasten the reduction of coal-based power generation to support the energy transition. First, the US should join the Powering Past Coal Alliance (PPCA) and commit an immediate and significant reduction in coal used as an energy source. The PPCA consists of 122 nations, localities, and organizations working to advance the transition from unabated coal power generation to clean energy. Second, the US should securitize or forgive old coal debt to make it economically beneficial for communities to choose to replace those plants with cheaper renewable energy generation. Third, the US should condition this financing on agreements to enact worker retaining, earlier retirement, and funding of healthcare and pensions for coal industry workers.

Natural Gas. Switching between consumption of fossil fuels on its own does not provide the long-term solution to climate change. However, natural gas can be an interim solution to reduce greenhouse gas emissions because it is cleaner than coal and oil. Like other fossil fuels, innovation in CCUS and other low-carbon technology is key to long-term industry viability. The US should adopt a comprehensive, long-term energy policy that is economically feasible and supportive of the United States in economic, security, environmental, and social terms. This long-term energy policy must be stable, consistent, and long-term because investments in the energy field require expensive and long-term investments. The US should also establish a national digital platform for energy innovations. This platform will be an environment for adopting and attracting innovations in energy sciences from the US and the world.

Natural Gas – Nord Stream 2. Nord Stream 2 is a natural gas pipeline currently under construction from Russia to Germany. The new pipeline will run through the Baltic Sea alongside the existing Nord Stream and deliver more gas to Europe. The Ukraine, whose role as a gas transit country will be undermined by the new pipeline, regards Nord Stream 2 as a "geopolitical threat to the whole of Europe."[373] Other opponents, including the US, the European Parliament, and Poland, consider it a threat to European energy security. Germany and Austria, among others, see Nord Stream 2 as a commercially sensible project that will ensure a highly reliable gas supply to Europe. Given Moscow's often disruptive role on the world stage – the Donbas conflict, malicious cyber activities, efforts to undermine democracy, transnational corruption – US concerns over Russia's capacity to use its gas reserves as foreign policy tools are understandable. However, the United States needs cooperation from its allies and partners to successfully deter a destabilizing Russia. Heavy-handed sanctions effectively telling Europe how to safeguard its energy security have been counterproductive and undercut US-German and US-European cooperation. The US strategy for Nord Stream 2 should not rely solely on hard-power economics but instead focus on diplomatic statecraft to negotiate a multilateral agreement among all affected parties. Renowned US statecraft and compromise can develop alternatives to overcome the contested aspects of Nord Stream 2 even as the US repairs its essential strategic partnerships. The US government should strengthen allied cooperation at every opportunity.

Nuclear. Nuclear power is one of the safest, cleanest, and most reliable energy sources; however, aging infrastructure and negative public perception relating to safety impede the industry's development. A promising emerging nuclear technology with the potential to overcome the shortfalls of traditional nuclear reactors is Small Modular Reactors (SMR). To accelerate the development of SMR technology and catch up to global competitors, the US should increase its support of SMR development, streamline the regulatory approval process, and ensure a coordinated, whole-of-government approach for exporting US SMR technology. Most importantly, the US needs to organize government agencies to work in a coordinated fashion in supporting SMR domestically and preparing for exporting the technology internationally. The US must ensure that the DFC, Export-Import Bank, DoE, US Agency for International Development, and all relevant agencies have sufficient, coordinated resources to globally support US safe SMR deployment.

Solar. Today's US solar industry generates tens of billions of dollars of economic value, employs more than 242,000 people, and is a key component of the US energy transition. The US government policy and regulations have proven effective in expanding utility-scale solar energy in the US. Enacted laws and executive orders incentivize solar industry investment, enable financing, resource R&D, facilitate government permitting and licensing process improvements, and enable adoption within the grid. The challenge is to balance the incentives, subsidies, and tax

credits that promote renewable energy while addressing the energy trilemma. The US solar industry would benefit from an industrial policy that more thoughtfully addresses key factor inputs (e.g., immigration, human capital, education, infrastructure, and policy) and that expedites resource decision timelines by the federal government to better compete with China's ability to direct funding quickly at the national level to state-owned enterprises. The US should also continue incentives, credits, subsidies, regulation, and innovation investments that foster strong competition for utility-scale solar, battery, and renewable solutions. Renewable sources like utility-scale solar stand to thrive as state governments stabilize markets with quotas to guide expectations, and the federal government supports with appropriate policies, incentives, financial support, and tax structures. Lastly, the US must improve electrical grid capabilities for handling renewable energy sources. This includes funding for regulatory agencies and grid operating agencies and investments in micro-grid, smart-grid, and net-metering technology that allows for integration, data capture, and demand response programs. Energy security and equity require grids to handle intermittent sources, micro- and smart-grids, batteries, frequency controls, and other technologies for improved grid resilience and reliability.

Wind. Although wind power is one of the fastest-growing renewable energy sources across the US, there are barriers to increased deployment that stand to limit future expansion and ability to achieve potential capacity. Government regulations and policies have been in flux over the past five years, which has caused some uncertainty in the wind power generation industry. The Biden administration's policies on clean energy and emphasis on reducing carbon emissions appear promising. Still, the US must consider a series of long-term policy initiatives and modifications to funding structures codified in legislation to ensure continued growth and development in US wind power capacity. First, the US should stabilize its Production Tax Credit (PTC) policy to be a more reliable and available incentive for future renewable energy growth and development. Implementing the PTC on a long-term basis would provide the wind power industry and associated markets with consistent incentives that could better help drive investment, planning, and expansion decisions.

Moreover, an available PTC will also help drive down the levelized cost of electricity across the US. A more comprehensive PTC approach would be to enact long-term legislation that coordinates timelines with renewable energy milestones. While some experts argue the wind power industry is mature enough to continue without the PTC, uncertainty in the PTC in 2012 and 2016 showed an annual wind installed capacity decreased in the following years. Without the PTC and other tax incentives, the nation risks a loss in available and competitive wind manufacturing infrastructure and capability.

Second, the US must define and establish a national clean energy standard (CES) that "aims to increase the share of US electricity generated from qualified clean energy sources."[374] Currently, the US lacks a universal definition of "clean" energy. Some proposals include renewable sources such as wind and solar, while others include nuclear power or certain natural gas technologies.[28] Establishing a national CES in legislation would codify a vision and goal for how the US will generate and consume electricity. Furthermore, a national CES could establish baseline expectations for state participation in meeting these goals by aligning federal resources to incentivize renewable energy growth. Under this construct, states with RPS that meet or exceed the national CES would be entitled to additional funds to fund energy infrastructure projects supporting future on and offshore wind development.

Third, the US should implement a carbon tax that would effectively put a price on emissions. Levying a tax burden on emitters using fossil fuels to generate electrical power would

incentivize individuals, businesses, and entire industries to demand a move to cleaner forms of power, especially if those costs are being passed to them as customers. The Congressional Budget Office estimates that setting a carbon tax at $25 per metric ton on most energy-related (electricity generation, manufacturing, and transportation) US greenhouse gas emissions could generate as much as $1.1 trillion over the next ten years.[29] The generated tax revenue would provide valuable resources for wind energy research, technology, and infrastructure development to expand onshore and offshore wind capacity, among other grid improvements.

Waste to Energy. Connecting the markets of waste management and energy production facilitates converting waste materials into usable electricity, heat, and fuel. WTE presents great potential in helping the US meet its Nationally Defined Contributions under the Paris Accord and hasten its energy transition. The US must implement a resource-informed policy to attract investors and entrepreneurs. While capitalism and environmental protection often can be in opposition, the US must recognize its profit-seeking culture as a center of gravity for implementing green energy solutions to address climate change. To foster WTE growth, the US must: increase WTE infrastructure proportionate to increases in consumption; augment private R&D with federal funding, increase resources and efforts to educate the American public on the negative externalities of their waste streams, methods to decrease the volume of waste, and the benefits of WTE; and impose a tax on the release of carbon from fossil fuel production and use with discounts for WTE infrastructure.

Circular Carbon Economy &Carbon Capture Utilization and Storage. The circular carbon economy (CCE), including carbon capture and storage (CCS) or utilization and storage (CCUS), can play a significant role in managing the CO_2 emissions while supporting reliable, resilient, cost-effective, and sustainable energy. CCS and CCUS are technologies that can apply to almost any CO_2 source for energy, environmental, economic, and national security opportunities. However, CCS/CCUS is not deployed at rate and scale to meet climate, CO_2, and energy objectives. To further advance CCE and achieve CCS/CCUS at scale, the US government must 1) align international, national, state, and local policies with industry, including the role of CCS/CCUS; 2) place a value or cost on carbon emissions; and 3) expand investment incentives, R&D financing, and government CCUS procurement to bolster private sector investment. These policies will advance international and national security interests, enable reliable, resilient energy, and reduce CO_2 emissions. Achieving global net-zero emissions will require a global, whole-of-nation approach with defined technological and industrial policies and priorities across numerous countries and markets. The US government must continue coordination and CCS/CCUS expansion through the UN Climate Change Conference, Climate Summits, the G20, and the World Economic Forum with allies and partners and leading carbon-emitting nations like China, Russia, and India. Within the US, the Special Presidential Envoy for Climate must lead across the agencies, departments, and industry to address climate change and CO_2 emissions. All government levels must collaborate to understand CCS/CCUS contributions for emission targets, enabling energy and economic security. Furthermore, the US government must pursue a cost on carbon emissions, such as in Canada, Australia, and the EU. Lastly, US federal, state, and local government incentives must include tax credits, investment subsidies, and loans to send market signals for CCS/CCUS, infrastructure investments, and industrial hub/cluster support. CCS/CCUS commercialization is critical to achieving long-term climate and energy goals, furthering value chain synergies, and promoting economies of scale for resilient, low-carbon energy and international and national economic expansion.

Critical Minerals. Minerals are critical for renewable energy technologies. As described in the policy recommendation in this paper's main body, US dependence on foreign supply chains threatens both national security and the energy transition. Listed below are more detailed policy recommendations related to advanced battery storage. First, public and private institutions should invest in new battery research and development to create less reliant technologies on rare earth minerals and critical commodities in the production of energy storage systems. Second, the US should create a national battery recycling program to encourage and facilitate the recycling and reuse of battery systems that contain rare earths and other difficult to procure inputs. The ultimate intent would be to use battery recycling as an urban mine, making the US less reliant on narrow global supply chains that can quickly become disrupted. The recycling program would diversify the energy storage and, specifically, battery supply chains and bring home the most vulnerable portions. The US government should mandate recycling capability be designed and built into the original manufacture of the products, building energy storage systems with the capability and intent of being recycled in the future. Third, the US must foster and develop relations with nations that hold the majority of resources required to produce modern energy storage and renewable systems (Chile, DRC, Canada, Mexico, etc.) to firm up the supply chain. The Department of Commerce should develop trade agreements with those nations to make it easy and advantageous for them to look to the US for trade before looking toward other less desirable countries such as our great power competitors. Additionally, the US government should identify and create a national stockpile for strategic materials required for critical energy storage systems.

Electrical Grid. The US electrical grid is vital to the nation's economy, national security, and national innovation system. Implementation of thoughtful, tailored policies will enable the transition to a more robust, resilient, and reliable network of transmission infrastructure necessary to support the nation's stated clean energy goals. Modernization will support the more efficient use of electricity throughout the country and should receive bipartisan support in Congress. Failure to take action will delay the effectiveness of renewable generation installations and negate the benefits associated with the continued electrification of the transportation sector. The grid must seamlessly move power generated in sparsely populated areas to metropolitan centers and bulk storage locations. Distributed generation combined with increased disbursed loads due to electric vehicle charging will strain the current grid. Domestic industry and the nation's security depend on reliable electricity to remain competitive and dominant. A modernized grid supports both of these requirements. The US should enact several policies to enable the national electrical grid to meet the challenge of climate change, decarbonize the economy, enhance national security, and promote innovation. First, a national backbone grid should be "…overlaid on the existing, fragmented system…[to enable] cheap power [to] chase high demand around the clock and across the country."[375] Second, the grid's intelligence needs to be increased to "…make power transmission more reliable, flexible, and convenient."[376] A so-called "smart grid" would include smart meters at the end customers to better inform them and the energy providers of real-time consumption, electric vehicles as potential energy storage and conditioning devices, utility-scale storage, and dispersed renewable generation. Third, the US should streamline government regulation and oversight with strict review cycle timelines and a final override authority (to approve or reject) at the Department of Energy level. This would help companies better scope their efforts knowing they could obtain a final decision in a timely manner. Fourth, and finally, these policy proposals should be paid for with a mix increased government funding on research, development and deployment and tax credits for those

companies willing to invest in the electrical grid. These are reasonable recommendations, and "historically, people on both sides of the aisle have wanted to see investment in infrastructure…[because it] is so important for the nation."[377]

Transportation. Transportation recently became the largest source of greenhouse gas emissions in the United States.[378] Unsurprisingly, US policymakers seeking to combat climate change have turned their attention to this sector. Through a recent executive order, President Biden is calling for Americans to switch from vehicles powered by internal combustion engines that burn fossil fuels to zero-emission vehicles (ZEV).[379] Policymakers must recognize that calling for a switch to zero-emission vehicles is not a panacea. Meaningful climate policy should incentivize their adoption and also address the transition's energy resilience and national security challenges. Foremost, US policy must improve the electricity grid to ensure it can provide the capacity to charge an increasing electrified transportation sector created by a ZEV transition. Without changing the energy source, the US will fail to maximize emission reductions. Modernizing the grid further requires addressing the new vulnerabilities created by the proliferation of smart-charging connections that threaten the nation's critical infrastructure. Moreover, grid modernization should consider laying the foundation for emerging vehicle to grid technology to utilize the benefits of ZEVs as distributed storage for peak load and emergency power. Second, policymakers must address critical mineral supply chain vulnerabilities that threaten to stifle ZEV supply by limiting battery availability. There are several ways to mitigate the vulnerability, including incentivizing the US mining, processing, and battery recycling industries and leveraging our partners and allies to secure new material sources. Third, US policy must incentivize ZEV market diversity by ensuring hydrogen fuel cell vehicles are part of the transition. This requires prioritizing clean hydrogen as an energy source, developing better hydrogen fuel cell technology, and building a hydrogen charging infrastructure. Opponents will perceive the initiatives as redundant and costly, making enactment politically difficult. Yet, diversifying with hydrogen will diminish ZEV demand for imported critical materials allowing their use elsewhere and provide resiliency in more extreme climates and electrical power outages. Lastly, Congress must protect the existing ZEV tax credits and rebates. Even as ZEV prices fall with technology improvements, the incentives are necessary adjustments for climate change's negative market externalities.

Energy Resilience. Energy security has always been a crucial part of national security. Today, when nations' energy systems are objectives of the adversary and terroristic attacks, prone to impact natural disasters, resilience and vulnerability of the energy system and its infrastructure have obtained critical importance in the light of the Great Power Competition and consistent struggle with terroristic groups. Recommendations for strengthening energy resilience starts with ensuring government agencies' control over security and safety measures on the national level. Periodical reassessment and review of energy infrastructure should be conducted, and results reported through the public channels to avoid potential political dirty games and covering. Exhausted equipment must be timely modernized, upgraded, or replaced. National regulators should be empowered to amend inadequate or too soft policies which can jeopardize energy system survivability and sustainability and lead to potential casualties and damages. Additionally, a flexible grid will provide higher efficiency of resiliency and survivability. Being connected to other large grids but split into microgrids will allow operators to supply additional power for higher demand or downed lines and make small systems self-sustained. The US should also ensure healthy competition in the electricity market, which will help develop an energy system and drive innovation. Lastly, to minimize human error, US policy must increase training.

The training from professional courses to interagency exercises must teach how to act in emergencies at different threat levels. All entities from utilities to respective governmental agencies must form training units to organize such activities and empower them to provide recommendations on security and safety measures improvement and oversee implementation.

Cyber. The ability to protect critical infrastructure, assets, systems, and networks against cyber-attacks is essential to ensuring energy reliability, national security, public health and safety, and economic prosperity. The US should enact the following policies to strengthen and maintain cybersecurity across the energy industry. First, the US should establish a formal mechanism for senior executive level dialogue across government and industries. As the CISA has already established a mechanism – known as the Critical Infrastructure Threat Information Sharing Network – to share information on attacks, the National Cyber Director (NCD) is positioned to elevate issues as a representative of the White House and is foster dialogue across the US government and private industry. Establishing a mechanism for dialogue across industry leaders with senior officials across relevant government institutions will be vital to consolidating broader political support for the collaboration needed to address the most significant vulnerabilities in a way that will not inhibit private sector functioning. Generally speaking, this will be key to ensuring that significant issues don't get diluted in the massive US government apparatus.

Second, the US should mobilize the nation's STEM talent base. To meet today's cyber defense and tomorrow's innovation landscape around 5G, AI, and quantum computing, the US government would be wise to use the new architecture of the NCD to set a national mobilization strategy for building tomorrow's workforce. To reclaim the advantage of its extraordinary university base, a new *national scholarship program* should be established to pay for promising US students who cannot afford the costs. At the same time, *immigration policy* should be revised to put limits on the number of visas provided to Chinese students, particularly those who intend on returning home after graduation. But to prepare for the marathon with China, there should be a *new early education initiative* aimed at middle and high school students to 1) encourage and motivate students to explore STEM as an important discipline, and 2) create "tracks" and other opportunities for interested students to begin developing their STEM skills more rigorously in preparation for higher education.

Lastly, the US must take measures to reinforce supply chain resilience. The weaknesses in the supply chain require immediate actions, as another SolarWinds could be catastrophic. First, the US government has to get control over the weaknesses in the supply chain. The government should quickly *revise and establish security regulations* with clear penalties for companies like SolarWinds and their leaders for negligent shortfalls. These regulations would increase costs, yet the costs would be minimal compared to the protected IP, secret information, and energy infrastructure weaknesses. Second, the DOE is looking to formulate an executive order for operators to vet third-party software and seek industry input into its formulation.[380] This will have to be a priority, and *new legislation* may be required to limit certain parts of the supply chain to national firms. Finally, *intensive dialogue with Russia, China, and the international community is needed to set norms* around cyber-attacks on supply chain software, much like what the President of Microsoft described as a "Geneva Convention" on cyber.[381] This would be crucial in setting the rules of engagement and perhaps avoiding what could easily devolve into future military clashes.

Cost of Energy Transition. The Energy transition will require initial capital investments, estimated at $131 trillion through 2050, for infrastructure and resources to expand

solar and wind generation capacity and storage, and to adapt the mix to the energy grid. Though many are skeptical of the price, these investments are necessary to energize the market for renewables and yield more positive than negative economic outcomes. The world's wealthy countries will have to lead to achieve the goals by making tangible investments in the private and public sectors. Specifically, they will have to identify a plan to increase the energy security of lesser developed countries and energy impoverished countries. The investments necessary to expand renewables in emerging markets are an opportunity for western banks as world leaders begin to make renewable energy incentivized and profitable to entice investors.

Moreover, they cannot continue to subsidize the high greenhouse emitting carbon industry and expect different results. The International Monetary Fund (IMF) recently revealed that it would spend $100 billion per year subsidizing renewable energy while spending over $5 trillion subsidizing fossil fuels. The fossil fuel market cannot compete against the renewable market without these subsidies. There will be damage to the fossil fuel market as it is with any technological revolution that has disruptive innovation. The traditional energy markets, including the Department of Defense, cannot afford to remain stagnant. They must innovate to become greener and to stay in business. The MENA rentier states that are not incentivized to develop productive and diverse economies because they rely heavily on their exports that account for upward of 38 percent of GDP are going to have leverage Sovereign Wealth Funds and their local banks to invest in other emerging industries to maintain stability and the shock of peak oil demand.

APPENDIX D

LIST OF ACRONYMNS

ASEAN	Association of Southeast Asian Nations
AWIA	America's Water Infrastructure Act
BRI	Belt and Road Initiative
BTU	British Thermal Unit
CAA	The Clean Air Act
CCP	Chinese Communist Party
CCUS	Carbon Capture, Utilization, and Storage
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CISA	Cybersecurity and Infrastructure Security Agency
CO2	Carbon Dioxide
CWA	Clean Water Act
DFC	Development Finance Corporation
DHS	Department of Homeland Security
DoD	Department of Defense
DoE	Department of Energy
DRC	The Democratic Republic of Congo
EIA	Energy Information Administration
ENR	Bureau of Energy Resources
EPA	Environmental Protection Agency
ERGI	Energy Resources Governance Initiative
ESSA	Every Student Succeeds Act
EU	European Union
EV	Electric Vehicle
EVA	Ethylene Vinyl Acetate
FERC	Federal Energy Regulatory Commission
GHG	Green House Gas
GPC	Great Power Competition
GWP	Global Warming Potential
IAEA	International Atomic Energy Administration
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
LNG	Liquified Natural Gas
MACT	Maximum Achievable Control Technology Act
MENA	Middle East and North America
MMst	Millions of Short Tons
MW	Megawatts
MWe	Megawatts Electric
MWh	Megawatts per hour
NATO	North Atlantic Treaty Organization
NCD	National Cyber Director
NDC	Nationally Determined Contributions
NEPA	National Environmental Policy Act

NOC	National Oil Companies
NPD	Non-Powered Dams
NREL	National Renewable Energy Laboratory
NSA	National Security Advisor
PNG	Pipeline Natural Gas
PREPA	Puerto Rico Electric Power Authority
PSH	Pumped-Storage Hydropower Facilities
PURPA	Public Utility Regulatory Policies Act
PV	Photovoltaic
RCRA	Resource Conservation and Recovery Act
R&D	Research and Development
RDD&CA	Research, Development, Demonstration, And Commercial Application
ROIC	Return on Invested Capital
RPS	Renewable Portfolio Standards
SCADA	Supervisory Control and Data Acquisition
SDWA	Safe Drinking Water Act
SMR	Small Modular Reactors
SVR	Russia's Foreign Intelligence Service
SWDA	Solid Waste Disposal Act
STEM	Science Technology Engineering & Mathematics
TSCA	Toxic Substances Control Act
UAMPS	Utah Associated Municipal Power Systems
UK	United Kingdom
UNFCCC	United Nations Framework Convention on Climate Change
US	United States
USAID	United States Agency for International Development
USD	United States Dollar
WACC	Weighted Average Cost of Capital
WTE	Waste-To-Energy
WWTP	Wastewater Treatment Plants

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