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Abstract:

This paper provides a survey of the United States (U.S.) energy industry. It begins by presenting plausible – if not probable – real-world scenarios, any one of which could cripple the country by affecting parts of the energy supply, generation, distribution, and transmission for months. It discusses energy industry foundations, which underpin the entire industry, and it then describes the current state of energy technology in the U.S. It synthesizes the information and insight gained from *twenty-one* in-class guest lectures, *twenty-four* domestic field studies, and *fourteen* international (Chilean) field studies.

In preparation for a Strengths, Weaknesses, Opportunities, and Threat (SWOT) analysis of the U.S. energy industry, the team reviewed lessons learned, trends, and strategies from on-the-ground reviews of Chile, Argentina, and Kazakhstan and evaluated how the U.S. could benefit. For this review, the team was fortunate to have senior military representatives from Argentina and Kazakhstan to contribute their invaluable perspective and experience. Ultimately, the team concluded that it is critically important to ensure establishment and execution of the recommendations contained herein. These recommendations would, if implemented, significantly improve the nation's economic growth potential, competitiveness, energy security posture, and military industrial complex through a balanced portfolio and ensure a high priority is placed on investments for energy research and development.

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2. Port of Houston, Barbours Cut Container Terminal, Morgan's Point, TX
3. Center for Strategic & International Studies (CSIS), Energy and National Security Program, Washington, DC
4. Cheniere Liquefied Natural Gas (LNG) Export Terminal, Cameron, LA
5. Congressional Research Service, Energy and Minerals Section, Washington, DC
6. Embassy of Canada, Washington, DC
7. Embassy of Chile, Washington, DC
8. Exelon Perryman Natural Gas Peaking Facility, Perryman, MD
9. Exelon Solar Facility, Perryman, MD
10. Exelon Trading Floor, Baltimore MD
11. Halliburton Research Center, Houston, TX
12. Houston Ship Channel, Houston, TX
13. Port of Houston Authority
14. Kinder Morgan, Deer Park Rail and Deep-Water Terminal, Pasadena, TX
15. Kinder Morgan, Ethanol Terminal, Baltimore MD
16. Kinder Morgan, Refined Products Terminal, Pasadena, TX
17. Member of the U.S. Senate, Washington, DC

18. Motiva Oil Refinery, Port Arthur, TX
19. Exelon Peach Bottom Atomic Power Station, Delta, PA
20. Port of Beaumont, Beaumont, TX
21. Port of Houston, Houston, TX
22. Rice University, The Baker Institute for Public Policy, Center for Energy Studies, Houston, TX
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Field Studies – International:

1. AES Gener Coal Power Plant, Puchuncaví, Chile
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3. American Chamber of Commerce (AmCham) in Chilean, Santiago, Chile
4. Chilean Department of the Army, Santiago, Chile
5. Chilean Ministry of Energy, Energy Policy and Prospective Division, Santiago, Chile
6. Chilean Ministry of Energy, Renewable Energy Division, Santiago, Chile
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9. GNL Quintero Liquefied Natural Gas Import Terminal, Quintero, Chile
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The Problem

On a Monday morning, just as the country is waking up to a new workweek, a team of terrorists attacks, boards, and explodes an outbound Liquefied Petroleum Gas tanker, sinking it in the Houston Ship Channel and thereby blocking the channel. The Kinder Morgan Pasadena refined products terminal fuel transfer facility located along the channel is shut down, and the connection to the Colonial Pipeline, which supplies the East coast, is physically destroyed (see Figures 1 and 2). That evening, while many in the country are still processing the morning's events, cyberterrorist actors attack Houston's electrical grid, leading to blackouts along the shipping channel and leaving much of the country's oil, gas, and chemical infrastructure cold and dark. Through these attacks, roughly 30-60 percent of America's daily refined oil products are cut off, the nation's largest petrochemical complex is isolated, and America's most critical energy node is physically and electronically isolated—and will be for weeks. Even as federal and state officials rush to mitigate the attack's impact and to neutralize the threat, they recognize that the country will take years to register the full economic and social impact of the day's events.[1]

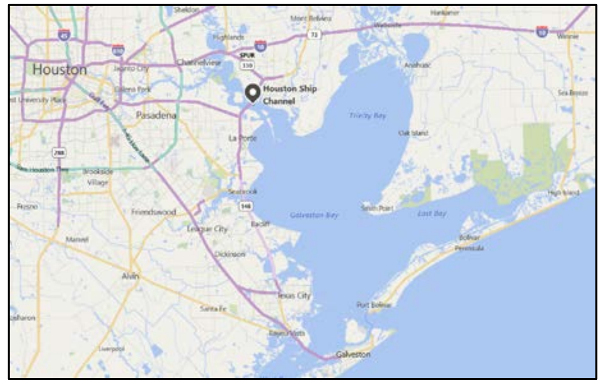


Figure 1: Houston Ship Channel

Although the above scenario is hypothetical, the vulnerabilities it highlights are real. Before Hurricane Harvey made landfall in 2017, most Americans barely noticed the potential threat to energy supplies and distribution found in the Houston area. Citizens watched the devastation from their well-lit homes and drove to work giving little thought to the sources of the gas fueling their cars. People in other parts of the country went about their lives not realizing how close they were to fuel and electricity shortages because of a storm on the Gulf Coast. The vulnerabilities present in south Texas, which is home to much of the nation's oil and gas refinery capacity and chemical production, represents one risk to America's economic and homeland security through the disruption of energy generation, distribution, and transmission.

The energy sector in the United States (U.S.) enables our prosperity because it is the foundation to the proper functioning of our critical infrastructure sectors, such as financial services, health care systems, transportation networks, telecommunication systems, and agriculture. The generation, distribution, and transmission of energy must be robust and resilient enough to support industry, residences, governments, commerce, health infrastructure, and more across the country. Factories, jobs in those factories, and service providers need reliable energy networks for full productivity. Additionally, exports such as natural gas require a sound and resilient network to provide endless kilowatt-hours to consumers outside the country. Reliable and secure energy is needed to keep the American economic engine humming. Sustained energy generation is also required for the U.S. to crowd out would-be competitors in energy markets. American prosperity currently benefits from oil and natural gas exports and may benefit from solar panel, windmill, and/or battery storage technology exports in the future. The key is to secure a reliable energy network and industrial base sufficient to fuel future economic growth.


Figure 2: Houston Ship Channel and Centralized Production

The nation's homeland security and economic prowess should not rest on fragile energy networks, industries, and enterprises. The country's energy supply is composed of systems within systems nested within systems, and when one interdependent system fails—they can all be impacted. Threats to the nation's energy supplies and networks are very real, yet few citizens recognize the need to bolster our energy security. America's leaders cannot allow nightmare scenarios to become a reality. National security and economic prosperity depend on energy resiliency. There is no room for failure.

Addressing this Complex Problem

The overarching question of whether the U.S. Government and the energy industry are ready to respond to a major threat remains unanswered. Additional national and state level policy is required to address the weaknesses in energy supply, generation, distribution, and transmission. Energy security is a key foundation to the future of the U.S. as a global leader. According to the December 2017 National Security Strategy (NSS), "America's central position in the global energy system as a leading producer, consumer, and innovator—ensures that markets are free and U.S. infrastructure is resilient and secure."[2] A diversified portfolio with access to domestic sources of clean and reliable energy provides the bedrock for a prosperous, secure, and powerful America well into the future.[3]

The future of national security and economic growth in the U.S. is heavily reliant on available, reliable, secure, and inexpensive energy. Resources abound, and in recent years, the domestic boom in oil and gas from shale gas and fracking has opened the door to a new era of U.S. energy security that enhances the nation's global competitiveness. After all, no one would have predicted that the U.S. would become an exporter of Liquefied Natural Gas (LNG) ten years ago.

However, a coherent national energy strategy is required to fully capture the economic prosperity and national security benefits available to the nation today while ensuring a vibrant and innovative energy industrial base for tomorrow. To advance this effort, this paper offers a survey of U.S. energy-related industries and sectors. It also proposes three national energy imperatives with policy recommendations designed to promote security, resiliency, reliability, and efficiency while also providing for economic growth. If implemented, these policies could help the U.S. sustain this newfound competitive advantage for years to come.

The first imperative is for America's leaders to develop a comprehensive energy strategy and action plan to ensure energy security for the future. The policy recommendations captured under the first imperative focus on three elements: education, economic growth, and energy security.

The second imperative is for policy makers to create a balanced portfolio through deliberate long-term investments in baseline energy production capabilities and renewables. The policy recommendations under this imperative involve incentives and tax credits for specific industries. Moreover, these recommendations focus on developing an array of flexible resources, which support the proposed strategy in day-to-day operations and in times of crisis.

The third imperative is for the U.S. to gain a global competitive edge through innovation, investment, and protection. The policy recommendations included in the third imperative further support the elements of the energy strategy by focusing on technological advances, investment in new resources, and the protection of networks and proprietary information.

This paper will first discuss the foundations that underpin the entire industry. Then, it will describe the current state of energy technology in the United States before turning to an analysis of international examples and prospects. Finally, the paper will describe the three imperatives - along with associated policy recommendations - that policymakers should enact to secure the nation's energy future.

Energy Industry Method of Analysis and Definitions

For the purposes of this paper, the U.S. energy industry will be analyzed vis-á-vis two major categories: Energy Foundations and State of Technology. Within each category, the paper presents a Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis. Where appropriate, these analyses are supplemented by assessments conducted using Michael Porter's "Five Competitive Forces" model. The Five Forces include Threat of New Entry, Buyer Power, Threat of Substitution, Supplier Power, and Competitive Rivalry. Both tools will provide insights into the state, health, and future prospects of the industry.[4]

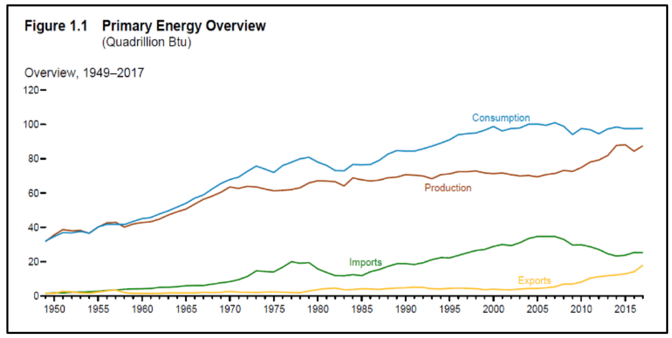
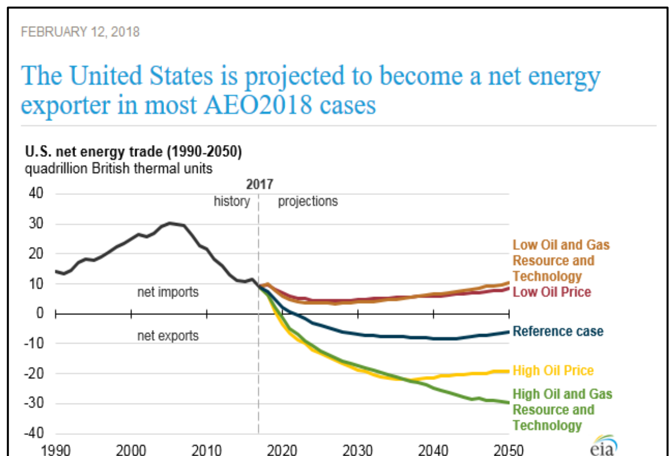


Figure 3: U.S. Energy Overview

The U.S. energy outlook has changed significantly in the last five years (See Figures 3, 4, and 5). The overall energy market in the U.S. contains several sub-markets for fossil fuels, renewables, nuclear power, and storage, to name just a few. The fossil fuel market is considered mature overall with a low threat of entry due to the capital intensity of new construction as well as to the lengthy process of exploration, permitting, and project development. Moreover, bargaining power of suppliers is moderate in providing established, low-cost energy to consumers while the current bargaining power of buyers is high due to the availability of cheap natural gas and maturing renewables.



The market for renewables is also expanding rapidly as the technology becomes less expensive and coal becomes more of an environmental concern. However, the maturing renewable energy industry continues to experience headwinds due to inexpensive and widely available fossil fuels such as natural gas. There is clearly an active competition between renewables and fossil fuels, which ultimately benefits the commercial and residential consumer base.

Meanwhile, the nuclear market has struggled due to regulatory and safety concerns. The disaster in Fukushima resulted in low public support for nuclear power expansion, and the market remains flat. The generation-supplier power is slightly higher than

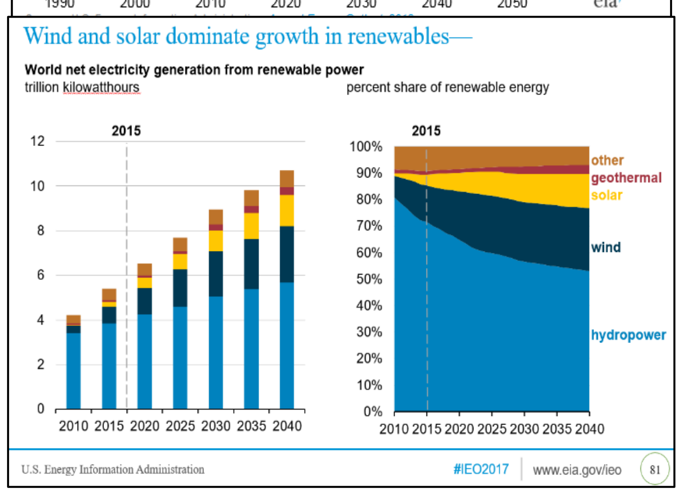


Figure 5: International Energy Outlook From EIA

buyer power due to its reliability and availability. Additionally, nuclear power generation is over 90% full-power output in contrast to the inherently variable generation from solar and wind. This gives nuclear power strong supplier leverage, especially at night and during overcast periods when solar power is unable to produce anything.

Storage technology is still immature, but the potential exists for it to become a key enabler for a major energy industry, generation, and distribution market shift. Once large storage technologies are mature, available, and affordable, many anticipate a huge shift away from large centrally controlled power generation plants to smaller power generation facilities (e.g., solar and wind paired with storage). This will not be a typical systems evolution but rather an energy sector revolution that will change the face of the U.S. and global energy generation, transmission, and distribution systems.

The following sections will examine the foundational underpinnings of these critical systems and emerging energy technologies that are currently disrupting - or threatening to disrupt - existing paradigms. As noted above, each section and subsection will include a SWOT analysis, which will serve as the basis for the subsequent policy recommendations.

Energy Foundations

The U.S. energy sector is composed of resources and generation capacity that depend upon foundational capabilities or attributes resident in the energy industry. The industry consists of inter-dependent systems, and these foundational elements undergird all of these systems. This foundation supports and enables the competitiveness of each sector's capabilities, underpins their use and security, and helps deliver today's energy needs required to support the U.S.'s vibrant and growing economy. This foundation also establishes an environment that helps propel the U.S. towards a more prosperous and secure future. This section will address the key energy segments of electrical grid, energy storage, cyber security, supply chain, physical security, energy efficiency, and research and development (R&D).

The Electrical Grid

Strengths: Our current legacy electrical grid has long been a national strength, having met the electricity demand of most U.S. citizens while largely providing reliable electricity at affordable prices. It is able to do so despite the complexity of energy producers, infrastructure, and government regulations, which were developed over time into a 'system of systems, nested within other systems' without the benefit of strong centralized planning. "The electric grid is more than just generation and transmission infrastructure. As depicted in Figure 6, it is an "ecosystem of asset owners, manufacturers, service providers, and government officials at Federal, state, and local levels, all working together to run one of the most reliable electrical grids in the world."[5]

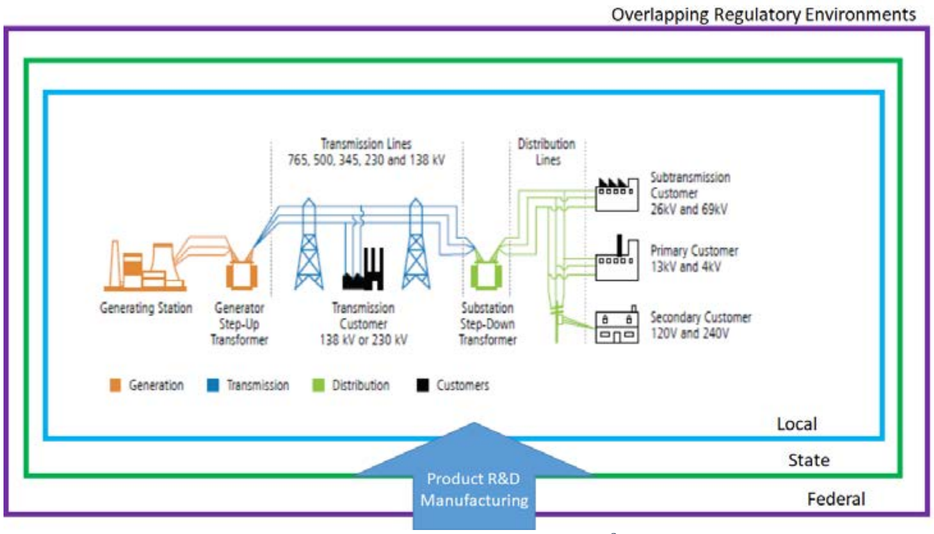


Figure 6: The Electric Grid [6]

Weaknesses: Up to this point, the grid has supported our nation's prosperity and energy security requirements; however, "our electric infrastructure is aging and is being pushed to do more than it was originally designed to do."[7] Existing weaknesses and challenges must be addressed to ensure the future prosperity and security of the U.S. For example, changes in our nation's demographics, regulatory restrictions and projected workforce shortfalls in the energy sector may cause a shortage of supply undermining our prosperity and energy security. "Demographic changes have driven more people to warm-weather climates that demand more electricity for air conditioning, usually the largest single electricity cost used for residential purposes; our electronic culture is also increasing demand. Additionally, the supply side is facing challenges from environmental regulations that restrict traditional fossil fuel-based generation plants from very long and heavily regulated deployment windows."[8] These challenges lead to lengthy and uncertain site permitting processes that drive up investment costs and significantly increase the payback period, even for environmentally friendly projects such as solar and wind or for power distribution infrastructure needed to meet growing demand.

Further, the absence of strong centralized planning and control, along with an aging grid infrastructure also presents a challenge to future energy security and national prosperity. Our current electrical grid "is assembled in a somewhat jumbled manner that reflects more than a century of additions, tweaks, and workarounds to provide electricity to nearly every home", but "even using the term 'grid' implies a level of organization that does not exist" because "while not completely autonomous, the three major U.S. grids located in the eastern and western U.S. and Texas are by no means centrally controlled, as each generation source, transmission provider, and local distribution organization has some say in the technology used and the processes to be employed."[9] Additionally, while we have three regional grids, the U.S. has yet to develop a networked system of micro-grids across the nation, which continues to expose our national grid to the risk of regional power outages in the event of a localized natural disaster or terrorist/criminal attack on critical nodes of our grid.

Opportunities: There are numerous opportunities and benefits in converting the nation's electrical grid to a Smart Grid. Some industry experts estimate a U.S. Smart Grid could result in a $2-trillion return on a $476-billion investment over 20-years through an increase in system reliability and improved system efficiency.[10] These opportunities may be realized with effective government regulatory leadership and active support of industry and effective education of and support from the impacted public. The goal of this transition should be to develop an environment for industry to easily and cost effectively integrate new sources of supply onto the grid while building a more resilient and reliable system that supports economic growth and prosperity. This vision also benefits the environment; expands the portfolio of available energy sources of supply on the grid by easing integration of large and small renewable projects; and supports new manufacturing, sales, and service jobs within this growing market. By expanding the number of renewable energy producers in the U.S., electricity production could expand to meet the expected demand increases associated with a vibrant, growing economy while avoiding the negative externalities associated with increased fossil fuel generation. Utilities benefit from a modern grid through improved security, reduced peak loads, increased ease of integration of renewables, and lower overall operational costs.[11]

Government encouragement of the development, integration, and long-term operation of micro-grids at a national scale would further enhance the resiliency and reliability of our nation's electrical grid. The incorporation of micro-grids would help protect our nation against large-scale power outages by providing us the opportunity to isolate damaged or destroyed sections of the grid while leaving the undamaged portions of the grid intact and fully operational. Indeed, "[the] value of Smart Grid technology is to balance a wide variety of energy resources to leverage them when they are available rather than try to depend on a single generation source to provide power to a particular load."[12] Combined with a Smart Grid that can help divert power around damaged sections of the network, micro-grids greatly strengthen our country's ability to generate and transmit electricity reliably, even under challenging circumstances, such as those experienced by Puerto Rico in 2017.[13]

A modern next generation grid that utilizes emerging technology in the deployment of smart, micro-grids will also improve the ability to provide enhanced situational awareness of the health and operation of the grid while providing increased customer situational awareness of their personal energy consumption. "Modernizing the grid to make it "smarter" and more resilient through the use of cutting edge technologies, equipment, and controls that communicate and work together to deliver electricity more reliably and efficiently can greatly reduce the frequency and duration of power outages, reduce storm impacts, and restore service faster when outages occur."[14] The fielding of a next generation grid also provides the U.S. the opportunity to establish an organization to centralize all three major domestic grids. Such a move would prompt the federal government, in conjunction with industry and academia, to establish common grid interface standards and procedures to ensure interoperability between all systems and processes throughout the network.

Threats: While these benefits and opportunities are compelling, one must deal with the threat of high transition costs measured in hundreds of billions of dollars. Given the cost estimate above, conversion to a Smart Grid will be expensive and could initially reduce industry's profits. Alternatively, utilities may raise consumer prices to fund these infrastructure improvements. Without more data available to demonstrate the economic and social benefits, including job creation as well as a more resilient, reliable, environmentally friendly generation system for consumers, these expenses make the transition less attractive for the public from a purely economic perspective. To move in this direction, taxpayers may be required to help make the significant up-front investment in infrastructure.[15] However, U.S. taxpayer is unlikely to accept higher taxes. Likewise, lawmakers are unlikely to support unpopular legislation requiring additional tax revenues to support grid transformation. More likely, industry will be required to provide the up-front capital investment and then pass those costs on to customers in the form of higher electricity bills. There is more opportunity for the electric industry to accomplish this in regulated markets where the customers have little or no alternative sources of electricity, and who must pay the proscribed electric rates.

A Smart Grid is also far more reliant on technology than our legacy grid. This reliance brings the benefits described above, but it also creates significant vulnerability to cyber threats. “Changes to smart metering, energy distribution, transmission, and generation will likely represent the most concern from a cyber security perspective” because “the infrastructure associated with these key elements of the grid represent the most critical part of the modern grid.”[16] Like all critical infrastructure segments in the U.S., protecting against cyber threats is in-part dependent on a robust research and development effort as well as on effective partnerships between federal, state, and local governments and between the public and private sectors.[17]

Energy Storage

“What enable[s] renewables to assume the lion’s share of society’s energy generation portfolio is making that energy available wherever and whenever it is needed. Transforming the energy situation so that renewables provide the majority of the world’s usable power requires one essential missing element: energy storage.”[18]

- Gregg Maryniak, Co-Founder and Secretary of the X-Prize Foundation

Strengths: Energy storage is a key enabler and a necessary foundation for the future of electricity generation. The main strengths of storage are in its ability to improve electric grid reliability and supply quality while helping to mitigate the negative externalities of fossil fuel generation by enabling the wider deployment of renewables. Energy storage smooths the natural variation in electrical output that comes with solar and wind. Pumped storage was an early solution. It was first deployed in the U.S. in the 1930’s and its use is dependent on favorable geography and access to water – an increasingly scarce resource in many regions of the world.[19] However, the use of battery technology does not have these dependencies and is a flexible, scalable, and rapid way to store electricity generated during periods of excess production (i.e. storing plentiful daytime solar to redistribute it at night). For example, the integration of small distributed batteries in Electric Vehicles (EV), as demonstrated in a recent Department of Defense (DOD) / State of California study and prototype project, promises to help support the grid during peak load conditions while also better integrating the variability of renewables.[20] On a larger scale, multiple countries have begun to capitalize on the falling price of batteries driven by economies of scale from increasing EV deployment.[21] Australia’s completion of the largest utility scale system to-date stores and delivers energy from wind to end regional blackouts for thousands.[22] Recently in the U.S., New York followed California’s deployment of a 1,300 MW project when state officials committed to build 1,500 MW of battery storage to better integrate its increasing share of renewables and to reduce the impact from fossil fuel emissions.[23]

Weaknesses: As attractive as batteries may be, many of today’s most popular types contain strategic materials such as Lithium (Li) – a potential weakness for the U.S. and a national security concern because deposits are predominantly found in China and Chile.[24] While Li-ion is ideal for small applications, the future of meaningful grid or large-scale use may lie in vanadium flow battery technology (V-flow). Developed in partnership with the Department of Energy (DOE), these batteries are fully containerized, deployable, nonflammable, scalable, infinitely reusable; are capable of operating in a wide range of environmental conditions; and deliver power for half the cost of Li-ion.[25] In 2017, San Diego began leading the U.S. in building a 2 MW prototype project to power ~1,000 homes for four hours.[26] While Brazil, China, Russia, and South Africa produce the majority of the world's vanadium; the U.S. and Canada are thought to have plentiful but undeveloped supplies of this rare but increasingly important element.[27]

Opportunities: With these attributes, V-flow batteries may open up new opportunities for enhancing U.S. energy security at home and abroad. Today, many energy distribution networks lack the resilience and security one would expect in the 21st century. Take the havoc caused by the 2017 hurricanes on the Gulf Coast and Puerto Rico, which impacted many lives and large swaths of the U.S. economy. Three-months after Hurricane Maria struck, 1.5 million Puerto Ricans were still in the dark.[28] Energy security experts looking at alternatives for how to rebuild the island's electricity system note its reliance on fossil fuels, its fragile grid system, and its failure to deploy renewable energy generation and storage devices as key reasons for Puerto Rico's plight.[29] In 2012, the Congressional Research Service estimated the economic impact from power outages caused by severe weather impacting our vulnerable infrastructure at $55 billion annually while noting the frequency of such events is on the rise.[30]

Threats: Resilient energy supplies are even more critical to the security of our military deployed overseas. Vulnerable distribution systems present new risks and costs in a combat environment. A 2009 report by the U.S. Army showed that the DOD sustained a casualty for every 24 fuel convoys in Afghanistan and one for every 39 in Iraq.[31] Much of this fuel was delivered to operate electricity generators at forward operating bases. The report showed more than 3,000 U.S. troops were killed or wounded between 2003 and 2007 while executing these fuel resupply missions.[32] With these examples, it seems current U.S. energy networks are an Achilles heel both at home and overseas. Efforts to build secure networks by leveraging storage paired with local renewable power generation distributed on smart microgrids could significantly enhance U.S. security.

While the U.S. energy industry may benefit from the technological advancement in V-flow batteries, an analysis of the U.S. battery industry suggests it may be under threat. Appendix A Figure 1 summarizes a Porter's 5-Force Analysis showing that the industry has intense internal rivalry with strong price competition amongst existing competitors. This competition resulted in a -.7% annual growth rate for the past five years and an anemic .5% growth projected over the next five.[33] The industry faces strong headwinds from suppliers given ~50% of costs are at the mercy of fluctuating commodity prices and given access to key production materials are at the whim of foreign suppliers.[34] Batteries are often manufactured in standard power outputs, and form factors driving a robust buyer competitive force because switching costs can be low. While the threat of new domestic entrants is low given the high barriers to entry, such as the need for skilled workers, intellectual property (IP), costly capital equipment, and important supplier relationships; the threat of international competition is high given lower labor costs and a strong dollar further undercutting U.S. export competitiveness.[35] In addition, a senior DOE official speaking on the condition of anonymity added that the greatest force facing this industry is the proliferation of U.S. IP overseas paired with foreign government subsidies. These subsidies tend to stimulate early demand, thereby giving offshore companies a first mover advantage in manufacturing at scale many of the energy technologies first developed in the U.S.

Recent U.S. flow battery advancements promise to neutralize the weaknesses described above and help the U.S. more fully capitalize on the strengths of energy storage while uncovering new opportunities to further U.S. energy security. To fully exploit these opportunities, the U.S. must enact policies to educate the public on the benefits of storage to U.S. security and prosperity, establish a healthy domestic battery demand, cultivate the industrial base for these technologies, and ensure domestic access to key production materials.

Cybersecurity

Business operations have become dependent on cyberspace, and there is a need for an increased focus on cybersecurity. The internet, automation, and interconnected systems have transformed critical infrastructure and the energy sector of the U.S. The energy sector's interrelated segments consist of thousands of geographically dispersed assets that are interconnected through cyberspace by a complex architecture of systems and networks. This proliferation of technology has resulted in increases in efficiency and the reduction of personnel needed to manage and operate the energy infrastructure, yet it also increases the vulnerability of the nation's energy infrastructure, as demonstrated in 2013 when Iranian cyber actors hacked into the Supervisory Control and Data Acquisition (SCADA) systems controlling the Bowman Dam in Rye, New York.[36] SCADA, a legacy control and user interface system for industrial applications, is just one example of the vulnerabilities policymakers and industry must continue to address together as technology and the Internet continue to evolve.

However, the challenge highlighted above is a difficult problem because the cyberspace domain is a complex environment, and its ever-evolving nature makes it difficult to manage, secure, and defend. It "is particularly difficult to secure due to a number of factors: the ability of malicious actors to operate from anywhere in the world, the linkages between cyberspace and physical systems, and the difficulty of reducing vulnerabilities and consequences in complex cyber networks."[37] There are thousands of attacks conducted daily against U.S. critical infrastructure and the energy sector. Numerous threat actors with varied objectives operate in cyberspace. Nation-state and state-sponsored threat actors employ sophisticated tactics, techniques and procedures to conduct intelligence, surveillance and espionage operations against the energy sector. The Department of Homeland Security (DHS) and the Federal Bureau of Investigation announced "Russian hackers targeted small commercial facilities networks where they staged malware, conducted spear phishing, and gained remote access into energy sector networks."[38] Russia is not alone in this activity; China, North Korea, Iran and many other state and non-state actors are also very active in cyberspace.

Strengths: The U.S. has many capabilities and strengths that can be leveraged to increase cybersecurity in the energy sector. The Obama administration declared the energy sector one of the nation's sixteen critical infrastructure sectors and instituted policies that "[advance] a national unity of effort to strengthen and maintain secure, functioning, and resilient critical infrastructure."[39] Also, cyberspace has been declared the fifth domain of warfare and this allows the utilization of DoD and other governmental organizations and resources to support the DHS in the protection of the nation's critical infrastructure. The U.S has a well-resourced cybersecurity and intelligence apparatus in place today. The U.S. Cyber Command, as well as intelligence organizations such as the NSA, all have trained personnel and expertise focused on information security and computer network defense and exploitation.

Weaknesses: However, weaknesses exist in cybersecurity for the energy sector. While the government has the capabilities and strengths noted above for public networks and infrastructure, most of the energy infrastructure is owned and operated by the private sector. As a result, cybersecurity is dependent upon effective partnerships between the government and private industry. To this end, the National Institute for Standards and Technology (NIST) cybersecurity framework, which is endorsed in government policy and consists of a set of standards, administrative guidelines, and best practices for improving cybersecurity, is offered to private sector entities as a set of voluntary measures to strengthen their cybersecurity posture.

While the framework is an important step, there is no enforcement mechanism to ensure organizations implement the guidance so getting the right balance of incentives to promote risk mitigation and innovation is critical for the private sector. Further, the information sharing between government intelligence organizations and private sector businesses is sluggish and does not provide timely information to the private sector. Lastly, the government does not provide financial incentives to promote investment in cybersecurity, instead relying to-date largely on market forces and industry's perception of the risks and costs to incentivize action.

Opportunities: There are opportunities to improve cybersecurity for the energy sector. DHS was directed to develop policy to incentivize investments in cybersecurity and promote the adoption of the NIST cybersecurity framework but DHS has failed to complete this task. The incentives could consist of tax breaks and government grants to stimulate investment while improving overall critical infrastructure cybersecurity. There is also an opportunity to improve the speed at which information is declassified and shared to provide timely and actionable cybersecurity intelligence to private industry. While concerns over protection of intelligence sources are legitimate, agencies can and should focus on separating sources and methods from the needed actionable information so the private sector can better proactively protect the nation's infrastructure.

Currently, military, and civilian agencies are constrained in their ability to respond to cybersecurity threats because the authority to conduct limited cyber operations in response to an attack is held at the highest levels of the executive branch of government. The opportunity exists to improve cybersecurity by expanding rules of engagement for responding to cyber-attacks.

Threats: A major threat to cybersecurity is the collusion of governments and corporations to undermine cybersecurity, such as, the relationship between Kaspersky and Russian intelligence. "Internal company emails obtained by Bloomberg Businessweek show that Kaspersky Lab has maintained a much closer working relationship with Russia's main intelligence agency, the FSB, than it has publicly admitted. It has developed security technology at the spy agency's behest and worked on joint projects the CEO knew would be embarrassing if made public."[40] Additionally, the threat exists of governments and corporations undermining the supply chain for consumer goods such as Chinese hardware companies Huawei and ZTE. "U.S. intelligence agencies warned Americans not to buy smartphones made by Huawei or ZTE, another Chinese tech company, saying the devices pose a security threat to American customers."[41] The last major threat to cybersecurity is complacency and/or a lack of a response by the U.S. government to malicious cyber activity and attacks by foreign governments. Such a threat is insidious because it encourages increasingly brazen behavior if left unchecked.

Supply Chain

An essential element of the NSS is building healthy and secure supply chains.[42] This is particularly important since the nation's energy dominance is a major portion of the Strategy's efforts to stimulate the economy and ensure future prosperity by leveraging the nation's abundant energy resources.

Strengths: To this end, there are many strengths in the U.S. energy sector supply chain that give the U.S. a competitive advantage. For example, according to the U.S. Energy Information Administration's (EIA's) 2018 Annual Energy Outlook through 2050, the U.S.'s "strong domestic production coupled with relatively flat energy demand allows the United States to become a net energy exporter over the projection period in most cases."[43] The report highlights that our nation's energy consumption will either exceed or fall 10% short of supply based on either an optimistic or pessimistic model. This U.S. energy production revolution will be driven by a 31% increase in natural gas, solar, and wind through 2050, with hydropower, nuclear power, and coal production remaining relatively flat.[44] Led by technological advancements, which allow new access and increased production of natural gas and oil based on now favorable geology for exploration, production costs will continue to decline allowing the U.S. to become a net exporter by 2022.[45] From field study interviews, it was clear that a key enabler in developing this production revolution and meeting future demand is the quality of the U.S. infrastructure system (roads, ports, railways, etc.) which acts as a foundation and engine of growth for the energy industry.

Weaknesses: Despite these strengths leading to a new era of U.S. energy security, the energy supply chain does have weaknesses. Our domestic oil refineries are clustered in three geographical regions: the West coast, along the Gulf of Mexico, and the Great Lakes Region. For example, the Colonial Pipeline moves 100 million gallons of gasoline, diesel, heating oil, and jet fuel along a 5,500-mile line between Houston and New York harbor.[46] When there is a short disruption in the line as there was in the Fall of 2016 after a deadly explosion, one-third of all the fuels consumed on the east coast were removed from the market resulting in soaring prices and reduced economic activity.[47] The high concentration of our oil refineries in these regions exposes our nation to the risk of losing a large percentage of our refining capacity in the event of major natural or manmade disasters impacting just a few pieces of critical infrastructure.

Similarly, domestic political resistance to the establishment of natural gas pipelines to transport U.S. produced gas to New England resulted in the region buying LNG from Russia, an adversary, to sustain Boston area citizens through the 2017-2018 winter. This situation creates an unacceptable situation where U.S. consumers are enriching a Russian gas company whose majority shareholder is on the U.S. sanctions list for their links to the on-going war in eastern Ukraine and Russia's illegal annexation of Crimea.[48] China and other foreign countries have also achieved dominance in the manufacturing of components required to produce renewable energy including securing access to many of the strategic materials required for similar production activities around the world. Their ability to produce these products at a lower cost or constrain the global supply of rare earth material gives them the competitive advantage required to push U.S. manufacturing firms out of business, making the U.S. dependent on foreign sources of supplies needed to improve and maintain our critical energy infrastructure.

Opportunities: The U.S. has the opportunity to strengthen the resilience of our energy supply chain by encouraging industry to establish a more dispersed supply chain throughout our nation instead of maintaining the majority of its production and refining capacity in tight geographic clusters. The U.S. should endeavor to strengthen trade, particularly with Western Hemisphere partners such as Canada, Mexico, Central America, and South America, in order to ensure access to energy supply sources in the event of a temporary loss in domestic capacity.

Threats: The U.S. energy supply chain also faces a series of threats to our future energy security. The loss of U.S. manufacturing dominance to foreign countries, including adversaries like China, combined with competitors' proven ability and willingness to steal and exploit U.S. energy-related IP, threatens our nation's competitive advantage when it comes to the development and implementation of new technology and processes within the industry. The threat to IP either drives a company to innovate faster or discourages investment in R&D altogether. Either outcome challenges the nation's technological prowess globally.

Environmental regulations also discourage investment and development of new energy sources such as low-cost LNG projects and undercuts traditional sources of energy supply from coal, making them less competitive and reducing the incentive for industry to maintain a broad portfolio of energy sources. Similarly, as mentioned above, domestic politics prevent the construction and operation of gas pipelines in certain regions of the U.S. reducing the availability of supply to regions and thereby hampering economic growth. Without the investment in critical infrastructure to distribute plentiful U.S. energy products like natural gas, the application of the NSS's vision of using energy to grow American prosperity will be uneven, forcing many, particularly those in New England, to be left behind.

Physical Security

Strengths: The physical security of our energy infrastructure is a perennial concern for our nation's law enforcement and intelligence agencies. Indeed, disasters - both natural and manmade - threaten to disrupt our energy supply and to thereby wreak havoc on our nation's economy. Fortunately, the energy sector has extensive experience in assessing and mitigating risks to its infrastructure. This experience has yielded several sophisticated methodologies for assessing risk—experience the sector augments by drawing upon similar techniques developed by the federal government, academia, and research centers.[49] Moreover, since the 9/11 terrorist attacks, the government has taken an increasingly active role in assisting the sector in securing its infrastructure. Both DOE and DHS offer energy companies the tools, technology, and expertise to help protect their assets from physical threats.[50] [51]

Weaknesses: However, the sheer size and distribution of energy operations makes maintaining physical security a daunting task. This is especially true for global firms, for whom securing the diverse assets, products, and supply chains requires significant investment in terms of resilience and protection.[52] Moreover, U.S. companies continue to depend heavily on foreign manufacturers for critical components, such as large power transformers (LPTs).[53] Finally, deep interdependencies exist among the various sub-sectors, and a failure in one industry impacts a host of others. Thus, vulnerabilities are not localized, and firms must depend on one another to properly address their individual vulnerabilities.

Opportunities: As significant as these weaknesses are, they beget significant opportunities. Indeed, because threats are sector-wide affairs, cooperation within the sector is already high as evidence from the Houston area field studies showing strong cooperation between federal, state, and local authorities. Nevertheless, opportunities to improve cooperation, particularly in terms of information and equipment sharing, always exist.[54] Other opportunities exist for U.S. manufacturers to fill key voids, such as LPTs, in domestic industrial capacity. Finally, additional opportunities exist to leverage domestic R&D efforts to harden infrastructure and enhance resiliency—steps that would protect systems against any number of threats.

Threats: Threats facing our energy infrastructure include both extreme weather and physical attacks. Natural disasters, such as hurricanes, tornadoes, and severe thunderstorms, can disrupt our domestic fuel supply as well as cause grid failures. For example, Hurricane Sandy severely damaged the electrical grid and left millions without power. Human attackers, however, can replicate the threats posed by nature. Should vandals destroy key grid components, for example, the resultant damage could cause cascading blackouts. Alternatively, should they target pipelines, they could create gas shortages whose impacts would reverberate throughout the economy. For these reasons, critical infrastructure systems make attractive targets for terrorists, and they would also be prime targets in a conventional war.

Energy Efficiency

U.S. energy efficiency policy initiatives and the resultant technological progress impact many sectors and activities in the U.S. economy, including transportation, numerous residential and commercial activities consuming electricity on the grid, and building standards, just to name a few. Such policies and R&D activities have a prominent place in U.S. strategy in ensuring the security and prosperity of the nation. These policies only help to strengthen our ability to meet current and future energy demands while offering new opportunities to meet the demands of a vibrant, rapidly growing U.S. economy.

Strengths. Many current initiatives were born out of the oil supply shocks of 1973 and 1979.[55] These exogenous events gave a sense of urgency and support to policymakers that allowed the passage of landmark legislative initiatives at the state and federal levels. For example, California led the nation with the first efficiency standards enacted into law in 1974.[56] Congress soon followed suit by establishing comprehensive measures, including the Energy Policy and Conservation Act of 1975, which established energy targets for consumer products; the National Appliance Energy Conservation Act of 1987, which created efficiency standards for many common household appliances; and the Energy Policy Act of 1992, which added standards for lighting, commercial water heaters, and heating, ventilation, and air conditioning systems.[57] While much has been accomplished since these laws were passed, sustained Congressional and Executive Branch support for efficiency policies and innovation activities to meet these goals has yielded impressive results even in the short-term, as shown in Figure 7.

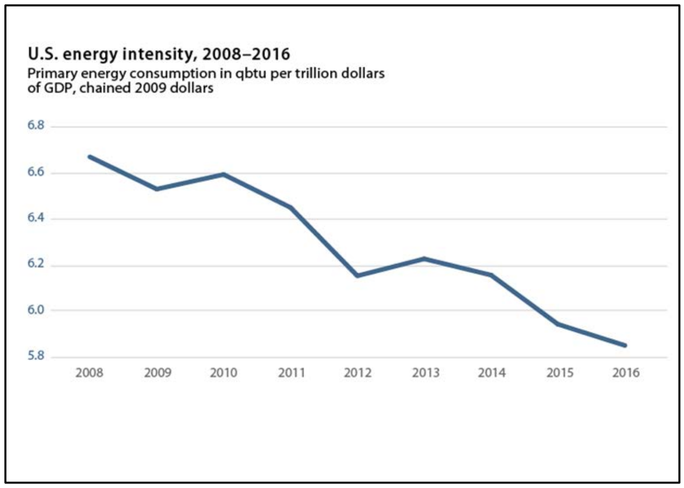


Figure 7: U.S. Energy Consumption

This success is likely because efficiency serves both policymakers' and consumers' interests by enabling them to do "the same amount of work - often in a better, cleaner and cheaper way - with less energy," so by improving the efficiency of our grid, our cars, our devices, our homes, and our buildings, we can decrease the total amount of energy we must produce to meet demand.[58] Indeed, we have benefited from more than four decades of focus in this area. In the U.S., while GDP tripled since 1970, our current energy consumption is half the level projected without initiatives like the ones listed above.[59] Since 2000, the U.S. electricity growth rate has plummeted and is expected to remain ~+1% despite strong economic growth.[60] Indeed, electricity demand is driven not only by economic growth but also by the result of successful energy efficiency initiatives.

Opportunities: Efficiency decreases our dependence on fossil fuels and improves the competitiveness of renewable sources.[61] The more renewables become economical and convenient, the more they will displace fossil fuel energy production.[62] That said, rather than attempting to replace fossil fuel energy at its current production levels, the U.S. should pursue the R&D of technologies that promise to reduce significantly the amount of energy we need to generate. In this regard, improved efficiency can quicken the pace with which renewable production levels surpass those of fossil fuels.

Advancements in this area have environmental implications as well. By decreasing the amount of fossil fuels needed to meet demand, efficiency effectively serves as a clean fuel in its own right.[63] According to the International Energy Agency (IEA), "improved energy intensity has been the biggest factor behind the recent flattening of global greenhouse gas emissions."[64] Moreover, by promoting renewables, efficiency also facilitates a reduction in carbon dioxide (CO2) emissions.[65] If history is a guide, California may be leading the nation again in this regard by adopting new landmark initiatives as state regulators recently approved a mandate to include solar panels on most new home construction.[66] For these reasons, Congress should carefully consider new national standards to help further diversify energy supply towards renewables while continuing to prioritize efficiency research. As shown in Figure 8, on the efficiency front, rejected energy, or energy lost in the system, comprises 66% of the total input, so opportunities are plentiful for further efficiency improvements.

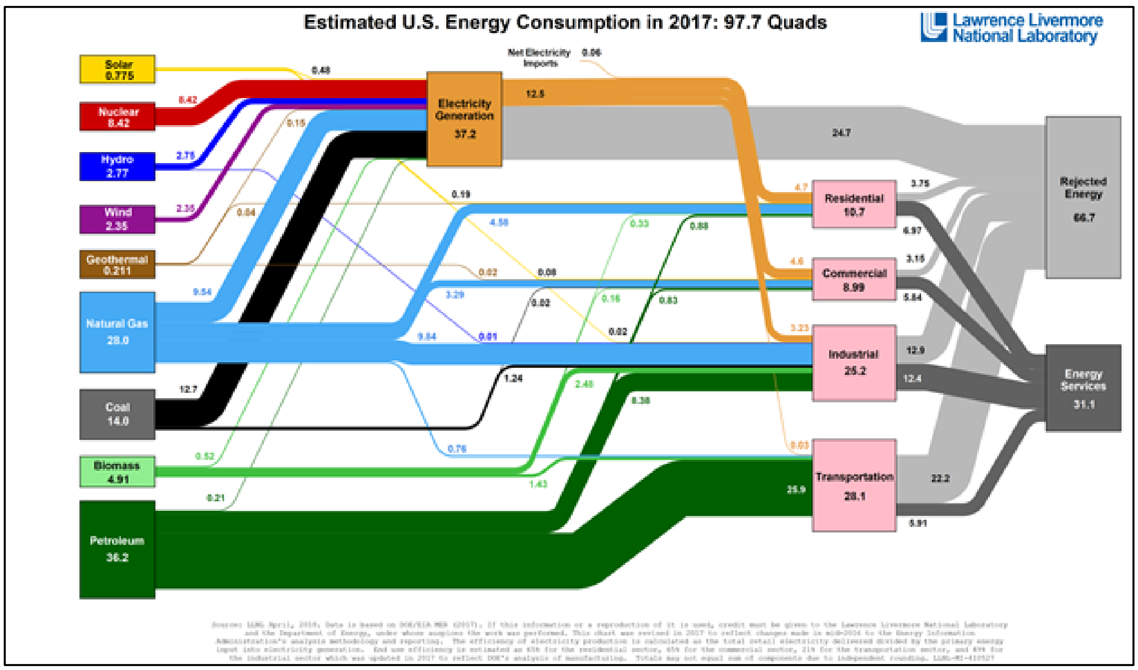


Figure 8: U.S. Energy Consumption and Losses

Research and Development (R&D)

R&D is the backbone of the U.S. economy, and according to the NSS, it is an essential element in preserving security and in promoting prosperity.[67] [68] Indeed, our nation's R&D efforts are responsible for the countless innovations that improve processes, goods, and services and thereby fuel our nation's economic growth while improving the standard of living of all American's. Without the ever-expanding sphere of knowledge and cutting-edge technologies that R&D generates, the quality of other nations' goods and services will eventually overtake ours, and we will then cease to be competitive in the global marketplace.[69] Should this happen, affected industries will atrophy, and we will become increasingly dependent upon other nations. Within the context of energy security, this means relying on potential adversaries for the materials, technology, and expertise we need to meet our growing energy demands.

Strengths: Fundamentally, the U.S. R&D apparatus enjoys a number of strengths, particularly when compared to other nations. For example, the U.S. enjoys an open, vibrant economic culture—one that values innovation and resiliency. Moreover, our nation's R&D budget has for decades eclipsed that of other nations, and government agencies, such as the DOE, direct these funds to a variety of programs designed to advance critical technologies, including nuclear energy, renewable energy, energy efficiency, and energy storage programs. These efforts leverage the resources provided by some of the world's finest research universities as well as by highly advanced, federally funded research laboratories. As knowledge expands, the U.S.'s robust private sector takes the lead in developing ideas. For this stage, R&D tax credits and IP laws act as incentives to create and commercialize new goods and services.

Weaknesses: Domestic R&D is not without its weaknesses, however. In recent years, the U.S. has decreased its research funding even as other nations have increased theirs.[70] Such funding reductions "stand to hurt many advances that will be crucial to our clean-energy future."[71] Indeed, recent technological advances, while promising, are not yet ready for commercialization "and might never make it if they [do not] receive funding over the coming years."[72] Moreover, the increased politicization of energy issues has created a divide between those advocating for a rapid transition to renewables and those favoring a more gradual shift. The resultant political instability has left researchers and CEOs alike unable to build sound investment strategies based on predictable government policies, regulations, and initiatives.

For example, even a program as historically successful as the Research and Experimentation tax credit is temporary, and given its past lapses, many companies are no doubt reluctant to invest too heavily in R&D because of the potential risks associated with the credit's expiration.[73] Additionally, the 2019 budget before Congress does much to add to make national R&D policies more unpredictable. Congress must determine whether to support the Administration's efforts to eliminate the entire budget of the Advanced Research Projects Agency-Energy (ARPA-E), the same organization that successfully developed the revolutionary flow battery, or to advance efforts to cut by two-thirds the DOE's Office of Energy Efficiency and Renewable Energy's budget, which funds the implementation of many efficiency initiatives discussed above.[74] Debates like these do much not only to raise questions in industry about supporting new investments to further U.S energy dominance but also to threaten the maintenance of high-tech skills required to sustain America's leadership in the world.

Opportunities: As the world becomes more aware of the effects of climate change, firms will face mounting pressures to decrease their carbon footprints, and as renewables become more cost competitive, they will offer corporations an affordable means to do just that. Moreover, advanced energy technologies like renewables are fast becoming vibrant industrial sectors, and through the right combination of government investment, tax incentives, and regulations, our nation could find itself the global leader in the development and manufacturing of these systems.[75] The economic and national security advantages of such robust domestic capacity are significant enablers for the economy and the U.S. conversation on their adoption should revolve around the economic and security benefits of doing so not around just furthering any environmental improvements. As a result, Congress and the Executive Branch should work to add policy stability to energy R&D to help the U.S. better compete with the likes of China, Germany, and others who are investing heavily in future energy capabilities.

Threats: The most significant threat the U.S. faces is that nations hostile to our interests may become global leaders. Far from being hypothetical, this scenario is already unfolding as our international competitors outpace us in developing and manufacturing key technologies, such as alternative energy systems. For example, Chinese solar panel manufacturers now hold a 20% cost advantage over their U.S. counterparts, and Chinese manufacturers also produce some of the world's most technically sophisticated wind-turbines.[76] Absent robust domestic industrial capacity, we may one day find ourselves unable to meet our energy needs without the aid of those whose interests do not align with our own, and on that day, we will be vulnerable to the sorts of supply disruptions that plagued the U.S. in the 1970s.[77] It is therefore critical that we spur technological innovation and restore our competitive advantages.

Key Takeaways: These foundational elements of the energy industry enable a competitive industry and a vibrant, growing U.S. economy. Decades of building, refining, and innovating have resulted in a diverse portfolio of energy resources, technologies, and capabilities that have provided an important 'fuel' necessary to preserve the nation's security and prosperity. U.S. policymakers should help further the recommended national energy imperatives by de-politicizing R&D policies, increasing R&D investment, increasing regulatory stability and certainty to support industry investment decisions, educating the public on the national and personal economic benefits of grid modernization, and strengthening trade as a hedge against supply chain risks while growing new opportunities for American resources and innovative capabilities abroad. The state and composition of technology and sources of energy continue to evolve, and an examination of the state of technology demonstrates how it continues to develop and mature.

State of Technology

Current State of the U.S. Energy Industry

The U.S. consumes approximately 97.4 quadrillion Btu of electricity per year. Figure 6 shows that in 2016, 37% was from petroleum, 29% natural gas, 15% coal, 9% nuclear, and 10% renewable energy. Approximately 6% of the renewable energy was solar (.6% of the overall total).[78] In 2010, 37% was from petroleum, 25% natural gas, 21% coal, 9% nuclear, and 8% renewable energy. Only 1% of the renewable energy was from solar (0.08% of the overall total).[79] Two key trends stand out from looking at these numbers. First, natural gas is quickly becoming a larger source of electricity in the U.S. To this point, it is mostly displacing coal, which is more expensive and produces more carbon emissions. The second trend is that renewables are growing rapidly (also replacing coal) and solar accounts for the biggest portion of this growth. As a percentage of the overall total, solar owns a 7.5 times larger slice of the pie than it did seven years ago. It is also the fastest growing segment of all the renewable sources (wind is second, which went from 11% of renewables to 21%).[80]

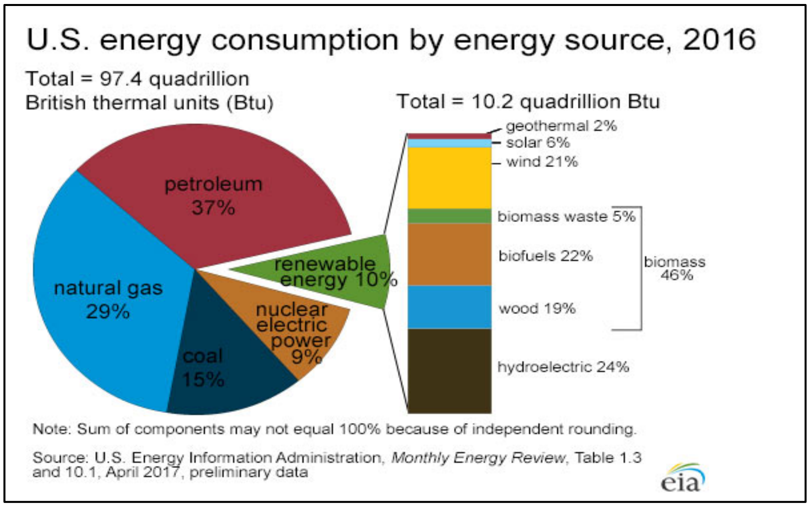


Figure 9: U.S. Energy Consumption by Source

The main reason that natural gas had such an increase in market share is that companies developed the ability to combine hydraulic fracturing, or fracking, with horizontal drilling, which has given them access to vast natural gas resources that were previously inaccessible.[81] This vast supply put downward pressure on prices and led to natural gas supplanting other forms of energy, most notably coal.[82] Natural gas is not, however, the only electricity source that has become cheaper in the last decade. Both solar photovoltaic (PV) and onshore wind have become more cost competitive which partially explains their gain in market share. The table to the right shows the estimated costs of new electricity generation in 2022 (a helpful timeframe in which to look at prices when considering government policy recommendations). Of note, the predicted cost of natural gas generation is $49.0/MWh. Solar and on-shore wind are $49.9 and $48.0 respectively, making them competitive on price (with current tax credits in place). Advancements in solar and wind technology promise to make them cost-competitive without government subsidy, which would mark a huge milestone and pave the way for significant market-driven

Table 1b. Estimated levelized cost of electricity (unweighted average) for new generation resources entering service in 2022 (2017 $/MWh)

Plant type	Capacity factor (%)	Levelized capital cost	Levelized fixed O&M	Levelized variable O&M	Levelized transmission cost	Total system LCOE	Levelized tax credit¹	Total LCOE including tax credit
Dispatchable technologies								
Coal with 30% CCS²	85	84.0	9.5	35.6	1.1	130.1	NA	130.1
Coal with 90% CCS²	85	68.5	11.0	38.5	1.1	119.1	NA	119.1
Conventional CC	87	12.6	1.5	34.9	1.1	50.1	NA	50.1
Advanced CC	87	14.4	1.3	32.2	1.1	49.0	NA	49.0
Advanced CC with CCS	87	26.9	4.4	42.5	1.1	74.9	NA	74.9
Conventional CT	30	37.2	6.7	51.6	3.2	98.7	NA	98.7
Advanced CT	30	23.6	2.6	55.7	3.2	85.1	NA	85.1
Advanced nuclear	90	69.4	12.9	9.3	1.0	92.6	NA	92.6
Geothermal	90	30.1	13.2	0.0	1.3	44.6	-3.0	41.6
Biomass	83	39.2	15.4	39.6	1.1	95.3	NA	95.3
Non-dispatchable technologies								
Wind, onshore	41	43.1	13.4	0.0	2.5	59.1	-11.1	48.0
Wind, offshore	45	115.8	19.9	0.0	2.3	138.0	-20.8	117.1
Solar PV³	29	51.2	8.7	0.0	3.3	63.2	-13.3	49.9
Solar thermal	25	128.4	32.6	0.0	4.1	165.1	-38.5	126.6
Hydroelectric⁴	64	48.2	9.8	1.8	1.9	61.7	NA	61.7

Figure 10: Estimated U.S. Levelized Cost of Electricity (courtesy of EIA)

changes in the nation’s energy portfolio going forward.

This section will address the state of current technology, to include a SWOT analysis of fossil fuels, renewable energy, and nuclear power. The fossil fuels discussion includes oil, coal, and natural gas. The renewables discussion consists of solar, wind, hydro, geothermal, and biomass waste.

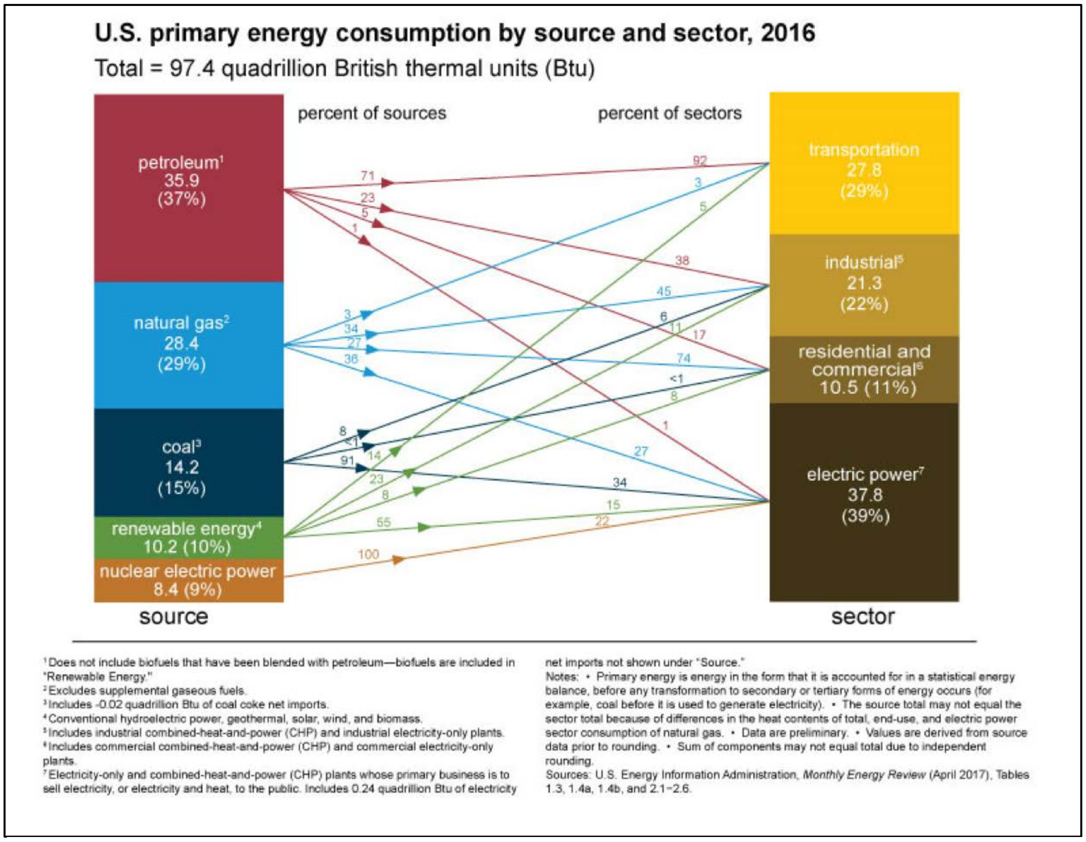


Figure 11: U.S. Energy Consumption by Source

Fossil Fuels

Fossil fuels, including oil, coal, and natural gas, have served as the primary energy source for the world over the last century.[83] Fossil fuels are nonrenewable energy sources, meaning that these sources exist in limited supply.[84] Fossil fuels provide a reliable and resilient form of energy, but the substantial harmful impact on the environment in the form of greenhouse gases has demonstrated a need to pursue alternative and more renewable forms of energy. DOE's National Energy Technology Laboratory (NETL) conducted a study whose conclusions included a continued need for fossil fuel power plants to meet power generation needs during severe weather events.[85] “A winter storm, known as a “bomb cyclone,” struck much of the eastern United States between December 27, 2017 and January 8, 2018, plunging the region into a deep freeze and sparking a significant rise in the demand for additional power for heat. Coal provided a majority of the daily power generation required to meet the emergency...”[86] This event demonstrated the importance of maintaining a diverse energy supply portfolio that provides energy security in extreme situations.

Oil and Petroleum Products

Crude oil is refined into petroleum products including gasoline, diesel fuel, jet fuel, heating oil, petrochemical feedstocks, waxes, lubricating oils, and asphalt. Petroleum accounts for the greatest share of energy consumed in the United States at 37%. EIA predicts that petroleum and other liquid products will continue to rank highest in energy consumption in the U.S. through 2040.[87] In 2016, approximately 75% of the U.S.'s petroleum consumption was in the transportation industry.[88]

Strengths: Oil continues to be utilized and required for a vast multitude of products, which protects the industry. In 2016, crude oil prices were at their lowest since 2004, and in 2017 they increased slightly.[89] Due to strong demand and weak near-term investment, EIA projects that crude oil prices will continue to rise in the near term.[90] The oil companies tend to be large corporations who dominate the industry. Some companies, like BP, are vertically integrated, which provides the benefit of operating in the entire supply chain, to include exploration, extraction, transportation, refining, and distribution.[91]

Weaknesses: As a fossil fuel and source of carbon and environmental emissions, a clear weakness of oil includes its harmful environmental impact. Oil spills, including the 2010 Deepwater Horizon spill, have tarnished the industry and brought to light weaknesses in safety and environmental risks. The 2005 explosion in the BP Texas City refinery left fifteen employees dead and 100 injured.[92] Weaknesses of the oil sector also include the security and redundancy of the refining capabilities since many facilities are situated along the Gulf Coast and could be adversely impacted by an extreme weather event or other disaster.

Opportunities: Opportunities for the oil sector include technological developments in shale oil and growth in the overseas market, which positively impacts U.S. energy security near-term. Oil companies are also presented with the opportunity to invest in renewable technology research as protection from a future reduction in demand for oil.[93] The growth of natural gas exists as an opportunity for oil companies to grow by expanding into the natural gas market.

Threats: Threats include the growth of renewables and more sustainable sources of energy, more regulation, and the growth of foreign oil markets. In the transportation industry, the growth of electrification of vehicles also poses a threat to this industry in the future. Threats can also include the instability in regions of the world with high oil production. The growth of environmental protection regulation will mean increased operating costs in the oil industry.[94] The unknown factor of oil price fluctuations makes for an unpredictable future in this industry.

Coal

The demand for coal for electricity generation has declined in recent years due to several factors. Market forces have drastically changed as the cost of natural gas has decreased, and technological advances have improved the ability to access natural gas. The impacts of climate change have generated a widespread demand for more renewable energy and energy sources with less harmful emissions to the environment.[95] EIA published predictions that show a decreasing demand for coal for electricity generation after which coal demand remains flat for decades.[96] In 2017, coal consumption was reported at 30% of U.S. electricity generation, which demonstrates a 7% decline since 2012 and is the lowest share on record. The U.S. coal market in 2017 included 82% for domestic power generation, 11% for exports, and 7% for metallurgical coal.[97]

Strengths: Coal's greatest strength lies in its reliability as a source of energy that has been tested over time. The NETL report concluded that the, "U.S. electricity market experience demonstrated that without the resilience of coal plants—its ability to add 24-hour baseload capacity—the eastern United States would have suffered severe electricity shortages, likely leading to widespread blackouts."[98] Coal is utilized in producing many products, including chemicals, cement, paper, ceramics, and metal. Steel, used in the construction industry, automobile industry, and other industries, is produced with coke, a by-product of coal. Methanol and ethylene, which are both coal gases, are used to make products such as plastics, medicines, fertilizers, and tar.[99] Coal provides economic benefit to the U.S. in employment and as an export to many nations.

Weaknesses: Although coal power displays several weaknesses, the greatest weakness of coal in our energy industry remains the harmful impact on the environment, including greenhouse gas emissions contributing to climate change. In 2012, 28% of total U.S. CO2 emissions were generated from coal-fired power plants.[100] CO2 comprised 82% of the total greenhouse gas emissions attributed to humans in 2015, and fossil fuel combustion comprised the largest source of overall greenhouse gas emissions.[101] Currently, coal also costs more than natural gas, making it a less desirable fossil fuel for energy production.

Opportunities: Opportunities for the future of coal include continued efforts to make coal cleaner.[102] "Clean coal technology (CCT) seeks to reduce harsh environmental effects by using multiple technologies to clean coal and contain its emissions."[103] Carbon capture and storage (CCS) technology has been demonstrated in several plants, including Petra Nova, the world's first post-combustion plant, which resides 30 miles southwest of Houston. This plant was implemented as a part of the Obama Administration's investment of $84 million in CCS technology and captures 1.6 million tons of carbon dioxide each year. The Intergovernmental Panel on Climate Change and the International Energy Agency both commended CCS technology.[104]

Threats: Threats to the future of coal include environmental impacts of coal-fired power production, lower prices of other fossil fuels, an uncertain political environment, unstable regulatory conditions, and the growth of renewable sources of energy.[105] With the shift from coal to natural gas, coal plants are being retired and new coal plants are not being constructed. Over the next two years through 2020, approximately 25 GW of coal-fired electricity generation will be retired. In 2017, the generating capacity in the U.S. totaled 260 GW, and in 2011 it totaled 310 GW.[106] Alternative sources of energy, including natural gas, oil, nuclear, and renewables comprise substitutes to coal that threaten coal's future. Competitors in the coal industry are struggling to keep their customers while competing to determine which companies will be able to remain in the market. Other outside forces, including politics, government, and regulation, contribute to the uncertainty of the industry's future.[107]

Natural Gas

Due to the shale production revolution, which leveraged hydraulic fracturing and horizontal drilling techniques, some geologists believe the world is entering a Golden Age of Natural Gas for the next 100 years.[108] This aligns with President Trump's NSS and provides the U.S. the ability to become an energy-dominant nation by strengthening its diversity with a robust energy resource. Natural gas is a leading energy source in the U.S. at 29% of total energy production and is projected to increase to over 40% by 2050.[109] Although the U.S. is currently not a member of the Paris Climate Agreement, the U.S. still plans to be a global leader in decreasing traditional pollution while simultaneously growing its economy and strengthening the redundancy of the energy industry.[110] One of the approaches to solving these problems should be leveraging natural gas.

Strengths: According to the EIA, as of January 1, 2016, the U.S. possesses approximately a 90-year supply of natural gas. Because of its low price and abundance, natural gas is becoming a dominant energy source.[111] Locations where natural gas is abundant should see an economic boom and will serve as critical injection points to the growth of the U.S. economy. Natural gas also burns the cleanest of all fossil fuels, with CO2 emissions 30% less than oil and 45% less than coal.[112] Natural gas provides a low-cost energy source not only due to technological advances in production but also due to existing pipelines and Compressed Natural Gas trucks.[113] As the U.S. continues to expand its LNG production facilities, this will strengthen natural gas's dominance in the energy sector as a reliable and safe source.

Weaknesses: Some of the original successes of natural gas stem from the implementation of the Clean Power Plan (CPP) Act, enacted under President Obama, which focused on improving emission standards while promoting energy diversity and redundancy.[114] The CPP led to a decrease in coal production and an increase in natural gas production, not only due to its low cost but also due to its ability to meet energy emissions standards. President Trump has demonstrated an interest in repealing the CPP. The repeal of the CPP could stabilize the production of coal but decrease the U.S.'s ability to reach emissions standards and potentially decrease the production of natural gas. The CPP provides for tax credits for renewables until 2020, but they do not apply to fossil fuels. Since natural gas is a much cleaner source than other fossil fuels, allowing new LNG customers to receive a tax credit could further promote its use and aid in building reliable infrastructure.[115] Natural gas also creates large amounts of methane gas during the exploration, drilling, and production process, thereby impacting the environment.[116]

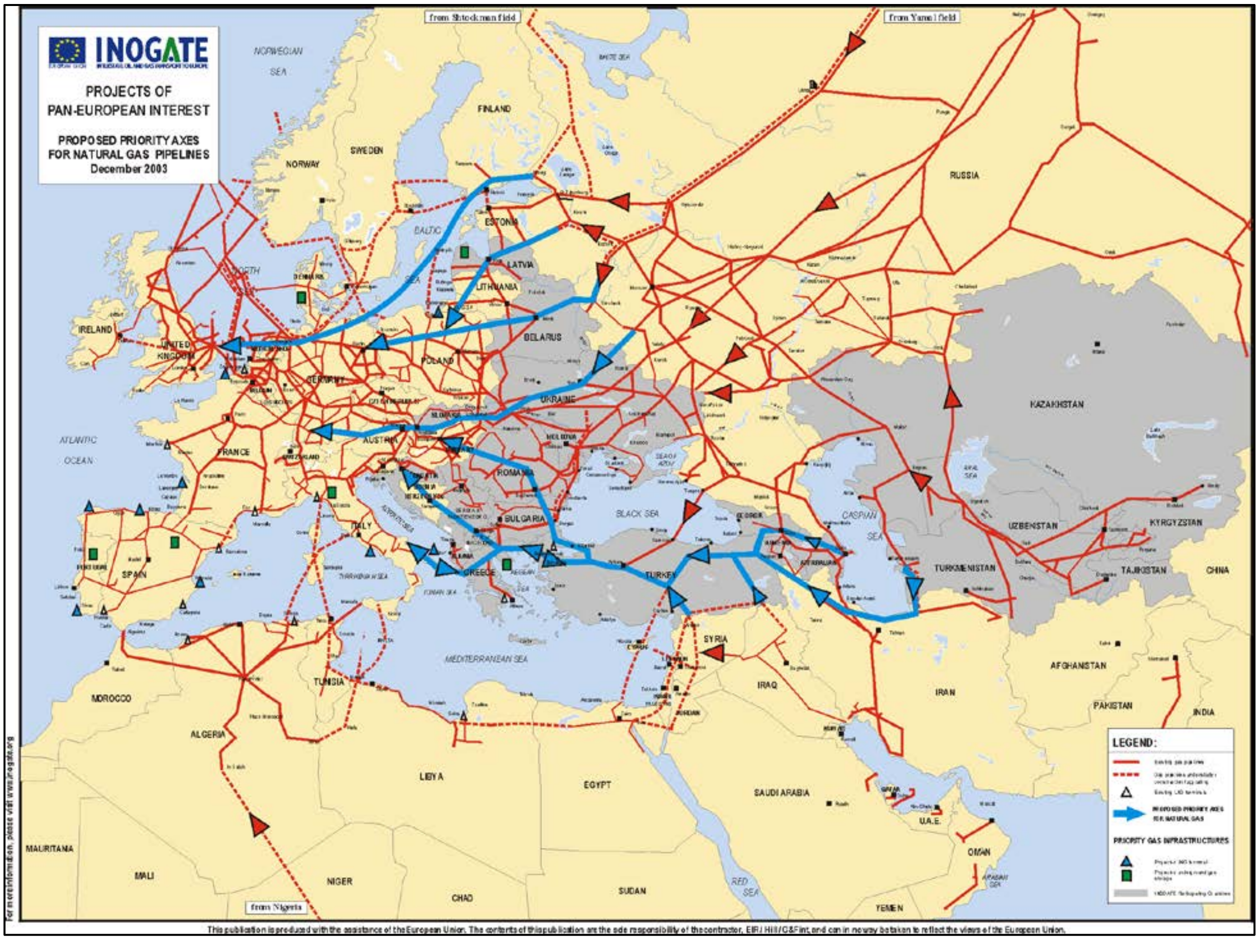


Figure 12: Europe, Africa, Russia Pipelines Interconnections

Opportunities: Domestically, natural gas is currently positioned to become a dominant energy source. Due to its low cost, it should play an increasing role in the nation's energy portfolio. Even as more renewables come on line, natural gas will play a critical role in the long-term. Internationally, natural gas also presents great opportunities. With Cheniere's initiation of LNG exportation from its Sabine Pass location, the U.S. has become an international exporter. Currently, about 92% of natural gas exports from the U.S. are shipped to Canada and Mexico with the other 8% being used to ship LNG around the world. This became possible because President Obama and the 115th Congress passed the Export American Natural Gas Act of 2015. This natural gas policy will enable the U.S. to be a net exporter by 2020, allowing U.S. companies to trade with over 40 LNG trade nations.[117] Geopolitically, LNG exports to Europe may play a critical role in decreasing the EU's dependence on Russia for natural gas.

Threats: The top natural gas producers include the Middle East, U.S., China, and Russia. Indeed, as time goes by, more and more countries are using natural gas as a reliable, resilient, and low-cost alternative energy source. Since some of these countries are island nations or contain contested boarders, receiving natural gas through a pipeline is not possible. This allows LNG shipping to be a viable method for receiving this product. The country that can compete best in the LNG market stands to reap great benefits from an economic and geopolitical perspective going forward. Another significant threat to natural gas could be our leadership's role in renegotiating or withdrawing from major trade deals, including the North American Free

Trade Agreement (NAFTA), Trans-Pacific Partnership (TPP), and Transatlantic Trade and Investment Partnership (TTIP). Our partners and allies look towards U.S. leadership to broker fair deals and to allow for free trade to improve stakeholders' respective situations.

Renewable Energy (Solar, Wind, Hydro, Geothermal, Biomass)

As mentioned above, renewable energy (energy from sources that naturally regenerate) from solar, wind, hydropower, geothermal, and biomass are quickly growing their share of the country's overall energy production. It grew from 8% of the total in 2010 to 10% of the total in 2016 with the rate of change steadily increasing along the way. This increase was sparked by society's demand for cleaner and renewable sources of energy. It was aided by federal and local government tax incentives. Moreover, in the case of solar and wind, the increase has been stoked by the steady decline in the cost of installing the systems. If demand continues to increase, costs continue to decrease, and engineers can discover ways to mitigate their intermittency, renewable energy is poised to become the dominant form of electricity generation in the U.S. in the decades to come.

Solar Power

There are two broad categories of solar energy generation. The first is distributed solar energy, which is defined as a small-scale operation that generates less than 1 megawatt. Although some of these systems are "tied to the grid," it is helpful to think of these as isolated systems designed to provide power to individual entities (e.g., solar panels on a homeowner's roof or an array of solar panels providing energy to a corporation or military base, as illustrated in Figure 13).

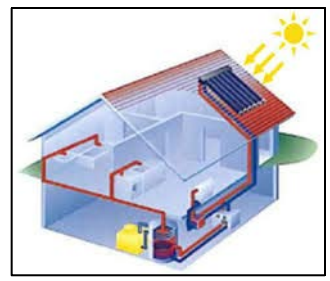


Figure 13: Small Scale Solar

The second is "utility-scale", which are larger systems designed to feed energy "to the grid."[118] Of the 775T Btu of solar currently being consumed in the U.S., 286T is on distributed systems, and 489T is on utility scale systems.[119] Distributed systems are almost exclusively photovoltaic (PV) systems, made up of the panels one typically thinks of when they think about solar power, see Figure 14. PV solar panels take energy from the sun and convert it directly into electricity. The majority of utility-scale systems are also PV systems, but some of them are concentrating solar power (CSP) plants. These plants concentrate solar energy (using mirrors or lenses) on a receiver, which then uses the heat to produce steam. This steam turns a turbine to create electricity. CSP plants are extremely expensive to build, so they are better suited for large projects that have the necessary capital and a large enough energy demand to recoup the upfront costs.[120] In 2017, 93.1% of solar power generation was from PV technology and only 6.9% from CSP.[121] Because PV technology is so dominant in the industry, this analysis will focus on that segment.

Figure 14: Utility Scale Solar Power Generation

Strengths: There are many reasons why solar energy should be an increasing part of the U.S.'s energy portfolio. First, it is renewable and will be available as long as the sun continues to rise.

Second, it is abundant. The amount of solar energy that reaches the Earth provides 10,000 times the amount of commercial energy used by humans on the planet.[122] Third, solar energy systems do not produce air pollutants or carbon dioxide. They have minimal effects on the environment and do not contribute to greenhouse gas emissions.[123] Lastly, solar generating systems have little to no operations and maintenance (O+M) costs once installed. Because of these reasons, solar energy is garnering increased support within the country and around the world.

Weaknesses: The amount of sunlight that arrives at the earth's surface is not constant; it varies depending on location, time of day, season of the year, and weather conditions. For example, more solar radiation reaches the earth's surface in Arizona than it does in New York (see figure below). And more solar radiation reaches the earth's surface in Australia and Chile than Canada and Russia (see figures below).

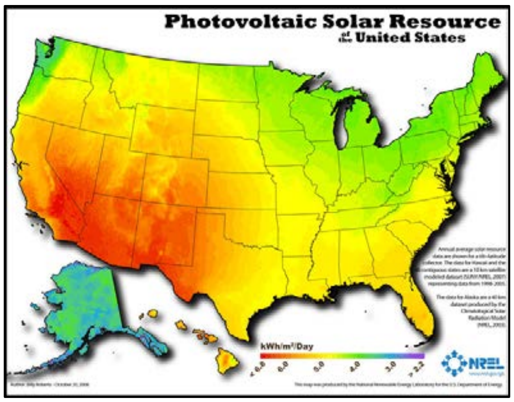


Figure 15: Solar Intensity Map

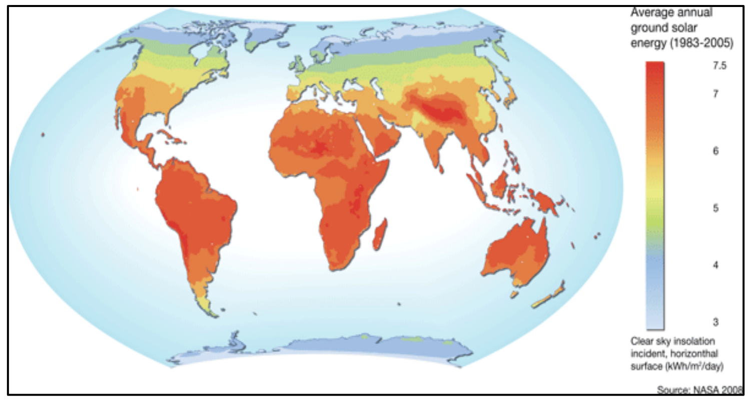


Figure 16: Global Solar Intensity Map

Also, solar panels cannot produce electricity at night and have decreased effectiveness under cloud cover. Next, the amount of sunlight reaching a square foot of the earth's surface is relatively small, so a large surface area is necessary to absorb or collect a useful amount of energy.[124] Additionally, it takes other forms of energy that pollute the atmosphere to make solar cells, although this impact is very small compared to the overall environmental impact from fossil fuel energy generation.[125] Lastly, some of the minerals and materials used to produce solar cells are rare and/or from conflict zones.[126]

Opportunities: In absolute terms, the growth in solar energy consumption represents a significant investment/growth opportunity. In 2010, solar energy consumption was 90T Btu, in 2016 it had grown to 570T, and in 2017 it was up to 775T.[127] Worldwide the trend is even more stark. Currently, solar makes up 1.5% of electricity generation, with some forecasting it to reach 20% by 2027.[128] It is clear that demand for solar energy is high, so the U.S. should position itself to take advantage. Even more dramatic, the industry is on the verge of becoming the cheapest option for electricity generation (when averaged across all areas of the country). Current solar panels are 10-20% efficient (at turning the sun's energy into electricity). Just a 24% increase in efficiency would make solar the cheapest option. Already, some experimental cells have exceeded 40%."[129] Moreover, some engineers think it may be possible to increase efficiency to 50%, which would be a 250% increase over current panels.[130] Not only would this drive costs down further, but it would make solar viable in most places on the planet to include the Northeast and Europe.

Threats: The biggest threat to the solar industry is the threat of substitute forms of electricity generation. In the past, many of these generation sources were cheaper than solar leaving the industry reliant on government subsidy.[131] Additionally, many of these substitutes can provide energy around the clock and in all weather conditions. For solar to be more competitive, it must not only become cheaper, but it must also become more reliable through innovation in energy storage capabilities. Lastly, overseas competitors threaten the supply chain. The U.S. currently imports over 85% of its solar panels. Most of these low-cost solar panels come from Malaysia, China, South Korea, and Mexico.[132] Of that group, China poses the biggest threat because they heavily subsidize the industry in an attempt to lower prices and gain a dominant market position.[133]

Wind Power

Producing energy from wind is a technology known since ancient times, when people used windmills to move pumps or stone wheels to mill grains.[134] Obtaining electricity from wind is just a variation on this old technique, based on the employment of windmills to rotate turbines to generate electricity. These wind turbines are typically installed in wind farms, on land or offshore, and can be connected to the electric grid to commercialize the electricity generated.[135] Although the wind energy industry in the United States has continuously grown since 1970, it still represents just 2.1% of the country´s total energy consumption.[136] Considering wind electricity production as a diversification of energy sources, and therefore a benefit for U.S. energy security, the federal government offers tax incentives to foster the wind industry.[137] Additionally, following the Institute of Energy Research, "more than half the states have renewable portfolio standards requiring a certain percentage of their electricity to be generated from qualified renewable energy technologies."[138] This has led electricity generation companies to include more sources like wind and solar in their portfolios.

Strengths: First and foremost, on-shore wind is becoming increasingly cost competitive with even the cheapest forms of fossil fuel generation. Wind electricity is also carbon free and helps preserve the nation's water resources.[139] Additionally, local communities may benefit, both by being able to produce electricity in isolated areas out of reach of the electric grid and by obtaining revenues from field leasing for wind farms, taxes, and electricity sales.[140]

Weaknesses: Despite the benefits of developing the wind energy industry, it has some weaknesses. The biggest weakness is that it is unpredictable. It is difficult to forecast when and how much the wind is going to blow. Wind can also be fairly localized; it is much more viable in the Texas plains than it is in Washington DC. Additionally, it takes a vast expanse of land (or coastal waters in the case of off-shore wind farms) needed to install sufficient windmills to generate a valuable number of megawatts.[141] Additionally, although wind farms are emission-free, they do impact the environment by affecting birds, by creating visual pollution, and by producing noise.[142] Lastly, it shares perhaps its biggest weakness with solar electricity generation in that it is unpredictable and intermittent.

Opportunities: The U.S. DOE's Wind Energy Technologies Office produced a report, known as "The Wind Vision Report", assessing "the potential economic, environmental, and social benefits of a scenario where U.S. wind power supplies 10% of the nation's electrical demand in 2020, 20% in 2030, and 35% in 2050."[143] In accordance with the Wind Vision Report, wind energy production will be potentially viable in all fifty states by 2050. Also, the wind industry supports a domestic supply chain, and it is affordable.[144] The way to counteract the aforementioned weaknesses is to improve the technology so that each unit can produce more electricity with a smaller footprint. And to develop energy storage options for use when the wind dies down. Finally, the U.S. produces between 50% and 90% of the windmills components, importing the remaining percentage, with current imports coming mainly from Europe (Germany, Denmark, and Spain) but also from China and South Korea.[145] Thus, opportunities exist to grow domestic manufacturing capacity.[146]

Threats: The main threats to the wind industry are environmentalists concerned about potential impacts as well as landowners who do not like the sight of wind-turbines from their land. Additionally, it may be difficult going forward for the industry to compete with natural gas (always available base-load power) or solar (another intermittent form of renewable energy) on cost.

Hydropower

Strengths: Hydropower is a valuable energy source that relies on the water cycle, making it a renewable energy source.[147] In fact, the hydropower produced each year in the U.S. is equivalent to nearly 500 million barrels of oil.[148] As the climate debate rages on in the country, the clean nature of hydropower should be viewed as beneficial in diminishing greenhouse gases and easing the dependence on fossil fuels. The current hydropower fleet contains 2,198 active power plants, with some states generating up to 10 percent of their power needs through hydropower.[149] Additionally, hydropower provided 42% of U.S. renewable electricity generation in 2016.[150]

While hydropower is low-cost and clean, it is also an important contributor to the grid. Hydropower enables greater integration of renewables, to include wind and solar, by utilizing excess generation and being ready to produce power during low generation periods.[151] Pumped hydropower storage can also ramp up electricity generation during periods of peak demand.[152] Hydropower possesses load-following and flexibility reserve, meaning it can provide variability existing in the load over longer timeframes.[153] Finally, hydropower provides “black start” restoration service through its capability to fire up power without support.[154]

Weaknesses: Environmental regulations provide a significant deterrent to further investment in hydropower technology. Although hydroelectricity is renewable and sometimes considered environmentally friendly, state governments and lobby groups scrutinize the technology because of potential damages that hydroelectric dams can cause to river resources.[155] The days of “big” hydropower seem to be over in the U.S. The industry was on the downturn at the end of 2017 and the last five years of severe droughts led to a decrease of water inflow for the industry, thereby limiting production.[156]

Opportunities: Given growing domestic energy demands, the environmental benefits of “clean energy,” and the importance of energy security for the U.S., policy makers may modernize the current hydropower fleet and incentivize the development of new technology. Currently, only 3% of the 80,000 hydro dams in the U.S. generate electricity, and there is room for growth.[157] The way ahead must be paved by the federal and state governments by investing in upgrades and innovation for existing facilities. This can be accomplished through technology advancement in areas such as increasing capacity and also though fitting existing pipelines, tunnels, canals, and aqueducts with conduits to generate electricity.[158] Furthermore, converting existing dams into hydroelectric generating facilities enables industry to use existing infrastructure, thereby lowering costs and even resulting in industry forecasts to increase at an annualized rate of 7.0% to $5.4 billion over five years to 2022.[159]

Incentivizing the development of the sub-hydropower industry is another key opportunity. Ocean wave, tidal, and in-stream hydrokinetic applications can take hydropower into the future.[160] Ocean technology examples include attenuators to capture wave power or vertical axis turbines to capture tidal power.[161] Free flow technology is in use in the Mississippi River, where crews are installing free flow hydrokinetic turbines to capture the flow of the river.[162] This capability allows crews to run turbines from free-flowing water, and there is no reservoir build up or significant changes to the natural environment.[163]

Threats: Overregulation and prohibitive permitting processes stifle growth and, in some cases, even the sustainability of the industry. Establishing new hydroelectric facilities has been difficult for stakeholders, as tough state and federal regulations and a lack of suitable locations has discouraged investment. Additionally, regulatory process inefficiencies result in delays and costs that cause long-term risks to hydropower owners, operators, and developers.[164] The industry also has many barriers to entry. The high cost of building new dams and infrastructure, as well as high revenue volatility, heavy regulation, and environmental concerns, all hamper industry growth.[165] Also, there is little motivation across the country to invest in hydropower when natural gas markets and other renewable sources are much more lucrative. Natural gas power plants are inexpensive to construct compared with hydroelectricity dams, and when gas prices decrease, natural gas-generated electricity becomes more cost-effective than hydroelectric power.[166] Finally, hydroelectric dams could cause extensive damage and casualties if breached by physical or cyber-attack, so must be better protected.

Geothermal

Strengths: Geothermal power is a renewable and clean energy source, as it harnesses steam from below the earth's surface to power turbines.[167] Geothermal power is considered reliable and consistent as compared to other renewables, such as wind or solar, which depend on intermittent sources to generate energy.[168] Additionally, the now growing geothermal market is poised for a breakthrough going into the next five years, with new technologies and increased awareness of renewable sources of energy.[169] Some of these technologies are on the demand-side at a more micro level and involve using geothermal to moderate temperatures in buildings. This increases efficiency and lowers energy costs.

Weaknesses: Geothermal industry growth slowed significantly in 2015 and 2016 due to low natural gas prices and phased out federal tax initiatives.[170] According to the Geothermal Energy Association (GEA), factors contributing to the slowdown in power plant construction included policy barriers, inadequate transmission infrastructure, high-drilling costs, and low demand for new geothermal power projects.[171] Continued low prices in other resource sectors may slow investment and growth in geothermal plants and technology. Additionally, geothermal is only viable for large-scale energy production in areas with high geo-thermal activity (see Figure 17);

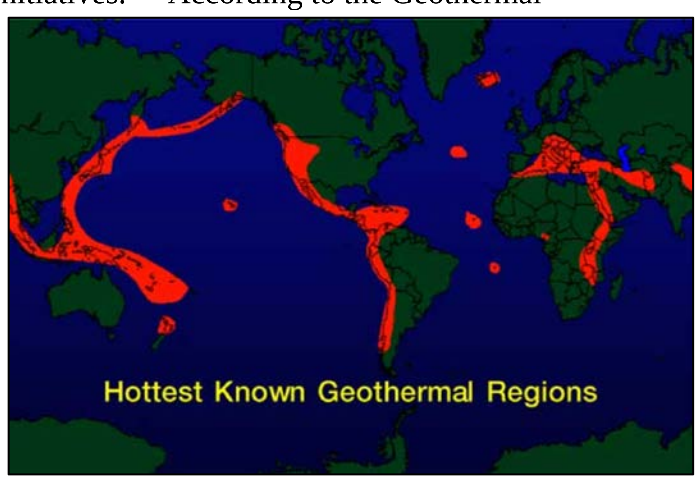


Figure 17: Geothermal Intensity Map

Opportunities: Opportunities exist to grow the geothermal industry in response to increased energy demands and heightened interest in renewables. The industry is projected to grow into 2022 as a result of improved federal and state legislation and the high price of electricity.[172] According to the United States Energy Information Administration, capacity increases are anticipated, and the number of geothermal power plants will increase with proper investment and industry focus.[173] Another opportunity is in increased innovation in technologies such as binary systems and enhanced geothermal systems.[174] These systems allow the production of electricity from subsurface reservoirs previously considered too tepid for steam production.[175] This technology will allow the industry to expand beyond traditional means and geographic constraints and will continue to drive growth for the next five years.[176]

Threats: Past policy and regulatory barriers hindered expansion; however, the emphasis on renewable energy resources promises to ease those restrictions. Additionally, the industry has moderate barriers to entry with diminished incentives for geothermal plant investment given the abundance of cheap natural gas. Without incentives and local tax credits, firms will be less likely to invest in future geothermal expansion efforts.

Waste to Energy

The Waste to Energy (WTE) industry generates electricity from Municipal Solid Waste (MSW) as well as agricultural and other wastes. MSW consists of paper, yard trimmings, food waste, plastics, metals, rubber, textiles, wood, and glass. There are about 258 million tons of MSW created annually in the U.S. Of this, 53% is sent to a landfill, 35% is recycled or composted, and 13% is used for energy recovery. As of July 2016, there were 77 WTE facilities in 22 states.[177] These plants earn revenue by disposing of waste and through the sale of electricity and steam to utility providers and manufacturing companies. They also recover and sell recycled metals. In 2016, the overall U.S. WTE industry revenue was $3.2 billion with profits of $249 million. It produced 0.49 quadrillion Btu of electricity which was 0.5% of the nation's total.

Strengths: WTE technology is mature and effective at a large scale. The "industry revenue is forecast to grow at an annualized rate of 2.6%" over the next few years.[178] Industry growth is strongly correlated with growth rates of the U.S. economy since rising industrial activity generates additional waste products.[179] The WTE industry is considered a source of renewable energy. The Energy Policy Act of 2005 and the Energy Independence and Security Act of 2007 "mandated higher investment in renewable energy (including WTE), so the industry began to grow strongly."[180]

Weaknesses: The main weakness for WTE is that it is not cost competitive for smaller size systems. It takes a community with a large amount of trash to make this technology economically viable.

Opportunities: Because of the cost and limitations of WTE electricity generation, future opportunities to provide electricity to the grid are limited. Larger municipalities that do not already have a WTE plant should look at the technology as a way to dispose of trash while generating electricity. With current technology, only large municipalities will have enough trash to make WTE cost effective. On a smaller scale, it is a technology the military should consider, both as a potential source of base-load power for stateside and deployed operating locations and as a backup source of power. The military requires the ability to handle long duration power disruptions, and WTE is an ideal backup source of power since it can use available waste products on the installation to power the mission while remaining independent from the external grid. Developing WTE for forward operating locations would support the National Defense Strategy (NDS) initiative of investing in resilient, adaptive basing.[181]

Threats: There are environmental concerns with the technology. Despite the appearance of being a highly sustainable method of disposing waste, there are concerns with WTE operations "about the pollution emitted from industry facilities."[182] Specifically, environmentalists have concerns over both air and water pollution. Because of these concerns, there is a heavy burden to comply with various municipal and federal regulations.

Nuclear Power

The U.S. nuclear power industry uniquely contributes to the overall energy enterprise in the nation by providing reliable, robust energy to the electric grid while also playing an irreplaceable role in national defense and security through its contribution to nuclear deterrence and nuclear non-proliferation. Indeed, the nuclear power industry consists of both the energy sector and the national defense and security apparatus, and this distinctive position should be appreciated when considering the future of nuclear power in the U.S., particularly with respect to developing nuclear-related policies at the local, state, and federal levels.[183] Clearly, policies addressing new technologies emerging in the wind power sector do not have as direct an impact on the national security of the U.S. as policies directing the future of the nuclear power industry.[184]

Today, nuclear power provides roughly 20% of the country's electricity (9% of the overall energy consumption), and it does so in a mostly carbon free manner.[185] However, the development of new commercial nuclear power plants in the U.S. has stalled, with the last new plant being commissioned nearly 30 years ago and current projects either being cancelled or significantly over budget and behind schedule.[186]

Strengths: Overall, the strength of America's nuclear power industry is that it is still the strongest in the world and provides the U.S. a leadership position from which to influence and direct global policy regarding the nuclear power industry as well as nuclear weapon programs and nuclear non-proliferation. Additionally, nuclear power provides clean, reliable, hardened energy to the U.S. grid. Optimally, nuclear reactors provide base load power to the U.S. grid due to the increased efficiency and cost effectiveness operating at a steady energy load - 24 hours a day, 7 days a week - while also complementing renewables such as wind and solar that struggle to provide consistent power. The self-sustaining nature of nuclear power plants is another strength of the industry. Commercial nuclear plants can produce energy for two or more years between refueling, allowing nuclear power plants to be protected from disruptions to the global supply chain that can be catastrophic to other electrical generation sources.[187] The nuclear power industry also contributes thousands of well-paying jobs and provides elite education and training programs for thousands of Americans.

Weaknesses: The two major weaknesses of America's nuclear power industry are the struggle to achieve cost competitiveness with other electrical power generation techniques currently available in the U.S. as well as the lack of construction of new power plants in the U.S. Both of these weaknesses are driven by nuclear power's inability to compete with inexpensive energy produced from natural gas power plants and renewable energy sources such as onshore wind and solar power.[188] This cost disadvantage is exacerbated by federal and state policies preferentially favoring solar, wind, and other "carbon free" energy sources over "carbon free" nuclear power. This relative cost disadvantage and consequent struggle to maintain competitiveness has wreaked havoc on the industry. Only General Electric and Westinghouse remain as U.S. nuclear plant companies with the latter being forced into Chapter 11 bankruptcy in 2017. The lack of an aggressive, optimistic narrative supporting U.S. nuclear power plants is an additional weakness.

Opportunities: The opportunities in the U.S. nuclear industry are centered not on attempting to compete in short-term cost with natural gas and certain renewables, but rather focusing on better leveraging nuclear power's unique attributes, such as energy reliability and robustness, as well as on capitalizing on emerging technologies. Developing and promoting policies and regulations to reward the reliability and consistency of nuclear power to make-up for inconsistencies associated with wind and solar power would increase the viability of the industry. Additionally, the development of Small Modular Reactors (SMR) and extending or reusing fuel are promising new innovations that may drastically change the nuclear power market. SMRs are "designed with modular technology using module factory fabrication, pursuing economies of scale production and short construction times."[189] SMRs provide the potential for the nuclear industry to explore new markets with shorter construction timelines and quicker approvals, thereby greatly expanding the versatility of the industry. Techniques to extend the life of and reuse fuel are also being developed and have the potential to significantly reduce the high long-term costs associated with spent fuel storage and fuel production. "Increasingly, today's used fuel is being seen as a future resource rather than a waste."[190]

Threats: The three major threats to the U.S. nuclear power energy sector are a catastrophic nuclear incident releasing nuclear material into the public (similar to what occurred at the Fukushima Daiichi Power Plant in Japan in 2011), the development of policies and regulations that target the nuclear industry and result in excessive legal and environmental issues that are economically insurmountable by the private nuclear energy sector, and competition from international competitors. Any of these threats could permanently break the commercial nuclear energy industry in the United States due to the precarious position of the industry today. Although 20% of the nation's electrical energy currently comes from nuclear power plants, the public reaction to an event in which nuclear material threatened the public would likely lead to aggressive movements to end nuclear power, similar to those in Japan, Germany, and Chile following the Fukushima incident. Although the legal and environmental hurdles currently in place have proven to be significant in contributing to halting the development of new nuclear power plants in the U.S., recent efforts to extend the operational lives of existing plants have been successful. However, each new regulation and requirement has a cumulative effect on the economic viability of commercial nuclear power plants, and if regulation expansion is not curtailed, the industry may not have a future. Lastly, the U.S. is struggling to compete for new international projects due to strong competition from Japan, South Korea, and of more concern, from Russia and China. Failure to compete with the latter two, could have geopolitical effects in the Middle East in the near-term and the world over in the long term. Furthermore, a failure to get the U.S. nuclear industry on solid-footing could have negative effects on the country's ability to effectively maintain its nuclear deterrent.

Key Takeaways

From this SWOT/market analysis, it is clear that the nation's energy sources can be separated into four distinct categories:

1) Economically competitive sources of energy that the U.S. should utilize both domestically and internationally (i.e., on the export market).

2) Strategically important energy sources that are no longer cost competitive and must be protected.

3) Niche renewable energy that can fill key roles based on local geography and politics and can become economically viable in certain regions.
4) Traditional fossil fuels that are no longer cost competitive but must be kept viable for diversity of supply and/or their importance to other aspects of the nation's economy and security.

Regarding the first category, the economically competitive sources the U.S. must leverage are natural gas, solar, and on-shore wind. The abundance of natural gas has given the country a gift. It is both cheaper and cleaner-burning than other fossil fuels which is a boost to energy supply, energy security, the overall economy, and the environment. Additionally, it is creating the opportunity for the country to become a net exporter of energy, which will be a further boon to the economy and also allow the country some geopolitical leverage in Europe and the Middle East. Solar has the advantage of being both abundant and renewable. Thanks to increases in efficiencies and low-cost solar panels from overseas, the price per megawatt hour is set to become the cheapest of all energy sources. This has led to an increase in solar utilization which is great for the economy but has come at a cost to the U.S. manufacturing sector. A big opportunity exists for the U.S. economy and manufacturing sector if it can create the next-generation high-efficiency solar panel, combine it with storage capability, and become a leader in solar energy solution export. The third source of energy in this category is on-shore wind. It is not as abundant as solar, but like solar, it is renewable and quickly becoming cost competitive. It also may provide a better renewable option for areas of the country and world that do not receive as much solar radiation like New York or Germany. It is another opportunity for the U.S. to develop the next-generation high-efficiency wind turbines, combine them with energy storage solutions and become a leader in wind technology export. ***The bottom line is that, for natural gas, solar, and wind, policy should be in place to encourage adoption, foster innovation and set the conditions to be export leaders. This should be PRIORITY 1.***

Regarding the second category, strategically important source of energy that is no-longer cost competitive but must be protected is nuclear power. It currently provides approximately 20% of the energy needs of the nation, has been a key export industry and geopolitical tool, and provides the backbone for the nation's nuclear deterrent. Market forces and overregulation have driven the industry to the point where it is struggling for survival. ***The bottom line is that, for nuclear power, policy must be in place to ensure its survival and viability. This should be PRIORITY 2.***

Regarding the third category, the niche renewable energy sources are hydropower, geothermal, and WTE. These technologies are not necessarily cost competitive on a large-scale across the entire country but could provide diversity of supply and potentially be economically viable in localized areas. New hydropower dam projects have become increasingly difficult to pursue. Because of this, the future in hydropower is in adding electricity generation to already existing dams and/or taking advantage of free-flow technologies that don't require dam construction. Geothermal can provide steady, renewable, base-load power in areas of the country with viable resources. Additionally, it can be utilized on a small scale to increase efficiency by regulating building temperature. Technology must progress to make these projects more economically viable. WTE is a mature industry with slow growth that is already being utilized in most metropolitan areas where it makes sense. There is still some room to grow, and if R&D can find ways to make the process cheaper and more efficient, it could become viable for smaller communities or military bases. ***The bottom line is that, for hydropower, geothermal, and WTE, policy should be in place to encourage localized adoption and to foster innovation to make***

them more viable. These should not be prioritized over natural gas, wind, and solar. This should be PRIORITY 3.

Regarding the fourth category, the traditional fossil fuels that are no longer cost competitive (for electricity generation) but must be kept viable are oil and coal. Oil is still the number one source of energy in the country. The transportation industry, specifically, is reliant on it. As is the U.S. military. Additionally, the economy as a whole is reliant on it for all of the products mentioned above. It must be kept vibrant relative to the demand (as the country and the world adopt electric and natural gas vehicles, demand for oil should decrease). Lastly, it is still of great geopolitical importance. Coal is still filling a role in electricity generation, but it is one that could be replaced by other forms of generation. Coal's long-term importance is in the by-products used by the economy. Coal should be kept viable until alternatives for those products are found. But it should be done in the cleanest way possible. ***The bottom line is that, for oil and coal, policy should not be in place to encourage adoption. Instead, market forces and the encouragement of adoption in other sources of energy, such as natural gas, solar, and wind, should be allowed to drive down the demand/use of oil and coal. Where necessary, policy should be issued or alternatives found to maintain viability in the by-products produced. This should be PRIORITY 4.***

International Studies

The international energy goals of the U.S. align with its core domestic energy objectives, focusing on maintaining fossil fuel abundance, reducing regulations to energy exploration, fostering economic growth, creating jobs, minimizing greenhouse emissions, and obtaining universal access to electricity. President Trump, through the NSS and the use of executive order, has enacted a series of energy-related reforms to open new areas for oil exploration, allow coal leasing on federal land, and complete the Keystone pipeline, which together, leverage America's economic power with the country's rapidly increasing energy exports—a strategy of energy dominance.[191]

The global strength and influence derived from its energy dominance can create many opportunities for the U.S. to achieve its broader diplomatic, security and economic goals, such as by expanding the North American power grid to Central and Latin America. The U.S. is currently connected to Canada and Mexico, and additional U.S. energy integration with other countries is an effective way to build resiliency within our borders by providing redundancy to critical energy infrastructure and by adding additional sources of power. Bringing electricity to people who do not currently have access is a powerful tool to break the cycles of poverty and illiteracy in developing countries and doing so could help reduce the flow of illegal immigrants to the United States.[192] Economically, American energy companies can leverage Smart Grid technology and transparent business practices to achieve a competitive advantage over their Chinese and European competitors in the region. During its trip to Chile, the Seminar met with many energy policy makers in both the public and private sectors, almost all of whom are wearily watching China's growing investment in Latin America and wondering why the U.S. is not more engaged. Energy policy, both international and domestic, is never made in a vacuum.

Chile has shown the tremendous social and political upside of developing energy policy in a transparent and inclusive manner, with the many different constituencies affected by the policy receiving an opportunity to provide input into the planning process – particularly the indigenous Mapuche communities.[193] From 2014-2016, Chile assembled 180 working groups representing the public and private sectors, as well as key constituencies to develop a cohesive plan – ENERGÍA 2050 – that helped spur development of renewable energy sources, (mainly solar), led to further integration of its electrical grid, deemphasized coal for electrical production, and ended the construction of large-scale hydropower projects. A former Chilean Minister of Energy stated that "the biggest energy problems are not technical, but social, getting buy-in and changing habits."[194]

Because it is not energy independent and all of its energy choices entail trade-offs, Chile has intentionally sought public buy-in on difficult energy policy decisions, like phasing out coal for electrical production. In 2017, Chile introduced a tax on CO2 emissions from large industrial and power generation sources with thermal power greater than 50 MW.[195] In 2013, the Bachelet Administration created public policies that brought more competition to the electrical markets, breaking the pricing monopoly of the large energy companies.[196] Perhaps Chile's most sensitive policy decision was to continue integrating its electrical, natural gas, and oil production capabilities with Argentina after that country unilaterally decided to halt natural gas exports to Chile in 2007, causing severe shortages and forcing Chile to substitute with very expense oil imports. Cutting its ties with Argentina would have been understandable, but in recent weeks, the Minister of Energy traveled to Buenos Aires to sign an agreement deepening the energy integration between the two countries.[197]

Today, thanks to its inclusive energy policies, Chile is experiencing an energy transformation on an unprecedented scale, harnessing renewables such as solar, wind, and geothermal to reduce its reliance on imported fuels and to meet its environmental objectives.[198] While hydropower is a significant source of clean energy, generating 29% of the country's electricity in 2017,[199] recent droughts and floods have made it less reliable. In 2015, after the Mapuche communities and their supporters protested against two new hydropower projects, the Chilean people and government decided that the social costs of big dams outweigh their energy benefits, leading to the emphasis on nonconventional renewable energy in ENERGÍA 2050. Chilean officials have set the ambitious goal of renewables providing 70% of the country's electricity by 2050.[200] The country is well-positioned to achieve this goal, especially since reforms introduced in the wake of the 2007 increased competition and supporting investment in renewables, thereby leading to a surge in solar and wind capacity. Today, 75% of solar projects (including 37 solar projects in the Atacama Desert region) and 24% of wind projects are located on state-owned land.[201]

Like Chile, Argentina has also designed its energy policy with the priority of integrating with its neighbors' energy systems in order to enhance the country's production and export capabilities. Indeed, Argentina has linked its electrical grid and natural gas market infrastructure with Brazil, Bolivia, Chile, Paraguay, and Uruguay, leading to an associated economic, social, and political integration process.[202] Regarding energy integration, there are multiple pipelines and grid interconnections linking the respective national systems, which are significant for Argentina in both hydroelectric energy and natural gas production, importation and exportation. One example of the energy integration process between Argentina and Chile, both national oil companies, ENAP (Chile) and YPF (Argentina), formed a joint venture to produce natural gas and oil from five offshore platforms in Argentinian waters, close to the Magellan Strait.[203] In addition, Chile and Argentina have one 200 MW electrical connection, and a network of seven gas pipeline links, allowing LNG imports at the GNL Quintero plant in central Chile to be exported, while Argentina provides gas to areas in southern Chile.[204]

On the other hand, a country that has not had much chance to integrate its energy sector is Kazakhstan, a major oil and natural gas producer. The country has a commodities-based economy, leaving it very vulnerable to price shocks and currency fluctuation. Kazakhstan has benefited from exports of energy resources for decades, with more than three-quarters of Kazakhstan's crude exports headed to European markets and 16% passing through a pipeline to China.[205] Russia, India and China also import much Kazakh coal, providing significant revenue to the country but also reinforcing Kazakhstan's dependence on coal to produce electricity for domestic uses.[206] To reduce its reliance on commodities, to diversify its economy, and to lessen its worsening pollution, Kazakhstan must develop renewable energy as described above, which today represents less than 1% of the entire Kazakhstan energy sector.[207] There is capacity to develop alternative sources of energy such as wind and solar, but the cost of electricity generation from fossil fuels is relatively low, making solar and wind power plants uncompetitive. Furthermore, there are very powerful special interests who dissuade Kazakh lawmakers from passing laws to support green energy because these interests stand to lose money.[208] On another front, Kazakhstan's domestic manufacturers find it very difficult to compete against low-cost Chinese companies developing new technology, such as solar panels and high capacity batteries. Only time will tell if active engagement by the Kazakhstan government can shape the public policy required to create competition, to integrate its energy infrastructure, and to develop renewable energy sources.

For all countries, the central challenge of crafting energy policy is to strike a balance between domestic energy demand requirements, available energy resources, economic growth, the social costs associated with energy production, and its international obligations in the face of climate change. The U.S. has dramatically increased its oil and gas production while reducing imports, making it less vulnerable to price shocks and supply restrictions. The U.S. has reduced its total CO_2 emissions by 758 million metric tons since 2005, more than any other nation on Earth.[209] Yet energy challenges lie ahead for the American people as they wrestle with questions regarding the coal industry's future, the necessity - or lack thereof - of a carbon tax, subsidizing the nuclear industry, developing the ANWAR oil field, investing in new grid technologies, and whether to withdraw fully from the Paris Climate Agreement.

Key Takeaways:

The lessons learned from looking at energy policy in other countries show that it is very easy for a nation to take its natural resources and energy supplies for granted. Without a national strategy, a balanced energy portfolio, and investments in the future, a nation is profoundly vulnerable, yet only an energy crisis and shortages will seize the attention of a nation, as happened to Chile in 2007. The most successful national energy policies tend to come from countries that have highly integrated energy systems. National level energy integration strengthens a country's energy systems by building resiliency, diminishes threats by improving relations between countries, opens new possibilities for renewable energy, and fosters economic opportunity. No matter the country, a successful energy policy requires that all stakeholders have a say in shaping the outcomes, that the process must be seen as legitimate, and that the policies must be well implemented.[210] Energy policy can be a vehicle that not only brings people together but also brings countries together.

Energy Imperatives/Recommendations

Imperative 1: Create an Energy Strategy for the United States (Keys: Education, Economic Growth, Energy Security)

The U.S. must plan for future energy demands through a comprehensive energy strategy focused on shaping the national energy conversation, maintaining economic growth, and ensuring security of supply and emergency capability. Energy in the U.S. is dependent upon adequate supply, generation, distribution, and transmission, yet the country has only scraped the surface of reinforcing critical infrastructure and guaranteeing resiliency with current assets in place. The government, in concert with industry, must provide for the future of the country both in economic progress and in energy security. To this end, policymakers should support **a new national strategy built on three elements**:

(1) Education and Stakeholder Buy in: Change the narrative and set a goal;
(2) Economic Growth: Support industry by creating domestic demand/manufacturing opportunities and prevent IP proliferation abroad;
(3) Energy Security: Guarantee access to energy through a flexible and resilient national grid.

Element (1) Education and Stakeholder Buy in: Change the narrative and set a goal: A 2016 Pew Research Center survey showed that the majority in the U.S. supports protecting the environment but partisan differences split the country over concerns regarding the impacts regulation could have on jobs and the economy.[211] This sentiment presents barriers for policymakers looking to advance an economically and environmentally friendly next-generation power infrastructure. According to a Center for Strategic and International Studies (CSIS) report, abundant natural gas has already brought economic advantages to the U.S. by providing cheap electricity, improving domestic industrial competitiveness, and delivering important benefits to the nation's trade balance—not to mention the accompanying geo-political influence and security benefits.[212] But what comes next after cheap natural gas?

The importance of gaining public/private support is critical to any successful strategy and associated policies requiring significant commitment, resources and trade-offs. When national and state leadership promote synchronized educational initiatives to raise awareness of environmental dynamics, use of constrained or abundant natural resources, explaining the food-water-energy nexus, and global/domestic market forces, the energy strategy will be much more likely to gain traction and succeed. Energy education efforts are key to establish and maintain momentum. The authors observed this approach applied successfully when meeting with the Chilean Ministry of Energy, Energy Policy and Prospective Division. The long-term vision, approach and intentionality of this leadership group was inspirational. They acknowledged that successful initiatives of this nature are fifty percent technical and fifty percent social dynamics. This momentum gained through education and communications will ensure strong enough support is in place to overcome powerful commercial and political forces that would prefer status quo.

Looking further around the world, 175 nations have ratified the 2015 Paris Climate Agreement and many have committed to developing and deploying the infrastructure required to reduce greenhouse gas emissions.[213] Germany's goal to remake its infrastructure to deliver 80%

of its electricity from renewables by 2050 is driving the country to deploy the technology and training to reshape its economy to that goal.[214] [215] These efforts have led Germany to important new export opportunities and to the creation of hundreds of thousands of new jobs that earn 12-14% more than traditional energy sector jobs.[216] The U.S. should make a similar drive. And with renewables becoming increasingly cost competitive (see Figure 2), it should do so behind a new narrative. To change the narrative, policymakers must look at the development and production of renewable energy projects as a way for the U.S. to remain economically competitive in the global economy. To do this, Congress should pass legislation to mandate at least 50% of U.S. electricity production from cost effective renewables by 2050. In 2017, President Trump said, "economic security is national security," so integrating cost competitive renewables with storage is one key way to grow U.S. security and prosperity.[217] As the U.S. makes this transition, the nation should take advantage of global demand and also commit to becoming a leader in the export of these new technologies.

Element (2) Economic Growth: Support industry by creating domestic demand/manufacturing opportunities and prevent IP proliferation abroad: In the book *Make it in America*, DOW Chemical CEO Andrew Liveris notes that for "decades, the U.S. has watched entire industries disappear from its shores – only to reappear abroad. Industries from solar panel technology to highly advanced computer circuitry, from wind turbines to smart phones – industries born in the U.S., now exist predominantly elsewhere."[218] Decades of erosion in the U.S. manufacturing sector, primarily due to the nation's failure to deploy policies to compete with rising economic powers, has led to the loss of more than 42,000 factories and one-third (~5.5 million) of all manufacturing jobs.[219] Around the world, countries are behaving more like companies by aggressively competing with incentives and subsidies, which hold some advantages over the typical U.S. laissez-faire economic approach. While the U.S. is still a leading innovator in the world, Liveris argues that, in the long-term, the U.S. cannot separate innovation from a desire to manufacture those goods – "where manufacturing goes, innovation inevitably follows."[220] To provide business and policy makers the tools to *Make America Competitive Again*, three policies are recommended:

1. Provide long-term certainty for business investment by committing to tax incentives for renewables and associated battery storage until the technologies are cost competitive without subsidy. Sunset legacy fossil fuel incentives.
2. Congress should expand and pass the Foreign Investment Risk Review Modernization Act (FIRRMA), which seeks to strengthen the Committee on Foreign Investment in the U.S. (CFIUS). This legislation would allow CFIUS to expand reviews to include potential emerging critical technology.[221] [222] Once passed, the White House Office of Science and Technology Policy should lead a joint inter-agency / industry dialogue to develop a list of emerging critical technologies for use in post-FIRRMA CFIUS reviews. Finally, FIRRMA's joint venture and R&D language should be updated to include a review of foreign student participation in university research activities based on an economic and security threat assessment. Further, policymakers should preserve and strengthen free trade agreements as a hedge against supply chain disruptions and to ensure continued business opportunities abroad for U.S. energy resources and capabilities.

3. Congress should establish a single federal organization to collect and disseminate foreign economic intelligence to state chambers of commerce and industry for the purpose of estimating and neutralizing the effect of foreign subsidies. Transparent to the public, this data would aid Congress, state legislatures, local governments, and industry in making informed subsidy, incentive, and investment decisions in support of U.S. industry development and growth. Policymakers should evaluate each critical area such as fossil fuels, renewables, nuclear, infrastructure, cyber and R&D on their own merits, deploying federal, state and local tax rates, incentives, and policies tailored to the needs of securing the health of the nation's critical industries and their ability to competitively build domestic demand.

Element (3) Energy Security: Guarantee access to energy through a flexible and resilient national grid: Given the resiliency, reliability, and security issues, as well as the desire to realize the opportunity to create a more flexible national grid with greater integration of low-cost renewables, U.S. policymakers should reshape domestic power generation and transmission systems, thus significantly improving energy security by reducing threats and vulnerabilities. To this end, the DOE should lead the energy industry in the next 1-3 years with the development of a deliberate plan to transition our grid to a modern next generation infrastructure that utilizes emerging technology in the deployment of smart, micro-grids. The intent of this policy is to provide the public through education and policy, an understanding of the consumer and national level economic benefits that come with pairing a modern next generation grid with the increased use of renewable energy sources. Additionally, DOE should further additional grid improvement initiatives to:

1. Establish interoperability between all nodes and systems within the grid. Over the next 1-5 years, government should partner with academia and industry to establish a single common set of interoperability standards, protocols, and procedures for the future grid. The DOE should also publish a timeline requiring that all energy grid components comply with these interoperability standards.
2. Assist industry with overcoming the costly financial burden of upgrading the grid. To this end, the Department of Commerce with support from the Department of Treasury, should offer tax incentives to investors who provide investment capital towards the grid modernization effort. These incentives should be established immediately and continue until the next generation grid is considered fully operational.
3. Establish a single centralized control body, similar to the Federal Reserve, to oversee the national grid. Members of this organization should come from the energy industry and the DOE. This organization's operating costs should be government funded, and the organization itself should be established and made effective as soon as possible in order to guide the implementation of the new grid in a unified direction.

In addition to transitioning to smart, micro-grids, the government must also ensure the associated supply chains are part of the country's energy security element as well. The government should conduct a detailed end-to-end assessment of the current energy supply chain to identify vulnerabilities, supply gaps, and provide risk mitigation measures. The DOE should serve as the lead agent for this study supported by leaders from the energy industry and academia. The study should execute within the next 1-2 years and provide actionable recommendations to Congress and the Executive Branch no later than the end of the second year.

Imperative 2: Create a Balanced Portfolio (Keys: Fossil Fuels, Renewables, and Nuclear)

Given the elements of a new U.S. energy strategy as discussed above, the second imperative further investigates the need for economic growth and energy security by establishing a balanced portfolio of energy resources. Deliberate and calculated investments in traditional baseline capabilities will augment supply for the Smart Grid while investing in renewables will provide resiliency for stressed energy sources and grids and will provide an environmentally friendly and clean energy source. Below are recommendations for fossil fuels, renewables, and nuclear power listed in priority order based on analyses in the State of Technology section.

Natural Gas

Because of its abundance and relative cleanliness to other fossil fuels, natural gas should continue to be an increasing percentage of the nation's portfolio in the short-term. Because natural gas has become the cheapest form of energy in the U.S., tax incentives on the investment and supply side are not necessary. However, it would be prudent to initiate some incentives on the demand side to start weaning the country off of less environmentally friendly fossil fuels. For example, the U.S. should provide a federal tax incentive for natural gas vehicles.[223] This legislation, introduced by Boone Pickens, provides a tax incentive of $7,000 to $64,000 for the purchase of cars, trucks, and buses depending on the weight of the vehicle.[224] It would endorse the Natural Gas Alternative Transportation to Give American (NATGAS) Act. Although there are tax incentives for hybrid cars (should remain in place), most natural gas incentives are conducted by the state with no federal support. Additionally, incentives and regulations should be put in place to promote the use of natural gas by ships. This would require state, federal, and commercial partnerships to establish a natural gas fueling network. This would be the first legislation geared primarily towards commercial vessels, like LNG tankers, focused on reduction of CO2 emissions. Lastly, federal government should maintain its standing in current trade deals and ensure as many of them as possible contain provisions for LNG export. Further, the federal government should encourage countries in eastern and central Europe to build LNG importing facilities to receive U.S. LNG and decrease their reliance on Russia for natural gas.

Solar

First and foremost, the federal government should continue to subsidize the solar industry in the short-term. Currently, this is being done with the Solar Investment Tax Credit, which grants residential and commercial customers a tax credit equal to 30% of solar panel costs.[225] Additionally, the USG offers a Renewable Energy Production Tax Credit (PTC) equivalent to approximately 2.3 cents/kWh on solar energy produced.[226] Next, it should eliminate the tariff on imported solar panels. The effect of these tariffs is increasing the cost of solar projects in an attempt to protect a manufacturing sector that is already defeated. That sector should instead be focused on the next generation of solar panels. These moves will encourage the continued growth in the industry.

The U.S. should commit to being the country that develops and manufactures the next generation of solar panels. The solar panels that are 50% efficient (or higher) could drive solar power costs to the point where solar becomes the energy source of choice without the requirement for government subsidy. To do this, the USG should partner with industry to share the technological advances that come from the STEP, DOE, and ARPA-E research initiatives. The government should then offer tax breaks to companies to set up manufacturing facilities and begin manufacture of the new solar panels. Furthermore, the federal government should combine this initiative with initiatives that are developing energy storage to produce renewable energy solutions that can be exported around the world to meet the ever-increasing demand. To protect this initiative, efforts should be made to strengthen cyber-security and the protection of intellectual property.

Wind

On-shore wind is becoming a cost-competitive form of renewable energy and should be included in the initiative to develop, manufacture, and export. Maintaining the present tax benefits should ensure continued adoption of this technology. Furthermore, the government should invest in R&D for the next generation, more-efficient wind turbine and work with industry to combine it with energy storage to create solutions for export. The model is similar to the one suggested for solar.

Nuclear Power Recommendations

To strengthen the U.S. nuclear industry, the federal government should pursue the following. First, it should ensure nuclear and renewable power are treated equally as carbon-free sources of power by educating the public on its benefits. Second, it should remove unnecessary regulation and streamline permitting to keep current plants operational and encourage the development of new plants. Next, it should provide tax incentives to make the generation of nuclear power more cost competitive. If that is not sufficient, it should look to provide direct funding (perhaps from DOE or DOD budgets) to ensure the industry stays viable enough to support the country’s nuclear enterprise. Additionally, it should provide funding for R&D of new technologies to include small modular reactors (SMRs). Lastly, it should provide legal and political support to aid U.S. companies in their bid to export large-scale and potentially SMR plants. Nuclear energy technologies (to include the possible addition of SMRs) should be included in the list of exports that will make the U.S. “energy dominant”.

Hydropower

To maintain the current hydropower fleet, policy should be aimed at increasing appropriations in future budgets for the DOE Water Power R&D program. Additionally, the federal hydropower owners’ budgets will ensure facilities are upgraded to meet future energy demands.[227] Investment should also be conducted in the sub-hydropower industry via federal and commercial firms. Finally, ocean wave, tidal, and free flow technology investments will provide more resiliency for stressed energy sources and grids and will provide an environmentally friendly and clean energy source.

Geothermal

Policy makers at the federal, state, and local levels should continue to reform regulations and incentivize geothermal development.[228] Providing tax credits and incentivizing additional geothermal capacity will provide more diverse options for the U.S. energy baseline. Additionally, federal and state agencies should adopt categorical exclusions for exploration activities and update leasing rules to promote successful geothermal discoveries and partnerships with industry.[229]

Waste to Energy (WTE)

For the U.S. economy, the use of WTE is relatively mature. Due to lower cost natural gas, WTE should only be considered in high population areas that require alternate methods for waste disposal. For this scenario/application, WTE is an excellent method to dispose of trash while creating electricity. The U.S. military should develop policy to assess the technology maturity used in deployable WTE systems and to demonstrate small-scale WTE systems on military bases to serve as long-term backup power. These systems could also be used to support the U.S. economy during times of national crisis, such as a major blackout.

Fossil Fuels Recommendations

In order to provide baseline energy capability, the country should capitalize on the diversity of U.S. fossil fuel energy sources. The U.S. must promote the role as a leader in global energy in all available resources while developing alternative options and protecting the environment. Acknowledging that each state possesses different energy needs and resources, the U.S. Government should develop regulations and policies flexible enough to support the unique needs of each state while creating the conditions for affordable shared resources. Additionally, the Clean Power Plan should be reexamined for legality and relevance across the spectrum of the 50 states.[230] Finally, strong consideration should be taken at the federal, state, and local levels of government regarding the physical security of all assets.

Oil

The federal government should continue tax incentives for oil exploration and continue to open up areas for exploration in an environmentally friendly way. This will ensure domestic supply of this still critical resource. It should slowly sunset incentives for production and refining to allow market forces and the increased usage of cleaner forms of energy to take the place of oil.

Coal

As a part of the U.S. energy strategy, to ensure a diverse and balanced portfolio of energy sources, and to protect the environment, the U.S. should maintain a baseline capability of coal-fired electricity generation and invest in clean coal technology for existing plants. As CCS technology provides the only method with potential for zero CO2 emissions, this should be the focus of innovation and technology development.[231] Tax incentives and loan guarantees should be instituted for CCS R&D. The USG should work with industry and local government to determine baseline needs for coal for the future.

Imperative 3: Maintain a Competitive Edge (Keys: Innovate, Invest, and Protect)

While the U.S. requires a defined strategy and a robust resource baseline capacity, the country must also maintain a competitive edge. This requires further augmenting the outlined strategy elements of economic growth and energy security. Through innovation, investment, and protection of energy resources - to include infrastructure and proprietary information - America can maintain and advance the country's competitive edge in energy.

Innovation Recommendations

Advancements achieved after years of prior research include innovations that helped the U.S. win World War II and the Cold War—all the while becoming the largest economy in the world. Innovation will ensure future success, and the U.S. must support focused leap ahead science and technology (S&T) activities and early technology demonstrations. Many of the above analyses highlight the importance of innovation to our energy security, and the necessary efforts could be pursued through implementation of the following policy recommendations:

1. Elected officials should allocate sufficient funding for pure research grants as well as for organizations, such as the National Science Foundation, Defense Advanced Research Projects Agency (DARPA), and ARPA-E, that pursue specific lines of high-risk/high-reward research.[232]
2. The administration should reinforce R&D priorities aligned with the overarching NSS and Energy strategy by ensuring DOE develops adequate processes for issuing grants in a timely fashion.[233]
3. Elected officials should also ensure DOE labs have sufficient latitude to pursue valuable research rather than dictating which technologies it should prioritize, something Congress has done in the past by funding specific DOE offices that oversee narrow R&D efforts.[234] [235]
4. Elected officials should ensure the labs have the authorities, policies, and procedures necessary to enhance partnerships with the private sector. Such relationships are crucial to ensuring that innovation is both relevant and ongoing. Indeed, while the labs should maintain a focus on pure research and leave applied research largely to the private sector, these two stages should not be viewed linearly.[236] On the contrary, "decades of research on innovation systems show that this 'linear model' of innovation does not reflect innovation's true interconnected nature or potential. Policies guided by the flawed linear model have created a disconnect between the labs and the private sector, a critical hindrance towards DOE's mission."[237] To encourage greater partnerships between the labs and the private sector, elected officials will need to authorize "the labs to enter into flexible collaborative R&D contracts and creative technology licensing agreements," and the administration will need to create policies supporting greater private access to lab facilities and research.[238]
5. Finally, elected officials should provide DOE with the authorization and funds to launch a nonprofit venture-capital firm designed to encourage entrepreneurship, innovation, and the commercialization of high-risk/high-reward technologies.[239] Solyndra's negative press coverage notwithstanding, DOE's recent efforts to wade into the energy venture

capital market have largely been successful, so the U.S. should build upon this solid foundation and ensure that start-ups have an opportunity to succeed.[240]

Investment Recommendations

Prosperity and competitiveness during and since World War II were built on the foundation of U.S. S&T investments. Advancements in radio navigation, radar, penicillin, synthetic rubber, rockets, jet engines, computers, advanced batteries, fracking, and nuclear power represent capabilities that are interwoven into our daily lives and that would not have happened without government investment. S&T leadership requires a focused investment strategy coalesced around solving an urgent problem, underwritten with sufficient government funding to support high-risk/high-reward efforts, and accompanied by a mechanism for building early demand so useful innovations do not die before being brought to market. Therefore, elected officials should encourage private investment by providing significant tax incentives for firms conducting energy R&D.[241]

Just as overall R&D will shape the next millennium, the battery industry will take the country into the future as it influences storage and grid capacity. To this end, a policy recommended to support the battery industry and its reshaping of the grid involves Congress and the President arresting the decline in both the overall U.S. and DOE R&D funding shown in Appendix A, Figures 3 and 4, respectively. A new era of great power competition outlined in the December 2017 National Security Strategy demands a commitment to lead in invention and innovation.[242] Finally, innovations from DARPA and ARPA-E have helped provide many of the advancements listed above. Congress should ensure adequate funding for ARPA-E in FY19 and beyond.

Cyber Infrastructure Protection Recommendations

The energy sector is the foundation of national security and economic prosperity. The U.S. must ensure that decisive actions are undertaken to defend against the growing vulnerabilities that are created with the proliferation of cyber systems throughout critical infrastructure. To improve the cybersecurity of critical infrastructure the following recommendations are made:

1. USG should partner with private industry to further collaboration and strengthen current cybersecurity standards (NIST framework). All private companies designated as critical infrastructure, to include most energy companies, should be encouraged to adhere to those standards. This encouragement could be done with an education campaign, with incentives, or by making the framework mandatory. USG should conduct a study to determine the appropriate path.
2. The DHS must work with Congress to establish a financial incentives package to spur investment by private critical infrastructure companies in cybersecurity. Every effort must be made to improve the information sharing process between government and private industry. Particularly, the speed at which cyber threat data is declassified and distributed in order to provide timely and actionable information to private industry.
3. Lastly, the Executive Branch should delegate the authority to conduct limited, retaliatory cyber operations to U.S. Cyber Command and the National Security Agency in order to provide these organizations the authorities needed to better defend against cyber-attacks. The trend to expand information technology integration into critical infrastructure will

not only continue but the rate of expansion will increase and we must be ready to defend these national assets from cyber threats.

Conclusion

This paper began by presenting a possible real-world scenario in the Houston, Texas area, which is a major hub of the national energy supply, generation, distribution, and transmission networks. This scenario highlighted how precarious our nation's position is, for although the narrative was fictional, the threat posed by energy disruptions to American life, economic prosperity, and overall national security are very real. Indeed, such disruptions may be caused by natural disasters or by hostile actors, and they may happen quickly or unfold over an extended period of time. Thus, the role of energy in the National Security Strategy as well as the National Defense Strategy cannot be understated. The very pillars which make the U.S. the most powerful nation in the world depend on energy for success.

After presenting the challenge we face, this paper provided assessments of the energy industry's foundations, specifically in terms of their implications for national security and economic prosperity. The foundations section addressed the areas that underpin the entire energy industry, such as cyber, electrical storage, and the grid. Further, this section described how vital these interdependent systems are to delivering today's energy needs required to support the U.S.'s vibrant and growing economy as well as our nation's security.

The paper then examined the current state of energy technology and associated industries. The state of technology section noted that overall trends include an uptick in the production of natural gas, which continues to increase its role in U.S. electric power generation, and the rapid growth of renewables. This section also identified economically competitive sources of energy as well as strategically important energy sources that should be maintained.

Subsequently, the paper provided an analysis of international examples and prospects, and in this section, the team reviewed lessons learned, trends, and strategies from on-the-ground assessments of Chile, Argentina and Kazakhstan. Further, the section assessed that the U.S. could benefit from further analysis of energy policies that come from countries with highly integrated energy systems, as national level energy integration strengthens a country's energy systems by building resiliency.

From the foregoing analyses, the team concluded that a national energy focus is required to ensure economic prosperity and national security for today and for the future. This paper offered three national energy imperatives with policy recommendations designed for the U.S. to sustain a competitive advantage for years to come. Only through targeted research, analysis, and vetted courses of action can U.S. leaders secure energy for future needs. The imperatives promote security, resiliency, reliability, and efficiency while also providing for economic growth. The imperatives outlined in the paper include:

<u>The first imperative</u> is for America's leaders to develop a comprehensive energy strategy and action plan to ensure energy security for the future. The policy recommendations captured under the first imperative focus on three elements: education, economic growth, and energy security.

<u>The second imperative</u> is for policy makers to create a balanced portfolio through deliberate long-term investments in baseline energy production capabilities and renewables. The policy recommendations under this imperative involve incentives and tax credits for specific

industries. Moreover, these recommendations focus on developing an array of flexible resources, which support the proposed strategy in day to day operations and in times of crisis.

The third imperative is for the U.S. to gain a global competitive edge through innovation, investment, and protection. The policy recommendations included in the third imperative further support the elements of the energy strategy by focusing on technological advances, investment in new resources, and the protection of networks and proprietary information.

The targeted use of taxpayer money will steer these imperatives to fund key R&D initiatives like next-generation solar panels, energy storage capability, and smart grids; to incentivize the use and export of key resources like LNG and renewables; and to stabilize strategic industries like nuclear power and clean coal that are vital to the country but struggle to compete on cost alone. This coordinated use of government funds will both assist in ensuring a robust national energy sector as well as position U.S. companies and technologies to thrive as market forces curve toward winners. Additionally, these imperatives will provide a path by which to develop strategy, enhance the diversity of America's energy enterprise, and strengthen security through improved policies.

Furthermore, although facilitating continuous improvement and innovation in the energy industry would not eliminate the threats or fully mitigate the effects of the Houston Ship Channel attack scenario, the recommendations would create a harder, more resilient target and would lessen the impact of such an attack on the national security of the United States. Policies aimed directly at upgrading existing capacity and also innovating for the future with technology will promote a balanced portfolio of resources to meet growing national needs. Energy forms the bedrock of national stability and security, and the industry must therefore be protected, enhanced, and improved for the prosperity and protection of the world's greatest nation.

As the American economy grows, so too will its energy demand, and the nation's energy sector must therefore be a top priority for our nation's leaders. This paper provided possible solutions and courses of action for leaders to consider when developing energy strategy and policy. These recommendations would, if implemented, significantly improve the nation's economic growth potential, competitiveness, energy security posture, and military industrial complex through a balanced portfolio and ensure a high priority is placed on investments for energy research and development.

APPENDIX A: Supporting Figures and Tables

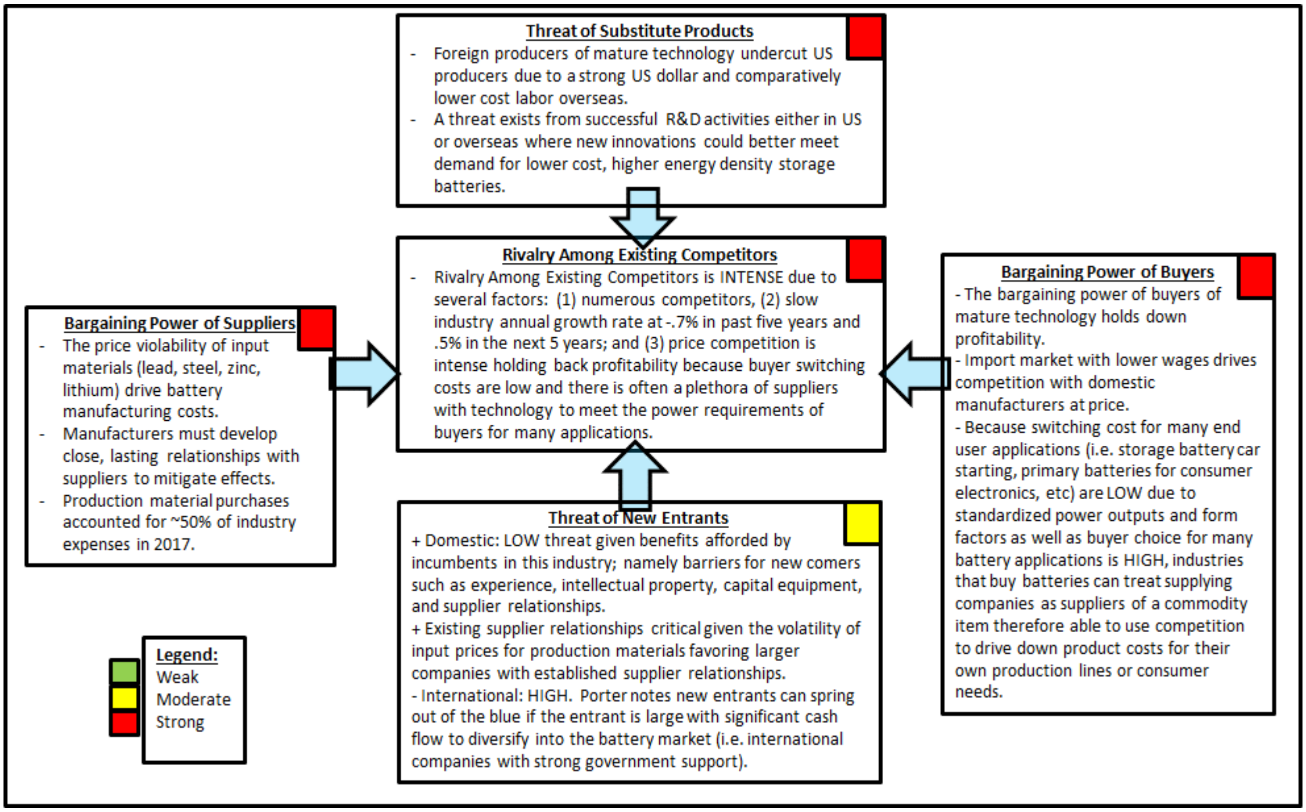


Figure 1: Porter's 5 Force Analysis of Battery Industry (Data Courtesy of IBIS)[243]

Competitive w/Coal & Gas Generation

Competitive w/Coal Generation Only

Plant Type	Range for Total System Levelized Costs (2016 $/MWh) Minimum	Non-weighted average	Capacity-weighted[2] average	Maximum	Range for Total System Levelized Costs with Tax Credits[1] (2016 $/MWh) Minimum	Non-weighted average	Capacity-weighted average	Maximum
Dispatchable Technologies								
Coal with 30% carbon sequestration[3]	128.9	140.0	NB	196.3	128.9	140.0	NB	196.3
Coal with 90% carbon sequestration[3]	102.7	123.2	NB	142.5	102.7	123.2	NB	142.5
Natural Gas-fired								
Conventional Combined Cycle	52.4	57.3	58.6	83.2	52.4	57.3	58.6	83.2
Advanced Combined Cycle	51.6	56.5	53.8	81.7	51.6	56.5	53.8	81.7
Advanced CC with CCS	63.1	82.4	NB	90.4	63.1	82.4	NB	90.4
Conventional Combustion Turbine	98.8	109.4	100.7	148.3	98.8	109.4	100.7	148.3
Advanced Combustion Turbine	85.9	94.7	87.1	129.8	85.9	94.7	87.1	129.8
Advanced Nuclear	95.9	99.1	96.2	104.3	95.9	99.1	96.2	104.3
Geothermal	42.8	46.5	44.0	53.4	40.0	43.3	41.1	49.3
Biomass	84.8	102.4	97.7	125.3	84.8	102.4	97.7	125.3
Non-Dispatchable Technologies								
Wind – Onshore	43.4	63.7	55.8	75.6	31.9	52.2	44.3	64.0
Wind – Offshore	136.6	157.4	NB	212.9	125.1	145.9	NB	201.4
Solar PV[4]	58.3	85.0	73.7	143.0	46.5	66.8	58.1	110.5
Solar Thermal	176.7	242.0	NB	372.8	134.6	184.4	NB	284.3
Hydroelectric[5]	57.4	66.2	63.9	69.8	57.4	66.2	63.9	69.8

[1]Levelized cost with tax credits reflects tax credits available for plants entering service in 2022, See note in Tables 1a and 1b.
[2]The capacity-weighted average is the average levelized cost per technology, weighted by the new capacity coming online in each region. The capacity additions for each region were based on additions in 2018-2022. Technologies for which capacity additions are not expected do not have a capacity-weighted average, and are marked as "NB" or not built.
[3]Due to new regulations (CAA 111b), conventional coal plants cannot be built without CCS because they are required to meet specific CO_2 emission standards. The coal plant with 30% removal is assumed to incur a 3 percentage-point adder to its cost-of-capital to represent the risk associated with higher emissions from a plant of that design.
[4]Costs are expressed in terms of net AC power available to the grid for the installed capacity.
[5]As modeled, hydroelectric is assumed to have seasonal storage so that it can be dispatched within a season, but overall operation is limited by resources available by site and season.
Note: The levelized costs for non-dispatchable technologies are calculated based on the capacity factor for the marginal site modeled in each region, which can vary significantly by region. The capacity factor ranges for these technologies are as follows: Wind Onshore – 36% to 45%, Wind Offshore – 41% to 50%, Solar PV – 21% to 32%, Solar Thermal – 11% to 26%, and Hydroelectric – 30% to 65%. The levelized costs are also affected by regional variations in construction labor rates and capital costs as well as resource availability.
Source: U.S. Energy Information Administration, Annual Energy Outlook 2017, January 2017, DOE/EIA-0383(2017).

Figure 2: EIA Regional Variations in Levelized Cost of Electricity[244]

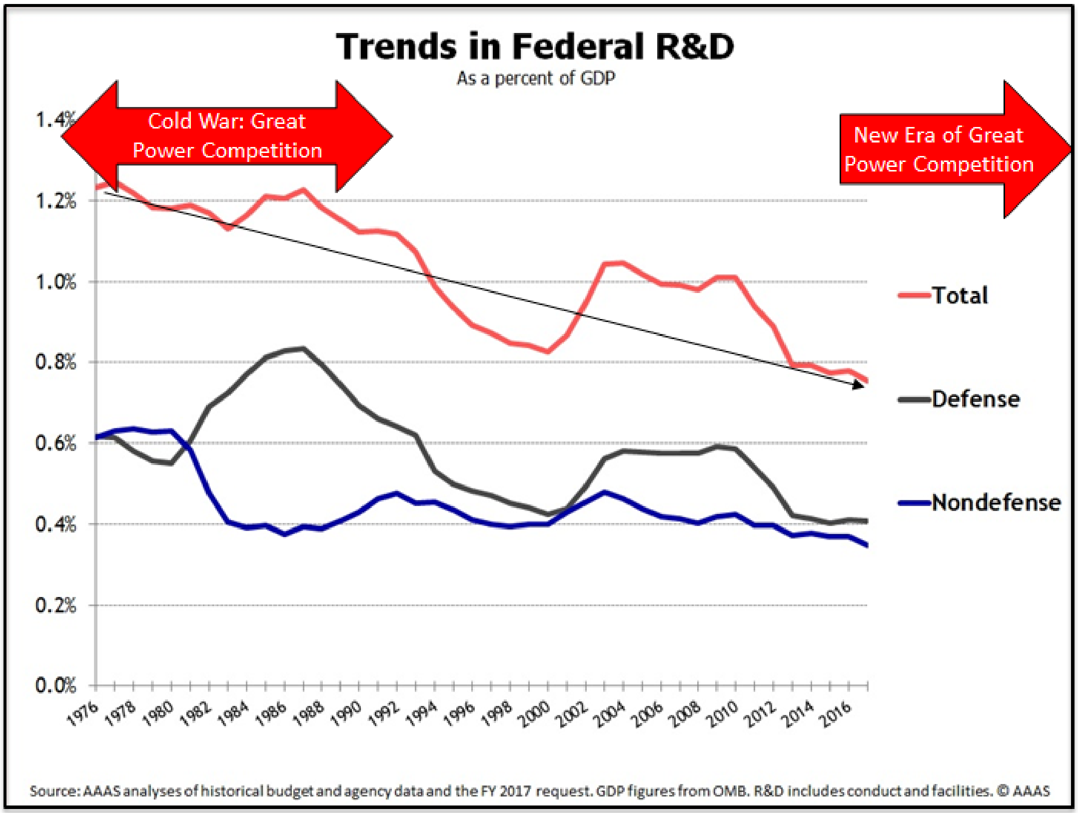


Figure 3: U.S. R&D Funding as a Percentage of U.S. GDP [245]

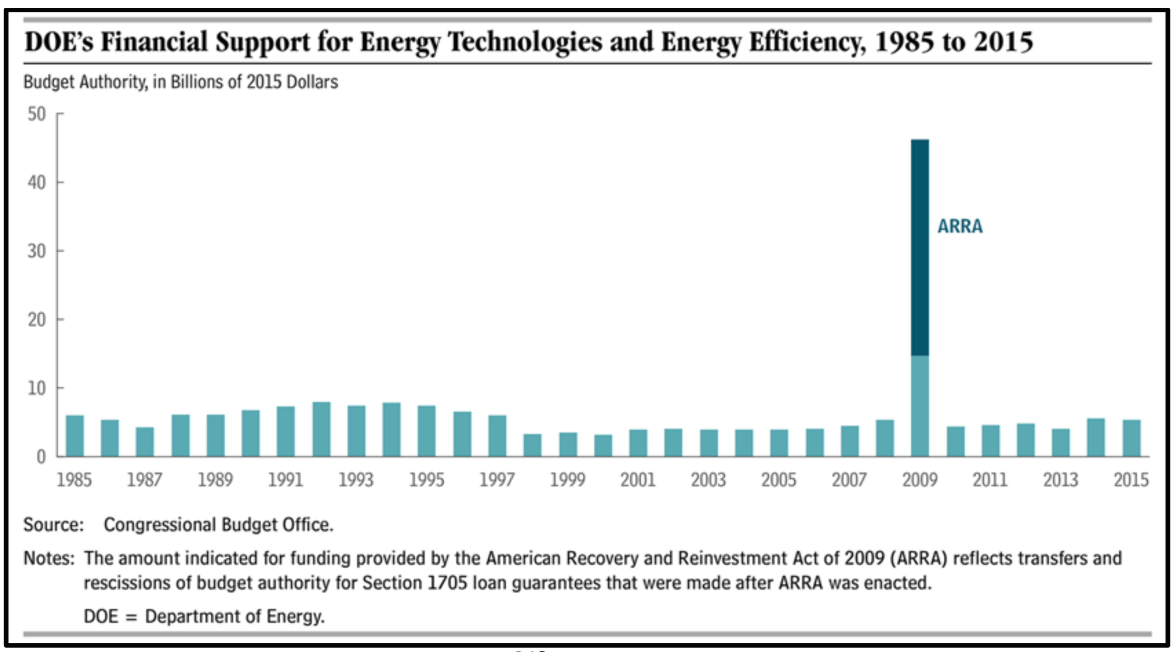


Figure 4: DOE R&D Budget Authority [246]

Appendix B

Exogenous Events—Electromagnetic Pulse (EMP)

As noted at the beginning of this paper, an exogenous event like a terrorist attack on a key component of the nation's energy infrastructure could have cataclysmic effects. Another potential threat is an Electromagnetic Pulse (EMP) or High-altitude electromagnetic pulse (HEMP) - the result of a nuclear weapon being detonated in the upper atmosphere producing a damaging magnetic field spanning about one third or more of the United States.[247] An EMP can consist of a short, microsecond burst that affects conventional electronics, such as computers and utility control systems using micro-chip technologies, or an event that last for minutes and can inflict permanent damage to high-voltage electrical equipment.[248] An EMP will damage the electronic circuitry of a piece of equipment that is plugged into a socket or turned on when EMP hits. A more technical definition and illustration can be found in EXHIBIT A.

Today's weaponized EMP delivery systems range from missiles, satellites or even weather balloons; they do not require precision due to the large footprint from one warhead. Adversaries such as N. Korea and Iran have already developed EMP offensive plans instead of expending their limited resources on ground targets.[249] Nuclear weapons that can generate EMPs can fit into satellites, be launched from a missile off a submarine, weather balloon or even freighters, which adds to the level of difficulty for the U.S. to counter this attack in multiple domains.[250]

Hypothetically, if an EMP event occurred above the East Coast, the Electrical Infrastructure Security Council (EISC) predicts the Eastern Interconnection, powering half of the nation, would shut down from Florida to Maine, from Washington, DC to Kansas. In addition, a domino effect of failures will hit the region's water and sewage systems, electricity-dependent gas pipelines, communication from satellites and GPS, landline telephones, cell phones, transportation, security, pharmaceuticals, food production, and distribution of all goods and services would discontinue. In addition, it would have devastating effects on our economy, potentially wiping out $1Trillion in assets.[251] The restoration of all the systems would require a coordinated effort lasting months.[252]

The U.S. may not be successful in large-scale restoration efforts. Specifically, manufactured resources required to operate the electrical grid, such as LPTs, are critical in restoration and resiliency efforts, but have numerous procurement, manufacturing, transportation and other challenges hindering a prompt resolution. Of significant importance, LPTs are custom-built units; the specifications take 12-16 months for production of one unit.[253] In fact, if a manufacturer could not source a particular part or raw material, the delay could range beyond 20 months and up to 5 years.[254]

Electromagnetic Pulse (EMP): Security Recommendations

At the national level, clear, actionable authority, and a strategy with mandatory standards regarding EMP resiliency is paramount. Vulnerabilities of our critical infrastructure to an EMP attack should also be escalated to a national security priority. Federal agencies associated with the energy sector should explore public private partnerships with manufacturers of critical infrastructure components and/or research and development opportunities for more resilient equipment, expansion of domestic manufacturers and development of critical technical expertise.

The aging fleet of LPTs will require replacements at a rate exceeding our current domestic capacity. Manufacturing firms should be incentivized and supported through federal funding and/or programs to reinvigorate the domestic LPT industry and similar critical infrastructure components. R&D funding should also be provided to explore potential replacement technology and/or material substitutions

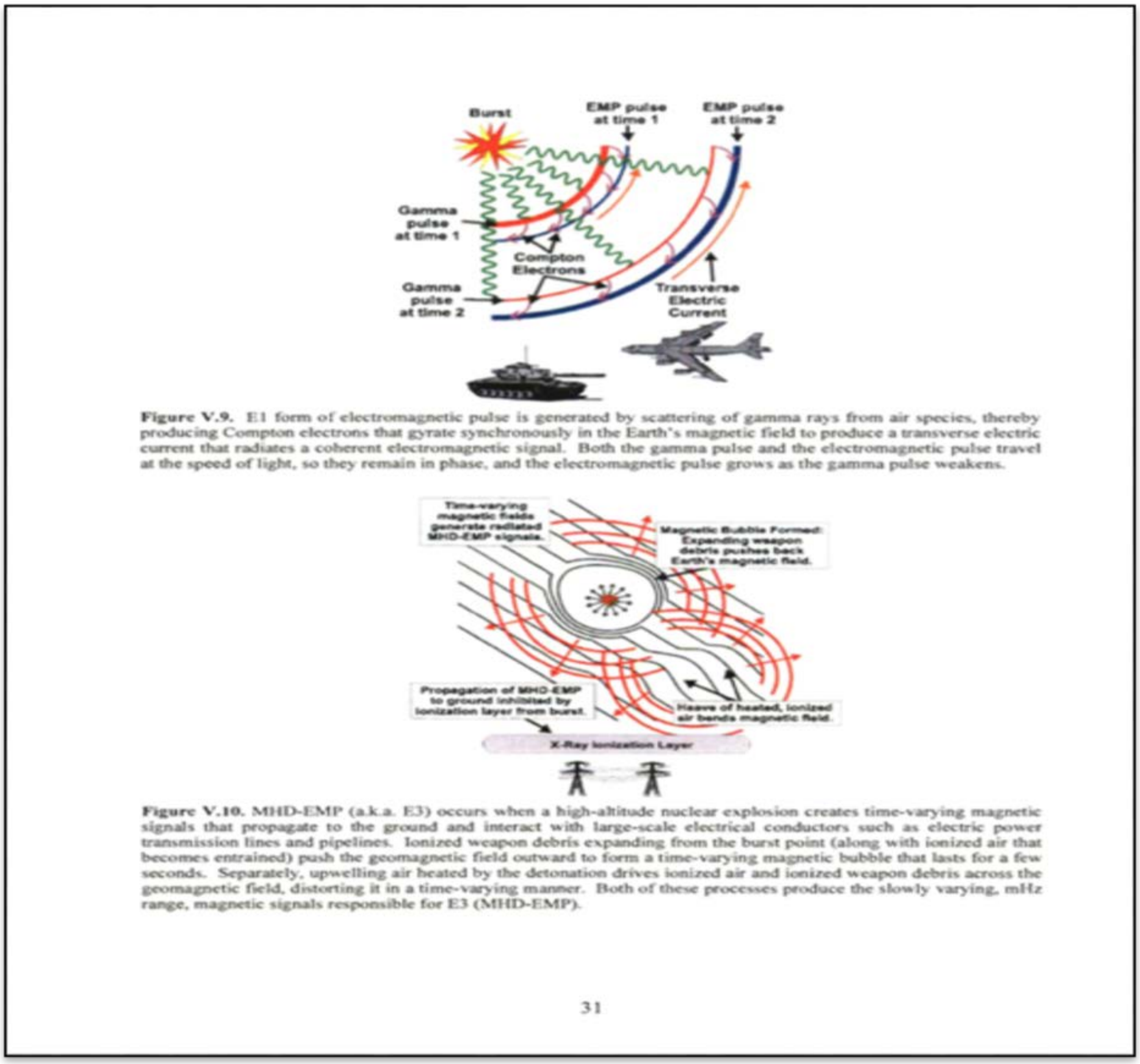


Figure V.9. E1 form of electromagnetic pulse is generated by scattering of gamma rays from air species, thereby producing Compton electrons that gyrate synchronously in the Earth's magnetic field to produce a transverse electric current that radiates a coherent electromagnetic signal. Both the gamma pulse and the electromagnetic pulse travel at the speed of light, so they remain in phase, and the electromagnetic pulse grows as the gamma pulse weakens.

Figure V.10. MHD-EMP (a.k.a. E3) occurs when a high-altitude nuclear explosion creates time-varying magnetic signals that propagate to the ground and interact with large-scale electrical conductors such as electric power transmission lines and pipelines. Ionized weapon debris expanding from the burst point (along with ionized air that becomes entrained) push the geomagnetic field outward to form a time-varying magnetic bubble that lasts for a few seconds. Separately, upwelling air heated by the detonation drives ionized air and ionized weapon debris across the geomagnetic field, distorting it in a time-varying manner. Both of these processes produce the slowly varying, mHz range, magnetic signals responsible for E3 (MHD-EMP).

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Figure 5: EMP (E1 and E3 defined by Defense Threat Reduction Agency

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