ADVANCED ENERGY AND U.S. NATIONAL SECURITY

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ADVANCED ENERGY AND U.S. NATIONAL SECURITY

To the reader:

It is undeniable that the global energy landscape is changing. Burgeoning populations in South Asia and Africa, together with rising affluence, are shifting major centers of demand away from Europe and the U.S. and increasing the world's overall demand for energy. At the same time, new technologies are making clean, affordable advanced energy widely available as well as allowing the extraction of fossil fuels from previously inaccessible sources. We see this combination of rising energy demand and the growing number of affordable energy choices as a tectonic shift in the global energy posture, one likely to impact every nation. ***As new energy options emerge to meet global demand, nations that lead stand to gain; should the U.S. sit on the sidelines, it does so at considerable risk to our national security.***

U.S. leadership in advanced energy development and deployment can yield domestic and international opportunities across our national security spectrum. Should America embrace and accelerate the use of advanced energy sources, it can open new markets for a wide range of goods and services, promote prosperity in emerging economies, and establish new energy tethers and political influence. Reducing global pressure on traditional energy supplies—especially oil and coal–can ease the potential for future conflict. Finally, as history shows us, ***the military that first embraces the improvements inherent in a new technology can gain advantage.*** We identify advanced energy as a national security priority.

In this report, we provide the Administration, Congress, and other Federal and State policymakers our assessment, observations, and recommendations concerning the national security impacts of a transition to advanced energy systems. President Trump's commitment to "promote clean and safe development of our Nation's vast energy resources," his acknowledgment that "the prudent development of these natural resources is essential to ensuring the Nation's geopolitical security," and his recognition that it is "in the national interest to ensure that the Nation's electricity is affordable, reliable, safe, secure, and clean, and that it can be produced from coal, natural gas, nuclear material, flowing water, and other domestic sources, including renewable sources" provides opportunity for today's emerging advanced energy technologies to play a critical role in meeting these goals.

To this end, we note that recent U.S. discoveries in unconventional oil and gas can provide a needed bridge to transition to a new advanced energy paradigm. The world needs clean, reliable, accessible, and affordable energy, and old energy systems alone will not satisfy the world's growing demand for energy. The U.S. should adapt our fossil fuel resources and advanced energy innovation to help fit that bill. ***We find that a U.S. energy stance centered on fossil fuels should not delay our planning for, development of, and investment in advanced energy systems at home and abroad.***

With the perspective of our collective years of senior military experience, and through the lens of national security, we see the opportunities and challenges that a major shift in energy presents. While we cannot predict the shift's exact trajectory, we understand that we must not wait to consider the global implications of a new energy world. We must make choices now, knowing that the impact of these choices may not be felt for a decade or more down the road. We also know that, when it comes to energy, we need to focus on our national security, both near- and long-term, and set our decision-making to drive these interests, not merely to react to the decisions of others. ***The stakes are too high to wait until others set the course.***

THE CNA MILITARY ADVISORY BOARD

This document presents the wide-ranging views of an advisory group of retired flag and general officers from the Army, Navy, Air Force, and Marine Corps on the subject of national security and advanced energy. Since 2006, this advisory group, referred to as CNA's Military Advisory Board (MAB), has examined the linkages between climate, energy, and national security, and has brought its vast operational, tactical, and strategic experience and perspective to domestic and international discussions. Past MAB reports include *National Security and the Threat of Climate Change; Powering America's Defense: Energy and the Risks to National Security; Ensuring America's Freedom of Movement: A National Security Imperative to Reduce U.S. Oil Dependence; National Security and the Accelerating Risks of Climate Change;* and the CNA MAB's most recent work, *National Security and Assured U.S. Electrical Power.* More information about the CNA MAB, including an archive of all past reports, can be found on the CNA MAB's website, www.cna.org/mab.

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EXECUTIVE SUMMARY

WHAT IS ADVANCED ENERGY?

For our discussion, advanced energy is the suite of technologies and systems that can lead to a more globally accessible, clean, and safe energy supply. These technologies include sources–such as nuclear, hydro, renewable, or alternative power–and the associated technologies and systems that distribute, store, and manage energy. They also comprise systems that make existing energy uses more efficient. Just as the 20th century was dominated by energy production derived from oil, coal, and natural gas, we expect the 21st century to have both greater energy efficiency from traditional sources and a greater array of new sources.

As senior military officers, we view national security broadly, factoring in economic strength, diplomatic prowess, and military capability. Fundamental to this equation is access to affordable and reliable energy. This study examines how advanced energy systems will impact the energy landscape and how these impacts will influence U.S. national security.

Over the coming decades, the global energy landscape will change dramatically. As the world grows from 7.4 billion people in 2016 to more than 9 billion by mid-century, changing demographics are expected to result in a 30-plus percent increase in global demand for energy [1]. Energy demand from demographic shifts in China and fast-growing, emerging economies in India and across Africa will overtake customary centers of demand.

Globally, technological change is underway in both the fossil fuel and advanced energy sectors. On the supply side, fracking and other recovery techniques are making fossil fuels more accessible, while advanced energy creates means for nations worldwide to produce power locally, using a wide variety of available energy sources and reduce dependency on imports. Technological advances mean that overall increases in energy demand will no longer be met by fossil fuels alone. At the same time, efficiency, biofuels, and other advanced energy improvements, as well as a global move toward electric vehicles, will cause demand for oil to begin to decline.

This changing energy posture – including new centers of demand and supply, new energy sources, and new methods of storage and use – will have an impact on global economics and global politics. Trade relationships and geopolitical dependencies molded by energy needs will be reshaped, resulting in new allies and adversaries alike. Some nations will prosper in this transition; others will falter. The consequences will have direct effects on U.S. national security.

This study brought together more than a dozen retired Admirals and Generals to examine the national security consequences of this energy transition over the next few decades. The U.S. has a choice: Will we be bystanders in the transformation, or do we participate and steer the process to our economic and security advantage?

The changing energy posture will impact global economics and global politics. Some nations will prosper in this transition; others will falter. The consequences will have direct impacts on U.S. national security.

Findings

A changing global energy landscape will have economic, diplomatic, and military effects, impacting the national security of the U.S. and its allies. Over the coming decades, rising energy demand, primarily from the world's emerging economies, will reshape the global energy mix, redefine trade relationships, and impact the geopolitics of energy among nations. China, India, and Africa will grow to become the new global energy demand centers in a technologically changing energy landscape.

Russia and members of the Organization of Petroleum Exporting Countries (OPEC)—notably Iran—are already positioning themselves to meet growing demand for fossil fuel in India and China. China is expanding its territorial claims in energy-rich areas and using energy investments in Africa to gain a stronger foothold. These mounting dependencies and an increasing global footprint present national security challenges for the U.S. At the same time, rising energy demand offers the U.S. and our allies new opportunities to build relationships in growing and emerging energy markets.

A historic global transition toward advanced energy is accelerating and will give rise to economic challenges–and opportunities–for the U.S., our allies, and our adversaries. The transition to advanced energy is driven by new technologies and approaches that will change how the world generates, stores, manages, and uses energy. As the transition unfolds, the energy mix and energy flows will depart from today's trends. Future energy supplies will be more distributed than the geographically concentrated oil, coal, and natural gas posture in today's portfolio. China, Russia, Japan, the E.U., Middle Eastern nations, and others have implemented national strategies to seize opportunities in the new energy landscape. The U.S. has not taken a similar strategic approach. Because the transition is dependent on technology and the pace of technological change, its specific outcomes are difficult to know with certainty.

Advanced energy systems will temper rising global demand for oil, impacting global diplomacy and influence, with direct national security implications for the U.S. Experts predict that consumption of all energy sources will increase through mid-century, given demographic changes and economic growth in the developing world. But advanced energy technologies–which bring efficiency as well as diversity of supply–will likely temper rising fossil fuel consumption and increase geopolitical options. For example, Europe's adoption of advanced energy is already decreasing its overall demand for imported fossil fuels and specifically reducing its dependence on Russian oil and natural gas.

Electric vehicle development has the potential for strong impact in the U.S., where light-duty vehicles account for more than 60 percent of total oil consumption [2]. Acceleration of this advanced energy technology could reduce significantly or eliminate much of the oil demand in the advanced economies in just one or two decades. This will allow some oil-importing nations, like the U.S. and those of the E.U., to loosen energy tethers and gain diplomatic leverage.

Electric vehicles will drive significant reduction in oil demand for the U.S. and other nations where petroleum is mostly used in light-duty transit.

However, electric vehicles will have less impact on oil demand in China, India, and other areas of the world that use proportionally less oil for cars and more for trucking, industry, agriculture, and petrochemicals. There, growing economies will likely result in stronger tethers to oil-exporting nations.

The transition to advanced energy can provide the U.S. military with additional options to improve mission effectiveness, reliability, and cost mitigation. The military's philosophy on employing advanced energy technologies is simple: Use them when they improve the effectiveness or resiliency of military operations. Advanced energy systems can accomplish this for our warfighters in forward operations and installations by lowering vulnerable logistical requirements, extending missions by reducing the need for fuel resupply, and lowering the number of combat forces needed to protect fuel supplies.

The military's philosophy on advanced energy is simple: Use them when they improve the effectiveness or resiliency of military operations.

DOD's next-generation technologies, platforms, and weapons systems will be much more dependent on reliable high-capacity electrical systems that will be enabled by components of advanced energy systems.

DOD installations, at home and abroad, require secure and reliable power to perform front-line, real-time military operations around the world. Advanced energy provides a means for installations to ensure that disruptions in commercial power supplies will have less impacts on their missions, as well as to reduce costs through efficiency and self-generation.

Growing demand for reliable electric power will drive the need for more resilient, more efficient, and more distributed electric power generation systems. Today, a critical hindrance to intermittent energy sources fulfilling this need is energy storage. Many countries have pledged to bring electricity to a significant share of the 2.6 billion people entirely without it or lacking access to reliable sources [3]. Meeting these commitments will spur growth in this energy sector. At the same time, projected population and economic growth, combined with the transition of much of the world's transportation to electricity, will drive electric power demand even higher.

Air Force Staff Sgt. checks a solar-powered security system at Kirkuk Air Base, Iraq.

We anticipate that the growing demand for electricity will be met increasingly with distributed advanced energy systems harnessing advanced nuclear, wind, solar, geothermal, hydro, hydrogen, and other energy sources. Because many of these systems can be decentralized and distributed, they can meet the energy needs of populations spread across large geographies, adding resilience by reducing grid vulnerability and risks of energy interruption.

In some advanced energy systems, such as solar and wind, energy production is intermittent–occurring only when the sun is shining or the wind blowing. But electricity demand is not always timed to when these systems are producing power. High-capacity energy storage systems are required to capture excess energy generated when the prime source is available, and to distribute the stored energy when it is not. Without improved large-scale, long-term energy storage, these intermittent supply options will serve only to augment or reduce demand on other power generation sources. Without large-scale storage, utilities will remain reliant on more traditional energy sources–natural gas or nuclear power–as primary fuels or to back up intermittent generating systems.

Strong leadership and investment in advanced energy can provide great opportunity for the U.S. to maintain competitive advantage. As the world transitions to advanced energy, the U.S. can maintain its historic competitive advantages in technology and expertise. However, this will require vision and strategic investment. China and E.U. member states are already in the vanguard of manufacturing, deployment, and market penetration. Ceding U.S. leadership here has inherent national security risk, including loss of global influence and diplomatic leverage, as well as forgone economic opportunities.

In the U.S., the 2007 Energy Independence and Security Act, signed into law by President Bush, ushered in programs designed to reduce dependence on foreign oil, increase energy sources for domestic electrical power generation, and set the nation on a course for energy independence. A decade later, we are trying to regain our footing.

The wide portfolio of advanced energy technologies provides options for U.S. energy independence through clean and safe development of our vast energy resources, while enhancing our geopolitical security.

National and state government policy can be a driver or a barrier to advanced energy innovation and adoption at home. Incentives such as the investment tax credit and renewable portfolio standard have accelerated development and deployment of advanced energy. These have been offset by regulatory and legal frameworks, particularly at the state level.

In summary, the world is at an energy crossroad. The coming decades are rife with opportunities for the U.S. if we take steps now to secure them. We have the standing, the expertise, and, with advanced energy technologies, the tools to secure an energy-independent future for ourselves and to improve the energy environment worldwide. We have only to be resolute.

The U.S. is still in a postition to lead an advanced energy transition.

Recommendations

The U.S. government should develop a comprehensive national energy strategy that promotes energy independence and U.S. engagement and leadership in the advanced energy future. Our recent discoveries in unconventional oil and gas provide the U.S. with newfound access to hydrocarbons, while advanced energy affords an even greater range of domestic energy options. Policymakers should review and update existing legal and regulatory frameworks, embracing advanced energy and its contribution to clean, secure energy independence. This includes encouraging energy efficiency and energy management–key components of advanced energy–to reduce overall energy demand.

The national security challenges and opportunities of the evolving global energy landscape, including advanced energy transition, should be fully integrated into national security and national defense strategies. The U.S. Departments of Defense, Commerce, Homeland Security, Energy, and State, as well as Congress and the Administration, must recognize that the transition to a new global energy posture with advanced energy systems is already occurring, with national security implications that are consequential and wide ranging. Policies should be updated accordingly.

The U.S. should identify and leverage global opportunities that will arise during the transition to advanced energy, especially in fast-growing India and Africa. The U.S. should use energy as a tool of diplomacy to secure our relationships with strategically important allies who would benefit from advanced energy deployment. The technological expertise gained will be invaluable to both emerging and advanced economies, and will provide great opportunity for U.S. businesses. The transition provides a vehicle for advancing stability, democratizing energy access, and supporting economic development in energy-hungry parts of the world.

The Department of Defense should identify, embrace, and deploy advanced energy technologies where they improve the effectiveness of military operations. The Services, the Combatant Commands, and the Joint Staff should continue to explore how advanced energy technologies can improve mission outcomes. DOD should more fully explore energy logistics risks through wargaming and analyses; expand energy performance in requirements for future systems; and invest in research, development, and deployment of advanced energy technologies that offer operational advantages. DOD should pursue innovations in advanced energy for its installations with equal commitment, looking at all alternatives for improving resilience and energy security while reducing energy costs, and including partnering with surrounding communities.

The U.S. should take a leadership role in the transition to advanced energy. The federal government should stimulate investment in the basic and applied sciences to spur innovation. It should reduce or share the risk of private investment in large-scale advanced energy projects, and double-down on investment and research for large-scale energy storage options. It should also spur education and workforce development to support a transition to advanced energy. Finally, the U.S. must design, develop, build, and install advanced energy systems at home. This will maintain our global leadership role in energy innovation and enable us to help set the trajectory of the advanced energy transition.

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ABOUT THIS REPORT

The CNA's Military Advisory Board (MAB) first assessed the relationship of the U.S. energy posture energy to our national security in a 2009 report, *Powering America's Defense: Energy and the Risks to National Security.* That study revealed urgent threats to major aspects of national security–military, diplomatic, and economic strength. We delved further in three subsequent reports.[1] After almost a decade's immersion in the subject, we concluded that our energy posture must allow us to adapt readily to longer-term changes in how energy is produced, stored, distributed, and used. Thus, we began the study discussed here, which considers the national security implications–both positive and negative–of the transition toward advanced energy.

The MAB and the study team, composed of CNA research staff, received briefings from energy experts, officials from the U.S. Departments of Defense and State, representatives of the U.S. intelligence community, scientists, engineers, policymakers, senior military officers, business leaders, regulators, regional and country-specific political science experts, and leaders of public interest organizations. The study team used a combination of literature review and analysis, expert roundtable discussions, subject matter expert interviews, Socratic debate, and a scenario-based exercise to inform the findings, recommendations, and discussions featured here. We re-examined our past reports and updated our understanding of the energy landscape, particularly global oil dynamics and the current U.S. energy trajectory. This examination afforded us a baseline for weighing the implications of alternative trajectories. (See Appendix A for our examination of the status quo trajectory.) We collaborated with experts in a forum strongly suited to identifying the regional and national security issues that would emerge in advanced energy transition, pointing also to issues requiring further investigation. (See Appendix B for details about our scenario-based exercise.)

The specific questions addressed in this report are:

1. What potential changes to the world's energy conditions will have the largest impact on global economies, militaries, and diplomacy?
2. What are the ways in which these conditions could affect America's national security interests at home and abroad?
3. What actions should the nation take to address the national security consequences of advanced energy?

The Military Advisory Board examines these questions from a strictly national security perspective.

Report Organization

Beginning with a definition of advanced energy, we examine the trends of a global transition toward a new energy construct, providing the necessary economic backdrop. Using this information, we then provide an in-depth examination of the national security implications of the energy transition. We apply our military expertise and experience to the ways in which advanced energy can impact DOD's capabilities and operations, assess the value of the U.S. taking a leadership role moving forward, and chart a course for the way ahead.

A note on our focus: We recognize the tremendous technological advances that have occurred in the fossil fuel industry, making oil and gas much more available, and also producing cleaner coal. Additional advances in the fossil industry will certainly take place. The national security implications of changes in this sector have been analyzed and reported out by others. In limiting extensive analysis herein, we do not discount these potential impacts. Instead, we have added our unique expertise and experience to focus on the less-analyzed topic of advanced energy and national security.

[1]These reports include: *Powering America's Economy: Energy Innovation at the Crossroads of National Security Challenges* (2010); *Ensuring America's Freedom of Movement: A National Security Imperative to Reduce U.S. Oil Dependence* (2011); and *National Security and Assured Electrical Power* (2015).

Clockwise from top left: National Renewable Energy Lab Testing Solar; Linear Transformer Driver; The Hellisheidi Geothermal Power Station; Connecting Tunnel Within the DESY Complex; Plastic photovoltaic cell; Batteries That Store Solar Power.

Defining Advanced Energy

For the purposes of our examination, we define advanced energy as a suite of modern systems including new and diverse sources that can be robust, interconnected, distributed, intelligent, supply agnostic, and efficient. This also includes systems that make existing energy uses more efficient. While often discussed as individual components like solar, wind, nuclear power, or microgrids, advanced energy can best be thought of as a system with the following characteristics and key attributes:

Supply–agnostic: The systems can use any locally available, clean, and secure non-fossil energy source–geothermal, wind, solar, biomass, nuclear, water, hydrogen, and/or other sources that we have the technology to harvest now or in the future.

Storage–integrated: An advanced energy system can capture excess energy for later use when demand exceeds the local supply. Storage technologies may include batteries of any chemistry, flow and solid-state batteries, pumped water, heated water or chemicals, flywheels, compressed gases, and other mechanisms yet to be invented. Storage technologies of the future can be seamlessly integrated as they become available.

Distribution–intelligent: It is likely that a principal carrier of advanced energy, from source to user, will be electricity. An intelligent control system manages supplies and loads to provide the services demanded by its users in the least costly and most reliable manner. Functional requirements that enable such a smart grid include the forecasting and management of supply, storage, and load. The intelligent control system will maintain power quality, have a great amount of autonomy, and be cyber secure.

System wide–efficient: The new energy construct will improve the efficiency of all energy systems, including fossil fuel systems, moderating overall energy demand increases.

THE TRANSITION TO ADVANCED ENERGY: AN ECONOMIC BACKDROP

The strength of a nation's economy underpins its trade and diplomacy and enables it to maintain a military robust enough to protect national interests. Economic well-being, in turn, depends on access to reliable, affordable energy. Put simply: Energy, economy and national security are inextricably connected. To begin to understand where advanced energy will be used and where it might not, we must first understand how energy choices are made.

Nations, the military, and even individuals make energy choices by weighing three interrelated, critical factors:

Access–Is the energy source available to meet my demand? Is it indigenous, or must it be imported? If imported, are there military costs associated with protecting the source, or costs associated with relying on untoward suppliers?

Performance and reliability–Will the source meet objectives at the time and place when the energy is needed?

Cost–What is the total cost of the energy at the point of consumption?

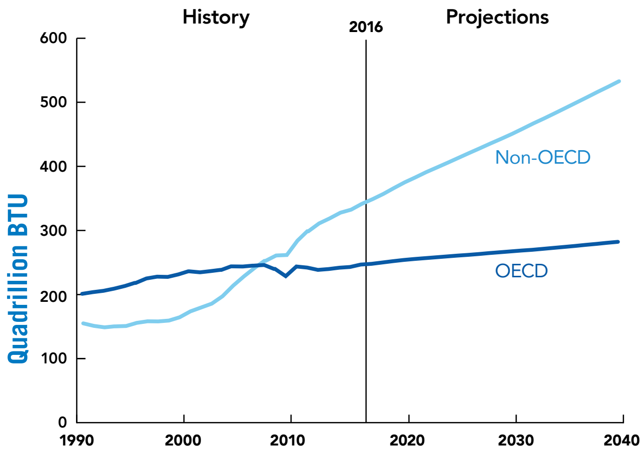
In this construct, advanced energy systems are increasingly providing users with more economical choices. We see this trend accelerating–posing both opportunity and risk for the U.S.

Access

Access to energy has two components: demand, or how much is needed; and supply, or where the energy can be obtained.

Today, demand for energy is increasing in most of the world, driven by population growth, the rise of the middle class, and urbanization. From 2005 to 2015, energy consumption worldwide grew by 30 percent, with Africa and the Asia Pacific region (including China and India) growing by 32 and 48 percent, respectively [1]. Over the next several decades, Africa's population is expected to more than double, to near 2 billion people. At the same time, India will grow by 400 million–more than the entire population of the U.S. This growth will produce a significant energy pivot toward these emerging economies, increasing consumption from all sources [1].

Figure 1. World energy consumption by region, 1990-2040



Data retrieved from *International Energy Outlook 2016*, May 11,2016

On the supply side, advanced energy systems are a growing factor worldwide, providing more than 7 percent of total energy consumed. Large nuclear power plants provide 4.4 percent, and renewables[2] add 2.7 percent–a 300-percent increase in the past decade [4,5]. Today, when the sun shines or the wind blows, both small and large nations and even individuals can generate their own energy, making them "prosumers"–producers and consumers combined.

Still other advanced energy systems are being designed and employed to increase energy supplies, including, but not limited to, small modular nuclear reactors, hydrogen-based systems and fuel cells, wireless and super-cooled energy power transfer systems, tidal and wave systems, and microgrids. And, even as advanced energy raises its profile in the global energy mix, fossil fuels are seeing their own technological advancements. Fracking, deep ocean drilling and other methods are

[2] Renewable sources including wind, geothermal, solar, biomass, and waste.

allowing extraction of fossil fuels once considered inaccessible. In short, the world has more energy choices now than ever before.

Close-up of solar panels, with a wind turbine in the background in Lombardsijde, Belgium

At the same time, however, the global demand profile for energy is also changing. In advanced economies, such as the U.S. and EU, slow population growth is dampening growth in overall energy demand, with improved fuel efficiency and electrification in transportation slackening oil demand especially. Africa and Asia are another matter. While advanced energy systems have grown considerably in these regions, they still produce less than 2 percent of total consumption. The pressure remains on fossil fuels. Since 2005, oil demand in Africa and Asia has grown by more than 30 percent. Natural gas demand has grown even more–59 percent in Africa and 71 percent in the Asia Pacific [1]. Indeed, Asia is now the world's largest consumer of oil, coal, and natural gas [1]. With insufficient indigenous sources to meet this swelling demand for fossil fuels, access to energy is a growing concern and shaping foreign policies in these areas.

Performance and Reliability

When making energy choices, performance–the ability to accomplish a specific task at the desired time and place–is decisive. For illustration, consider the U.S. Navy. Through the mid-1800s, it transitioned from sail power to coal- and steam-driving paddlewheels or propellers. This freed tactics and operational execution from the direction and force of the wind. By the early 1900s, the fleet had shifted from coal to oil, increasing both range and performance. By the mid-1900s, the Navy had harnessed nuclear power for submarines and aircraft carries. This eliminated the need for submarines to surface to recharge batteries, significantly improved stealth and performance, and improved the range and speed of aircraft carriers. This century finds the Navy moving to electric hybrid gas turbine propulsion plants, again improving efficiency and reducing the need to refuel, while increasing operational availability and performance.

Civilian ground transportation has undergone similar transformation. In the early 1900s, horses were replaced by internal combustion engines, significantly improving the performance of automobiles over carriages. Today, electric vehicles (EVs) are at the leading edge of another tectonic shift. EVs already have better torque and acceleration than most internal combustion engines, achieve ranges exceeding 200 miles on a charge, and are moving to cost parity with gas-powered cars. But the advanced energy revolution extends beyond cars. Trains are using magnetic levitation, like China's Shanghai Maglev Train [6]. Heavy-duty trucks will not be far behind. Siemens has been testing overhead powerlines on highways for trucking in Germany, Sweden, and California. The U.S. truck designer, Nikola Motor Company, recently unveiled its Nikola One, a semi-truck with a fully electric drivetrain powered by high-density lithium batteries and on-the-go hydrogen fuel cell technology affording a range of 800 to 1,200 miles [7].

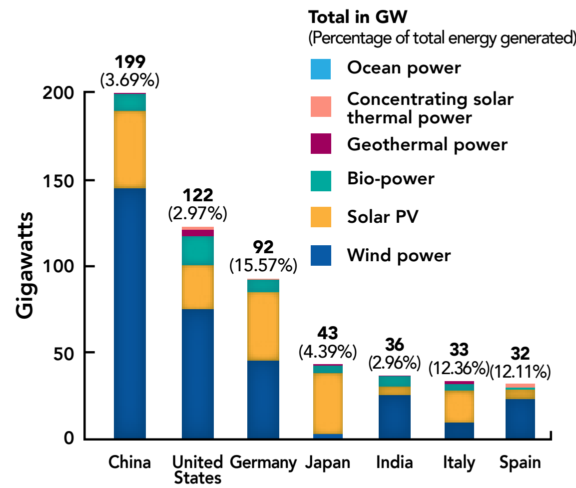
Advanced energy is also slowly beginning to make its mark on aviation. In choosing aircraft energy, power density–the rate at which a system can perform work per unit mass–is a critical performance factor. Long-range passenger, cargo, and combat aircraft demand high power density. To date, that has been supplied almost exclusively by liquid fuels. However, the U.S. Navy and Air Force have now certified all their aircraft to fly on an advanced energy biofuel mix. Meanwhile, the Navy has demonstrated Aqua Quad, an energy-independent, ultra-long endurance, hybrid-mobility unmanned combat drone powered by solar power that can be deployed in sub hunting [8]. The Royal Air Force (U.K.) and Airbus have deployed Zephyr, a High Altitude Pseudo-Satellite (HAPS) drone that runs exclusively on solar power and fills a capability gap between satellites and "air breathing" aircraft capable of 24x7 ISTAR (intelligence, surveillance, target acquisition, and reconnaissance) for weeks without refueling [9]. Google is developing a similar solar-powered aircraft able to fly almost continuously as a communications relay hub to beam Internet to remote areas. And Germany recently flew a four-seat passenger plane on hydrogen fuel cells.

Advanced energy holds promise beyond transportation. Wind, photovoltaic solar (PV solar), biofuel, geothermal, and concentrated solar power (CSP) are

Solar Impulse 2. The first round-the-world flight powered by renewable energy

often touted as systems that are continually improving performance and are now beginning to displace traditional energy sources. Figure 2 represents their recent contributions.

Figure 2. Renewable Power, Top Countries – 2015



Derived from *Renewables 2016 Global Status Report.*

Renewable advanced energy systems now generate about 3 percent of the world's total energy consumed, and nuclear power generates nearly 5 percent, with a more than 90-percent production profile [10]. Advances in nuclear power in the form of small module reactors (SMRs) were recently reviewed by the Defense Science Board (DSB)[11]. With the SMRs simple design, inherent safety, and little-to-no contribution to weapons grade nuclear proliferation, the DSB found they were "transportable and deployable in military [Forward Operating Bases] FOB … and expeditionary force situations, and could eliminate the need for logistics fuel otherwise dedicated to producing electrical power." The DSB further found that those who chose to use SMRs "could become the beneficiaries of reliable, abundant, and continuous energy, rather than the most energy-challenged segments."

In summary, many advanced energy systems are poised to achieve performance parity with traditional energy sources.

Costs

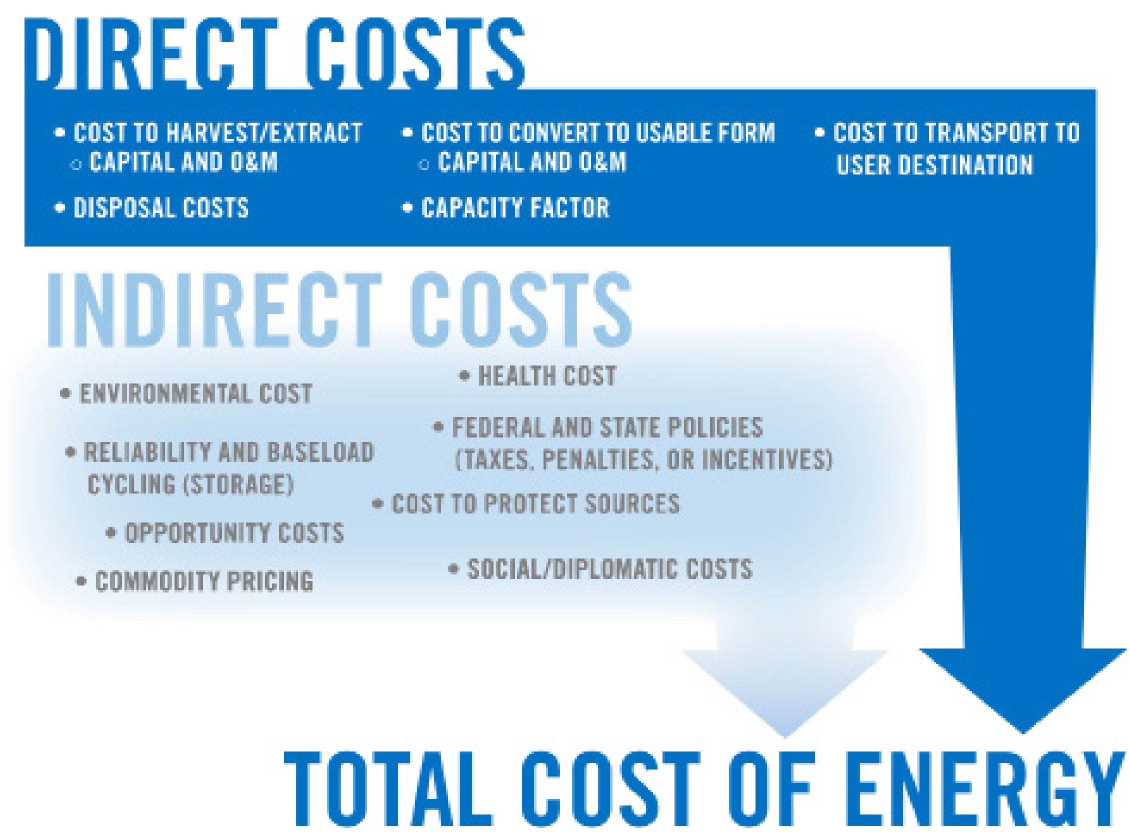
The final factor in weighing energy choice is cost. This involves more than merely buying a solar panel, a wind turbine, or an SMR. Total cost is a function of direct and indirect costs. Shown below is a model and the major contributors to each cost type.

Direct Costs

Direct costs apply to expenditures of getting energy to the consumer. For traditional energy sources, they include costs of constructing and operating wells or mines, extracting the energy, and either refining it or formatting it to be used in power plants. Add to this, transportation costs include those incurred in building and maintaining the distribution system, including: trains, ships, pipelines, or an electrical grid. For some systems, like nuclear power or lithium batteries, disposal costs may also be a significant factor.

As demand for fossil fuels increases, extraction costs are rising, especially for oil and especially in the U.S. At the same time, we have seen significant cost reduction in some advanced energy components, most notably photovoltaic solar (PV solar) panels. As shown in Figure 3, the cost of PV solar panels has dropped from around $5.00 /watt at the beginning of this century to $0.57 in 2015. In many areas of the U.S., the most expensive part of solar installation is no longer the panel, but the inverters, controllers, other system components, and installation labor.

In power generating systems, one of the largest hidden direct costs is the capacity factor. How large must the plant be to meet demand? For plants with high-capacity factors and little down time for maintenance or other disruptions, like nuclear power, the capacity factor approaches 100 percent. These plants can be sized to just meet the requirement. Systems like some wind and most solar produce power about 1/3 of the time, giving

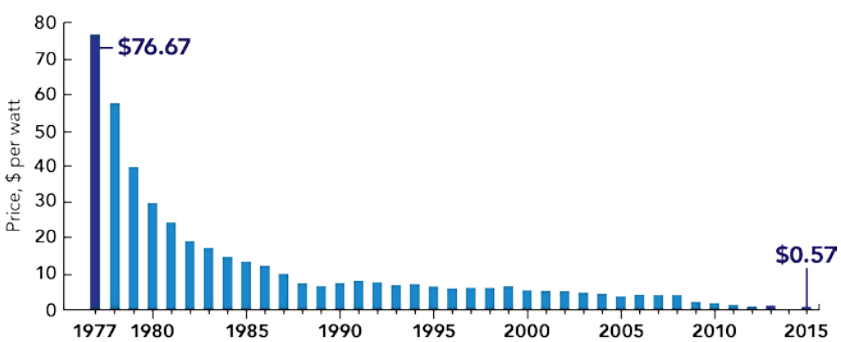


them 33-percent capacity factors. These must be sized to achieve three times the requirement.

Other costs, like those associated with moving energy to the end consumer, may be significant but difficult to apportion. For example, the price paid at the pump for gasoline includes a portion of the cost for the thousands of trucks that weekly bring the fuel from distribution centers to filling stations. It includes the cost of building the filling stations and paying the staff who work there. Some advanced energy systems may be able to fold into existing distribution with minor or no added cost, like the 10-percent ethanol (biofuels) that many Americans currently use in their cars. Others can fold into existing distribution with more extensive modification, like the 35 hydrogen refueling facilities in the U.S. that have already been added as "gas stations." [12] Still other systems may benefit from other models, like electric recharging at shopping centers and businesses, which may add construction cost, but provide more convenience. Some stores already provide "free" EV charging to draw shoppers.

Figure 3. The Swanson effect

Price of crystalline silicon photovoltaic cells, $ per watt



Derived from Bloomberg New Energy Finance and Nature Energy

Indirect Costs

The indirect costs associated with energy systems are more varied and sometimes more difficult to monetize. They include items such as federal and state policies (taxes, penalties, or incentives), reliability and baseload cycling (storage), the cost to protect sources with military or other personnel, environmental costs, health costs, social and diplomatic costs, and even costs associated with price volatility.

Policemen inspect oil pipelines at Al-Sheiba oil refinery in Basra, Iraq – February 2011

The significance of these indirect costs is made clear by the U.S. Energy Information Administration (EIA), which states that federal and state policies for utility-scale wind and end-use solar markets are the most important factor in projecting growth of these energy sources[13].

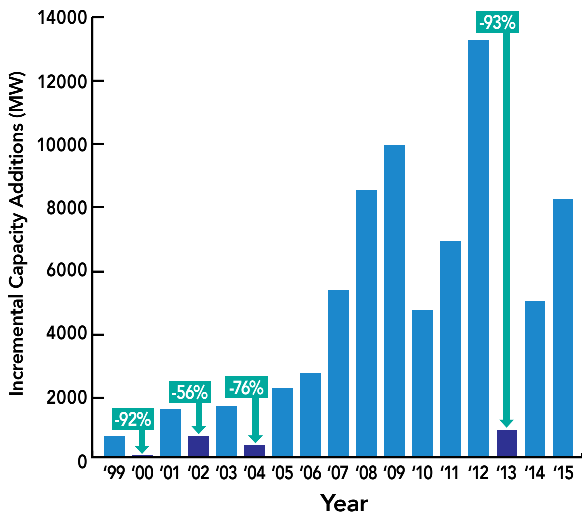
A key indirect cost–and barrier–to adoption of intermittent energy sources is baseload or reliability cost. Without utility-scale storage systems, all intermittent systems, whether wind, solar, tidal, or those yet to be developed, cannot serve as the primary or baseload power source for a community or city, as they do not produce continuous power. Until utility large-scale storage is available, baseload supply would come from existing or new generators using other fuel sources, like fossil fuel or biofuel, or from some type of energy storage (batteries, compressed air, pumped hydro, and others), all of which add to the intermittent system's cost. Some large storage facilities are already in place

Federal and state policies for utility-scale wind and end-use solar markets are the most important factor in projecting growth of these energy sources.

but are not yet designed to provide sustained baseload capabilities.

Some indirect costs, like tax credits for installation of new systems or fines for excess pollution, are straightforward and often important factors in indirect energy cost. Figure 4 shows the impact of the U.S. government's production tax credit (PTC) on the wind energy system installation. Note that when the PTC expired there was a considerable drop in added capacity.

Figure 4. Impact of Production Tax Credit



Derived from U.S. Energy Information Administration (EIA), Electricity – Current Issues and Trends.

There are hosts of other indirect costs, difficult to monetize, but with real potential burdens on energy choice. As an example, if a nation moves to advanced energy systems before the design end of service of existing structures, those old systems become stranded assets and their residual value are an indirect cost of the new system. But perhaps the clearest examples of indirect cost are impacts on the environment and health. Some estimate that air pollution in China and India, related almost exclusively to burning fossil fuels, is the leading cause of 1.3 million annual deaths in each country [14]. What cost should be assigned to these lost lives? The World Bank estimates that air pollution-related health problems cost the global economy about US $225 billion in lost labor income in 2013 [15].

The Full Cost of Advanced Energy and Electric Vehicles—a Case Study

The transition to Electric Vehicles (EVs) illustrates the three key factors of energy choice: *access* to electricity, *performance* parity with internal combustion (IC) engine vehicles, and total *cost*—including sticker price and the cost to operate and dispose of the vehicle.

In nations with advanced economies, charging EVs will soon become more convenient than today's gas stations. Wherever there is electrical power and room for a car to park, there is a potential refueling station. This could be a home, an office, a shopping plaza, or a location dedicated to battery charging. Convenience will rise as manufacturers design EVs with more charging capacity or come up with a means to quickly swap out batteries. Access will require more effort in areas of the world that lack an electrical distribution system to widely power EVs. Lack of electrical infrastructure can limit market penetration.

Performance parity will be achieved when EVs achieve the range of IC engines and are comparable in speed and acceleration with equivalent carrying capacity. Advances in batteries already provide EV ranges exceeding 230 miles. Trends indicate that battery improvements over the next decade will allow ranges exceeding those of today's standard internal combustion engine. EVs already outperform most IC cars in acceleration and torque, have 10-times fewer parts, and require less maintenance.

Finally, we come to cost. Batteries are the fulcrum for EV prices. As batteries improve and become less expensive, economic market forces will push EVs ahead. And when it becomes cheaper to power a vehicle of equivalent performance by an alternative to petroleum, namely electricity, economics will propel a transformation of the global fleet.

It is not a matter of "if"; it is only a matter of "when."

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ACCELERATING THE TRANSITION TO ADVANCED ENERGY

As we have seen, energy choices turn on access, performance, and total cost. We know there is inherent uncertainty in the future of each–especially costs associated with varying governmental policies to favor one form of energy over another. Consequently, it is extremely difficult to predict the energy patterns of the future. Critics note that expert forecasts, particularly the annual International Energy Agency (IEA) World Energy Outlook, consistently underestimate advanced energy trends [23]. Since 2000, the IEA has revised its wind energy forecasts upward five-fold and its solar energy forecasts fourteen-fold. As military leaders, we know we cannot wait for absolute certainty to begin weighing and refining national security and national defense strategies. The demonstrated uncertainty in expert forecasting is reason enough to consider that advanced energy trends are accelerating making our analysis all the more urgent. (See Appendix A for a discussion of the national security implications of the status quo trajectory, continued reliance on fossil fuels).

Experts have come to the consensus that the global energy mix is changing, with advanced energy systems poised to assume an increasing role in the global energy landscape.

Advanced energy acceleration may be driven by more rapid technological progress on a variety of fronts. Alternative scenarios, including those published by the IEA, BP, Shell, and even OPEC, explicitly acknowledge and describe the potential for the transition to accelerate. The range of influences includes: improved energy efficiency in buildings and vehicles; more rapid adoption of transportation advances, including increased saturation of electric vehicles and EV ride-sharing and car-pooling; breakthroughs in energy storage; policy drivers; and greater utilization of renewable systems in electrical power generation [1,4,17].

Experts have come to the consensus that the global energy mix is changing, with advanced energy systems poised to assume an increasing role in the global energy landscape. But, as history shows, energy transitions do not occur overnight; they gain momentum over years or decades. It is certain that the global energy system is now in the early stages of a transition. How quickly the transition will progress, and what might be the impact of disruptive technology breakthroughs, are not as certain.

Sooner and Sharper

The transition to advanced energy, particularly the potential for acceleration, must be examined in the context of the expected 30-percent growth in global energy demand. Common across experts' base-case and acceleration-case scenarios is that, through mid-century, consumption of all energy sources, including hydrocarbon-based fuels, will rise. While expert scenarios predict that advanced energy will displace portions of global oil demand, the ever-increasing total energy demand, primarily driven by demographic changes and economic growth in the developing world, will counter this [1,4,17].

Unlike in the past, market forecasts explicitly acknowledge the makings of an energy transition, thanks to increasing reliance on advanced energy. The same forecasts describe a future fuel mix that departs from the oil and coal dominance of the past century. Should the transition exceed experts' expectations and demand for oil, especially, fall sooner and more sharply, the resulting changes in geopolitical dynamics and shifting global spheres of influence could have a greater impact on U.S. national security.

Envisioning Acceleration

The transition will not occur all at once. The transition to advanced energy systems likely will not occur on the same time scale across the globe. Nations like the U.S., where a sizable portion of domestic oil consumption goes to fuel passenger vehicles, will realize significant reductions in oil demand with earlier adoption of electric vehicles, while nations like China,

Saudi man walks on a street past a field of solar panels at Al-Oyeynah Research Station, Saudi Arabia.

with only 13 percent of oil demand going to cars, will not. Across the globe, trillions of dollars of investment in infrastructure will be required. Those countries that can most afford to make this transition probably will do so first, facilitating technology transfer and investment among their allies and countries of strategic importance. Further, the utter magnitude of increasing energy demand in emerging economies will pressure nations seeking economic growth to obtain energy resources by any means available, old or new.

The transition will be geographically uneven.

Differences will be driven by a combination of factors, including access to intellectual capital, availability of financing, energy demand patterns, local energy resource endowments,[4] and the presence or absence of strong governance. In some areas of the world, water scarcity may limit traditional methods of power generation or even fossil fuel extraction; in these areas, energy systems with little water demand, like wind and solar, will be preferred. In advanced economies, the sheer scale of incumbent energy systems and the ease with which consumers now obtain energy present potential barriers to rapid modification or replacement of current infrastructure

On the other hand, countries like India, where new energy construction will boom, can move directly to advanced energy systems instead of installing traditional fossil fuel-based infrastructure. The speed with which consumers adopt energy-efficient products and distributed energy systems will be influenced by varying degrees of lock-in across housing stocks, commercial facilities, military installations, industrial plants, and transportation systems. These conditions may give rise to advanced energy systems "leap-frogging" in developing parts of the world that are less constrained by investment in and physical ties to the status quo. Relatively rapid transitions are possible; the Netherlands' transformation into a natural-gas dependent nation and France's rapid transition to nuclear power serve as examples [18,19,20]

[4] An energy endowment is the amount of energy a nation can produce from indigenous sources of any type.

Other factors driving the transition

Efficiency. Energy efficiency has historically been viewed as the "hidden fuel," cutting demand for energy without fanfare[21]. In 2010, energy savings from efficiency among IEA member nations exceeded the demand met by any single energy source–including oil, gas, coal, and electricity [21]. Achieving efficiency gains across the whole of the energy system–capture, generation, transmission, distribution, and end use–is an integral part of the advanced energy transition. Estimates indicate that successful investments in energy efficiency could enhance global economic output $18 trillion by 2035 [21].

Supply diversity, distributed generation, and energy access. As the advanced energy transition unfolds, the global energy supply will become more diversified and energy systems will become more distributed. Because the transition is technology-driven, the range of sources that can potentially harness usable energy is broader than a fossil fuel-based system with a limited number of sources (oil, coal, and natural gas).

As the advanced energy transition unfolds, the global energy systems will become more distributed.

Advanced energy systems can be used for demands currently met by large-scale energy systems (e.g., electric power grids and vehicle fuel networks), as well as currently unmet demands in areas where contemporary large-scale energy networks are infeasible (due to economic or other considerations). The global potential for increased energy access, particularly in areas not attractive to the current fossil fuel-based systems, may power economic growth in both the world's advanced and emerging economies.

We already see these trends. In the U.S., wind and solar electricity capacity, including both utility-scale solar collectors and distributed photovoltaic (PV) solar, have experienced rapid growth. In the past few years, wind has increased by more than 100 percent and solar by over 900 percent [22]. Wind and solar capacity growth represents about half of gross capacity additions over the same period. However, in the context of the full energy mix, today wind and solar, respectively, provide just 4.7 percent and 0.9 percent of total U.S. generation [13].

Challenges remain...

As the world transitions to advanced energy, the likely shifts in geopolitical influence and global economic conditions will impact U.S. national security. The range of possible outcomes under accelerated conditions warrants study. Of particular concern to us is this: Increases in global energy demand may dwarf advanced energy gains. This could occur if the rate of transition does not keep pace with or exceed demand, and if some of its significant challenges, like the need for large-scale energy storage solutions, are not addressed in a timely fashion.

We have learned through experience that the time to plan and prepare for future highly consequential events is well before those events take hold. Planning and preparation require analysis of all possible scenarios, from instances with low consequence and high probability to those with high consequence and low probability. In the following section, we assess the regional and broader outcomes of an accelerated transition as they specifically relate to U.S. national security.

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U.S. NATIONAL SECURITY IMPLICATIONS OF ADVANCED ENERGY: CHALLENGES AND OPPORTUNITIES

National security and energy have been inseparable since the advent of the Industrial Revolution. This remains true today. Energy is the basis of economies, which are the engines of political and military power. Therefore, the availability of energy resources has had significant sway on international relations. We offer the following observations in the context of our view of national security and energy as linked to diplomacy, economy, and the military.

Diplomatic

In 1907, the U.S. sailed the Great White Fleet–the first-ever navy flotilla of battle ships to circumnavigate the globe. This accomplished three major objectives for U.S. national security:

- It established energy relationships between the U.S. and many nations as coaling stations were built around the world to support the fleet.
- It opened diplomatic relations with Japan and other Asian partners.
- It showed the world U.S. military power and reach.

Together, these developments provided the U.S. with new energy assets, new markets, and new trade relationships.

Advanced energy has the potential to transform the geopolitical landscape. Over the coming decades, despite projections of a net rise in demand for fossil fuels, we see advanced energy systems potentially increasing their presence in the overall energy mix from single-digit shares to well over 25 percent–as much as 50 percent or more in some countries. Despite uneven penetration around the world, advanced energy will impact import-export balances for hydrocarbons and associated dependencies and tethers, reshaping some and creating others. This change must be examined in the context of the dramatic expected increases in global energy demand, driven mostly by China, India and Africa.

An acceleration of advanced energy use may slow dramatic increases in the overall anticipated demand for oil. Advanced energy systems may also allow coal demand to peak sooner than forecast. On the other hand, we expect natural gas demand to grow significantly in the short-to-intermediate term, given the electric power sector's increasing primary energy requirements. There will be regional differences as all of this plays out. Advanced energy's trajectory will allow many Western nations to reduce their overreliance on hydrocarbons. Some developing nations, meanwhile, may move directly to advanced energy, skipping many geopolitical and environmental pitfalls associated with hydrocarbons. But in China and India, burgeoning energy demand will likely increase the use of fossil fuels despite large-scale deployment of advanced energy.

An acceleration of advanced energy use may slow dramatic increases in the overall anticipated demand for oil.

We assess that advanced energy will weaken traditional oil exporters' (in particular Russia) potential ability to hold dependent nations hostage to petroleum by mitigating the use of energy exports as a tool of coercion. For example, over the next decades, the U.S. and advanced nations in Europe will have more energy options and be less dependent on–even independent from–traditional energy suppliers, notably OPEC members and Russia. Yet developing nations like China and India, with their increasing overall demand for energy, may build or strengthen ties to oil exporters such as Russia and Iran. In addition, large energy consumers, like China, may seek to expand territorial claims to increase indigenous fossil fuel resources. Any growing influence of Russia and Iran, or Chinese intervention in the South China Sea or Spratly Islands to pursue fossil fuels or other interests, presents significant national security concerns for the U.S. (See Figure 5). Acceleration of the transition to advanced energy may reduce these fossil fuel pursuits and tethers, and moderate our concerns.

Figure 5. Spratly Islands and South China Sea

Globally, advanced energy systems will move billions of people out of darkness and facilitate their education and connectivity, enabling nascent markets to access a full range of goods and services. Nations seeking to lead the advanced energy charge are investing in systems worldwide, aiming to: (1) secure access to growing markets; (2) establish new forms of energy dependencies based on advanced energy technologies, and thus geopolitical linkages; and (3) in the case of the E.U. in particular, reduce the global carbon footprint. As developing nations gain access to electricity, their economies will grow, they will enjoy better health and prosperity, and they can become new trading partners with stronger diplomatic ties to the U.S. or other nations willing to engage. Developing nations should be encouraged to pursue clean energy choices, but not at the expense of depriving energy of any type from distressed populations. When it comes to spreading energy to emerging parts of the world, we assess that electrons are as important as elections when it comes to global influence.

In 1973, unhappy with the U.S. backing of Israel in that year's Arab-Israeli War, OPEC embargoed oil exports to the U.S., trying to sway American diplomacy with the economic power of energy. The six-month embargo cost the U.S. economy an estimated 2 percent of GDP in 1974 and resulted in nearly five quarters of contraction [23]. Many argue it deepened the global recession of the mid-1970s. President Carter was moved to declare the Middle East an area of vital strategic interest to the U.S., a status it still holds today.

Economic

Growing populations and economies will require energy to secure affordable supplies of the key natural resources–food, water, and shelter– essential for economic prosperity and well-being. These energy needs will increasingly be shaped by advanced energy systems. Not only will advanced energy impact the supply and demand of fossil fuels, changing both markets and revenues streams, it will have its own supply and labor markets and give rise to new energy trade partnerships. These economic impacts will influence global GDP levels, government revenues, and flows of government goods and services to satisfy citizen expectations. The changes will spur diplomatic and economic consequences with direct impacts on national security.

Advanced energy has the potential to change supply-and-demand dynamics and prices for hydrocarbons, particularly oil and natural gas. As global demand for oil slows, surplus supplies may lead to price suppression. In this case, low-cost oil producers like OPEC may gain market share over high-cost producers like Norway, the U.K., the U.S., and even new wells in Russia. But in a prolonged lower-price environment, oil revenues and profits may drop despite higher-volume sales. Natural gas, meanwhile, will be used as a bridge fuel during the transition to full advanced energy, and see its demand rise.

OPEC's petrostates and other major exporters like Russia–reliant on oil revenue to drive their economies, fund their governments and militaries, and provide services to their populations–are particularly vulnerable to low oil revenues. This is a double-edged sword. Loss of oil revenue can weaken the governments of U.S. adversaries like Russia and Iran; however, these same revenue challenges would also confront and perhaps weaken our allies, like Saudi Arabia, Iraq, and Kuwait. We have witnessed firsthand what can happen in the Middle East when governments are weakened and power vacuums arise–Iraq, Libya, and Syria provide illustrations. Many petrostates are considering ways to mitigate this risk. Saudi Arabia and the United Arab Emirates, for example, have already implemented strategies and programs designed to diversify their economies and government revenue streams.

As advanced energy sources come on line, OPEC's influence over the global energy posture–manipulating oil supply as a means of controlling price–will diminish. With less ability to control price and, by extension, revenue, OPEC nations will experience internal competition for market share. Historically, the lack of an oil "market manager" gives rise to price volatility. This stifles investment, complicates budgeting, and drives tensions within and across nations. However, nations with advanced energy alternatives to oil, like electrified transportation, can weather oil price fluctuations, enjoy stable energy prices, and better predict future costs.

Globally, advanced energy will also give rise to new labor demand, with employment opportunities in construction, installation, and operation of new systems; system integration; research and development; and manufacturing. Millions of jobs will be created worldwide to support the growing advanced energy sector. However, it is unlikely that all displaced hydrocarbon workers will fill these new jobs. Some workers will lose, others will gain. The transition's long-run impact on labor markets is unclear, and must be monitored and carefully managed.

Military

In the 1930s, Japan relied almost exclusively on U.S. oil imports to fuel its expansion into China and Southeast Asia. The U.S. became increasingly concerned about this expansionism, reported Japanese military atrocities in China, and Japan's 1940 treaty alliance as an Axis power. As a tool of diplomacy, the U.S. reduced its supply of oil to Japan. Japan then began occupying parts of Indonesia to meet its oil needs. The U.S. objected, and, in late 1941, halted all oil exports to Japan. Japan retaliated by attacking the U.S. Navy in Pearl Harbor. Energy played a critical role in bringing a reluctant U.S. into WWII.

Changing geopolitical energy tethers and new dependencies are likely to alter missions for some militaries charged with protecting energy supplies.

We assess that growing energy demand is one driver of the Chinese military build-up to protect energy supply lines. Even with China's accelerated transition to advanced energy, we see its demand for oil and natural gas increasing over the next few decades. This will not only increase Chinese dependency on Russia, Iran, and other oil and gas suppliers, it will likely push them to exploit more indigenous hydrocarbon sources, embrace fracking, and seek territory with proven or potential hydrocarbon reserves, such as that near the Spratly Islands or even in the Arctic. This will require a counterbalance from the U.S.

Many believe that reduced domestic dependence on Middle East oil will enable the U.S. to reduce its military presence in that region. As military experts, we do not share this view. First, the U.S. has strategic interests beyond the Middle East's oil resources, not the least of which is our ongoing struggle against violent Islamist extremists. Second, the U.S. has committed to support partners in the region. Finally, the Middle East, as a low-cost oil producer, will remain the world's largest supplier of oil for the foreseeable future. Even if the U.S. cuts direct dependence on OPEC for its own energy, the free flow of oil from the Middle East, enabled by stability in the region, is critical to the global economy upon which the U.S. economy depends. Finally, given the many long-standing rivalries among nations in the Middle East, U.S. presence promotes regional stability.

Russia is another area of interest. If increases in advanced energy lead to an oversupply of oil with sustained price suppression, Russia's GDP and government revenues will likely decline, limiting its ability to maintain, train, modernize, and employ its military. But the size and capability of Russia's military do not necessarily foretell its level of engagement. The U.S. military must remain amply sized and strategically positioned to support our allies and curtail any Russian aggression.

Other Considerations

In May of 2012, a Senate Armed Services Committee investigation discovered counterfeit electronic parts from China in the Air Force's largest cargo plane, in assemblies intended for Special Operations helicopters, and in a Navy surveillance plane. Sen. John McCain said it was "abundantly clear that vulnerabilities throughout the defense supply chain allow counterfeit electronic parts to infiltrate critical U.S. military systems, risking our security and the lives of the men and women who protect it." Sen. Carl Levin called this a problem that "threatens national security, the safety of our troops, and American jobs."

Advanced energy systems will orient trade toward movement of technology and components, rather than extraction and flow of energy commodities. Intellectual property may grow in value, requiring more vigilant protection. Economic risks may arise from planned obsolescence, in which technologies are designed to "wear out," or with lock-in to immature or inefficient technologies. Cyber espionage will be a growing threat. All these issues can rise to the level of a U.S. national security concern.

At present, we can't precisely know the potential new tethers associated with advanced energy. There is speculation that supply tethers may develop around the specific materials or the resource inputs needed for some technologies. Examples cited include "rare earth" materials used in magnets, and lithium and cobalt used in batteries. Still other critical materials may not yet be identified. While some of these materials, namely rare earths, are actually plentiful around the globe, extraction is most economical in only a few areas, notably China. The same can be said of lithium–there is plenty to go around, but some countries enjoy production-cost advantages. Currently, no materials are so limited that their availability for use in advanced energy systems rises to the level of a U.S. national security concern.

There are, however, complex national security challenges involving the overlapping linkages between energy, water, and food. In some places, crop lands are used to grow biofuel feedstock instead of food. In others, energy-intensive desalinization diverts fuel from other sectors to make fresh water. In still other areas, energy production, generation, and extraction methods are water-intensive, and compete for the very water vital to human sustenance. Agriculture is also energy-intensive, and is becoming more so as production moves from rice and grains to meats and fruits. Dams being built to produce electricity compete with the water needs of downstream nations. As major waterways flow across national boundaries, trans-boundary cooperation in ensuring water and energy security becomes increasingly important. Isolated solutions aimed at just one sector of the water-food-energy triad may have unintended or even fatal consequences in other sectors.

In conclusion, the movement toward a new energy era offers the U.S. (as well as our allies and adversaries) opportunities for enhanced diplomatic influence and relationships, increased economic prospects, and a review of military mission. It will likely lead to dramatic changes in global spheres of influence.

Global Impacts—a MAB Perspective

As senior military officers, we are no strangers to energy challenges. We confronted them as individuals, both theoretically and practically, during our military careers. And we have explored them together as members of the Military Advisory Board, analyzing the nexus of energy and national security in several reports over the past decade.

In the next section, we draw as much on that collective experience and perspective as we do on data. We investigate the transition to advanced energy–and the implications for the United States–in five world power centers:

China, where growing energy demand exceeds domestic resources, compelling it to pursue an expanding world-wide footprint to ensure adequate national supply.

India, whose demographic and economic changes could make it a principal driver of the global energy landscape by mid-century.

Russia and Europe, which offer the clearest illustrations of energy's role in national security and geopolitics.

OPEC and the Middle East, the oil-rich nations for which a worldwide transition to advanced energy–and away from hydrocarbons–has profound consequences.

Africa, where energy demand arising from rapid growth is coupled with insufficient infrastructure–presenting opportunity for the U.S., but also for our competitors in the struggle for influence.


Poor air quality in Chengdu, China

China

As senior military officers, we see China's increasing appetite for energy as a distinct potential U.S. national security concern. It is our view that over the coming decades, despite shifts to advanced energy power systems and electric vehicles, China's growing energy demand will continue to exceed its ability to meet needs internally, resulting in more oil and natural gas imports. This will drive China to secure more energy supplies abroad, grow its military to protect it international interests—including energy—and establish stronger relationships with Iran, Russia, and others that do not share U.S. values.

We are also concerned that, absent U.S. involvement, the billions of dollars China is investing in advanced energy systems around the world, especially in developing nations, will tie these nations to China diplomatically and economically, resulting in Chinese advantage over the U.S. in both trade and geopolitics.

China, with its rapid economic growth, is already the world's largest energy consumer. As of 2016, China was also the world's largest net oil importer and a growing natural gas importer, ranked fifth in the world [24,25]. It remains the world's top coal producer, consumer, and importer, accounting for almost half of global coal consumption [26].

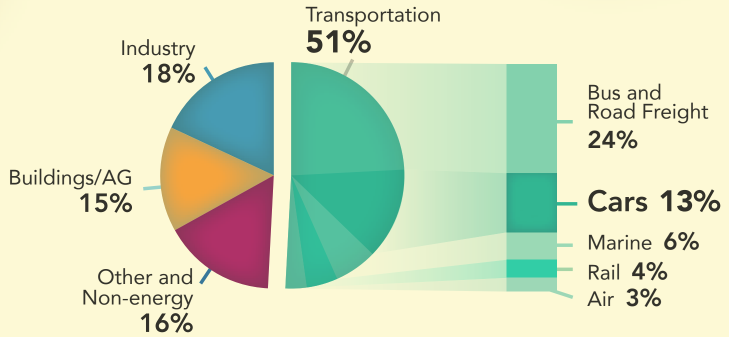
We note that much of China's expanding global footprint and associated diplomatic efforts are aimed at increasing its access to energy (among other drivers including access to markets) [27]. For example, in 2013 the Chinese state-owned entity CNOOC spent $15 billion to acquire Canadian oil producer Nexen in China's largest-ever foreign takeover [28].

While many factors are driving China's growing presence in the Middle East, Africa, the North Sea, and its campaign for Observer Status on the Arctic Council, energy—especially oil and natural gas—plays a key role. Experts speculate that China's ongoing island-building near the Spratly Islands—an area of territorial dispute in the South China Sea—is a means to lay claim to oil and mineral reserves, as well as fishing grounds [27]. Further, we think that China's actions today provide insights on how it will position itself in the future energy landscape.

Advanced Energy's Potential Impact on China

Driven by economics and government policy, China's transition rate to EVs will likely exceed the U.S. rate; however, we do not assess the same dramatic impact on oil demand. In the U.S., cars and other light-duty vehicles account for nearly 60 percent of the oil consumed. In China—with much heavier oil use in industry, heavy trucks, petrochemicals, and buildings—cars and light-duty vehicles account for about 13 percent of consumption [29]. Even conversion of all the cars and light-duty vehicles in China will impact less than 15 percent of overall oil use [29]. On the other hand, nearly all China's growth in oil demand is to meet growing demand for cars. Wide acceptance of EVs in China–picture hundreds of millions of vehicles–will slow that growth rate, but place tremendous new demand on the electrical grid to meet transportation energy needs.

China oil consumption – 2015



Derived from International Energy Agency, "People's Republic of China Final Consumption (2014)."

Overall population and economic growth will add even more demand for electricity and all the energy sources used to produce electric power. This, combined with China's aim to reduce coal use to improve its deteriorating air quality, leads us to see a particularly marked increase in the nation's demand for natural gas.

Most experts predict growth in China's demand for oil and natural gas in the coming decades, along with its advanced energy transition. This will force China to exploit additional internal resources, including new reserves; to use advanced extraction methods like fracking; to import additional quantities from existing sources and/or expand their presence in the South China Sea; and to seek access to new energy supplier and markets around the world. The latter presents potential U.S. national security concerns.

Even with an accelerated transition to advanced energy, China will likely demand more oil and natural gas from current energy suppliers—most notably Russia and Iran. In 2016, Russia became China's largest supplier of oil [30]. Russia is positioning to meet growing Chinese oil and natural gas demand with new pipelines under construction or approved [31]. Not only would additional Chinese petrodollars fund the Russian economy and government, these growing energy tethers would further strengthen Sino-Russian relations, which have historically presented challenges to U.S. national security.

In addition, China is already strengthening energy ties with Iran, signing a 25-year strategic cooperation agreement in 2016 [32]. Late that year, the state-owned China National Petroleum Company signed an agreement with the National Iranian Oil Company to develop phase 11 of the South Pars gas field off the coast of Iran [33]. Further growth in Chinese purchases of Iranian energy resources may strengthen existing ties and add to the coffers of a key state sponsor of terrorism, posing a direct threat to U.S. national security.

In the coming decades, we foresee China's demand for oil and gas resources (among other factors) motivating China to secure its "own" offshore reserves, most notably in the South China Sea. We find that securing energy resources and supply lines is one driver for China's increased military posture—and its formation of a blue water navy with global reach [34].

Advanced Energy as a Tool of Global Influence

As China looks for more oil and gas around the world, it will seek to build relationships, open new markets, and gain geopolitical influence. We see the Chinese using advanced energy systems to accomplish these objectives.

China is already setting the direction for advanced energy. For example, in 2015, China invested more than $100 billion in renewables globally (excluding large hydro), representing more than a third of all investment worldwide, and 2.5 times that of the U.S. China is already manufacturing more wind turbines and solar modules than any other country, and estimates indicate it will install more than a third of global wind and solar capacity between 2015 and 2021 [4]. As of 2015, China accounted for 3.5 million of the 8.1 million jobs in the global renewable energy sector [35].

In our view, China's pursuit of advanced energy is both encouraging and presents challenges. The more advanced energy systems China deploys domestically, the less dependent it becomes to Russia and Iran, and the less money it pumps into those regimes. This is a positive development for U.S. security.

On the other hand, we assess that, as today's leader in commercialization and deployment of advanced energy technologies, China will continue this trajectory and position itself as an "advanced energy exporter," particularly in emerging economies. If successful, China will serve as the "go-to" partner for financing, infrastructure development, and the technology support necessary to meet other nations' new energy demands. Signs of China's positioning are clear. In 2009, then Chinese premier Wen Jiabao announced that China would carry out 100 renewable energy projects in Africa alone [36]. Absent strong engagement by the U.S. and others, through these new ties, China can gain influence, create dependencies for Chinese technologies and technical assistance, reap economic gains from new markets, and build relationships in areas of U.S. strategic interest.

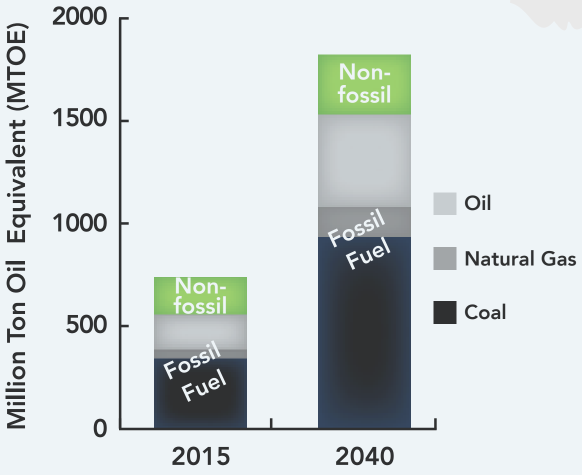
As advanced economic nations also embrace advanced energy, we assess that China seeks to influence global technology choices and systems. For example, energy experts at Columbia University find that Chinese foreign direct investment in the European Union is "integrating the Chinese and E.U. renewable energy industries." [37] This assessment includes more than 200 Chinese renewable energy investment initiatives across Germany, Bulgaria, Luxembourg, and Italy. These partnerships allow China to gain access to and develop influence with key U.S. allies while setting a transition trajectory that gives it the greatest benefit–whether economic or diplomatic.

Finally, we note that Chinese investment in energy resources, both traditional and advanced, spans the globe. Our experience tells us that, in the emerging energy landscape, China's projects—such as those already seen across Latin America, Africa, and South Asia—are targeted to secure power for its long-run energy needs and to expand its global influence.

India

As senior military officers, we view India's transition to advanced energy as a set of challenges and opportunities for the U.S. Over the next few decades, India's population is projected to grow from 1.2 billion to 1.6 billion–adding more people than the current population of the U.S. In just the next decade, India's population will surpass China's [38]. India recently overtook China as the world's fastest-growing economy, and its contribution to global GDP may soon outstrip that of Japan, currently ranked third [39,40]. Amid this growth, trends suggest a significant share of the future Indian population will move from abject poverty to the more energy-intensive middle class [41]. We believe India's continued demographic and economic changes will make it the principal driver of the global energy landscape by mid-century.

India Energy Growth 2015–2040



Derived from International Energy Agency, "India Energy Outlook."

Our experience tells us that rapid population growth, economic expansion, and unprecedented demand for energy will likely give rise to: (1) growing levels of competition for limited resources, which may spur conflict; and/or (2) increasing acceptance of technological solutions, such as those offered through advanced energy systems. As India emerges as a dominant economy globally, the U.S. could bolster our developing relationship through increased commitment to advanced energy, becoming India's provider of choice. This would strengthen both the diplomatic and economic partnerships.

India is the world's third largest oil importer behind China and the U.S., historically importing over 90 percent of its supply from OPEC nations [42,43]. Oil meets roughly a third of India's demand for energy to power its industry, transportation, households, services, and agricultural sector. Coal and biomass (wood or charcoal, animal waste, trash, etc.) round out most of the balance, making India rival China for "the world's poorest air quality." [44,14] In contrast to the developed world, electricity accounts for a mere 20 percent of India's final energy consumption [44].

India is anxious to replace its current energy models with a strong commitment to renewables, bringing hundreds of millions of its citizens distributed, clean, and sustainable electrical power.

Future Trends and Impact

Given mushrooming economic and population growth, India is expected to double its energy demand by 2040 [45]. At the same time, urbanization will further drive energy choices. Three of the world's top five most-populated urban areas are projected to be in India: Mumbai (42.4 million), Delhi (36.2 million), and Kolkata (33.0 million) [46]. Urbanization will require significant shifts in India's energy posture, moving it away from wood and charcoal toward energy sources that can support urban residential and transportation needs. Residential electricity demand may easily increase by more than five times the current level [45].

India is seeking to meet more of its burgeoning energy needs through clean advanced energy systems [45]. It has committed to following: "… a cleaner path than the one followed hitherto by others at corresponding level of economic development (sic)." [47] India has already set goals aimed at adopting renewable and more energy-efficient technologies—including advanced energy systems, primarily solar, wind, and nuclear—to develop more than half its new electrical capacity by 2040 [45].

Yet, even if this goal is met, powering the other half of new electricity capacity will require coal, likely making India the largest contributor to global growth in coal demand. Other hydrocarbons will see rising demand as well. Because India lacks a robust electrical grid, we do not expect EVs to be widely accepted there; oil demand will grow with the addition of 260 million passenger vehicles [45]. With an expanding vehicle fleet and widespread substitution of liquefied petroleum gas (LPG) for fuel-wood in household cooking, India will experience the greatest increase in fossil fuel consumption of any single nation [45].

Achieving India's aggressive energy trajectory will require an estimated $2.8 trillion in energy system investments [45]. Herein lie tremendous economic and diplomatic opportunities for the U.S. But we need to move quickly, for there is already competition. For example, in 2015 China supplied 66 percent of the 44 million solar panels installed in India, and it is anxious to grow market share [48]. Australia and Indonesia are jockeying to be India's major coal suppliers, while Russia is seeking to increase its stake in both India's oil and nuclear power sectors [45].

India's aggressive energy trajectory will require an estimated $2.8 trillion in energy system investments. Herein lie tremendous economic and diplomatic opportunities for the U.S.

The strengthening strategic energy relationship between Russia and India is of mounting concern. In 2016, India entered into a $12.9 billion agreement giving the majority Russian government-owned oil company Rosneft and its partners a 98-percent share of India's Essar Oil Company [49]. This included 49 percent of the Essar-owned Vadinar refinery and its associated port located at a strategic point near Pakistan [50]. Shortly thereafter, a consortium of Indian oil companies gained a 15-to-30 percent ownership stake in several Siberian oil fields, further strengthening the Indian connection to Russian oil and, by extension, Russian government influence [51]. The Indo-Russia relationship in nuclear energy development has also forged ahead [52]. As of early 2016, Russia was the only country to have directly engaged in the Indian nuclear energy sector, going so far as to assist construction of two advanced light water reactor power units, one of which began commercial operation in December 2014 [53-55]. Russia is prepared to build over a dozen more nuclear energy facilities in India over the next 20 years [56]. While the U.S. is in negotiations to build six reactors in India, it seems to us that we are missing a wide range of opportunities in the world's fastest-growing energy market. The strengthening tie between India and Russia is both reminiscent of Cold War geopolitical dynamics and counter to U.S. national security interests.

Acceleration's Potential Impact

If India accelerates its advanced energy transition by electrifying the transportation sector, thereby diversifying its energy supply, it could realize internal benefits. First and foremost, it could bring electricity to millions more citizens at a quicker pace. This could increase productivity, opening new markets for goods and services—an opportunity not only for India, but for its trading partners. From a U.S. national security perspective, acceleration can simultaneously reduce India's growing dependency on Russian energy and provide the U.S. with an opportunity to sell advanced energy systems on the subcontinent. In our military assessment, a more energy-independent India is better for U.S. national security than one heavily reliant on Russian energy resources.

Russia and Europe

When considering energy as a component of national security and geopolitics, we needn't look beyond the energy relations between Russia and Europe. We have repeatedly witnessed Russia using energy exports as a tool of coercion against Europe and as a steady stream of funding for its military and global agenda. We also note that the different fossil fuel endowments of Russia and Europe result in differing approaches to their advanced energy transitions. These differences, particularly in the possibility that new technologies may accelerate the move to advanced energy, will likely have significant impact on the Russo-European relationship. Just as important, the differences will affect the ability of each to advance their global agendas. Both the changing internal relationship and the global implications present opportunities and challenges for U.S. national security.

Russia is the world's third largest energy producer and the world's fourth largest energy consumer, although it accounts for a mere 2 percent of the world's population and just 3 percent of the world's GDP. It is the world's largest exporter of total hydrocarbons (oil, natural gas, and coal). As of 2012, the oil and gas sector accounted for over 70 percent of total Russian exports—an impressive 16 percent of GDP, and 52 percent of their federal budget revenues [57,58]. Russia depends on fossil fuels.

Europe, stretching from Ukraine in the east to Greenland in the west, includes 50 nations, each with its own energy endowments and policies. European countries that border the North Sea, like Norway, the U.K., and the Netherlands, have exploited ocean floor oil and gas reserves. Eastern European countries have relied on indigenous or imported coal and natural gas for stationary power, while importing most of their petroleum. A few nations, including France, Slovakia, and Belgium, shifted to nuclear energy to supply a considerable share of their electric power. Still others, most notably Denmark, Spain, Estonia, and Germany, are embracing advanced energy to generate substantial power through the deployment of advanced systems (e.g., wind, solar, biofuels). But Europe remains a net energy importer.

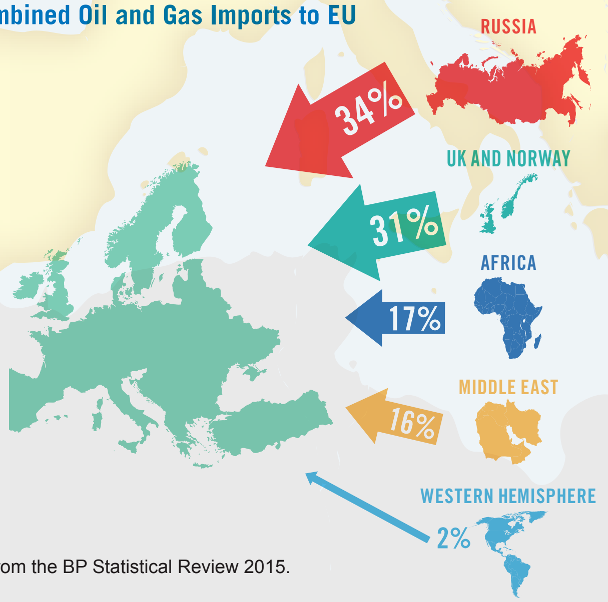
We recognize that the E.U. does not include all of Europe, and that it may be a disservice to the unique cultural, national, and governance systems to look at the area as a collective. Nonetheless, for purposes of this case, we believe that looking at the energy dynamics of the European Union, which includes more than half the nations in Europe, provides valuable insights. Most significant, the E.U. energy posture is directly tethered to Russia, which supplies over 30 percent of its coal, oil, and natural gas imports [59,60]. Several E.U. nations and former Soviet states, like Belarus and Estonia, are almost completely dependent on Russia or indigenous sources (or a combination) to meet their energy needs [61,62].

In addition, more than half the Russian gas imported by E.U. members is transported via pipeline through Ukraine and the Baltic Sea pipelines, affording Moscow tremendous leverage. Russia has exercised this leverage in the face of ongoing disputes over the Ukraine. For example, in the middle of winter in 2007, Russia drastically reduced the volume of gas flowing through Ukraine, cutting supplies entirely to Bulgaria, Greece, Macedonia, Romania, Croatia, and Turkey. More recently, Europe's reliance on Russian energy has hindered its ability to respond to Moscow's annexation of Crimea. While Europe supported sanctions against Russia, it did so weighing the economic costs of potential Russian energy retribution.

Future Trends and Impact

The energy trend in the E.U. is toward advanced energy as a means of breaking the tether to Russian and other foreign energy supplies, as well as lowering carbon output. The E.U. has issued a Renewable Energy Directive with a binding target of 27 percent final energy consumption from renewable sources by 2030 [63]. Germany, for example, has used strong government incentives and regulations to deploy advanced energy systems that supply 32 percent of growing electricity consumption and nearly 13 percent

Combined Oil and Gas Imports to EU



Derived from the BP Statistical Review 2015.

of primary energy consumption [5]. In the right weather conditions, Germany briefly produces nearly 75 percent of its electricity needs using wind and solar power [5].

At the same time, Russia has shown little interest in advanced energy investment other than nuclear and hydro power. Yet Russia has a pragmatic view of the changing energy landscape over the coming decades. According to Russia's own Energy Outlook 2040:

> [S]hifts in the global energy sector, especially in hydrocarbon markets … will result in a slowdown of Russia's economy by one percentage point each year on average due to a decrease in energy exports. … Russia will be the most sensitive to fluctuations in global hydrocarbon markets among all major energy market players within the forecast period [64].

To prevent this outcome, Russia is actively seeking to expand its oil and natural gas markets into the two fastest growing energy markets in the world: China and India. As detailed in our China case study, Russia is building oil and natural gas pipelines directly into China to position itself to meet expected growing demand there. As detailed in our India case study, Russia is buying Indian oil infrastructure to ease exports into that nation, and hopes to build more than a dozen nuclear reactors for New Delhi in the next 20 years [56]. Simultaneously, India is partnering with Russian state-owned oil producers in Siberia. Needless to say, Russia's developing energy ties with Asia come with significant U.S. national security concerns.

We assess that, should technology breakthroughs accelerate the advanced energy transition, speeding the reduction of global oil demand and sustaining low prices for oil and natural gas, Russia will bear a heavy burden. With high associated costs for new fields, resulting in underused production potential, Russia could be priced out of market share [64]. Should Europe gain better access to Western gas and/or advanced energy, forecasts show Russia's exports of gas could decrease by 15 to 20 percent and its oil exports by 25 to 30 percent [64]. The resulting revenue losses could reach $40 billion to $50 billion annually, equivalent to roughly a third of Russia's current fossil-based energy revenue [64]. Since oil and gas are linked in many ways to the broader economy, the effects would ripple across all sectors. As was seen in the 1990s, a weakened Russian economy could inhibit the government's ability to support robust military capabilities. However, our military experience suggests the Kremlin may still show strength to assert control over its western borders–a threat to the security of Europe and the NATO partners.

Europe may similarly face lost economic opportunity. A sustained low oil price environment will likely preempt expensive North Sea offshore oil projects, resulting in potential loss of market share for European suppliers.

Advanced Energy as a Tool of Global Influence and Carbon Reduction

We have described Russia's efforts to expand its global influence by establishing new oil and gas ties with China and India. Similarly, the E.U. is looking at advanced energy in Africa as a means to build relationships, gain influence, and reduce carbon, while bolstering economic prosperity at home. For example, in November 2016, Neven Mimica, the E.U. Commissioner for International and Development, said:

> [T]he European Union confirms its strong commitment in Africa for both reducing emissions and improving energy access for the world's poor. … [B]y 2020, the E.U. has promised to facilitate investments that will increase the renewable electricity generation capacity of at least 5 GW. This is already half of the 10 GW goal of the Africa Renewable Energy Initiative for 2020 [65].

The European Commission also sees advanced energy as a source of economic growth, asserting that in this decade the renewable energy sector has provided almost a half-million new jobs and generated around 140 billion euros (roughly $148 billion) [65]. According to the commission, this development "makes the E.U. a major player on the international market." [66]

In sum, Russia is a growing national security concern, to the U.S. and to Europe. Europe's current over-dependence on Russian energy limits its geopolitical response to Russian aggression around the world. But advanced energy developments may improve this situation. A robust, energy-independent Europe–home to many NATO members and our strongest allies–would be good for U.S. national security. By similar measure, accelerating the advanced energy in developing areas like China and India could cause Russia's petroleum revenues to drop—also good for U.S. national security.

OPEC and the Middle East

OPEC, the Middle East, and U.S. national security have been linked for more than 40 years. While the U.S. has denounced subjugation by Middle East monarchies, government corruption in OPEC's African members, and the communist dictatorship of Venezuela, we have pumped billions of dollars into these regimes to quench our thirst for oil. OPEC supplies 40 percent of the total oil produced in the world, controls 60 percent of what is traded globally, and holds over 80 percent of the world's proven oil reserves [67]. OPEC's actions can influence international oil prices and even global GDP [68]. Thanks to recent development of unconventional oil resources, the U.S. is less dependent on Middle Eastern oil, but still imports significant quantities from Nigeria and Venezuela, both OPEC members [69]. Because of U.S. and global dependency on OPEC oil, the manner in which OPEC nations cope with a worldwide transition to advanced energy and away from hydrocarbons is of great interest.

For many OPEC and Middle East countries, oil is lifeblood. For example, oil production and exports account for 50 percent of GDP in Saudi Arabia, 35 percent in Nigeria, and 25 percent in Venezuela [70]. Oil revenues comprise a substantial share of government funding in nearly all these countries and are variously used to subsidize goods and services, including internal energy consumption; to provide annual remittances or patronage; and to fund many other programs benefiting citizens [71]. Similarly, oil exports and internal revenues bolster the activities of state sponsors of terror, such as Iran and Syria [72,73]. Oil revenues, often extracted through smuggling, have also funded violent extremist movements, such as the Islamic State of Iraq and Syria (ISIS) and Al Qaeda in Yemen, and lesser-known groups employing terrorism, such as the Movement for the Emancipation of the Niger Delta (MEND) [74-78].

Advanced Energy's Potential Impact on Petrostates

As military leaders, we assess advanced energy systems as having the potential to reduce global oil demand by mid-century. This could impact the revenue streams of OPEC and Middle East oil exporters' economies and governments [79]. Resulting subsidy and remittance reductions or loss of government services could give rise to public dissatisfaction and increase the risk of instability [71]. In nations ill-equipped to adjust, weakened governance structures may allow violent extremist movements to expand. As we have witnessed, disruptions in Middle East stability negatively impact oil production and quickly result in supply constraints with significant global economic ramifications [79].

Experts remain uncertain whether reduced global demand for oil will translate to reduced revenues for all OPEC producers [1]. While conventional wisdom indicates that a decrease in global oil demand will impact all suppliers, a slowing of oil demand may, in fact, allow low-cost producers—like some in OPEC—to increase market share and sell *more.* The uncertainty lies in whether oil oversupply suppresses prices, with proportionate decreases in revenue. The potential risk of revenue losses leading to civil unrest in OPEC countries is a U.S. national security concern.

As we have witnessed, disruptions in Middle East stability negatively impact oil production and quickly result in supply constraints with significant global economic ramifications.

Further, we believe that the stress of a sustained low-profit environment, combined with long-standing animosity between some OPEC members (like Iran and Saudi Arabia), might weaken or restructure some or all of the OPEC. Moreover, a weak or failing OPEC would likely result in increased oil price volatility. During periods of great energy price volatility, consumers and businesses trim spending and investment, and GDP is depressed. This places economies at risk, and can even drive the failure of fragile governments—all threats to U.S. national security [80]. Price volatility serves as an indirect cost of energy, and the price stability of most advanced energy systems can hedge volatility associated with gas and oil.

Preparing for Advanced Energy through Economic Diversification

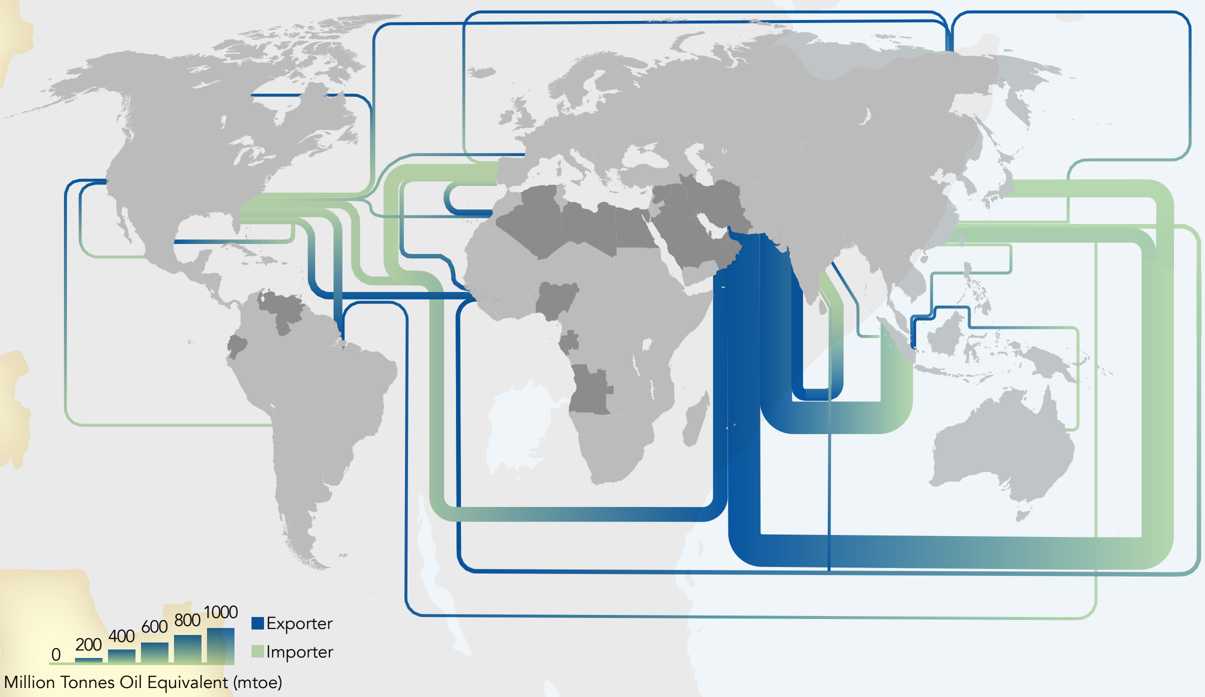
Many OPEC and Middle East governments are studying the impact of advanced energy systems and considering options for the new energy landscape [81]. The OPEC 2016 Energy Outlook specifically notes the dramatic rise of renewables as a potential game changer over the next few decades [17].

To hedge against reduced oil revenue, some OPEC nations are looking to diversify their economies. We note such initiatives as Saudi Arabia's Vision 2030, the U.A.E.'s emerging commercial ship repair sector, and Bahrain's development of a banking and financial services sector [82]. Others are looking to advanced energy systems and renewables to diversify their energy and economic portfolios. For example, Saudi Arabia recently committed to invest $30 billion to $50 billion in solar and wind energy, while conducting feasibility and design studies for the country's first nuclear power plant [83,84]. These initiatives provide some insulation against the potential downturn in oil revenues and the associated national security risks. They also offer U.S. advanced energy companies opportunity to partner in the area.

Impact on U.S. Military Mission

The U.S. military, as an arm of U.S. policy, is committed to promoting stability in the Middle East. Although the U.S. is less dependent on the region's oil, leaders here recognize that Middle East nations still supply most of the oil for the world that drives the global economy, to which the U.S. is inextricably tied. Threats to Middle East stability hamper global oil flows and places global economies—and by extension, the U.S.—at risk. In addition, the U.S. has other strategic interests in the area, including countering violent extremism, stemming proliferation of nuclear and other weapons of mass destruction, supporting friends and allies (e.g., Israel), and protecting U.S. citizens and businesses. Amid this array of concerns, it is unlikely that the U.S. military will withdraw from the region.

2015 World Dependence on Oil

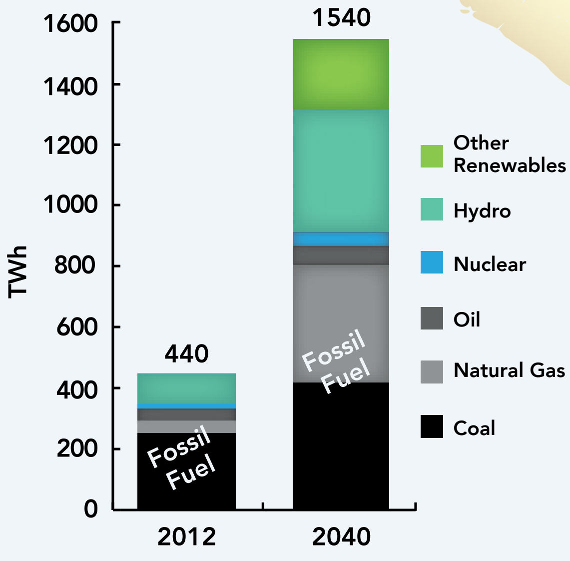


Derived from IEA sankey diagram.

Africa

As senior military officers, we view the transition of most African nations to advanced energy as a great opportunity for the U.S. The African population overall, representing much of the developing world outside Asia, is expected to more than double from just under a billion to near 2 billion by mid-century [85]. Many African nations have experienced considerable middle-class growth, which has driven up demand for goods and services. However, the geographic distribution of rising incomes is uneven and the trajectory of continued growth uncertain, given regional integration issues and inadequate infrastructure [86,87]. African leaders are addressing these challenges with projects to develop energy, transportation, finance, and information and communications technology infrastructure [87].

Electrical power generated in Sub-Saharan Africa 2012–2040



Derived from IEA Africa Energy outlook.

U.S. commitment to countries with developing economies is more than the offer of a helping hand. It is about creating markets for U.S. goods and services, building strong economic ties, and preventing conflict—especially in areas of strategic interest. As we have seen elsewhere, rapid population growth, economic expansion, and increased demand for energy have consequences. First, competition for resources may aggravate tensions and lead to conflict. Second, necessity will drive willingness to adopt new technologies, notably advanced energy systems. By increasing our commitment to advanced energy, we could become the provider of choice to much of the African continent.

Today's Energy Trends and Tethers

With low per-capita energy consumption and high fossil fuel endowment across major areas, Africa is a net exporter of oil, significantly to Europe, India, and the U.S. But, given the continent's rapidly growing population and collective economy, its status as an oil exporter and its associated geopolitical tethers will likely change in the coming decades.

Today, Africa's developing nations rely heavily on biomass (wood, grass, and charcoal) for energy, with only 11 percent of their final energy consumption fulfilled with electric power [88]. With anticipated population growth, current over-dependence on charcoal will be unsustainable. Other countries around the world, like Haiti, Brazil, Panama, and Indonesia, also engage in unsustainable charcoal practices to produce a rudimentary form of energy that can be stored and transported [89]. Such nations are anxious to replace their current energy sources with the distributed, clean, and sustainable solutions that advanced energy systems can provide.

Future Trends and Impact

Relative to nations with advanced economies, Africa's power sector—energy access, installed capacity, and overall consumption—is underdeveloped [90]. Access to electricity is at its worst in sub-Saharan Africa, a region that accounts for 13 percent of the world's total population but 48 percent of those who lack access to electric power [90]. Only South Asia rivals this imbalance [90].

Without access to modern energy sources, the economies of sub-Saharan nations, in particular, will be at a competitive disadvantage, and the region's economic growth potential will not be realized [90]. Should these economies emerge, the partners who provide the means and the technologies to foster energy access will be strongly positioned to seize opportunities for trade and economic growth.

The U.S. has fallen behind Europe and Asia in African energy sector investment [91]. The Chinese investment footprint in the region is considerable and of particular concern [91]. Industry analysts suggest that China has pivoted toward current and emerging energy-producing areas, including East Africa, as part of a global strategy to ensure its access to secure and reliable energy resources [92].

In 2013, the Chinese National Offshore Oil Corporation entered into a $2 billion contract to develop the Kingfisher oil field in Uganda. Africa's largest hydropower project, the Grand Ethiopian Renaissance Dam on the Ethiopia-Sudan border, is being financed with the support of several Chinese state banks [92]. On a broader scale, since 2000, China has been Africa's largest trade partner [92].

China is providing direct investment and loans for transportation and energy infrastructure development across Africa [92]. Although Chinese investment is substantial and has generally surged since the beginning of the 21st century, a nuance is often missed [92]. Approximately a third of China's loans to Africa are secured by commodities like oil. The lending agreements tie financing to future purchases of Chinese goods and services [92]. In other words, China is using loans to gain access to energy and at the same time ensuring a market for its exports [92].

Advanced Energy as a Tool of Global Influence

Africa, along with the rest of the developing world, will have to address tremendous growth in energy demands over the coming decades. Nations with advanced economies that invest in these areas will open new markets and establish economic and geopolitical ties. The race for advanced energy influence is already on, and China was first out of the gate. China has financed $6.7 billion in dams, and together with other renewable projects is responsible for 30 percent of the sub-Saharan African energy capacity added in the past five years [93,94]. Just one week after taking office, Chinese President Xi Jinping promised more than $20 billion in loans for African infrastructure, with a proportion of this funding heading to the energy sector [95].

The European Union and its member states are also investing in African energy development. Europe has provided facilities and funds, established energy initiatives, and pledged support for providing energy access for 500 million people by 2030 [96]. Trailing in these efforts, the U.S. recently pledged $7 billion in financial support over five years, with the goal of providing electricity to 20 million African households [97]. While indicating a trend of interest in Africa, these investments combined only scratch the surface. Estimates run as high as $3 trillion for necessary energy investment by 2040 in sub-Saharan Africa alone [98].

Acceleration's Potential Impact

If Africa accelerates its advanced energy transition by embracing advanced energy systems, it could skip many of the pitfalls of fossil fuel reliance and realize several internal benefits. First and foremost, it could bring electricity to millions more people at a much quicker pace, potentially leapfrogging over the need to develop a full fossil fuel infrastructure. This would increase productivity, correct the artificially high cost of doing business, and increase GDP. It would also accelerate the opening of new markets for goods and services, an economic opportunity not only for Africa but also for its trading partners.

From a U.S. national security perspective, an accelerating transition has the potential to increase Africa's growing dependency on China for advanced energy systems unless others, like the U.S. or the E.U., expand penetration into Africa's advanced energy markets. As military leaders, our assessment is that increased Chinese influence in Africa is not in the best interest of the U.S.

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MILITARY IMPLICATIONS OF ADVANCED ENERGY

> "[DoD] should explore alternate and renewable energy sources that are reliable, cost effective, and can relieve the dependence of deployed forces on vulnerable fuel supply chains to better enable our primary mission to win in conflict. The purpose of such efforts should be to increase the readiness and reach of our forces." [99]
>
> James Mattis, U.S. Secretary of Defense

Advanced energy won't just play a part in shaping the roles and missions of the military; it will also impact the military's ability to perform those missions. In forward operations, advanced energy can reduce the logistics burden–lowering costs in lives and dollars. At bases and installations around the world, it can improve resilience and lower energy costs. Installations at home and abroad are increasingly dependent on energy for real-time command and control, remote operations of unmanned air and ground units, and intelligence analysis. In addition, the Defense Department is developing a new strategy—"The Third Offset Strategy"—that places specific focus on next-generation technologies, platforms, and weapons systems to sustain our competitive advantage. These new systems, such as rail guns and directed energy weapons (lasers), will be more dependent on reliable high-capacity electrical systems that will require advanced energy components. Secure power is essential now, and will be even more so in the future.

The growth of advanced energy technology is likely to yield new military advantages beyond what can easily be foreseen.

Moreover, the growth of advanced energy technology is likely to yield new military advantages beyond what can easily be foreseen. Throughout history, with each significant revolution in technology, the nations that adopted it most effectively have achieved profound military advantages. For example, the development of the railroad and the telegraph in the 1800s revolutionized military transport and communications. Tanks, mobility, and the Blitzkrieg provided 1930s Germany with tremendous operational advantage, while the invention of SONAR turned the tide for the U.S. in the Battle of the Atlantic. More recently, the application of information technology, GPS, and laser guidance to enable precision strike has given the U.S. military an enormous conventional military advantage over its adversaries. Advanced energy could well yield similar advances.

Operational Energy

Operational energy is the "energy required for training, moving, and sustaining military forces and weapons platforms for military operations. This term includes energy used by tactical power systems and generators, as well as by weapons platforms themselves. … [It is] the energy used in military operations, the energy used in direct support of these operations, and the energy used in training that supports unit readiness for military operations, to include the energy used at non-enduring locations (contingency bases)." [100]

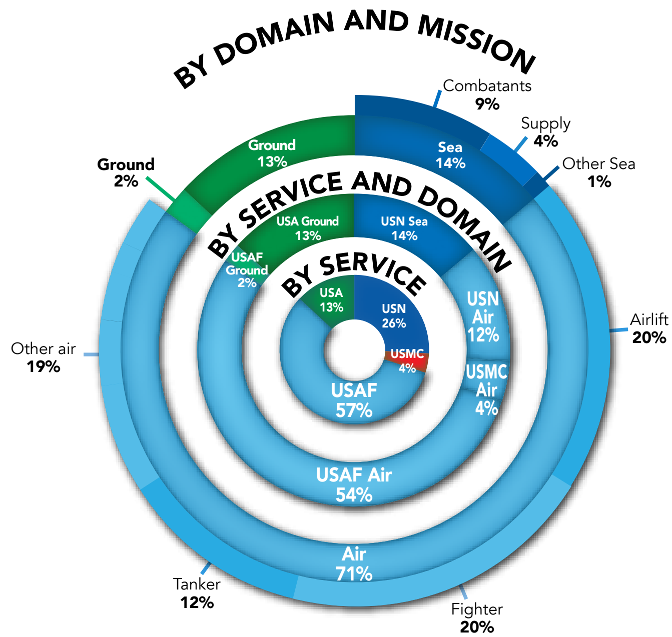
Throughout our military careers we have each, individually and collectively, focused on the risks associated with moving, securing, and using energy in operations. In our second MAB report, *Powering America's Defense: Energy and the Risks to National Security*, we noted that since "energy use at forward operating bases presents the most significant energy-related vulnerabilities to deployed forces, reducing the energy consumed in these locations should be pursued as the highest level of priority." There is both cost and risk associated with transporting and protecting energy supplies moved in the operating environment. Supply lines are vulnerable to adversaries, force protection is pricey, and the risk of supply disruption can impact the mission. As advanced energy options are deployed and reduce the need for these supply lines, U.S. military mission effectiveness is strengthened.

In 2015, General Joseph Dunford, Chairman of the Joint Chiefs of Staff, wrote, "[we] will continue to analyze, evaluate, and assess where increased energy demand necessary for improved combat capabilities intersects with operational energy and energy security constraints or vulnerabilities. We will further refine and improve plans, strategy, procurement, force development and policies regarding energy considerations as it relates to mission success." [101] His commitment, as well as that of many of us while on active duty, has caused DOD to increase efforts to employ advanced energy technologies at the tip of the spear. For example, the U.S. military now uses solar photovoltaic panels to power mortar pits, wind turbines to power command and control centers, and advanced batteries to lighten the energy load on individual soldiers at the tactical edge.

DOD has embraced alternative energy systems to enhance operations for over half a century. Today, more than 25 percent of the Navy's combat fleet is nuclear-powered, including all U.S. carriers and submarines [102]. In past decades, the military operated nuclear-powered cruisers and even designed a nuclear-powered aircraft. Today, at forward operating locations, military forces are using solar and wind to generate electricity and micro-grids to improve energy efficiency while lowering logistic demands. The Defense Science Board recently evaluated the use of small modular nuclear reactors to provide power to forward operating bases. It found "that there is an opportunity to 'invert' the paradigm of military energy. The U.S. military could become the beneficiaries of reliable, abundant, and continuous energy through the deployment of nuclear energy power systems." [11]

Advanced energy and efficiency reduce the logistics risk in the battle space and extend operational reach, endurance, and stealth. Convoys that bring fuel to forward bases and tactical vehicles are vulnerable

Figure 6. Operational Energy Use, FY 2014



Derived from Department of Defense 2016 Operational Energy Strategy.

targets. An Army study found that, in 2007, at the height of the war in Afghanistan, one in every eight fuel convoys was attacked by the enemy, with one in every 24 resulting in an American casualty. At sea and in the air, refueling ships and aircraft tankers carry operational risk and are targets for our enemies. Reducing the need to refuel, whether by lowering fuel consumption or finding alternatives to liquid fuels, is a priority as DOD seeks to improve operational effectiveness and lower risk.

Advanced energy and efficiency reduce the logistics risk in the battle space and extend operational reach, endurance, and stealth.

While DOD has made significant strides in cutting energy demand in forward locations, its largest advanced energy challenge is achieving equivalent energy density, flexibility, and availability of today's liquid fuels. As shown in Figure 6, more than 90 percent of today's operational energy goes to fueling platforms, aircraft, ships, and land vehicles [103]. More than 75 percent of total operational energy is consumed by aircraft alone [103]. Aircraft and large platforms will likely be among the last systems and sectors that transition away from petroleum because of the required energy density of these systems. Yet we encourage DOD to continue looking for ways in which rapidly evolving alternative energy technologies can improve force effectiveness, just as the Navy did with nuclear power in the 1950s.

Installations and Bases

Advanced energy has immediate potential to increase the resilience of permanent installations, especially for mission-critical elements, while reducing long-term energy costs.

Installations are the bases from which the military fights, trains, and lives. And in modern warfare, many of our fixed installations, here and abroad, are performing front-line, real-time military operations 24 hours a day—remotely piloting aircraft, for instance, and conducting real-time intelligence analysis. To perform these tasks, there are over 500 DOD installations worldwide, including nearly 300,000 buildings [104]. In 2015, these installations had an energy bill of $3.9 billion dollars, nearly 25 percent of DOD's $16.7 billion total energy budget [105].

The DOD has made advanced energy sources for installations a priority. This is being driven "to ensure the energy resilience and reliability of a large percentage of the energy it manages, reduce the amount of budget allocated to this energy, and treat installation energy as a force multiplier in the support of military readiness." [106] To realize this objective, the DOD has set a goal to procure at least 25 percent of total facility energy from renewable energy sources, while installing 3 gigawatts of renewable energy directly on its installations, by FY 2025 [105].

Currently, DOD installations buy virtually all electricity from the commercial grid. Advanced systems enable increased use of energy from distributed sources like biomass, geothermal, small modular nuclear reactors, solar, wind, and many others. This type of distributed generation improves resilience and can reduce costs.

In our 2014 report, *National Security and Assured U.S. Electrical Power*, we found commercial power supplies can be interrupted by natural hazards, planned

Nellis Air Force Base, Nevada.

attacks, and other events. These disruptions can affect power to critical DOD missions, including defense of the homeland, forward military operations, or other operations conducted at installations directly supporting warfighting missions overseas. The current state of the U.S. grid makes our domestic installations vulnerable. Comprehensive adoption of advanced energy has the potential to distribute power generation, improving the resiliency of DOD missions against commercial power disruptions and lowering their vulnerabilities, while simultaneously reducing costs.

DOD is building advanced energy systems at several installations by pursuing a combination of production, power purchase, and unused land leases to utilities. In February 2014, DOD opened its largest land-lease solar project, a 16.4-megawatt (MW) photovoltaic array at Davis-Monthan Air Force Base (AFB), Arizona [105]. This topped the previous leader in renewable energy on bases, the 14.2-MW solar power plant at Nellis AFB in Nevada. In 2015, the Navy commenced construction of Mesquite Solar 3, in Arizona, to provide more than a dozen California installations with 210 MW of direct power—more than 10 times the previous level [107].

We applaud DOD's efforts to use alternative energy to strengthen resilience for its installations. We also recognize that in many areas this transition is nascent, and we encourage DOD leadership to spread the effort more broadly. This will require a new energy business model, one in which advanced energy systems on an installation can provide valuable services back to the utility while the grid is operating and then "island" the installation to support critical missions should the grid go down or power be interrupted. This model provides opportunity for DOD to buy more energy resiliency for an installation, but at a lower rate compared to the current cost. Although the initial investment in infrastructure may be costly, the time to recoup the investment through lower sustained energy costs can generally be measured in years. Further, creative public-private partnerships can be used to lower or cost-share investment outlays, further shortening the recoupment period.

We have found that the ability to apply advanced energy on DOD installations varies widely based on state regulations and local market conditions. State regulations differ in the extent that they allow or prohibit independent power production, and federal law bars DOD from procuring energy in violation of state laws. State limiting of which entities can be licensed to generate and sell power creates a disincentive for DOD to move toward advanced energy.

In sum, advanced energy systems can improve military operations in the field by reducing logistics risks and lightening loads, and at our bases by adding resilience and reducing energy costs. These factors can be leveraged to increase U.S. military capability and capacity.

LEADING THE WAY

WHY U.S. LEADERSHIP—WHY NOW?

It is undeniable that the world is moving to develop and deploy advanced energy technologies and systems to better generate, store, and manage energy. It is distinctly possible that this global trend will accelerate. To capitalize on opportunities and minimize challenges while pursuing energy independence, we firmly believe the U.S. should lead the global energy evolution. The U.S. should empower American creativity to invent, develop, integrate, and deploy advanced energy solutions. Failure to lead compromises our global influence and national security.

Current Secretary of Energy Rick Perry at Buffalo Gap Wind Farm, TX 2006

At first glance, some may question why the U.S. should deliberately pursue advanced energy. After all, we are now the largest oil and natural gas producer globally due to domestic advances in unconventional production. *Why would we want to risk our status as a fossil fuel superpower to embrace advanced energy?*

The strengths of the U.S. energy run deeper than its fossil fuel endowments. The domestic landscape is flush with an unparalleled mix of robust and yet untapped wind, solar, hydro, nuclear, and other energy potential. Further, U.S. culture is rooted in innovation and problem solving; this nation is home to the most productive technology research and development programs in the world. The systems these programs can deliver, if deployed at scale, may lower overall energy costs to consumers and improve U.S. prosperity. They may bolster U.S. diplomatic ties, global market influence, and worldwide penetration of U.S. products and expertise. It is precisely the alignment of these factors that demands that the U.S. to lead in the global transition to advanced energy.

As the transition to advanced energy progresses, energy leadership will be broader than any country's hydrocarbon endowments or ability to export petroleum, coal, and natural gas. Rather, leadership will be derived from a wider portfolio of energy options. It will turn on a commitment to creating systems based on the integration of diverse energy sources, improved approaches to energy generation and distribution, innovative energy storage and management solutions, and, above all, willingness to continuously assess, invest, and improve. The U.S. is capable of meeting all these challenges and, therefore, can determine the path of advanced energy.

The domestic landscape is flush with an unparalleled mix of robust and yet untapped wind, solar, hydro, nuclear, and other energy potential.

LEADING IS IN THE U.S. ETHOS

The United States has a long history of leading technological transitions. In Thomas Edison's and Nikola Tesla's laboratories, the U.S. charted the global course of electricity, freeing the world from darkness and empowering development in much of the modern world. The Wright brothers ushered in powered flight, allowing man to soar with the birds. In the 1940s, a team at Iowa State University built the world's first electric computer, and Bell Laboratories invented the transistor, leading the world into the digital age. From the cotton gin to the first artificial heart to harnessing nuclear power, the sheer number and reach of U.S. inventions and innovations have touched the whole of society.

For the U.S., the demands of advancing technologically have been considerable and the benefits tremendous. But the nation's efforts as a technological leader have always extended beyond goals of making lives better and jobs easier. At the center is U.S. standing in the world order. There is perhaps no better example of this than the U.S. space program.

> "Those who came before us made certain that this country rode the first waves of the industrial revolutions, the first waves of modern invention … and this generation does not intend to founder in the backwash of the coming age of space. We mean to be a part of it—we mean to lead it." [108]
>
> President John F. Kennedy

WHAT LEADERSHIP MEANS

Leaders assess the current situation and trends, establish a vision and vector for the future, and motivate themselves and others to achieve the vision.

With respect to the global energy posture, we assess the world as overwhelmingly dependent on oil and other fossil fuels, with ever-growing demand looming large. Concurrently we, like many experts, see strong trends suggesting that major parts of the world are moving to advanced energy systems at an accelerating pace. The question for U.S. leaders is this: "What should the U.S. vision and vector be in this future energy-driven world order?"

Our vision is a truly energy-independent United States with the capability to drive the trajectory of advanced energy worldwide.

Through aggressive energy efficiency programs and systems that intelligently manage the variety of readily available domestic sources, the nation could reduce or limit its energy requirements to a level where it meets its own demand. With the capacity afforded by new advanced energy systems, the U.S. would no longer have to rely on high-cost unconventional oil and natural gas production for primary energy. By remaining a player in the global energy market, but with the backing of robust advanced energy systems, the U.S. could be an exporter of advanced energy technologies and expertise as well as excess energy inputs—natural gas, for instance—without risking heightened domestic energy price volatility.

Indeed, the U.S. can harness innovation to lead in this era, just as it did at the dawning of the ages of flight, nuclear power, and information technology. Through ever-increasing moves toward advanced energy, the U.S. will find itself well positioned in the longer term, as global demand for and the supply of fossil fuels, particularly oil and coal, continue to fall. We can achieve domestic energy independence—producing all the energy we need, now and in the future—by advancing the deployment of advanced energy systems at home and enjoying energy at costs below or rivaling those on the global market. And as more of the world builds new energy systems, we will have new trade opportunities for a full range of goods and services.

THE CURRENT STATE OF GLOBAL ADVANCED ENERGY LEADERSHIP

Unlike the dynamics in hydrocarbon-based energy markets, leadership in the advanced energy economy is not the exclusive province of nations and regions with natural resource endowments. Leadership in the advanced energy arena is a function of determination, commitment, ingenuity, and innovation. The U.S. national character is well aligned to these drivers.

The reality is that the U.S. is falling behind. Emerging economies are now claiming an increasingly larger share of global energy research, development, and demonstration investment, as well as escalating their advanced energy technology manufacturing capabilities [109]. Advanced economies, including many European Union members and Japan, have also demonstrated commitment and capability in developing the advanced energy economy.

But China is emerging as the single most prominent player in advanced energy, and the single greatest challenger to the U.S. in setting and leading this trajectory. As early as 2008, researchers began to take note of China's considerable progress toward a leadership role in the transition toward nonhydrocarbon-based energy [110]. In 2015, China published its 13th Five-Year Plan, which clearly indicates the government's desire to become the global leader in new energy technology [111]. Advanced energy technology development is a core focus of China's national economic and industrial policies [112].

Examples of China's push toward leadership status in the transition are seemingly endless. China is now the world's leading wind power market, and is home to a flourishing wind energy industry, not coincidently, supplies most of its own turbines [112]. This change has occurred virtually overnight; just a decade ago, China had few turbines, and most of those were imported [112]. China claims roughly a third of global commercial investment in advanced energy, followed by the European Union and the U.S. [113]. With respect to commercial investment for both solar and wind, China has emerged as the leader [113].

The potential economic benefits of being on the leading edge of the advanced energy economy have clearly pivoted toward China. In 2015, China was home to 3.5 million of the estimated 8.1 million jobs in the renewable energy sector worldwide, while the U.S. claimed a mere 800,000 [35]. China also claims 34 percent of the 1.3 million jobs available in the global hydroelectric power sector [35]. Employment in the Chinese renewables sector now exceeds the 2.6 million employed in the country's oil and gas sector [35].

While the U.S. has made domestic strides in advanced energy, government-driven uncertainties still present obstacles. The segmentation of energy policy across the local, state, and federal levels forces potential investors to make risk assessments based not only on current policy regimes, but also on potential changes to those regimes [114]. Monitoring policy across multiple decision-making bodies consumes investor resources and adds risk for investors. Even where the administrative and regulatory regime is known, compliance can be time-consuming and costly [114].

The associated burdens and uncertainty add to the costs of advanced energy development. For example, the aging U.S. electric power grid will require transmission, distribution, and control upgrades to accommodate high proportions of energy from multiple new sources. Adherence with the planning, permitting, and regulatory approval processes required to gain approval for these upgrades is lengthy—time is money [114]. Also, specific institutional structures make it difficult to connect advanced energy generation technologies to the grid system. Further, for independent non-utility generation (e.g., most renewables) domestic restrictions prevent access to the grid, in some areas, and thereby increase the cost of advanced energy generation [114]. Without an overarching energy governance framework, overcoming regulatory inertia is difficult [114].

If we fail to remove barriers to embracing advanced energy at home, we may struggle to build sufficient technological expertise. We could then find it difficult to assume and capitalize on a leadership role in the advanced energy economy, even as the rest of the world forges ahead. If we cling to our incumbent energy system, the price of domestic energy may exceed our competitors' energy costs, potentially rendering our goods and services uncompetitive in a global economy.

To recap: If the U.S. embraces leadership of the advanced energy transition, we can realize a wide range of long-held goals. We can achieve energy independence and enhance our long-term prosperity, our diplomatic influence, and our relationships worldwide. And we can reduce the national security risks inherent in 21st-century challenges.

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ENERGY INDEPENDENCE WITH ADVANCED ENERGY—CHARTING THE COURSE

The role the U.S. plays in the transition to advanced energy will determine our global competitiveness, our diplomatic standing, and our national security for years to come. Domestic strength lies in analyzing the range of possible outcomes and in planning for both the most likely and the most consequential cases. At this early stage in the transition, we can make decisions that result in long-desired energy independence, present new national security opportunities, and mitigate national security threats arising as the global energy landscape evolves. The global move to advanced energy will happen whether we participate or not. It has implications for relations with U.S. adversaries and allies, for national security, economic status, and military capability and mission. We have two choices: We can watch and follow, or we can lead.

For the past four decades, the U.S. has sought to become energy independent. We have faced four major challenges in achieving this goal: (1) Our culture prizes mobility and car ownership; (2) More than 70 percent of the oil used in transportation goes to automobiles; (3) Until recently, our domestic oil production fell far short of demand and was declining. 4) We have a national commitment to clean air and water. Advanced energy and other technologies are addressing the first three challenges, and allowing us to better meet the fourth. Within 10 years, we anticipate technical advances to give electric vehicles lower cost and better performance than today's petroleum-powered cars. Within a few years of EV cost and performance parity, U.S. oil production will exceed demand, at levels far below today's, and we will achieve oil independence.


New solar panels and decommissioned nuclear power plant, Sacramento, CA.

But advanced energy and energy independence involve more than electric vehicles and oil. In Midwestern states, we already see more wind turbines than silos. Our neighbors are installing rooftop solar power systems, tankless water heaters, and Energy Star appliances, while airports and shopping malls are adding vehicle charging stations. Advanced energy systems are popping up everywhere, from Penobscot Bay, Maine, to Kaheawa, Hawaii, to the battlefields of Afghanistan. The American public and private sectors are investing in technological innovations that are already changing the way we generate, distribute, store, and use energy. We see it everywhere we look.

Today's tremors foreshadow major tectonic shifts in the global energy landscape. But as in tectonics, these energy shifts will take time, and they will not occur evenly around the globe.

Some argue that, given our vast fossil fuel resources, advanced energy development is a needless economic burden. We do not share that view. Every president from Donald Trump[5] back to Ronald Reagan has committed to clean, affordable energy. Whether the power source is nuclear, sun, wind, wave, or hydro, advanced energy systems can provide the cleanest and most affordable energy when both direct and indirect costs are considered.

The rest of the world is already moving ahead. Iceland produces nearly 100 percent of its power through renewables, and Germany routinely meets a third of its electrical demand with wind, biomass, and solar power, with plans to source at least 80 percent from advanced energy sources by 2050 [115,116]. Meanwhile, China has the largest deployed solar capacity, and has committed to invest $316 billion in renewables by 2020 [117]. In India and Africa, with fast-growing populations and rising affluence, trillions of dollars will be invested, much of it in advanced energy systems. Today's tremors foreshadow major tectonic shifts in the global energy landscape. But as in tectonics, these energy shifts will take time, and they will not occur evenly around the globe.

In this study, we have laid out the national security challenges of the changing energy landscape, not the least including these developments: Russia and OPEC nations, notably Iran, are already positioning themselves to meet growing demand for fossil fuel in India and China. China is expanding its territorial claims in energy-rich areas and using energy investments in Africa to gain a better foothold there. China, Russia, and other nations are creating new energy tethers by selling advanced energy systems—including nuclear reactors and solar and wind systems—in developing parts of the world. New energy demands, especially in developing areas, afford the U.S., our allies, and our adversaries new opportunities to build relationships in growing and emerging energy markets. But to do so, we must embrace advanced energy as integral to our energy independence.

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[5] Presidential Executive Order on Promoting Energy Independence and Economic Growth. Donald Trump

By the authority vested in me as President by the Constitution and the laws of the United States of America, it is hereby ordered as follows:

Section 1. Policy. (a) It is in the national interest to promote clean and safe development of our Nation's vast energy resources, while at the same time avoiding regulatory burdens that unnecessarily encumber energy production, constrain economic growth, and prevent job creation. Moreover, the prudent development of these natural resources is essential to ensuring the Nation's geopolitical security.

(b) It is further in the national interest to ensure that the Nation's electricity is affordable, reliable, safe, secure, and clean, and that it can be produced from coal, natural gas, nuclear material, flowing water, and other domestic sources, including renewable sources.

Achieving independence and leading through advanced energy will require the U.S. government to moderate its perspective on domestic energy resources and the timeframes in which they are valued. Domestic policy must move away from one- to four-year planning cycles and consider the longer term. Only then can we set the vision, incentivize the U.S. brain trust, deploy advanced energy at home, and share these innovations widely, but strategically.

Throughout our military careers, we have seen that leading by example is one of the most effective forms of motivation. Today, we are at a pivot point, where we can strategically identify and promote opportunities to lead this transition. We offer the following four steps to achieving a future in which the U.S. drives the trajectory of advanced energy worldwide and powers our country on homegrown innovation and our own natural resources.

First and foremost, set the vision: The U.S. government needs to signal the nation's commitment to energy independence and global leadership by clearly articulating a vision that embraces advanced energy as an integral part of the way forward. As an initial step, the federal government should work with state governments to identify and remove barriers to the domestic design, development, and deployment of advanced energy technologies and systems. The federal government can provide the states with direct incentives to reform legal and regulatory environments, including provisions that underpin traditional utility business models, to create a more open and competitive energy economy.

At the same time, federal departments and agencies should develop and assist state-level model business frameworks for utilities, to allow for widespread integration of advanced energy technologies. The federal government should pace the transition by working with states, the private sector, and university and other research centers to set reasonable but ambitious goals, with structured timelines for achievement. With this guiding framework in place, stakeholders can track progress and hold each other accountable for reaching milestones. Policy frameworks that give rise to favorable conditions for investment are critical to instilling confidence in investors seeking to develop domestic advanced energy capacity [114].

Second, incentivize the U.S. brain trust: U.S. leadership will require public and private sector investment in advanced energy research, development, and deployment. Voluminous though it may be, public investment alone will not set the nation on the path to success. One of the most striking, longstanding dynamics in the success of our scientific and technical research enterprise is the number of breakthroughs that have come through developments in seemingly unrelated fields of study. Collaborative public-private arrangements can link laboratory developments with commercial interests, raising the potential to meet the challenges of adoption. Programs for multi-round, long-horizon competitive models of public funding have also proven to be successful facilitators of advancement. On the other hand, regulatory risk and the associated uncertainty are stifling investment, curbing a sustained private-sector commitment to research and innovation. Stable policy and regulation send the private sector the message that government is committed to leadership in this transition. A clear and unswerving vision has the potential to unleash billions of latent investment dollars.

Today, we are at a pivot point, where we can strategically identify and promote opportunities to lead this energy transition.

Third, deploy at home: We must demonstrate our commitment to advanced energy by first acting at home. Through domestic, scale-level deployment, the U.S. will develop the credibility and technical capability required to engage in meaningful energy diplomacy, a key tool in future foreign policy.

The wide range of topographic, land use, and climatic profiles across this nation's considerable land mass affords the U.S. unrivaled opportunity to develop experience in deploying and integrating advanced energy technologies and systems suited to almost every part of the world. If barriers to the transition are removed, the U.S. can become a global example of advanced energy supply-and-demand approaches. This has recent precedent: As the U.S. began to address its aging electricity grid through a variety of modernization efforts, it emerged as a global leader in the development and deployment of smart grid technologies [118].

Finally, we can reap direct economic benefits through a domestic shift toward advanced energy. U.S. infrastructure is aging, and modernization via deployment of advanced energy systems will bring jobs to American communities. With cheaper, more reliable domestic energy, energy-intensive manufacturing sectors that once shied away from U.S. locations may find them more attractive.

Fourth, share widely, but strategically: Global leaders' shared interest in a stable flow of energy gives rise to myriad opportunities for cooperation, and multilateral approaches early in the transition may prove pivotal in mitigating tensions that arise [119,120]. It is critical that the U.S. be a strategic partner worldwide to advance our economy, our diplomacy, and our overall influence.

Embracing this role requires diplomatic and resource investments to nurture energy markets that can sustainably and securely meet the demands of an increasingly affluent global citizenry [119]. By strategically sharing advanced energy technology, expertise, and lessons learned, the U.S. can develop and deepen partnerships with other nations, while also providing investors the range of successful scale-level examples they need to hasten their participation.

With an early commitment to advanced energy at home, the U.S. will develop the technical capacity, expertise, and credibility to engage as an advanced energy leader around the globe. We have the potential, through energy leadership, to strengthen ties with current allies; partner with nations of strategic interest to us, such as Russia and China; and build beneficial relationships with nations that are currently neither friend nor foe. Ultimately, our decisions can enhance our international influence and national security.

With cheaper, more reliable domestic energy, energy-intensive manufacturing sectors that once shied away from U.S. locations may find them more attractive.

To summarize: We believe the advanced energy transition should be treated as a national priority. We note that recent U.S. discoveries in unconventional oil and gas can provide a needed bridge to transition to a new advanced energy paradigm. The world needs clean, reliable, accessible, and affordable energy; old energy systems alone will not satisfy the world's growing demand for energy. The U.S. should adapt our fossil fuel resources and advanced energy innovation to help fit that bill. In so doing, the U.S. must recognize that economic strength is a foundational element of national security.

Our energy choices today, and how we prepare for the changing energy landscape, will have lasting impact on national security, now and for generations to come.

APPENDIX A: THE NATIONAL SECURITY AND THE ENERGY STATUS QUO

The MAB has described the threats of America's continued reliance on fossil fuels, and on oil in particular, in earlier reports, but it's worth recounting these through a speculative lens. What if we do not wean ourselves from oil, natural gas, and coal in favor of renewable sources of energy? What are the likely consequences to our economic, diplomatic, and military security–and thus to our national security?

Discussion of America's continued reliance on fossil fuels must consider the significant changes to the U.S. energy sector and the effects of these changes on global energy security in recent years. The Shale Revolution–the surge since 2010 in U.S. production of unconventional shale (tight) oil and gas through hydraulic fracturing (fracking) and horizontal drilling of shale rock–has turned America into the world's leading oil and natural gas producer, making us a bona fide player in global fossil fuel markets. At the same time, Canada has also emerged as a major supplier of fossil-based fuels. These unexpected developments have transformed the global energy sector in substantive ways by partially shifting the center of oil production, and thus economic leverage, from the Middle East and Russia to North America, while enhancing U.S. and global energy security.

To examine the national security implications of a world in which the status quo for energy production and consumption persists, we must first establish parameters and key assumptions about that world's energy demand and sources. Since our focus is on the status quo, we assume a future of continued demand for fossil fuels. Increases in energy demand for transportation and stationary power are met by existing fossil-based fuels. To bind the scenario, we consider an outlook of 20 years.

A summary of our assumptions, based on both current energy trends and conservative future projections, is listed below [1,3,5].

Under the status quo case we assume:

> Global population growth, rising incomes, and an increase in vehicle ownership in emerging economies result in continued growth in global energy demand. Specifically, energy demand for stationary power and transportation both increase by roughly 30 percent. The transportation fleet remains largely dependent on petroleum. There is not a marked transition to or increased demand for electric vehicles.

> Oil followed by natural gas and coal remain the predominant sources of energy, accounting for about 80 percent of all energy production and consumption both globally and within the United States. Renewables account for about 9 percent of all energy consumption globally.

> China and the United States remain the world's top energy consumers. While U.S. production of shale (tight) oil lessens national demand for imported oil, America still imports about 24 percent of the oil it consumes, mostly from Canada, Saudi Arabia, Venezuela, and Mexico [121].

> The Middle East leads crude oil production and exports, accounting for about 30 percent of each. The United States imports only about 9 percent of the oil it consumes from the Middle East, but Asia Pacific and Europe rely heavily on Middle Eastern oil.

> The United States leads natural gas production, but Russia leads natural gas exports. Europe receives approximately 80 percent of Russian natural gas exports.

The takeaways of the above future-world conditions under a status quo energy scenario are obvious: America and the rest of the world continue to rely on fossil-based fuels to meet most of their energy needs. In addition, although the United States does not rely on the Middle East or Russia as its primary sources of oil and natural gas, respectively, much of the world does, including U.S. allies in Europe and Asia Pacific. The result is that OPEC nations continue to dominate the global oil export market and thus largely control the price of oil, while Russia remains the primary supplier of natural gas to Europe.

These realities diminish U.S. influence around the world. Below, we explore the consequences of such a scenario from a planning framework with economic, diplomatic, and military dimensions.

Reliance on oil would continue to make us vulnerable to abrupt supply chain disruptions and threaten our economic stability. As long as the United States relies primarily on oil to meet its energy demands, we can expect periodic disruptions in supply that could significantly impact our ability to make and move goods, services, and people, thereby undercutting our economy. In the past 15 years, catastrophic natural disasters and refinery fires have abruptly halted U.S. access to and delivery of oil for weeks or months. In 2005, Hurricane Katrina shut down oil production in the Gulf of Mexico Outer Continental Shelf for months. In 2012, after Superstorm Sandy hit the U.S. Northeast coast, supply chain failures required the military to deliver petroleum to impacted areas. Beyond natural disasters are the potential for deliberate attacks; the vulnerabilities of pipelines around the world are well documented. There is clear risk to an economy dependent on petroleum that is extracted in one place, refined in another, and then transported again for distribution.

Price shocks would continue to threaten our economy. Over-reliance on fossil fuels would complicate critical investments in homeland defense and national security systems given the uncertainty of costs, as we would expect considerable price volatility with dramatic swings in supplies and real or perceived threats to oil infrastructure. This is true whether we use our own or foreign oil, since price is determined by global supplies. Price volatility could also discourage private-sector investments in new energy technologies. Furthermore, since we cannot produce enough oil domestically to meet our own demand, continued reliance on fossil fuels would also extend our long-standing trade deficit, putting the country at an explicit disadvantage in the global economy.

However, there is an upside to U.S. and global reliance on oil and natural gas: At least in the near term, the production of shale (tight) oil and gas would result in U.S. jobs and reliable tax revenues. The likely duration of this shale oil "boom" is uncertain, due to shale oil's sensitivity to price fluctuations in the overall oil market [122].

Dependence on fossil-based fuels would make our allies beholden to our adversaries and diminish American influence. While the United States would not depend heavily on the Middle East for oil or on Russia for natural gas, the reliance of our allies in Europe and Asia Pacific on these actors would undercut our ability to exert maximum influence in critical regions around the world. More specifically, the "tethering" of our allies to OPEC nations for oil and to Russia for natural gas would constrain our allies' foreign policy. This negatively impacts U.S. global influence and the possibility of U.S. cooperation with international partners.

Just as past U.S. dependence on Middle Eastern oil limited our capacity to exert influence, for fear of losing U.S. or global access to energy, our partners in Europe and Asia Pacific would be similarly encumbered for the foreseeable future. Russia has shown itself willing to punish Europe when conflict arises, as demonstrated by its moves since the early 2000s to cut off of gas supplies in response to pricing disputes [123].

Oil-rich and oil-hungry nations that are potentially or actually hostile to the United States would maintain strong influence. Since oil would continue to hold strategic value, both hostile countries that possess it and our adversaries that want it would continue to yield considerable power, albeit for slightly different reasons. Even though American dependence on Middle Eastern oil has subsided, the world's reliance on oil would continue to directly fund our adversaries (e.g., Iran and its nuclear weapons program), thereby empowering them and threatening our national security.

Global dependence on oil would also compromise our ability to achieve desired outcomes in international conflicts, given our adversaries' complicated relationships with oil-rich countries. An example is the attempt by the U.S. and most of Europe to halt investment in Sudan in pressuring the Sudanese government to end the genocide in Darfur. These efforts failed because China continued to invest in Sudan and argued against international sanctions in order to ensure its access to Sudan's oil.

The world's overreliance on oil would continue to tax our military and likely cost American lives. History suggests our dependence on oil would likely result in military missions to secure production and delivery of the high-value energy source. This would play out in ways that have consequence for our national security:

> The U.S. economy is dependent on global trade, and global trade relies on oil produced by Middle Eastern countries. It is in the best interest of the U.S. to ensure the consistent and reliable flow of oil from the Middle East. Due to oil's strategic value and the fragile nature of many nation states with the largest reserves, we might expect oil production facilities and supply lines to serve as consistent "flash points" among warring factions in the region. We could also expect oil production and delivery infrastructure to be targets for actors wishing to harm the United States. For these reasons, U.S. intervention and the loss of some American service personnel would be likely.

> The U.S. military would continue to protect supply lines transporting oil to U.S. bases. Supply lines delivering fuel to forward operating bases, ensuring the military has the fuel it needs to operate, would continue to require protection from enemy forces. The military would have to deploy convoys comprising armored vehicles and other combat resources to the areas at risk of attack. Fuel convoy missions come at a hefty price, in both money and lives. This has been demonstrated in Iraq and Afghanistan in the past 10 years.

The world's overreliance on oil would continue to have a destabilizing effect on some oil-rich countries' political, economic, and social infrastructure, which could threaten peace and security around the world. Ironically, the same natural resource that has made some countries so rich is associated with a variety of ills in other nations. These issues–slower economic growth, instability, and conflict–are sometimes referred to as the "resource curse," and typically affect low- and middle-income countries where fossil-based energy exports comprise a sizeable portion of GDP. Such economies are especially vulnerable to volatility in energy prices and thus likely to experience seasons of boom and bust.

Some countries that invest disproportionately in their oil at the expense of other sectors—to the point that trade in other sectors is not profitable—may experience "Dutch disease," the negative impact on an economy of anything that gives rise to a sharp inflow of foreign currency. Venezuela, Algeria, Iraq, and Russia are well-documented examples. In extreme cases, conditions can lead to significant economic hardship or collapse, destabilization, civil unrest, and/or government overthrow. Such circumstances contributed to the 2011 revolution in Libya and to the current recession in Nigeria, which could not handle the recent steep decline in oil prices. In a world that remains dependent on oil, we would expect these and other countries to continue experiencing political, economic, and social hardship resulting from the natural resource "curse" of oil. In the worst cases, conflict could further destabilize a country and region, and potentially wreak havoc on other parts of the world.

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APPENDIX B:
SCENARIO-BASED EXERCISE DESCRIPTION

As we began this research, it became clear that relatively little research has examined the national and regional security issues that will arise as the world transitions toward a new energy landscape. To address this gap, we designed and conducted a scenario-based exercise to identify a range of emerging issues for further exploration. Exercise participants included MAB members, regional and national security and foreign policy experts, and the study team.

During the day-long exercise, participants were presented with a scenario in which the world had begun a transition to advanced energy. The scenario incorporated expected changes in global population and affluence, as well as increased energy demand; reflected an upward shift in the proportion of power generation expected to be provided by advanced energy systems; and projected advanced energy systems' capacity to meet new energy demands. The narrative included an assumption of increasing electrification of the transportation sector.

Rather than imagining a world entirely absent of oil, natural gas, and coal, our scenario placed participants only partway through a large-scale transition to advanced energy systems. Fossil fuels still dominated global energy supplies, but with a declining presence. New energy technologies were becoming increasingly effective, affordable, and successful in displacing fossil fuels in the marketplace, and at an increasing pace. This approach allowed MAB members and the invited experts to explore some of the geopolitical consequences of changing relationships around energy and how disruptions to current dynamics could be effectively managed, as well as how to position the U.S. to maximize security and global influence in the face of a shifting global energy landscape.

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APPENDIX C:
BIOGRAPHIES

ADMIRAL FRANK "SKIP" BOWMAN, USN (RET.)

FORMER DIRECTOR, NAVAL NUCLEAR PROPULSION PROGRAM
FORMER DEPUTY ADMINISTRATOR-NAVAL REACTORS, NATIONAL NUCLEAR SECURITY ADMINISTRATION

Admiral Frank "Skip" Bowman served for 38 years in the U.S. Navy, rising to the rank of Admiral. His last active duty assignment was the dual position of Director of the Naval Nuclear Propulsion Program and Deputy Administrator for Naval Reactors in the National Nuclear Security Administration (NNSA) in the U.S. Department of Energy. In addition, as a flag officer, Admiral Bowman served as Chief of Naval Personnel, as Director for Political-Military Affairs, as Deputy Director for Operations on the Joint Chiefs of Staff, and earlier in his career, on other operational and staff assignments in the Submarine Force.

Admiral Bowman currently serves on the board of directors of BP, plc, and Morgan Stanley Mutual Funds.

He holds a bachelor's degree from Duke University, MS degrees in Nuclear Engineering and Naval Architecture/Marine Engineering from the Massachusetts Institute of Technology, and an honorary Doctor of Humane Letters from Duke University.

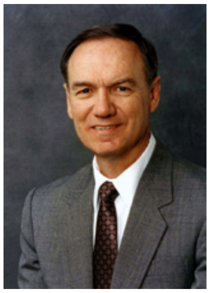
GENERAL JAMES T. CONWAY, USMC (RET.)

FORMER COMMANDANT OF THE MARINE CORPS

General James T. Conway served for 40 years in the U.S. Marine Corps and was the 34th Commandant of the U.S. Marine Corps. He also served as a member of the Joint Chiefs of Staff and as a military advisor to the Secretary of Defense, the National Security Council, and the President. Previously, General Conway served as President of the Marine Corps University, a division commander, the J-3 Joint Staff and other operational and staff assignments in the Marine Corps.

General Conway serves as the co-chair of the Energy Security Leadership Council and on the Board of Advisors for the Jewish Institute for National Security of America.

He holds a bachelor's degree from Southeast Missouri University and attended the Seminar XXI M.I.T. Fellowship program and Seminar in International Relations at the John F. Kennedy School of Government at Harvard University.



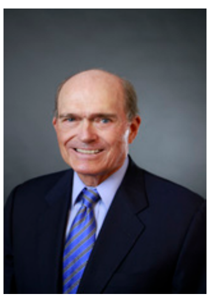
LIEUTENTANT GENERAL KEN EICKMANN, USAF (RET.)

FORMER COMMANDER, AERONAUTICAL SYSTEMS CENTER, WRIGHT-PATTERSON AFB

Lieutenant General Ken Eickmann served for 31 years in the U.S. Air Force, where his last active duty assignment was as the Commander of the Aeronautical Systems Center and Installation Commander of Wright-Peterson Air Force Base. Prior to that, General Eickmann was the Commander of the Oklahoma City Air Logistics Center and Installation Commander of Tinker Air Force Base, Deputy Chief of Staff for the Pacific Air Forces, Deputy Chief of Staff for Logistics, and Chief of Staff for Air Force Materiel Command.

General Eickmann is currently a Senior Research Associate in the College of Engineering at the University of Texas, Austin;. He served six years on the Air Force Science and Technology Board; and has chaired numerous energy related studies for the National Academy of Sciences and the National Research Council.

General Eickmann holds a bachelor's degree in mechanical engineering from the University of Texas Austin, and a MS in Systems Engineering from the Air Force Institute of Technology. He is a graduate of the University of Michigan School of Business and the John F. Kennedy School of Government at Harvard University.



LIEUTENANT GENERAL LAWRENCE "LARRY" P. FARRELL JR., USAF (RET.)

FORMER DEPUTY CHIEF OF STAFF FOR PLANS AND PROGRAMS, HEADQUARTERS U.S. AIR FORCE

Lieutenant General Larry Farrell served 33 years in the U.S. Air Force. His Air Force service encompassed duties from combat fighter pilot and commander to system management, acquisition management, planning, budgeting and strategy. He served 23 years in fighter operations at several levels of command. After that he served as System Manager for the F-4 and F-16 weapons systems worldwide, Planner/Programmer for U.S. Air Forces in Europe, Air Force Programmer, Deputy in the Defense Logistics Agency, and Vice Commander in the Air Force Systems Command. His last assignment was as Deputy to the Air Force Chief for Planning, assembling the $100B plus Air Force Program.

General Farrell he led the National Defense Industrial Association as President and CEO for 13 years His board service extended to defense companies as well as the commercial medical space. General Farrell also participated in numerous studies both as member and as chair. He chaired two acquisition reform studies for the Secretary of the Air Force and participated in numerous studies at the Center for Naval Analysis on climate, energy security, and Afghanistan.

General Farrell graduated from the Air Force Academy with a BS in Engineering Science. He has an MBA from Auburn University and has attended the National War College, the Kennedy School for Executives in National Security, the Kellogg School for Corporate Governance, and Executive Training at Texas A&M.

BRIGADIER GENERAL GERALD E. GALLOWAY JR., USA (RET.),

FORMER DEAN AT THE UNITED STATES MILITARY ACADEMY, WEST POINT
FORMER DEAN AT THE INDUSTRIAL COLLEGE OF THE ARMED FORCES, NATIONAL DEFENSE UNIVERSITY
VICE CHAIRMAN, CNA MILITARY ADVISORY BOARD

Brigadier General Gerald E. Galloway served for 38 years in the U.S. Army in the U.S., Asia, and Europe. His last assignment was as the Dean of the Academic Board at the U.S. Military Academy at West Point. He served with the Army Corps of Engineers as a Presidential appointee to the Mississippi River Commission, Chair of a White House committee to assess the causes of the 1993 Mississippi River Flood, and Commander of the Vicksburg District of the Corps.

Currently, General Galloway is a Glenn L. Martin Institute Professor at the University of Maryland and a Faculty Fellow of the Hagler Institute for Advanced Study at Texas A&M University. He is also an elected member of the National Academy of Construction, the National Academy of Public Administration, and the National Academy of Engineering, and has served on thirteen committees of the National Research Council, chaired two studies on the future of Army Logistics, and is a member of the National Academys' Resilient America Roundtable.

General Galloway is a graduate of the U.S. Military Academy and holds master's degrees from Princeton University, Pennsylvania State University, and the U.S. Army Command and General Staff College. He completed his doctorate at the University of North Carolina at Chapel Hill.

VICE ADMIRAL LEE F. GUNN, USN (RET.)

FORMER INSPECTOR GENERAL OF THE DEPARTMENT OF THE NAVY
VICE CHAIRMAN, CNA MILITARY ADVISORY BOARD

Vice Admiral Lee Gunn served for 35 years in the U.S. Navy. His last active duty assignment was as Inspector General of the Department of the Navy, where he oversaw the Navy Department's overall inspection program. Admiral Gunn served in the Surface Navy in multiple theaters. He commanded a frigate, a destroyer squadron, and the Third Fleet amphibious group, and he was the Combined Naval Forces Commander and the Deputy Combined Task Force Commander for Combined Task Force United Shield in Somalia. Following retirement from the Navy, Admiral Gunn was the President of the Institute for Public Research at the CNA Corporation from 2003 until his retirement from CNA in 2015.

He currently serves on the board of directors for the American Security Project; on the U.S. Global Leadership Coalition; as Chair of the Board of Advisors to the Presidents of the Naval Postgraduate School and the Naval War College; on the Global Perspectives Initiative at the University of Central Florida; and as an executive board member of the Surface Navy Association. He is the past President of the Surface Navy Association. He also chairs The Gunn Group, advising on energy, water, climate and national security.

Admiral Gunn holds a bachelor's degree in experimental and physiological psychology from the University of California Los Angles and a MS in Operations Research from the Naval Postgraduate School.

GENERAL DONALD J. HOFFMAN, USAF, (RET.)

FORMER COMMANDER, AIR FORCE MATERIAL COMMAND

General Donald J. Hoffman served for 38 years in the U.S. Air Force. His last active duty assignment was Commander, Air Force Materiel Command, where he managed a workforce of 80,000 with a $60B budget. He also served as the Military Deputy for Air Force Acquisition in the Pentagon and as the Director of Requirements at Air Combat Command. He served in various operational and staff assignments in Europe, the Middle East, and the United States. He has commanded at the flight, squadron, group and wing levels, and has served on the staffs of U.S. Central Command, U.S. European Command, Air Education and Training Command, Air Combat Command, and Headquarters U.S. Air Force.

A graduate of the U.S. Air Force Academy, General Hoffman has a master's degree in electrical engineering from the University of California, Berkeley, and has attended the National War College and the National Security Management Course at Syracuse University.

GENERAL PAUL J. KERN, USA, (RET.)

FORMER COMMANDING GENERAL, U.S. ARMY MATERIEL COMMAND

General Paul Kern served for 37 years with the U.S. Army. His last active duty assignment was Commanding General of the Army Material Command, where he was responsible for research, development, and maintenance of the Army's weapons systems. General Kern also served as the Senior Advisor for Army Research, Development and Acquisition and as a Senior Military Assistant to Secretary of Defense Willian Perry. He led an internal investigation of abuses in Abu Ghraib prison in Iraq at the request of Secretary of Defense Donald Rumsfeld.

General Kern now serves as the senior counselor with the Cohen Group and on various advisory boards including the Truman Center and the University of Michigan Department of Mechanical Engineering.

He holds master's degrees in both civil and mechanical engineering from the University of Michigan, and he was a Senior Security Fellow at the John F. Kennedy School at Harvard University.

GENERAL RONALD E. KEYS, USAF (RET.)

FORMER COMMANDER, U.S. AIR FORCE AIR COMBAT COMMAND
CHAIRMAN, CNA MILITARY ADVISORY BOARD

General Ron Keys served for 40 years with the U.S. Air Force. His last assignment was as Commander of the Air Combat Command, the Air Force's largest major command. General Keys also served in senior positions as the Director of Operations for European Command, Commander of Allied Air Forces Southern Europe, and Commander of the U.S. 16th Air Force.

Since retiring, General Keys has advised the U.S. Air Force on energy strategy planning. He is a senior advisor to the Center for Climate and Security and the Bipartisan Policy Center and an Embry-Riddle Aeronautical University trustee, and he counsels various DoD- and non-DoD-related firms on advanced technologies, cyber, remotely piloted aircraft, and other defense related issues.

General Keys holds a BS from Kansas State University and a MBA from Golden Gate University.

REAR ADMIRAL NEIL MORISETTI, BRITISH ROYAL NAVY (RET.)

FORMER UK FOREIGN SECRETARY'S SPECIAL REPRESENTATIVE FOR CLIMATE CHANGE
FORMER COMMANDANT, UK JOINT SERVICES COMMAND AND STAFF COLLEGE

Rear Admiral Neil Morisetti served for 36 years in the British Royal Navy. His last active duty appointment was as the U.K. Government Climate and Energy Security Envoy, where he engaged with global policy makers to address the security implications of global climate change. His prior assignments included Commandant of the U.K. Joint Services Command and Staff College and Commander of U.K. Maritime Forces. He commanded ships ranging in size from the patrol boat HMS CYGNET, in Northern Ireland, to the aircraft carrier HMS INVINCIBLE, and he was Commander UK Maritime Forces before commanding the Joint Services Command and Staff College

Admiral Morisetti currently serves as an Honorary Professor and Director of Strategy at University College London's Science, Technology, Engineering and Public Policy Department, and he is a Freeman of the City of London.

He is a graduate of Britannia Royal Naval College and holds a BS in Environmental Sciences from the University of East Anglia.

VICE ADMIRAL ANN RONDEAU, USN (RET.)

FORMER PRESIDENT OF NATIONAL DEFENSE UNIVERSITY
FORMER DEPUTY COMMANDER U.S. TRANSPORTATION COMMAND

Vice Admiral Ann Rondeau served for 38 years in the U.S. Navy. Her last active duty assignment was as the President of the National Defense University. Admiral Rondeau served in the Surface Navy in a myriad of mission areas: fleet operations, strategy, policy, logistics, operational analysis, training, education, business enterprise, and installation management.

Currently, she is the president of the College of DuPage. She also serves on a variety of advisory boards including the Board of Trustees of the American Public University System, the Council for Higher Education Accreditation, the German Marshall Fund, the Atlantic Council, and the Canadian Defense College Foundation.

Admiral Rondeau holds a bachelor's degree in history and social science from Eisenhower College, a masters' degree in comparative government from Georgetown University, and a doctorate in education from Northern Illinois University and has attended several senior executive training and education courses.

LIEUTENANT GENERAL KEITH J. STALDER, USMC (RET.)

FORMER COMMANDING GENERAL, U.S. MARINE CORPS FORCES, PACIFIC

Lieutenant General Keith Stalder served for 37 years in the U.S. Marine Corps. His last active duty assignment was as the Commander of Marine Forces Pacific. His previous assignments include command of II Marine Expeditionary Force, Marine Corps Training and Education Command, 3D Marine Aircraft Wing, and 1st Military Expeditionary Brigade.

General Stalder is a Senior Fellow at the Center for Naval Analysis and the CEO of Keith Stalder and Associates, LLC; and the National Commander of the Marine Corps Aviation Association.

General Stalder holds an undergraduate and graduate degree in aeronautics from Embry-Riddle Aeronautical University and has studied at the Marine Corps Command and Staff College, the Armed Forces Staff College, and the NATO Defense College.

REAR ADMIRAL DAVID W. TITLEY, USN (RET.)

FORMER OCEANOGRAPHER AND NAVIGATOR OF THE NAVY

Rear Admiral David Titley served in the U.S. Navy for 32 years. His last active duty assignment was Oceanographer and Navigator of the Navy. He also served as the Deputy Assistant Chief of Naval Operations for Information Dominance. While serving in the Pentagon, Dr. Titley initiated and led the U.S. Navy's Task Force on Climate Change.

Dr. Titley is now a Professor of Practice in the Department of Meteorology at Penn State, a Professor of International Affairs, and the founder of Penn State's Center for Solutions to Weather and Climate Risk. He serves on a variety of boards for organizations including the Bulletin of the Atomic Scientists, the Center for Climate and Security, and Citizens Climate Lobby. He has served on and chaired numerous National Academy of Science ad hoc committees.

His education includes a BS in Meteorology from the Pennsylvania State University, an MS degree in Meteorology and Physical Oceanography and a doctorate in meteorology, both from the Naval Postgraduate School. He is a fellow of the American Meteorological Society, and received an Honorary Doctorate of Philosophy from the University of Alaska, Fairbanks.

GENERAL CHARLES F. "CHUCK" WALD, USAF (RET.)

FORMER DEPUTY COMMANDER, HEADQUARTERS U.S. EUROPEAN COMMAND (EUCOM)

General Chuck Wald served 35 years with the U.S. Air Force. His last active duty assignment was as the Deputy Commander of the U.S. European Command (USEUCOM). General Wald's previous assignments include Commander of the 31st Fighter Wing at Aviano Air Base, Italy; Commander of the 9th Air Force and U.S. Central Command Air Forces; and leading the development of the coalition air campaign during Operation Enduring Freedom.

General Wald currently serves as the Vice Chairman of the Federal Practice Advisory Partner of Deloitte and is on the board of directors for the Bipartisan Policy Center.

He earned his commission through the Air Force ROTC program in 1971. He earned his masters' degree in international relations from Troy University and received a BA in pre-law from North Dakota State University. He has also completed coursework at Harvard University and the National War College.

LIEUTENANT GENERAL RICHARD C. ZILMER, USMC (RET.)

FORMER DEPUTY COMMANDANT FOR MANPOWER AND RESERVE AFFAIRS, HEADQUARTERS MARINE CORPS; FORMER COMMANDING GENERAL OF MULTI-NATIONAL FORCE, AL ANBAR, IRAQ

Lieutenant General Rick Zilmer served for 36 years with the U.S. Marine Corps. His last active duty assignment was Deputy Commandant for Manpower and Reserve Affairs, Headquarters Marine Corps. He also served as the Commanding Officer First Battalion, First Marines; Commanding Officer 15th Marine Expeditionary Unit; Commander General Multinational Forces – West; and Commanding General III Marine Expeditionary Force, Okinawa, Japan.

General Zilmer graduated with a bachelor's degree in education from Kutztown University in 1974 and holds a MAdegree in national security and strategic studies from the College of Naval Warfare.

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