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Industry Study

Final Report

U.S. ENERGY INDUSTRY VISION 2011 – 50 by '50

The Industrial College of the Armed Forces
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ENERGY INDUSTRY STUDY SEMINAR 2011

ABSTRACT: Demand for energy is growing rapidly around the world, and is projected to grow even faster in the future. In the United States (U.S.), preserving national security, economic prosperity, and even our future ecological survival requires a transition away from an energy mix dominated by imported hydrocarbons (i.e. fossil fuels) to one that is dominated by domestic sources of renewable and clean energy. This paper lays out a vision and recommendations toward deriving 50 percent of U.S. energy supplies from renewable sources by the year 2050. To accomplish this vision, the U.S. needs to enact policies and make investments that encourage the required transition to renewable energy technologies, modernize the electrical generation, transmission, and distribution systems, and improve the security of these various energy systems. Although the challenges are daunting, failure to proactively address them will only make matters worse. Implementing the policy recommendations advanced in this paper will not only ensure economic and national security for the U.S., it will also unleash the American spirit of innovation and restore and enhance our leadership role and technological prowess. The path is ambitious but clear and the goal is within grasp – what is needed is bold and consistent leadership, the political courage to enact change before change is forced by external forces, and a rejuvenation of the American spirit of innovation and entrepreneurship.

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Introduction

The United States' (U.S.) economy and way of life depend heavily upon a steady supply of reliable and affordable energy. Transportation, communications, financial systems, manufacturing, and even the ability to produce and distribute food, water, and consumer goods are all impossible without ready access to energy in its many forms. The U.S. economy is inextricably linked to the global economy and to access to worldwide energy resources for production of energy and transportation. Both historical and recent conflicts and tensions in the Middle East show how volatile and tenuous the world's reliance on unstable nations for the predominant source of the world's energy – petroleum oil – can be. In addition, terrorists have made it clear that they intend to conduct physical and cyber attacks to interrupt global energy supplies and power production to damage U.S. and world economies.

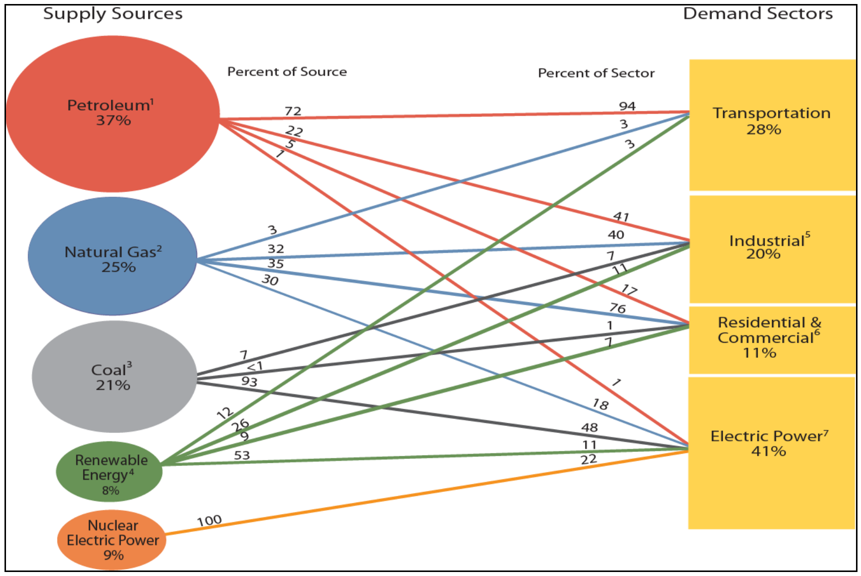
Within this paper, the authors define the energy industry, propose an ambitious vision for the U.S. energy industry in 2050, and discuss key trends, challenges, and political issues facing implementation of this U.S. energy vision. The authors review individual energy sectors in the U.S., including hydrocarbons (oil/gas/coal), nuclear, and renewable energy (solar/wind/biomass), and discuss energy efficiency and security, including fuel cells, energy storage, smart grid, and critical infrastructure. Finally, the authors conclude with policy recommendations that lay out a path to achieve the vision for renewable, sustainable, secure and clean energy by the year 2050.

Energy Industry – Definition and Market Analysis

The U.S. energy industry does not fit neatly into an easily defined market. It is rather a diverse combination of separate but deeply integrated industries that involve the extraction, refining, generation, transmission and distribution of electricity and solid, liquid or gaseous fuels. Energy suppliers can be classified by energy source, including non-renewable (petroleum, nuclear, coal and natural gas), renewable (solar, wind, geothermal, hydroelectric, biomass, bio-fuel), and secondary (electricity, hydrogen and conservation). Energy sources are also measured by how much air pollution or harmful emissions are generated – i.e., how "clean" the source is. As indicated in the chart below, most U.S. energy production is non-renewable, non-clean and based on fossil fuels. Generally, energy consumers are classified as industrial, commercial, residential or transportation, but the electric grid is used by all these sectors. Transportation is nearly all petroleum-based while U.S. electricity production is dominated by coal-fired utilities (see Chart 1).

The diverse U.S. energy industry is highly fragmented, heavily and inconsistently regulated at the federal, state and local level, and strongly interconnected in a globalized energy market. Many sectors of the overall energy industry are mature (i.e., nuclear, coal, hydroelectric), while others, like solar and bio-fuels, are emerging and rapidly evolving as new technologies and processes improve their commercial viability.

However, even mature industries are buffeted by technological improvements and mounting regulations, especially regulations established to offset the negative environmental externalities produced by hydrocarbons. Energy market trends are primarily driven by world and U.S. gross domestic product (GDP) growth. Demand is increasing for all forms of energy.



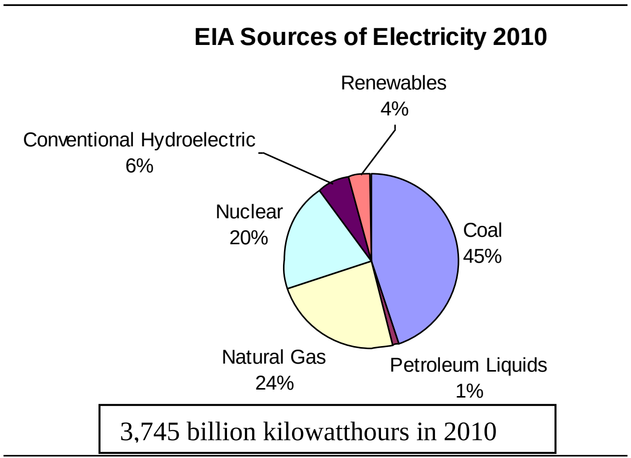
1. U.S. Primary Energy Flow by Source and Sector, 2009 (Quadrillion Btu)[1]

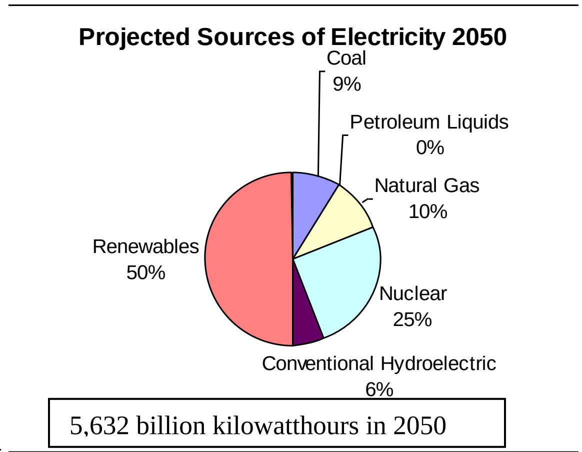
However, new suppliers face significant barriers to entry due to the requirement for large infrastructure and capital commitments as well as the high degree of regulation in the energy industry. It can take years to bring new energy supplies on line. As a result, energy supply is inelastic while demand is highly elastic, which leads to harmful levels of volatility, particularly in energy prices. These barriers also limit the threat of substitute products to only the most minor niches. The rivalry between existing competitors is strong with the wide variety of new technologies used to improve profitability.

U.S. Energy Vision: "50 by '50"

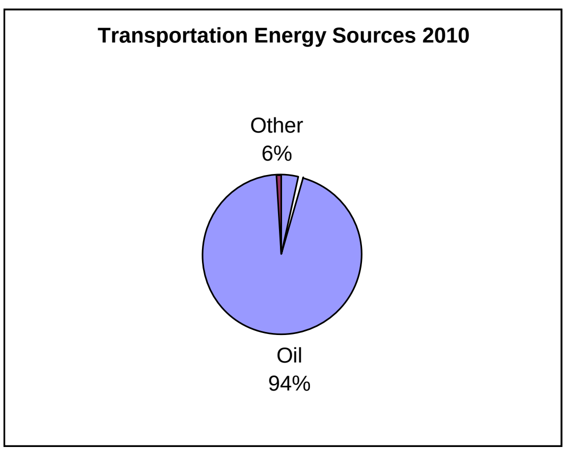
The 2010 National Security Strategy (NSS) identifies energy security as a challenge threatening U.S. prosperity.[2] National energy security challenges include a reliance on energy supplies (primarily oil) from unstable parts of the world, an inefficient electrical grid, and the growing impact that hydrocarbon combustion has on global warming and the resulting climate change. The principal uses of energy are for transportation and power generation. The U.S. transportation sector currently relies overwhelmingly on petroleum (94%),[3] while the U.S. power generation sector currently relies mainly on coal (48%), natural gas (18%), and nuclear (22%), with small amounts coming from hydroelectric and renewable energy sources.[4] The ambitious goal set forth within this paper is to introduce policies that will encourage the development and use of renewable energy resources and reduce dependence on fossil fuels so that 50 percent of all U.S. energy will come from renewable sources by 2050 – hence the vision "50 by '50."

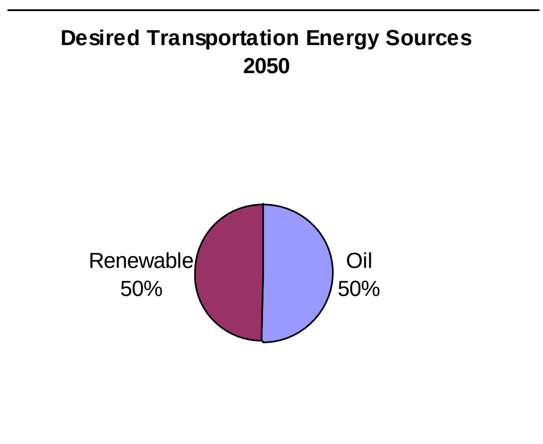
The first set of graphs below depicts both the current energy mix in the U.S. and the desired energy mix for 2050 for the production of electricity. To achieve the desired mix, the power generation industry would shift from 69% to about 19% fossil fuels, with renewable energy sources increasing to make up for the reduction of fossil fuels and to cover the projected increase in total electricity demand.[5] The second set of graphs depicts the current and desired mix for transportation, with the sector shifting from nearly entirely oil sources of fuel to only 50% reliant on oil for transportation.





Source: U.S. Energy Information Administration, Annual Energy Review 2009 (August 2010)





Trends, Challenges and Political Issues Facing U.S. Energy Industry

As the global population and world GDP increase through 2050 and beyond, the global demand for energy will continue to rise dramatically. Most of the growth in energy demand will occur in developing nations as they attempt to construct and electrify cities, increase transportation, and develop manufacturing industries. While world demand is growing, world supply of easily accessible fuel is decreasing, requiring more expensive technologies to access remaining fossil fuel supplies, and development of new, but relatively expensive technologies to provide future energy.

> "Strong long-term growth in GDP in the emerging economies of non-Organization for Economic Cooperation and Development (OECD) countries drives the fast-paced growth in energy demand. In all non-OECD regions combined, economic activity—as measured by

GDP in purchasing power parity terms—increases by 4.4 percent per year on average, compared with an average of 2.0 percent per year for OECD countries."[6]

Unless we can develop alternative renewable and clean technologies, declining supply and growing demand will continue to increase energy prices in the traditional hydrocarbon global energy market.

While no one can accurately predict what the world will be like in 2050, certain readily identifiable driving forces will shape the world over the next 40 years:

- Worldwide population will continue to grow for many decades, with the United Nations (UN) predicting an increase from the current 6.9 billion to over 9.1 billion people;[7]

- U.S. population is projected to grow to 403 million; China to 1.41 billion; and India to 1.61 billion people;[8]

The Energy Information Administration (EIA) projects that if current laws and policies remain unchanged, worldwide energy demand will increase 49% by 2035, with non-OECD countries accounting for 84% and OECD countries responsible for 14% of the growth.[9] The International Energy Agency (IEA) similarly foresees significant increases in global energy demand by 2050 if no changes are made to existing policy and significant energy efficiencies are not realized, with 90% of the growth attributable to non-OECD countries:

- Primary energy demand increases by 84%;
- Liquid fuel demand increases by 57%, with petroleum products meeting more than 90% of transport energy demand;
- Coal demand increases by 138%;
- Natural gas demand grows by 85%

Even though most of this population growth and increased demand will occur in the developing world, the U.S. economy is inextricably linked to the world economy and what happens in world energy markets affects the U.S. energy industry. With the U.S. shouldering an increasing burden from debt and entitlements, it cannot afford the current trajectory which over the long term will lead to a larger portion of U.S. GDP being spent on energy. The future of U.S. energy supply and security is also uncertain due to unpredictable world political events, like the Middle East uprisings, the nuclear reactor incident in Japan, and ever-present terrorist threats. Finally, the long run implications of global climate change caused by the increasing concentration of greenhouse gases in the atmosphere compel a U.S. response.

In concert with this dramatic increase in population and demand over the next 40 years comes uncertainty about supply, new technologies, and environmental impacts. Fossil fuels dominate the current mix of sources that supply worldwide and U.S. energy demand, because they are currently abundant, technologically and economically obtainable, and politically protected by their vast industries, markets, infrastructures, and lobbying groups. However, they will rise in price and eventually become depleted – only the timing is arguable. Additionally, traditional combustion of fossil fuels is harmful to the environment and is leading to climate change with uncertain but perhaps devastating global consequences.

The IEA reported in its 2010 World Energy Outlook that conventional crude oil production "peaked" in 2006, and unconventional oil sources (e.g. heavy crude, shale oil and oil sands) are significantly more difficult and expensive to produce.[10] Despite skepticism about "peak oil," there is little doubt that proven conventional oil reserves will be heavily depleted by 2050, while the costs of producing unconventional oil will rise. Coal is plentiful, but this fuel source contributes the highest rate of CO_2 of all the hydrocarbons and hence is the "dirtiest" of the fossil fuels. Natural gas is cleaner, and the U.S. has recently discovered vast tracts of shale gas, but it still produces greenhouse gas emissions and is heavily water-intensive to extract.

Nuclear power, which technologically has the capacity for base-load power generation, faces political challenges in the coming years due to the huge capital investment required as well as NIMBY ("not in my backyard") issues - exacerbated by events such as the nuclear power plant crisis in Japan. Renewable energy technologies like wind and solar power are gaining ground throughout the world, yet they are not ready to become part of the base-load electric power generation mix in the U.S. due to existing policy and technical limitations.

U.S. energy security is also threatened by aging infrastructure, efficiency losses, and security challenges. The U.S. electrical grid is aged and crumbling. Without substantial upgrades, more frequent outages will occur and the grid's inability to handle projected increases in demand will begin to stifle economic growth. As referenced in the chart below, the Department of Energy (DoE) indicates that in 2009 the U.S. wasted 56% of its primary source energy during the conversion of fuel to power stage;[11] the electricity industry wasted 65% of input energy; and the transportation industry wasted over 75% of the input energy.[12] Reduction in the inefficiencies in these two areas alone could greatly improve the nation's energy posture, increase national security, and strengthen the economy (see Chart 2).

Finally, even though one cannot accurately predict the world's climatic and environmental conditions in 2050, these risks must be recognized and managed. The Intergovernmental Panel on Climate Change (IPCC) and other reputable and objective scientific sources find the link between anthropogenic (i.e., human-caused) greenhouse gas sources and global climate change to be very likely,[13] although a considerable level of skepticism remains. On the world stage, the U.S. is not perceived as a leader in combating global climate change, and leadership in this arena has been bestowed upon countries such as those in the European Union that have ratified the Kyoto protocol and taken steps to reduce their greenhouse gas emissions (e.g., via taxes on energy, cap-and-trade legislation). In the face of scientific evidence and observable environmental facts and trends, the uncertainty associated with the degree and timing of global climate change driven by increasing greenhouse gases must not be an excuse for inaction to effect positive change.

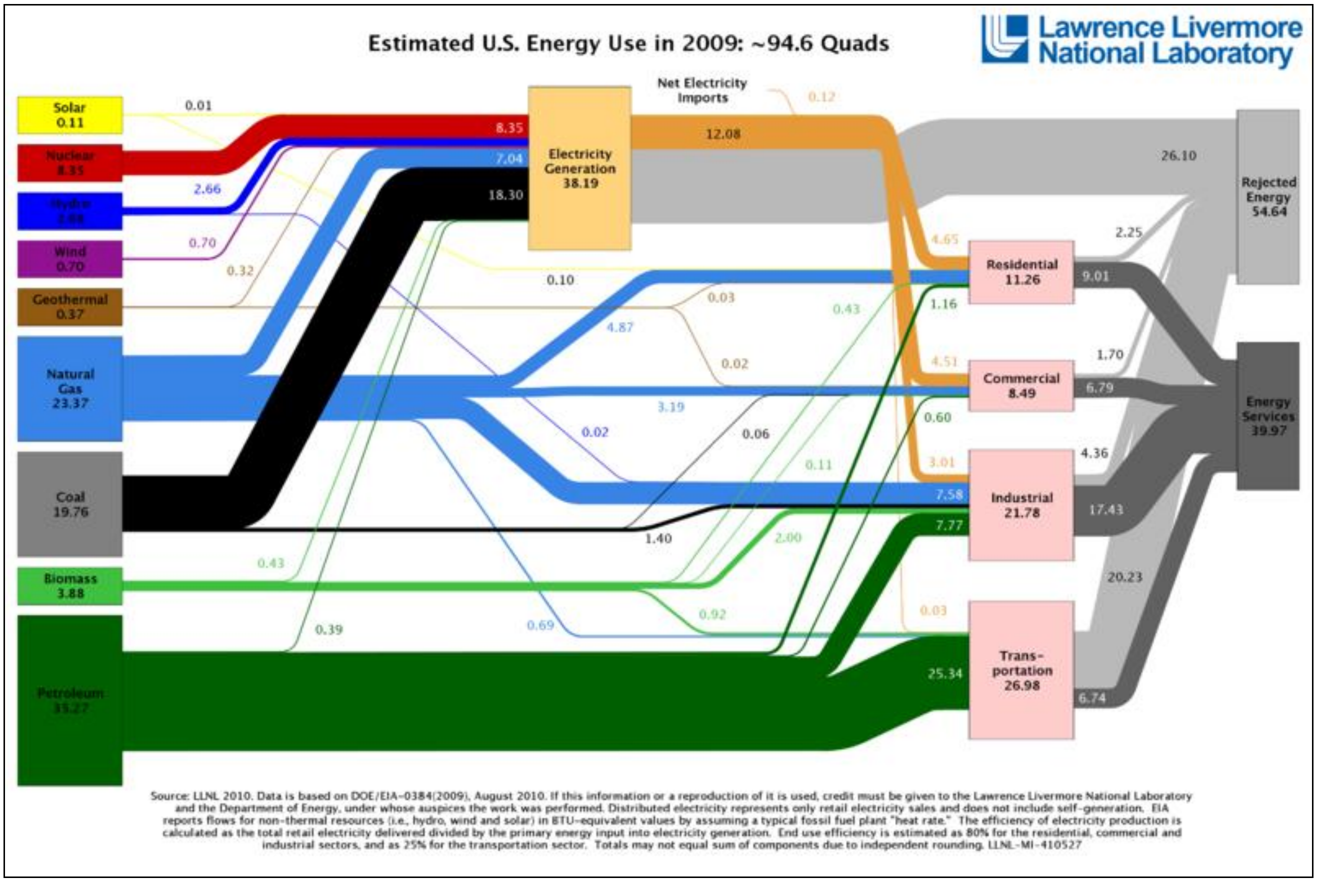


Chart 2

We recognize that a goal of 50 by ’50 is ambitious and that America cannot suddenly change its policies or habits overnight. We also recognize that there is no “silver bullet” to energy security and sustainability. Every President since Nixon has stated the need to reduce America’s dependence on foreign oil, but U.S. reliance on imports of oil grew from 36.1% in 1974 to 66.2% in 2009.[14] While the U.S. is slowly developing new sources of clean, renewable, and alternative energy, and promoting greater demand efficiencies, it has no comprehensive, predictable, and sustainable energy policy to provide momentum. In March 2011, President Obama laid out an ambitious blueprint for energy security through 2035, which included a significant percentage increase in clean and renewable sources of energy, improved demand efficiencies, and investment in innovation and clean energy research and development.[15] The challenge with all such statements, and with the proposals laid out herein, is translating the policy into reality through a divided and partisan Congress, obtaining necessary funding in a fiscally-tight budget environment, managing Federal/State/Local divisions, and securing private sector buy-in and support. These challenges are daunting, but none is insurmountable. Congress has passed significant energy legislation in the past 10 years, and succeeded in passing (controversial though it is) a major health care bill;[16] many States are enacting renewable or clean energy requirements that are more stringent than federal standards;[17] many of the recommendations in this paper are “revenue-neutral” (e.g., a carbon tax, replacing fossil fuel subsidies with subsidies for renewable technologies) or are focused on targets, standards, and tax incentives; and many companies argue that it is very risky for them to invest in new technologies or new ventures within the U.S. without greater predictability in U.S. government policy.

While these political and economic constraints present challenging institutional barriers, America's current "ad hoc" approach to energy policy will constrain the implementation of an energy strategy to meet the U.S. energy and environmental needs through 2050 and beyond. That is why the U.S. needs to change its approach to energy to become the world leader in innovation, manufacturing, and use of new and sustainable energy sources and technologies. U.S. leadership in sustainable, renewable, and clean energy technologies will improve our national energy security, foster economic growth, and create jobs.

Survey of Key Energy Technologies

Set forth below is an assessment of existing and envisioned energy sources, technology and related issues. Along with the previous energy overview section, it builds the case for our list of recommendations to achieve our goals of "50 by '50" and place the U.S. as the world leader in renewable, sustainable, secure and clean energy.

Hydrocarbons

The current mix of sources that supply U.S. energy demand is dominated by hydrocarbons, including oil, coal, and natural gas. They are the long-standing, supremely-reigning, energy-providing incumbents, protected from usurpation by the vast industries, markets, infrastructures, and lobbying groups that have grown up around them over the past many decades. Hydrocarbons are, however, being depleted from the earth and thus will not last indefinitely. Further, they contribute significantly to environmental pollution due both to their extraction from the earth and their combustion to provide energy. That said, they will continue to be a major energy source for the U.S. and world for decades to come.

Oil pervades the U.S. economy. It is used to fuel the vehicles that transport people and goods, pave roads, manufacture consumer goods, and lubricate the equipment that makes consumer goods and that extracts more hydrocarbons from the earth. Though the U.S. has a considerable supply of proved oil resource and refining capacity, it is still a net oil importer and is not investing enough in new or replacement capacity to meet demand. As with other OECD countries, the demand for oil in the U.S. is expected to be steady through 2030, while global demand is expected to increase significantly driven by non-OECD countries (led by China and India) to rise by more than 70 percent.[18] Since oil is a global commodity, increased demand over the coming decades will drive costs upward (assuming a constant supply), while disruptions from embargoes, civil unrest, or shutdowns in transportation chokepoints (e.g. the Suez Canal) lead to extreme price volatility in this important worldwide commodity. Indeed, in isolated areas such as Hawaii which depend on imported oil for the vast majority of their energy needs, the extreme price volatility of oil has a truly dramatic negative impact on its citizens and overall economy.

The U.S. has abundant, secure, and readily accessible and geographically distributed supplies of coal, which provides approximately 45 percent of the electricity in the U.S. In 2009, the U.S. was the sixth largest exporter of coal in the world, and demand is projected to continue to rise as China's economy continues to expand and demand additional energy sources. Even more so than other hydrocarbons, the coal industry produces large negative environmental externalities during both mining and energy production. While burning of coal produces the most harm to air quality, coal mining also causes mercury pollution and environmental problems that include among other damages ecosystem degradation, water and air pollution, stream interruption, land instability, methane gas release, and acidified water.[19] Coal will continue to play an important role in the U.S. energy mix. However, cleaner methods of extraction and combustion for energy supply need to be developed to minimize both impact on the environment and disruption to the coal business.

Natural gas burns cleaner than oil and coal. It is currently cheaper than oil, new reserves are being discovered every year, and technological advances make its extraction from the earth more feasible and affordable. Because of these reasons, the natural gas market has enjoyed tremendous growth over the past few decades. Further, every major outlook forecast indicates continued growth in demand for natural gas, and the U.S. has transitioned from a position of net-importer to net-exporter of natural gas. Demand for gas is expected to grow at an average annual rate of 1.8 to 2%[20] with non-OECD countries' natural gas demand growing three times faster than OECD countries.[21] While this seems small, at this rate by 2035, the demand for natural gas will be 35% more than current production.

Environmental concerns resulting from the combustion of hydrocarbons are leading many throughout the world to search for cleaner energy sources. Within the realm of hydrocarbons, natural gas has a much lower CO_2 emission rate when compared with burning oil and coal. Thus, there are efforts underway throughout the world (especially within OECD countries) to replace coal power plants with cleaner fuel sources like natural gas. To abate carbon emissions, technologies to capture and store these emissions are being developed. Current technologies exist for smaller coal-fired electric plants (i.e., 250 megawatts (MW) or less), but have not been applied to larger plants[22] mostly because of the costs. Interestingly, fees levied in Norway in 1993 made it more economical to store CO_2 than pay emission fees. In 1996 Exxon/Total created a large scale Carbon Capture and Sequestration (CCS) project for natural gas.[23]

The UAE and Qatar serve as good examples of how even small hydrocarbon-rich nations are proactively preparing for the eventual depletion of their fossil fuels.[24] The UAE is investing aggressively in nuclear power; Qatar is spending heavily on educating its population. Both are rapidly diversifying their economies despite their massive hydrocarbon endowments. For both, fresh water is the scarcest resource, requiring them to use significant amounts of their energy for desalination plants. The UAE possesses the seventh largest oil and natural gas reserves in the world, but while it is a net exporter of oil, it is a net importer of gas which is the principal source for its electrical generation. To make up for the deficit, the UAE has partnered with Qatar to receive natural gas via the Dolphin pipeline, the first cross-border gas pipeline in the Gulf region. However, with only one-to-three days' worth of natural gas in reserve, the UAE will suffer dramatically in case of a prolonged disruption. A major interruption of gas translates to a loss of electrical production with the equally detrimental cascading effect of ceasing water desalination. Realizing the precarious situation, the UAE is pursuing nuclear energy as another source of base load electricity. Qatar similarly generates immense amounts of revenue from its vast natural gas resources and LNG distribution, but is seeking to diversify its economy to improve food and water security. As one of the world's largest producers and consumers of energy, the U.S. can hardly afford to be less visionary than these countries.

Nuclear

As a low-carbon technology, nuclear energy is an important component to a diverse and viable clean energy portfolio into 2050. As a substitute to carbon-based energy sources, nuclear power holds strategic importance from environmental, political and economic perspectives. The nuclear plant fleet in the U.S. is aging and no new plants are under construction. The Nuclear Regulatory Commission (NRC) estimated 42 months to complete the review of all the applications prior to a final decision and construction typically requires another five to seven years for each reactor. EIA projects that the U.S. nuclear industry can add about 8 gigawatts electric (GW) of new nuclear capacity by 2035, and upgrades to existing power plant capacity will add an additional 4GW.[25] The latest designs for large nuclear power plants offer enhanced safety and performance, and are ready for wider deployment over the next few years. If every one of the 26 U.S. reactors currently under NRC license review is approved and built, plus all proposed current plant license renewals are approved, the U.S. total electric capacity for nuclear power of 100 GW is maintained until the year 2030. As an alternative, Small Modular Reactors (SMRs) provide potential advantages of lower capital costs, reduced construction time, and a modular "build-to-need" design that may open nuclear expansion at a greater rate. SMRs face impediments due to new design certification times, fee structures, force protection, waste disposal, and public opinion concerns but may provide a reasonable path to nuclear growth in a fiscally constrained environment over the next 40 years. Research and development (R&D) in the area of nuclear fusion also offers opportunity to develop an infinite energy source – representing a complete "game-changer" in the nuclear field.

Despite these promising technologies, it is uncertain how many new nuclear reactors will actually be built in the U.S. Expansion of nuclear energy requires strategic communication by the U.S. government toward long-term commitment to nuclear power and to encourage public acceptance. A major expansion effort does not require new technological breakthroughs but does require construction funding, sustainable methods for the disposal of high-level radioactive waste, and an investment in education for the necessary workforce to build, operate and maintain a new generation of nuclear power stations.

Without a game-changing technology, the U.S. needs an aggressive strategy to maintain nuclear capability and capacity to provide reliable, safe, clean, base-load electricity, and build new plants to push toward our projected 25% load in 2050. This effort will require building large replacement reactors of current design at a rate of approximately five a year from 2030 to 2050 to provide an estimated 140 GW capacity by 2050.

Renewables

The use of renewable energy sources such as solar, wind, biomass, geothermal, hydroelectric, and bio-fuels has increased over the last few years, though it still represents a small portion of worldwide energy use. The EIA reported that renewable sources of energy made up 10.92% of U.S. energy production in 2010.[26] In general, renewable energy is more expensive and more output-variable than conventional fossil fuels. However, new research, technological advances, government mandates, and incentives are making expansion of renewable energy types more feasible.

Solar energy is by far the most abundant and reliable renewable energy source available. All the energy stored in Earth's reserves of coal, oil, and natural gas is equivalent to the energy of just 20 days of sunshine.[27] Covering four percent of the world's desert areas with photovoltaic (PV) cells would satisfy global demand for electricity.[28] Current solar energy systems are either solar thermal or PV. PV cells have the unique advantage of the ability to convert sunlight directly into electrical current without moving parts or the need to make steam. Although initial capital costs (installation) are high for solar systems, maintenance costs are among the lowest when compared to other energy-production platforms, and solar systems have long life spans of typically 20 to 25 years. That said, each environment can present unforeseen challenges, such as the efforts required to clean PV arrays in the deserts of the UAE to keep those cells fully operational.

Despite its vast potential, current solar technology faces several limitations that prevent unlocking its true potential. Like wind, solar is a variable/intermittent power source that requires a breakthrough in energy storage in order for these energy sources to make major contributions to base-load electric power generation. Recent demonstrations of utility-scale solar power plants in Nevada and Arizona are successfully storing solar energy within molten salts, which allows the plants to continue distributing electricity on cloudy days or even at night. Utilities-scale solar energy projects require large tracts of empty land, and delays in land use permitting cause undue risk and restrict solar projects' access to financial markets. High initial capital investment makes producing energy from the sun still several times more expensive on average than burning fossil fuel, as long as the costs of carbon emissions are not factored in. However, overall kilowatt-watt (KWH) costs for solar energy systems are declining due to ongoing R&D to improve efficiency, realization of economies of scale, and the installation of utilities-scale power plants.

Solar energy is growing rapidly despite its limitations, but it must grow even faster if the U.S. is to reach the ambitious renewable energy goals set forth within this paper. Like wind, if utilities-scale solar projects companies are to provide the huge growth in renewable energy the U.S. requires, they must have a streamlined permitting process, loan guarantees, and access to land and water.

Wind power also has potential to grow in the U.S., but without technological advances in energy storage and smart grids (to address base load issues), wind's contribution to alternative, renewable energy, will remain limited. According to the National Renewable Energy Laboratory, the contiguous U.S. has the possibility to install 10,459 GW of onshore wind power,[29] which is about nine times larger than current total U.S. electricity consumption.[30] The mechanical conversion of wind energy results in about 90% efficiency compared to 35% efficiency from conventional thermal plants.[31]

Though the use of wind power has been increasing in recent years, the U.S. is falling behind other countries in the use and manufacturing of wind power. China is currently the global leader in new wind farm installations. Last year, China increased installations by 27% to provide more than 16 GW of new wind generation. The U.S. is the second largest market yet added only 5 GW in 2010 compared to 10 GW in 2009. The U.S. wind market entered 2011 with 5,600 MW under construction, more than double the year prior, due in large part to the December 2010 extension of the investment tax credits. Manufacturers responded by bringing at least 14 new manufacturing facilities on line in the U.S. With these new investments, wind energy is now up to 20,000 manufacturing jobs across 42 states.[32]

Although there are currently more land-based wind farms, offshore wind generation has more potential for growth. United Kingdom studies provide an offshore capacity figure of 36% compared to 27% for onshore wind farms where the wind is less reliable.[33] Another advantage includes the ability to build closer to some load centers like large east coast cities, thereby helping to reduce transmission losses and avoid bottlenecks. Offshore sites also expand the number of locations available to provide wind resources. These advantages must be balanced against the up to 50% higher development costs for foundations in offshore wind projects compared to land-based equipment. Additionally, sub-sea cables are more expensive than overhead transmission lines.

Biomass has the potential to provide significant amounts of local power generation, while bio-fuels have the potential to provide significant energy for transportation. Biomass is organic matter that has used photosynthesis to store energy. The most common forms of biomass used today are wood products, grasses, plant and animal residue, aquatic plants (e.g., algae), and municipal and industrial organic waste. Biomass is converted to energy through several different processes, including burning it to produce steam to turn a turbine (direct combustion) or to produce heat (combined heat and power (CHP)), "gasifying" it to produce combustible gases, "co-firing" or "repowering" it for use with coal to generate lower harmful emissions, or converting it to liquid fuels.[34]

The EIA reported that in 2010 biomass provided the largest share (51.98%) of energy production from renewable sources.[35] Different biomass fuels have different costs and benefits associated with them. EIA estimates that there are 590 million wet tons of biomass available in the U.S. annually, but currently only 20 million wet tons (3 GW of capacity) are available at $1.25 per million British thermal units (Btu) or less (compared to $1.23 per million Btu for coal).[36] It notes that biomass energy crops are not currently being grown commercially in the U.S., but that if the U.S. imposed a high Renewable Portfolio Standard (RPS), the use of biomass energy sources would increase significantly.[37]

Demand-Side Efficiencies

Energy efficiency is one of the key cornerstones in future energy policy, whether talking to domestic or international policy makers. The UAE government, for example, mandated building and resource efficiency to help meet energy requirements in their Abu Dhabi Vision 2030.[38] The State of Hawaii also mandated a 30% efficiency rate as part of their plan to reduce their dependency on oil imports.[39] President Obama's Secure Energy Blueprint commits to reducing oil demand through efficiencies, technology and conservation, and proposes a 20% reduction in building energy footprints by 2020.[40] Additionally, most EIA projections of future energy assume dramatic gains in building and transportation efficiency, including increased miles-per-gallon vehicles, energy efficient appliances, and higher-efficiency buildings. To encourage more energy-efficient buildings, the U.S. government mandates new federal buildings meet minimum Leadership in Energy and Environmental Design (LEED) requirements to reduce their overall carbon and water footprints. Additionally, cogeneration in commercial buildings is a growing trend that leverages residual heat to create additional power, and thereby creates more efficient energy per Btu.

Energy Storage and Fuel Cells

Successful transition of the U.S. energy sector away from fossil fuels will require significant improvements in energy storage (ES) devices across three specific fields. ES devices are broadly classified as chemical, electrochemical, electrical, mechanical, and thermal storage systems. Examples include electrochemical devices (e.g., batteries), electrical devices (e.g., capacitors), mechanical devices (e.g., flywheels and pumped hydroelectric), and thermal systems (i.e., ice storage and molten salt). Effective and affordable ES solutions are needed to exploit the full potential of renewable but intermittent energy sources such as solar and wind technologies. Additionally, lighter, cheaper ES devices with longer ranges will allow electric vehicles (EV) to play a majority role in the transportation sector. Although EV are four times more efficient than conventional cars, their cost, primarily due to batteries, makes them relatively expensive and the lack of battery charging stations outside of the home makes them impractical for many.[41] However, the Department of Energy's Battery and Electric Vehicle Program predicts a reduction by a factor of 10 in EV battery costs, a 75% decrease in weight, and a ten-fold increase in expected life by 2030.[42] Finally, modernizing the electricity grid and improving its efficiency will require further development of large-scale ES devices. Due to substantial overlap among these three ES fields, investing R&D dollars in ES technologies offers a high rate of return where a breakthrough in any area can be readily applied to the other two. Investment in advanced ES systems not only improves national security by decreasing energy vulnerabilities, it has secondary benefits of supporting economic growth and high technology job creation across many industries including the electronics, transportation, utilities, and medical fields.

Fuel cells use hydrogen and oxygen to generate electricity; the only by-products are water and heat. The simple reaction that takes place inside the fuel cell is highly efficient. When a fuel cell is sited near the point of use, its waste heat can be captured and used (cogeneration). Fuel utilization in cogeneration systems can exceed 85 percent.[43] Another advantage is versatility – since they are scalable, fuel cells can be stacked to achieve a wide variety of power output, including on the megawatt scale. Also, because they can operate independent of the electrical grid, fuel cells offer opportunities to modernize the grid by moving away from reliance on centralized high-voltage power generation with substantial transmission line losses to more efficient and secure distributed generation models.

In the transportation sector, fuel cells offer potential renewable and clean energy to fuel the passenger vehicle fleet. "If just 20 percent of cars used fuel cells, we could cut oil imports by 1.5 million barrels every day."[44] Even if the hydrogen used in a fuel cell is produced from fossil fuels, fuel cell vehicles can reduce emissions of carbon dioxide by more than half. Although current fuel cell vehicles possess a range of 200 miles on a tank of hydrogen, the technology remains expensive, costing 10 times more than electric cars which are also on the market.[45] Some states are out in front of the Federal Government on the issue of refueling infrastructure. California and Hawaii are conducting important pilot projects, with Hawaii testing prospects on several islands for transforming its entire vehicle fleet from internal combustion to hydrogen fuel cells.

Smart Grid and Critical Infrastructure

The current electric grid and infrastructure in the U.S. has reliability and security issues. The Department of Energy found that: "America's electric system, 'the supreme engineering achievement of the 20th century,' is aging, inefficient, congested, and incapable of meeting the future energy needs of the Information Economy without operational changes and substantial capital investment over the next several decades."[46] Major power disruptions like the 2000 California Energy Crisis, 2003 Northeast Blackout, and the 2011 Texas Blackout, along with major reports like the 2009 National Electric Transmission Congestion Study, highlight the vulnerabilities and crumbling infrastructure of the U.S. electric grid. Typical grid failures occur due to aging infrastructure, operating error, and natural disasters (e.g., lightning, solar flares, high temperatures, precipitation, high winds). In addition, actions taken in the cyber domain are a new and growing threat to the grid. Such vulnerabilities and risks demand that the electrical grid be resilient and flexible.

While the grid is decaying, electricity demand is rising. The estimated cost to expand the current grid to meet the expected growth is $134B.[47] The electric industry and government must work together on solutions for maintaining and upgrading the electric grid. One technique that can improve resiliency and flexibility is the employment of more smart technology into the grid.

The Smart Grid is a public-private initiative to modernize the electrical grid to meet the requirements of the 21st century. The Smart Grid uses smart devices, monitoring and two-way communications to manage electricity generation, transmission, distribution and use efficiently. Benefits of the Smart Grid include efficiency, employment and security.

The Smart Grid provides the ability to smooth the costly peak electrical demand. The data provided by the Smart Grid will allow users to take advantage of off-peak usage. In addition, the installation of PV and cogeneration systems will reduce demand and increase net efficiency of the electrical grid. The installations of PV and cogeneration systems are both components of the Smart Grid initiative. Further, the Smart Grid has the potential to identify and eliminate wasteful investment while enabling conservation. The ability to identify quickly anomalous readings and do better trend analysis leads to better asset awareness and portfolio management.

Building the Smart Grid has tremendous value as an economic engine. When it comes to employment, the construction will provide decades of construction and equipment manufacturing jobs in the U.S. In addition, the Smart Grid would be an innovation engine for new markets (like residential power management), new financial techniques (like graduated pricing according to demand), and renewable energy systems which will rely on the Smart Grid to integrate them into the national electric grid.

With the Smart Grid, the electrical generation, transmission, distribution and consumption of electricity will be dependent upon automated capabilities. Unfortunately, the introduction of millions of smart devices utilizing two-way communications will greatly increase the number of cyber vulnerabilities within the Smart Grid. Adhering to the National Institute for

Standards and Technology (NIST) guidelines for Cyber Security of the Smart Grid, distributing power generation and reducing consumer dependence on the grid will mitigate some of these risks and vulnerabilities. The Smart Grid is a needed, balanced approach to modernizing the electrical grid, both to accommodate 21st century requirements and to establish a solid foundation for the needs of the 22nd century and beyond.

Critical infrastructure is key to our prosperity and enables the U.S. to project globally and to protect our national values through use of instruments of national power. In the U.S., critical infrastructure is an open, complex, technologically advanced and interconnected collection of assets, systems, and networks that are as much as 85% owned and operated by the private sector.

Of the 18 Critical Infrastructure and Key Resources (CIKR) Sectors identified in the Department of Homeland Security's (DHS) National Infrastructure Protection Plan (NIPP), three relate directly to energy: Dams, Nuclear Reactors, and Energy. The DHS's mission includes "preventing terrorism and enhancing security, securing and managing our borders, enforcing and administering our immigration laws, safeguarding and securing cyberspace, ensuring resilience to disasters."[48] Since the vast majority of these critical assets are privately owned, protecting them properly requires Public-Private Partnerships (PPP). PPPs are formed to fill gaps in protection where neither the USG nor private owners have the resources to provide sufficient protection alone. The costs of lowering risk factors to infrastructures are not usually funded sufficiently by the private sector until there is a crisis. Furthermore, technology options for mitigating threats are not considered practical by most CIKR owners and operators due to the lack of technology maturity and excessive costs. At odds with mitigating risk factors are investor and shareholder interests in maximizing profits and keeping expenses down.

Further complicating the picture are the mutually-reliant interdependencies that exist between CIKR sectors. This underscores the vulnerability of the U.S., based on the complex relationships and vast interconnectedness of the assets, systems and networks that make up the CIKR. The scope of cross-sector infrastructure interdependencies emphasizes the potentially devastating consequences of cascading effects resulting from a single disruption or failure of service. The difficulty is identifying and evaluating the scale and complexity. Since a disruption in one interdependent infrastructure causes a disruption in a second or third, cascading linkages between cross-sectors are far reaching and may exacerbate recovery operations.

In response, PPP models across the nation provide a framework to exchange ideas and best practices, facilitate security planning and resource allocation, and establish effective coordinating structures among partners.[49] Through continued strengthening of PPPs, our nation will be more resilient and better able to protect our CIKR.

Policy Recommendations

Achieving our "50 by '50" vision requires bold and consistent leadership, the political courage to enact change before change is forced by external forces, and the spirit of innovation and entrepreneurship. Towards achieving this vision, the authors make several recommendations which, when implemented as a suite of policy actions, begin this bold transition:

- Establish and Communicate Predictable, Long-Term Energy Policies
- Increase Investment in Targeted Energy R&D and Restructure Subsidies
- Implement a Phased Carbon Tax
- Lead Transformation to Renewables-Based Transportation Infrastructure
- Modernize Electricity Transmission and Distribution Systems
- Achieve Efficiencies to Reduce Demand-Side Need
- Use Natural Gas Resources as a Bridge from Hydrocarbons to Renewables
- Encourage Development of Biomass and Waste-to-Energy Plants
- Minimize Corporate Taxes For Renewable Energy Firms
- Increase Collaboration With Industry and Foreign Entities

Each of these recommendations is discussed in detail in the following pages.

Establish and Communicate Predictable, Long-Term Energy Policies

Long-term predictability and certainty in tax rates, subsidies, loan guarantees and investments would allow U.S. businesses and investors to plan with confidence for the long-term, rather than flounder in the ambiguity that has plagued them for years. Such predictability also provides flexibility for newer, renewable energy technologies to be transitioned in optimally over time. For example, once a predictably-increasing carbon tax was imposed, carbon emitters would have the choice to pay the tax if the costs of alternative energy technologies were too high. With time, the well-designed tax would predictably rise and alternative energy technologies would advance, thus making environmental and economic sense for the desired pathway of gradual transition to an energy mix that consists of 50 percent renewable sources by 2050.

Not all government energy policies have to cost money. In many areas, the U.S. government can make important progress by simply ensuring its policies are not part of the problem. Since 1992, the Federal Production Tax Credit for wind energy has been extended multiple times but only after first being allowed to expire. These expiration/extension cycles cause needless uncertainty and adversity for investors and lenders in this capital-intensive industry. Worse, lack of consistent long-term policy unnecessarily complicates project planning, procurement of long lead item supplies, and maintenance of a competent and ready workforce.

The permit process is another area where government energy policy needs to be more consistent over time. Efforts by the Departments of Interior and Energy to streamline the permitting process by identifying marginal or environmentally degraded federal land near existing transmission lines in the desert southwest for utilities-scale solar and/or wind projects should be accelerated and repeated on a national scale. While the effort is a noteworthy step in the right direction, it was still too little too late for several large projects (one on a former landfill owned by the city of Phoenix) which were cancelled when their financing collapsed due to excessive permitting delays.

Increase Investment in Targeted Energy R&D and Restructure Subsidies

The U.S. government should work together with industry to make the United States the world leader in clean and renewable energy R&D, technology maturation, and process improvements to create a new U.S.-based manufacturing energy industry. The key areas for such investment are energy storage, nuclear, CCS, and renewable technologies.

Energy Storage Solutions. Effective and affordable energy storage solutions at the grid, industrial/commercial, residential, and automotive levels represent the most important technological breakthrough required to reach "50 by '50" goals. The priority for R&D investment is to improve energy storage systems to support batteries for EV and Plug-In Hybrid Electric Vehicles (PHEV) and larger-scale energy storage systems. Funding for these improvements can be provided by restructuring current subsidies. Improvements already underway for transportation technologies should further reduce these vehicles' price tags and enable broad market penetration within two decades, removing the need for subsidies. However, additional R&D is required now to increase vehicle range through improved magnets, batteries, and lighter weight vehicles. To alleviate the problematic intermittent electrical generation from renewable resources like solar and wind, further R&D is needed to produce larger-scale energy storage systems, including advancements in chemical, electrochemical, electrical, mechanical, and thermal storage systems. Subsidy restructuring should begin with elimination of the oil and coal subsidies which are currently projected to reach $45.6B by 2021. Besides redirecting these funds to R&D investments for ES systems, they can be used to fund competitions, leveraging private investments. For example, the Department of Defense's Defense Advanced Research Projects Agency (DARPA) estimated the $2 million prize in its "Grand Challenge" contest drew investments totaling as much as $100 million plus the equivalent of $155 million in labor.[50] Similarly, ethanol subsidies could be eliminated and the savings redirected toward R&D to improve the large-scale production of bio-diesel.

Nuclear. The U.S. government needs to make a clear and long-term commitment to nuclear power and encourage public acceptance of it as a proven, advanced, reliable, and relatively safe method of producing low-carbon power. Until a technological breakthrough in renewable energy or nuclear fusion is in place, the U.S. government must maintain sufficient nuclear energy capability and capacity to grow its current 20% of base-load electricity to 25% by 2050. The age of current nuclear plants, improvements in large reactor design and safety, and the advantages inherent in SMRs indicate it is time to upgrade. Financial constraints on the U.S. government and public concerns about nuclear safety dictate that the most reasonable path is a mix of large reactor and SMR deployments with extra focus to reduce design certification times, fee structures, force protection requirements, and address public opinion through education regarding the advantages of new reactor designs. U.S. government funding support will still be required. The most cost-effective options are loan guarantees to reduce the cost of financing nuclear power plant construction, and to provide disposal arrangements for high-level radioactive waste. Additionally, tax incentives are needed for investment in education to ensure the necessary workforce is available to build, operate and maintain a new generation of nuclear power stations.

CCS. Currently 48% of electricity consumed in the U.S. comes from burning coal. While this abundant and secure energy resource will continue to play a vital role in the coming decades, the U.S. government needs to reduce its use of coal and shift to cleaner coal technologies by partnering with industry to develop environmentally sustainable and cost-effective methods of coal extraction and coal-fired energy production. Government/business partnership is key to addressing CCS transportation and storage issues, with the government assuming partial liability for long-term storage. The U.S. government should gradually eliminate existing coal subsidies as called for in President Obama's budget, which would free up $2.6 billion for investment in clean and renewable energy production and installation of CCS technology in coal-burning plants over the next ten years. The elimination of these subsidies and the higher costs due to CCS will make coal less cost-effective compared to other technologies that are more environmentally friendly. To help offset the economic impact of CO_2 reduction requirements, the U.S. should reduce corporate and other taxes and fees levied upon the industry.

Renewable Technologies. Federal and State government policies can support a market for renewable technologies which in turn encourages more private investment in needed R&D. Therefore, providing loan guarantees, tax credits, grants, renewable energy standards, and streamlined permitting processes supports the transition to the 50 by '50 vision. Loan guarantees are required to ensure stable financing for wind and utilities-scale solar projects, especially those with output above 100 Megawatts. Furthermore, grants to states will allow flexibility, provide a demand signal, and spur continued private investment for renewable energy. To improve planning stability, Congress should enact Renewable Energy Standards (RES) on a graduated scale, requiring an increasing percentage of electricity production to come from renewable sources. Although the Departments of Energy and Interior have made progress in identifying suitable sites for alternative energy projects on federal land, a streamlined permitting process and greater stability of loan guarantees and subsidies would reduce unnecessary risk and allow these projects competitive access to financial markets. In addition to utilities-scale projects, policies encouraging small scale systems such as rooftop solar panels are required. Roof top solar systems avoid expensive transmission lines and reduce the need to site large-scale solar projects on previously undeveloped land. Rooftop solar and other point-of-demand power generation can also provide lower energy costs, greater energy efficiency, minimal impact from a grid failure, reduced demand on the Smart Grid, reduced CO_2 emissions, and improved energy security.

Government policies should include tax credits for homeowners as well as grants to those states with excellent solar resources for programs that reward innovation in incorporating solar panels into urban areas. Congress should extend from 2016 to 2020 the 30% tax credit for solar and other renewable energy funded under the American Recovery and Reinvestment Act of 2009 (ARRA). From 2020 to 2030, the credit should drop to 15%, and then be phased out completely by 2040.

Implement a Phased Carbon Tax

Our economy is overly dependent on fossil fuels because they have been relatively cheap. However, their market prices do not capture the negative externalities associated with carbon emissions or the cost of growing dependence on an increasingly volatile energy source located in unstable territory. The U.S. and the world will bear the true costs of these negative externalities sooner or later – whether through coping with the results of climate change, health related issues due to greenhouse gasses and chemicals released during extraction and burning, or through additional deficit spending to defend access to fossil fuels around the world. This recommendation calls for addressing this market failure gradually and on our own timetable, rather than waiting for crisis to force change at potentially unbearable cost. The most efficient approaches to correcting market failures involve giving businesses and households an economic incentive to change their own behavior,[51] in this case to transition over a period of forty years to an energy mix based on 50 percent renewable and clean sources.

Policy tools such as carbon taxes and cap-and-trade schemes internalize the negative pollution externalities of fossil fuel combustion while simultaneously leveling the playing field for alternative energy technologies. Additionally, because such an approach attaches a cost to the negative externalities associated with fossil fuels, the U.S. government would actually realize revenue from such an approach rather than spend it (e.g., on more subsidies).

Of the two incentives-based options (i.e., tax or cap-and-trade), the simpler, more direct tax has several advantages, especially if it is designed to rise steadily and predictably over time.[52] A well-designed carbon tax would be very simple relative to the complex cap-and-trade alternative, thus making it cheaper to implement and enforce, and less prone to manipulation and corruption. The simplest carbon tax could be imposed early in the production or distribution cycle of fossil fuels based on the fuel's carbon content, which is readily measurable[53] and a good surrogate for carbon emissions.

The transition from subsidizing carbon (mainly coal and oil) to taxing it must be gradual to avoid excessive disruption to industry. The U.S. government should phase in the carbon tax while phasing out subsidies for oil and coal, with revenues raised by the tax invested in the energy R&D sector.

Lead Transformation to Renewables-Based Transportation Infrastructure

By 2050, a significant portion of the U.S. transportation sector can realistically run on renewable sources. EV and PHEV technologies are proving themselves and becoming market-ready now, and economies of scale and mass production will significantly reduce their cost in the years to come. In addition to funding R&D in energy storage solutions, the U.S. government should establish standards for roadside battery charging stations, and clarify the process for permitting current gas stations to become all-fuel (e.g., adding hydrogen, electric, and natural gas) stations wherever market and economic conditions permit. To help ensure market conditions are broadly favorable, the U.S. government should augment gasoline taxes with road usage taxes that capture all users and that can be adjusted depending on a given vehicle's technology, weight, and regional differences. Revenue from the road-use tax should be used to maintain the highway system, as traditional gasoline tax revenues drop due to increasing fuel efficiency and use of electric vehicles. Further, the U.S. government should enact a separate gasoline tax that will keep the minimum price at the pump stable and high (equivalent to $4.50 in 2011 dollars) even if the price of oil declines in the future. Putting a hard "floor" under gasoline prices would send a consistent demand signal to the market for improved efficiency. Revenues generated by the additional gas tax would fund further R&D to speed and ease the transition away from a petroleum-based transportation sector. Finally, as petroleum will remain an important part of our transportation sector, even in 2050, additional refining capacity such as the Elk Point Refinery[54] should be completed to refine crude oil from the Canadian oil sands more efficiently and to maintain spare U.S. refining capacity.

Modernize Electricity Transmission and Distribution Systems

Smart Grid. One of the most important areas where policy can be part of the solution without needing to spend lots of money is in setting standards and priorities for modernizing the electrical grid. The U.S. electrical grid should be modernized into a Smart Grid to help meet the "50 by '50" vision. As a first step, the U.S. government should make the standards and protocols created by the NIST mandatory. For smart grid equipment to communicate freely, all stakeholders must adopt the same standards for data and protocols before heavy investment in duplicative or non-compatible infrastructure begins. Further, the NIST should establish a personal certification process for operators and maintainers of the Smart Grid that would include cyber security and operational security training. The second step is to promote a national forum of government and industry organizations to set priorities for adopting Smart Grid technologies. Specifically, they should focus initially upon those technologies that will support the use of renewable energy sources such as wind and solar and the more efficient use of existing resources like cogeneration. They should also endeavor to inform and harmonize national, regional, state, and local goals for energy efficiency and reliability. As a third step, state and local governments should remove any remaining regulatory and market barriers to the integration of distributed energy production, such as small commercial and residential solar panels and wind turbines, to facilitate broader incorporation of innovative generation and resiliency in the grid. In addition, they need to restructure electricity rates to incentivize utility companies to invest in the Smart Grid, thereby maximizing the benefits and savings for both producers and consumers. As a fourth and final step, government and industry should communicate the value of the Smart Grid. Customers must understand the business case and the savings they will realize from a more reliable, less costly electric grid. They must also understand the value of a smart grid that can better integrate variable solar and wind power while limiting the need for additional electrical generation capacity and the resulting pollution.

Cogeneration. The U.S. government should provide tax incentives to private businesses to invest in cogeneration systems in order to reduce demand on the grid while using these more efficient power generation systems to reduce security risks through distribution of generation sources. The ultimate goal is to have cogeneration facilities use renewable energy sources. Initially, natural gas, CCS, or bio-diesel power turbines can be used until fuel cells become economical. Fuel cells would need to drop in price from $4,000 to $700 per KWH to be competitive with current diesel generators. Beyond price, however, fuel cells have many advantages over traditional turbines including: high reliability, high quality of power, reduced emissions, and low noise.[55] The tax incentives would reduce the cost to owners of using fuel cells and would be phased out as the price drops.

Achieve Efficiencies to Reduce Demand-Side Need

Energy efficiency is one of the key cornerstones in future energy policy as a mechanism to bridge the gap between future energy needs and projected sources of supply. To support that objective, dramatic gains in energy efficiency in electricity generation, transmission and use as well as transportation will be required. Further adoption of energy-efficient appliances, fuel-efficient vehicles, and higher efficiency/lower energy consumption buildings is required. Continuation and expansion of U.S. government mandates for LEED-certified federal buildings should be pursued to reduce the carbon and water footprint. Currently these standards only apply to new federal buildings but not to retro-fit existing buildings or to new commercial buildings. Additionally, cogeneration in commercial buildings to convert residual heat to additional power will also be required to promote needed energy efficiencies.

Use Natural Gas Resources as a Bridge from Hydrocarbons to Renewables

To achieve the vision of "50 by '50," U.S. reliance on natural gas will need to decline by 2050. However, abundant, newly accessible domestic natural gas reserves provide the U.S. an important energy source to bridge the transformation of electrical generation away from coal and the transportation sector away from oil. Cheap, abundant shale gas, which burns cleaner than both coal and oil, will ease the cost of the necessary transformation and can provide the needed source of energy for fuel cells and other alternative technologies. Domestic natural gas reserves also serve as a risk reduction/ hedging energy source if the transition to renewable energy sources takes longer or proves significantly more costly than projected. World demand will also absorb excess U.S. natural gas capacity. However, a clearer understanding of the environmental impact of the chemicals used in hydraulic fracturing will be required. Companies involved in fracking must be required by law to disclose to the EPA the exact make up of their chemicals. The carbon tax proposed above will provide incentives for zero carbon emission Natural Gas power production facilities.

Encourage Development of Biomass and Waste-to-Energy Plants

The U.S. government should provide subsidies, tax credits, or loan guarantees to States, communities and companies to enable them to build biomass- and waste-to-energy plants in every U.S. community of greater than 500,000 people. Biomass is a renewable energy source that has the potential to provide significant amounts of both reliable base-load electric power as well as bio-fuels for transportation, and generates much lower harmful emissions than hydrocarbons. Converting household and industrial waste to energy can also reduce landfills up to 90 percent. However, standards must be set to ensure that biomass and waste-to-energy plants are developed in a way that they do not compromise recycling efforts, or deplete or displace forests, food crops, or necessary plant residues.

Minimize Corporate Taxes For Renewable Energy Firms

To regain a position as a world leader in the manufacturing of renewable technologies and its enablers, and to encourage U.S. manufacturing investment in these technologies' production, the U.S. government should minimize or eliminate corporate taxes in renewable energy related fields. Reduced corporate taxes would encourage companies to remain in the U.S. to develop and produce these new technologies, vice the off-shoring that is currently being experienced for many of these manufacturing processes.

Increase Collaboration With Industry and Foreign Entities

The U.S. government should invest in projects that leverage private investment (e.g., the FutureGen CCS technology development program) and investments by other governments (e.g., U.S. participation in the sustainable city program in Masdar City, UAE). The U.S. government should significantly increase and formalize its collaboration with foreign R&D programs, especially with allied countries with strong intellectual property protections. This includes working with national labs, universities, and foreign industry to spread cost and risk. R&D

funding policies will be needed well into the future, regardless of and in combination with other policies.

Conclusion

While the U.S. energy industry has allowed the U.S. economy and its citizens to prosper for the past century or more, its current state within the current globalized world demands proactive steps to keep it, and the energy-dependent U.S. economy, thriving. The current U.S. energy supply mix is dominated by fossil fuels, which are depleting with time, harmful to the environment, and fraught with security of supply and price volatility issues that endanger the way of life for every U.S. citizen. For these reasons and more, the U.S. needs to take action to achieve a long-term strategic vision in which, by the year 2050, 50 percent of the nation's energy supplies are provided by renewable energy sources.

To accomplish this vision, the U.S. needs to enact policies and make investments that encourage the required transition to renewable energy technologies, modernize the electrical generation, transmission, and distribution systems, transform the transportation system, and improve the security of these various systems. Several policy recommendations were offered within this paper. Implementing these recommendations will lead to a fundamental transformation of the U.S. energy posture, which is vital to our future national security and prosperity. They involve significant costs and risks which need to be managed and shared equitably. Government policies to facilitate and manage the transformation must be transparent and stable over time to reduce uncertainty and drive down risks and costs. Tax credits, loan guarantees, R&D subsidies, and other government investments in energy are an important part of the equation and provide substantial return on investment by stimulating innovation and by promoting technology leadership, economic prosperity, and job creation. Implementing the policy recommendations advanced in this paper will not only ensure economic and national security for the U.S., it will also unleash the American spirit of innovation and restore and enhance our leadership role and technological prowess. The path is clear and the goal is within grasp – all that is needed is bold and consistent leadership, the political courage to enact change before change is forced by external forces, and the spirit of innovation and entrepreneurship.

ENDNOTES

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