PRESIDENT'S COUNCIL OF ADVISORS ON SCIENCE AND TECHNOLOGY • NOVEMBER 2006

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The Energy Imperative

Technology and the Role of Emerging Companies

About the President's Council of Advisors on Science and Technology

President Bush established the President's Council of Advisors on Science and Technology (PCAST) by Executive Order 13226 in September 2001. Under this Executive Order, PCAST "shall advise the President ... on matters involving science and technology policy," and "shall assist the National Science and Technology Council (NSTC) in securing private sector involvement in its activities." The NSTC is a cabinet-level council that coordinates interagency research and development activities and science and technology policy making processes across federal departments and agencies.

PCAST enables the President to receive advice from the private sector, including the academic community, on important issues relative to technology, scientific research, math and science education, and other topics of national concern. The PCAST-NSTC link provides a mechanism to enable the public-private exchange of ideas that inform the federal science and technology policy making processes.

As a private sector advisory committee, PCAST recommendations do not constitute Administration policy but rather advice to the Administration in the S&T arena.

PCAST follows a tradition of Presidential advisory panels on science and technology dating back to Presidents Eisenhower and Truman. The Council's 35 members, appointed by the President, are drawn from industry, educational and research institutions, and other nongovernmental organizations. In addition, the Director of the Office of Science and Technology Policy serves as PCAST's Co-Chair.

Acknowledgements

PCAST would like to acknowledge the many entrepreneurs, private equity investors, university personnel, and Federal government staff who contributed during the preparation of this report. Their input about the many energy technology developments taking place in America's universities and companies was invaluable. We would also like to acknowledge the help of the National Venture Capital Association, Eric Wesoff of Sage Marketing, and Wasiq Bokhari of Quantum Insight in preparing the lists of newly formed companies in the energy sector that appear herein.

The Energy Imperative

Technology and the Role of Emerging Companies

Report of the President's Council of Advisors on Science and Technology

EXECUTIVE OFFICE OF THE PRESIDENT
PRESIDENT'S COUNCIL OF ADVISORS ON SCIENCE AND TECHNOLOGY
WASHINGTON, DC 20502

November 8, 2006

President George W. Bush
The White House
Washington, DC 20502

Dear Mr. President:

We are pleased to transmit to you a copy of the report, *The Energy Imperative: Technology and the Role of Emerging Companies*, prepared by your Council of Advisors on Science and Technology (PCAST). Focusing attention on the Nation's energy needs has been a top priority for your Administration as well as for PCAST.

In May 2001, the Administration's National Energy Policy report called for policies that engage business, government at all levels, and citizens to work together to provide dependable, affordable, and environmentally sustainable energy for our future.

Since that time, your Administration has launched initiatives to accelerate energy technology research and development in a number of key areas, including clean coal, nuclear energy, hydrogen, cellulosic ethanol, solar and wind energy, and fuel-efficient cars and trucks. The Advanced Energy Initiative that you announced in your 2006 State of the Union Address proposes a significant funding increase for these technologies, which will help to enable a secure energy future for our Nation.

In 2003, PCAST reported on the state of the electric power system and the need to address the growing demands being placed on it. In this report, the Council reviews a wide range of technologies that could substantially increase the Nation's energy supply, ensure its competitiveness, and improve U.S. energy security through greater reliance on home-grown solutions, while reducing local and global environmental impacts. The report particularly focuses on innovations coming from the entrepreneurial sector. In the past five years, more than 100 new, U.S.-based companies have been started to commercialize energy-related technology.

Our recommendations focus on immediate steps that could be taken to reduce our Nation's reliance on foreign oil and to reduce atmospheric emissions from energy production and use. In the area of electricity generation, we call for steps to accelerate the deployment of advanced nuclear power, clean coal technology, renewable sources such as solar and wind energy, and energy efficiency technologies. In the area of transportation, we suggest steps for a major transition to biofuels and to electric or hydrogen-powered vehicles. With these new transportation technologies, American consumers will have a choice of fuels that previously has not been available.

PCAST is encouraged by the Administration's ongoing attention to energy. We hope that this report and actions that result from it will move the Nation toward the goals you have outlined for energy security and an improved environment.

Sincerely,

John H. Marburger, III
Co-Chair

E. Floyd Kvamme
Co-Chair

President's Council of Advisors on Science and Technology

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Executive Summary

Overview

An abundant supply of clean and affordable energy is vital to the economic growth, quality of life, and security of the United States. Energy provides essential services for many aspects of modern life. In recent years, however, economic and political factors have stressed the global supply of oil and natural gas, driving the prices of these commodities to new highs and increasing the risk of a damaging energy shock. Meanwhile, increases in greenhouse gas emissions, in part resulting from fossil fuel combustion, are linked by many scientists to global climate change. Combined, these issues create an imperative for change in the Nation's energy systems and infrastructure in order to ensure national energy security while protecting the environment.

Technology innovation opens up new opportunities to overcome these challenges. U.S. universities and national laboratories lead the world in research that generates technology breakthroughs, while the Nation's industrial sector and its entrepreneurs are leaders in creating innovative commercial products. Emerging technologies from the private sector and the research community could enable cleaner and more efficient use of energy throughout the economy.

In recent years, entrepreneurs have begun to focus on technologies that could significantly increase the efficiency of the Nation's energy use and reduce carbon emissions. In fact, over a hundred companies founded in the last decade — many of them within the last five years — are commercializing energy innovations. Most of this entrepreneurial activity has been in solar energy, biofuels, fuel cells, and energy storage devices. Venture capital investment in the U.S. energy sector totaled nearly $1B in 2005 and is on track to more than double that amount in 2006. The President's Council of Advisors on Science and Technology (PCAST) members believe that these efforts, combined with technology development funded by the Federal Government, private equity sources, and large corporations, could lead to substantial improvements in the Nation's energy infrastructure.

Electric power is the fastest growing energy sector. U.S. demand for electricity is expected to increase by about 50% over the next 25 years (EIA-DOE 2006a). Continuing current trends, a substantial portion of this increase in demand will be supplied by natural gas power plants, leading to a sharp increase in imports of natural gas from suppliers outside of North America. Meanwhile, the transportation sector accounts for two-thirds of U.S. oil consumption. Oil imports, which supply roughly 60% of U.S. demand, are a major energy security concern. PCAST analysis suggests that national and global energy challenges in the electric power and transportation sectors could be met in large part by a combination of diverse approaches, including renewable energy, nuclear energy, biofuels, advanced vehicles, and energy efficiency technologies.

Renewable energy sources such as solar and wind energy, for example, are expected to become increasingly competitive with fossil-fuel-based electricity generation. While renewable sources are unlikely to completely replace conventional power plants in the foreseeable future, the share of non-hydroelectric renewable electricity generation in the U.S. could grow to 10% or more by 2030 and to over 20% by midcentury.

Meanwhile, energy-efficient building and industrial technologies could help reduce the projected need to build hundreds of new power plants in the United States by 2030.

Nuclear energy is a proven alternative to fossil fuels, which some analysts regard as the least expensive option for expanding U.S. electricity generation capacity. Further, because it produces virtually no atmospheric emissions, PCAST members believe that nuclear power is the best large-scale option available today to reduce CO_2 emissions in the electric power sector. Coal gasification plants with carbon capture and storage could also provide large amounts of new generating capacity with near-zero atmospheric emissions. In sum, improving energy security and substantially reducing the growth of emissions in the electric power sector will likely require aggressive deployment of nuclear, coal gasification, and renewable energy technologies.

Biofuels offer a clear, near-term opportunity to reduce the Nation's dependence on oil. Biomass — raw plant matter that can be converted into biofuels — can be produced from crop residues, wood waste, forest industry by-products, and perennial grasses. With potential improvements in crop production and biorefineries, cellulosic biofuels could replace a significant percentage of the Nation's gasoline use by 2030. Biofuels could also reduce greenhouse gas emissions compared to fossil fuels, because most of the carbon released in the processing and use of biofuels is absorbed during plant growth. Furthermore, development of a large biofuels industry would offer vast potential for wealth creation in rural America.

An alternative path to reducing dependence on oil for transportation is through greater use of electricity to power vehicles or mass transit systems. With expected cost reductions in energy storage, "plug-in hybrid" vehicles with large battery packs could become widely available. In concept, these vehicles operate on electricity alone for most trips but use a gasoline engine for longer drives. Ultimately, all-electric vehicles or hydrogen fuel-cell vehicles may compete with conventional, gasoline-fueled cars and trucks. Efficient vehicle technologies such as lightweight materials could also reduce transportation fuel use. Considered together, alternative fuels and advanced vehicle technologies offer the potential to dramatically reduce the projected amount of oil imports by 2030.

Energy efficiency technologies for buildings, the electric grid, and industrial processes could substantially reduce energy consumption in these sectors. Besides benefiting consumers, reduced energy use avoids the generation and distribution losses that would otherwise be incurred to supply that power. Including related power generation losses, the building sector accounts for 40 percent of primary U.S. energy consumption, and the industrial sector accounts for an additional one-third. A comprehensive analysis suggests that less than half of this energy is actually converted to useful energy for consumers. Innovations in lighting, appliances, heating and cooling systems, and industrial processes could moderate the projected growth in electricity demand over the next two decades, providing economic, environmental, and energy benefits.

This report describes an array of technologies that by 2030 could help achieve energy security and a more economical and environmentally sound energy infrastructure, both in the United States and globally. The report focuses on entrepreneurial activity. Yet entrepreneurs and the private sector represent just one component of the "innovation ecosystem." In many cases, commercial innovation emerges from Federally funded basic research conducted at universities or national laboratories. Basic research is vital to overcoming fundamental hurdles to commercialization of new technologies. In general, successful market adoption of breakthrough innovations results from complex interactions among the private sector, the Federal Government, State governments, universities, and the marketplace.

Therefore, this report suggests that innovations currently in commercial development by entrepreneurs and energy companies could lead the way to dramatic changes in the Nation's energy infrastructure. PCAST offers the following recommendations, grouped by category, as early steps that the Federal Government could take to accelerate this process and consolidate near-term gains.

Recommendations for Federal Energy Policy

Overarching Recommendations

1. **Increase Federal support for science and technology research and development.** Many of the advanced energy technologies described in this report have originated, at least in part, from Federally funded research. The President's American Competitiveness Initiative supports future innovation by proposing to double funding for the National Science Foundation (NSF), the National Institute of Standards and Technology (NIST) in the Department of Commerce (DOC), and the Department of Energy (DOE) Office of Science. Meanwhile, in order to accelerate the near-term commercialization of energy technologies, the President's Advanced Energy Initiative proposes a 22% increase in clean energy research and development (R&D) funding in DOE in FY 2007. PCAST recommends that Congress fully fund these initiatives and consider funding for an expanded Advanced Energy Initiative research effort in future years, including at the U.S. Department of Agriculture (USDA).

2. **Promote EPAct 2005 incentives.** Financial support measures targeted to assist commercialization — low-interest loans, tax incentives, capital contributions, and price subsidies, among others — are in many cases vital to bringing new energy technologies to market. The Energy Policy Act of 2005 (EPAct) established incentives for virtually every area of energy technology (see Table IV-2). DOE, USDA, and other agencies have taken significant steps to implement these provisions. PCAST recommends that DOE and USDA promote these incentives as currently targeted and report back on whether they are having the desired effect or whether modifications are necessary. If ongoing monitoring shows that goals are being reached sooner than the Act anticipated, PCAST recommends moving up the timelines and making the goals more aggressive. Also, some of the EPAct incentives expire in 2007 and 2008; those that have proven to be successful should be extended.

3. **Support State initiatives.** Individual States are funding many programs to improve the competitiveness and availability of renewable energy resources for their businesses and residents. These programs tend to focus on resources that are most readily available in each State, such as hydroelectric, geothermal, biomass, wind, wave, or solar energy. Because States and their public utility commissions have the ultimate authority for most decisions related to the electric power infrastructure, the Federal Government should work with the States to expand successful programs and encourage the States to cooperate with each other on "best practices" developed through these projects.

4. **Position the Federal Government as an early adopter of new technology.** The Federal Government is both a large producer and a large user of the Nation's energy resources. Therefore, the Federal Government should expand its role as an early adopter in order to demonstrate the commercial feasibility of advanced energy technologies. PCAST suggests that the Federal Government redouble its efforts to implement EPAct provisions of this type.

Electric Power Generation

As stated earlier, domestic electricity demand is expected to rise by 50% over the next quarter-century. This has two policy implications. First, the overall energy efficiency of the electric power sector must be improved. In an earlier report (PCAST 2003), this Council recommended policy actions, several of which have been implemented, to reduce inefficiencies in the Nation's electricity generation and transmission infrastructure. Complementing this, the present report includes a discussion of the need to improve the energy efficiency of end-use applications. Even with improved efficiency, however, a substantial increase in electricity generation capacity will be needed. Non-hydroelectric renewable energy can be an important contributor to U.S. power generation by 2030, but more new capacity will likely be supplied by fossil fuel and nuclear power plants. Thus it is crucial to accelerate deployment of next-generation nuclear and coal gasification plants, which can help achieve both economic and environmental goals.

5. **Expand nuclear energy as a clean, base-load power source.** Nuclear energy has the potential to be the lowest-cost source of electric power (OECD/IEA 2005), and it produces very low life-cycle emissions. The EPAct legislation provides incentives to encourage utilities to work with the Federal Government to reinvigorate the domestic nuclear industry. PCAST recommends that the Federal Government use its best efforts to ensure that the risk insurance and other incentives outlined in the EPAct are taken up by utilities so that new nuclear plants can contribute to the electric grid beginning in 2015, as the first step in a significant expansion in nuclear power capacity. PCAST further recommends that Congress increase the scope of the production tax credit for advanced nuclear power plants beyond the EPAct-specified 6,000 megawatt capacity limit. The goal for the Nation should be to add at least 36,000 megawatts of new nuclear generation capacity by 2030.[1]

6. **Resolve the nuclear waste containment issue.** New reactor designs and reprocessing technologies that are under consideration could reduce the amount of high-level waste generated by nuclear plants, but they will not eliminate it. In order to expand nuclear energy capacity, the nuclear industry needs assurance that a permanent waste disposal site exists. All stakeholders need to work together to ensure that the proposed underground waste facility at Yucca Mountain, NV, is established as soon as possible.

7. **Build coal gasification plants instead of natural gas facilities.** The EPAct provides incentives for the construction of high-efficiency, low-emission coal gasification power plants. PCAST recommends that the Federal Government use its best efforts to maximize the value of these incentives for public utilities. States should be encouraged to establish energy policies that support national energy security objectives rather than depending solely on "least cost" parameters. Based on existing trends, most new electric power capacity will be supplied by natural gas plants and conventional coal plants, leading to an increase in overseas natural gas imports and greenhouse gas emissions. Through its higher generating efficiency, coal gasification technology could make better use of the Nation's huge domestic coal reserves while reducing energy losses and carbon emissions compared to conventional coal plants. This technology also enables relatively low-cost carbon capture. With the benefit of several commercial-scale demonstrations over the next decade, next-generation coal gasification plants could become competitive with conventional power plants, reducing the need for new natural gas plants to supply clean base load power (NRC 2003). Thus, the Federal Government should work with the States, taking full advantage of the EPAct incentives, to encourage deployment of coal gasification power plants.

[1] This figure is based on maintaining a constant proportion of U.S. electricity generation from nuclear energy (EIA-DOE 2006d, Table 73).

8. **Improve the efficiency of legacy electric power plants.** Current regulations inhibit utilities from making needed improvements to old power plants. These regulations should be modified to allow utilities to improve the efficiency and environmental performance of legacy coal plants without incurring an onerous economic penalty, as long as the upgraded power plants will produce fewer emissions per megawatt of generation capacity than they would without the upgrades.

9. **Support renewable energy plans.** Many States have incentive programs to increase the percentage of their grid power requirements supplied by renewable sources. These programs focus on utility-scale projects (defined as 1 megawatt output or more); to date, over $475M has been obligated for some 18 different projects, mostly involving wind energy. These programs, together with State renewable portfolio standards, could help increase the level of renewable electricity generation substantially over the next two decades. The DOE should be tasked to track these programs and to encourage broader use of those approaches that are showing the most promise. Additionally, the Federal Government should aggressively pursue, and consider increasing, the EPAct goal for at least 10,000 megawatts of non-hydroelectric renewable generation capacity to be approved for siting on Federal lands by 2015.

10. **Reduce regulatory barriers to installation of renewable distributed generation technologies.** Today, grid interconnection and net metering rules vary by State, and even by utility or other electric service provider within a State, resulting in a patchwork of requirements across the United States. Some States do not even have regulatory interconnection standards. This inconsistency creates high barriers to penetration of renewable distributed generation technologies (such as solar photovoltaic cells) into the U.S. market. Therefore, the Federal Government should work with State governments and utility regulators to facilitate the broad adoption of consistent interconnection and net metering standards, which would create a more predictable and consistent business environment for technology suppliers and project developers. The Federal Government should also examine access to transmission lines for new renewable electricity providers, especially in rural areas.

Transportation

Increasing concerns about energy security provide a strong motivation for the United States to reduce its requirement for imported oil. This goal can be achieved by developing new domestic oil fields, competitive alternative fuels, and vehicles with higher fuel efficiency. Currently, most entrepreneurial activity in this area is aimed at biofuels or efficient vehicle propulsion systems. The following recommendations could facilitate commercialization of these technologies.

11. **Encourage industry to expand the availability of biofuels and flex-fuel vehicles.** The Administration should convene a roundtable of stakeholders, including automakers, energy companies, fuel distributors, and fleet managers, to develop a private-sector roadmap with specific commitments to increase the nationwide availability of biofuels and the percentage of flex-fuel vehicles (FFVs) among new car offerings. The stakeholders should also collaborate on fuel and vehicle standards that maximize market efficiencies and biofuel flexibility.

12. **Increase the supply of E10 and other biofuel blends.** The EPAct established or extended several incentives for the production of ethanol. E10, which contains 10% ethanol and 90% gasoline, helps reduce smog formation and has provided a major market for ethanol producers. PCAST suggests that the Administration encourage broader use of E10, as well as higher-percentage blends of ethanol (or other biofuels), in order to surpass the EPAct goal of 7.5 billion gallons of ethanol by 2012. For example, use

of 10% ethanol in all transportation fuel would equate to 12–14 billion gallons of biofuels. Widespread use of richer biofuel blends could increase ethanol use far beyond this level.

13. **Eliminate the ethanol import tariff for E85 applications.** The EPAct provides incentives for distributors of E85, a fuel containing 85% ethanol and 15% gasoline. Some private companies considering distribution of E85 are hindered by the current lack of a reliable and cost-competitive supply of ethanol. Thus, PCAST supports opening the biofuels market so that the import of foreign sources of ethanol (primarily from Brazil) for E85 would be permitted without a tariff. This should be viewed as part of an integrated industrial development and trade strategy.

14. **Modify the Volumetric Ethanol Excise Tax Credit (VEETC) to match competitive realities.** Currently, blenders of E10 and E85 fuels are granted tax incentives based on the amount of ethanol they bring to market. This incentive effectively reduces the cost of producing these fuels. Competitive considerations, however, would suggest that as the price of oil rises, the need for a tax incentive decreases; conversely, as the price for oil decreases, the need for a subsidy increases. PCAST recommends that these realities be placed into the regulations such that the VEETC slides from high to low as the price of oil moves from low to high. If set at appropriate levels, this change in the VEETC would help lower the price at which biofuels are competitive with gasoline. Additionally, States should consider taxing fuels on the basis of energy content rather than volume; most States currently tax fuels by volume, which effectively penalizes E85, because it contains only about 75% of the energy per gallon as in gasoline. PCAST recognizes that the timing of these types of changes is critically important and should be weighed with long-term investment horizons in mind. The current ethanol industry has only recently experienced strong growth, compared to the decades of profitability for the petrochemical industry with its multiple historical subsidies. Over the next several decades, the Nation — and the world — may be similarly building out a new biofuels industry; therefore, changes to the current tax structure should be carefully phased in.

15. **Identify lands suitable for energy crop production.** Several different crops capable of yielding in excess of 10 tons of biomass per acre are under consideration for use as energy feedstocks. Suitable lands for perennial grasses — potentially the largest source of biomass — could come from the Conservation Reserve Program or other Federally managed lands. An inventory of Federal lands suitable for conversion to energy crops would help expedite the shift to large-scale production of biomass for energy. PCAST recommends that USDA be tasked to specifically identify lands most suitable for energy crop production.

16. **Support cellulosic biomass conversion technologies.** PCAST endorses the recently announced roadmap for developing cellulosic ethanol (USDOE-SCI/EERE 2006) and encourages the DOE and USDA to also consider the potential of other biofuels such as butanol, methanol, and others, as well as the suite of biobased products. Given recent progress in developing cost-effective enzymes and improved biomass yields, large-scale production of cellulosic biofuels appears feasible by 2015.

17. **Encourage production of FFVs.** For many years, automobile manufacturers in the United States have been providing flex-fuel capability for a small percentage of their new cars and light trucks, enabling these vehicles to operate on either E85 or gasoline. To enhance future flexibility, PCAST suggests that the Federal Government use its influence to encourage vehicle manufacturers to rapidly provide flex-fuel capability in as many models as possible. FFVs give consumers a choice of fuels and create much-needed competition in transportation fuels. This recommendation could be implemented in part through the industry roundtable described in recommendation #11.

18. **Expand use of E85 in Federal Government vehicles.** The Energy Policy Act of 1992 requires Federal agencies, with certain exceptions, to purchase alternative fuel vehicles for 75% of their fleet vehicles. Many agencies purchase FFVs to comply with this requirement, but E85 has often not been available for their use. Last year, the EPAct instituted a requirement that Federal agencies use E85 in all FFVs unless a waiver is granted by DOE. PCAST recommends that this provision be applied aggressively in order to expand ethanol availability by providing a growing market.

19. **Review CAFE standards regularly and make needed reforms.** Corporate Average Fleet Economy (CAFE) standards on passenger cars have not been updated for more than 15 years, even though many efficient vehicle technologies have become available. Therefore, PCAST recommends that Congress pass legislation to give the U.S. Department of Transportation (DOT) the flexibility both to set passenger car fuel economy regulations and to structure the program to be consistent with the revised light truck CAFE program. DOT should also be made responsible for reviewing the standards at least every three years in order to assess the feasibility of further increases in the CAFE standards.

20. **Modify CAFE regulations to encourage non-fossil-fuel use.** The CAFE program should be modified to further encourage deployment of FFVs. Although FFVs currently receive CAFE credits, these incentives are capped at a relatively low percentage of new vehicle production. Therefore, the CAFE incentives should be restructured to encourage a larger percentage of the fleet to have flex-fuel capability. Additionally, plug-in hybrids, which are expected to be commercially available in the next few years, should be granted targeted CAFE credits to encourage their manufacture.

Energy Storage

It is difficult to overstate the importance of energy storage. The efficiency and cost-competitiveness of renewable electricity generation and alternative-fuel vehicles could be significantly improved by the availability of low-cost, high-capacity storage. For example, because solar and wind power generation is intermittent — the sun and the wind are not constantly available — these systems require energy storage if they are to serve as a reliable supply of electricity throughout the day. In the transportation sector, advanced energy storage technology could enable affordable family-sized vehicles that travel 200 miles or more on a single, rapid battery charge. Low-cost energy storage could also improve the commercial feasibility of hydrogen fuel cell vehicles. Therefore, PCAST makes the following recommendations.

21. **Support research on nanomaterials for energy storage applications.** The National Nanotechnology Initiative is to be commended for supporting research that is advancing understanding of nanomaterials broadly, including for energy storage applications. Progress toward improved energy storage systems will depend on continued strong support for research on novel nanoscale and nanostructured materials. Promising technologies should be identified and targeted to receive support for further development and prototyping in order to expedite technology transfer to and application by the private sector.

22. **Encourage the manufacture of energy storage products in the United States.** The manufacture of most batteries has moved offshore. Energy storage should be considered a key sector for the Federal Government to target with domestic manufacturing incentives. Such incentives could encourage the growth of an energy storage “ecosystem” spanning from materials development to the manufacture of finished products, helping to ensure that the United States leads in this core area of energy technology.

23. **Initiate a basic research initiative on next-generation energy storage technology.** The Federal Government should initiate significant funding for basic research to investigate radically new chemistries

and concepts for electrochemical or electric storage, with the goal of achieving an order-of-magnitude improvement in cost and energy density compared to today's lithium battery technology.

End-Use Energy Efficiency

While several recommendations above relate to improving the efficiency of the electric power and transportation sectors, there are also significant opportunities to improve "end-use" efficiency in the residential, commercial, and, on a national scale, industrial sectors. Building and appliance efficiency improvements can reduce consumer costs and yield a substantial reduction in primary energy input (e.g., coal, natural gas, and nuclear energy), including energy used for power generation and transmission.

24. **Expand the Energy Star program as broadly as possible.** The Energy Star program, managed by the U.S. Environmental Protection Agency (EPA), helps to raise public awareness of the "after purchase" costs of energy for many products. To the degree possible, all products that impact energy, from kitchen appliances to windows to automobiles, should carry an Energy Star rating. The EPA should update each standard regularly to ensure that it is stretching the private sector to integrate the latest energy efficiency technologies that can provide economic benefits to consumers.

25. **Encourage mainstream use of energy-efficient and renewable energy technologies in buildings.** Consumers and businesses are increasingly interested in owning their own distributed energy systems, which often use photovoltaic (PV) solar cell or fuel cell technology. The EPAct offers incentives to consumers and businesses to install solar and other efficient systems, but these products are often not available as an integrated option for new homes or commercial buildings. Thus, in order to expand adoption of economically attractive and energy-efficient systems for homes and commercial office space, the Administration should encourage greater collaboration between stakeholders in this sector, including builders, trade associations, labor unions, State and local regulators, realtors, lenders, investment bankers, pension funds, appraisers, insurers, consumer groups, and utilities. A strong collaboration among these stakeholders could help overcome the market barriers — including a lack of information, outdated codes and standards, high transaction costs, and fragmented procedures and regulations — that inhibit the use of commercially available technologies that provide financial, energy, and environmental benefits.

26. **Establish programs to install efficient lighting.** Dramatic improvements have been made in the efficiency of household and commercial lighting. The transition to these new technologies, however, has been uneven — moving quickly in some applications such as traffic lights, but more slowly, for example, in the residential market. Besides assigning Energy Star ratings to all lighting products, the Federal Government (as mandated in the EPAct) should lead the way by switching most of its lighting to efficient bulbs, in order to demonstrate their value while helping to reduce manufacturing costs by increasing the volume of these products. Consumer incentives for installing high-efficiency lighting should be retained and, if appropriate, expanded.

27. **Set standards to improve motor-driven appliance efficiency.** Mandatory Federal standards for the efficiency of residential heating, ventilation, and air conditioning (HVAC) units increased by 30% in January 2006, as part of the National Appliance Energy Conservation Act. Additionally, the EPAct establishes an HVAC maintenance consumer education program and mandates an increase in the efficiency of commercial HVAC units by 2010, in addition to new standards for 14 other product categories. Still, some appliance efficiency standards in Europe and Japan remain stricter than those of

the United States, suggesting that further increases in the minimum efficiency requirements may be economically feasible. The Federal Government should consider raising appliance efficiency standards based on the availability of improved technologies, such as low-cost brushless DC motors for efficient HVAC units.

Each stage of the energy infrastructure — the production, storage, transportation or transmission, conversion, and use of energy — involves many unique technologies. Clearly, no single silver bullet can meet all the Nation's energy needs in a cost-effective and environmentally responsible way. Rather, all of the technologies mentioned in these recommendations and in the balance of this report must be considered as potential contributors to a long-term shift from heavy dependence on fossil fuels to more efficient, clean, and domestically available technologies such as renewable energy and nuclear power. This report seeks to highlight new ideas stirring in universities, government laboratories, and private enterprises that could dramatically change the Nation's energy infrastructure and systems by 2030. PCAST's recommendations consist of near-term opportunities for the Federal Government to encourage development of these technologies in order to advance national and global energy goals.

I. Background and Overview

Energy Challenges and the Need for Innovation

An abundant supply of clean and affordable energy is vital to the economic growth, quality of life, and security of the United States. Energy provides essential services for many aspects of modern society, including transportation, communications, manufacturing, information technology, healthcare, and residential convenience and comfort. Concerns about national energy security and the environment, however, create an imperative for change in the Nation's energy systems and infrastructure.

The global economic and environmental costs of energy are increasing as developing nations shift to more energy-intensive economies. In recent years, economic and political factors have stressed the global supply of oil and natural gas, driving the price of these commodities to new highs and increasing the risk of a damaging energy shock. President Bush has stated that the United States is "addicted to oil" and has set a goal to reduce dependence on imported oil (President 2006c). Meanwhile, the risk of global climate change is linked by many scientists to emissions of greenhouse gases (NAS 2001), especially carbon dioxide, which is a product of fossil fuel combustion. Global greenhouse gas emissions are increasing at a rate of about 25% per decade, roughly in proportion to the increase in energy consumption (EIA-DOE 2005). All of these issues highlight the need for dramatic change in how the United States and other nations manage and use energy.

Technology innovation opens up new opportunities to overcome these national and global challenges. Energy companies, automotive manufacturers, and technology suppliers are funding development, sometimes in partnership with the Federal Government, of innovative products and systems that could transform our existing energy infrastructure. Additionally, entrepreneurs and private equity sources have begun to focus on energy technologies, including electricity generation from renewable and low-emission sources, alternative transportation fuels, and efficient transportation and building systems. PCAST members believe that breakthroughs resulting from these efforts could change the economic factors that have, until now, held back many alternative energy sources from being widely adopted in the marketplace.

Almost certainly, fossil fuels will continue to play a major role in the Nation's energy systems for decades to come. More research is needed to improve the efficiency and environmental cleanliness associated with the production and use of fossil fuels. At the same time, rapidly increasing demand for energy — and the consequent high prices and environmental challenges — have raised the profile of alternative energy sources such as biomass, solar, wind, hydrogen, and nuclear energy. Significant and growing amounts of private equity have begun to flow into these technologies as investors recognize that even a small portion of the global energy market represents an attractive financial opportunity. Clean Edge (2006), a marketing research firm, reports that global sales for wind and solar power products in 2005 amounted to $11.8B and $11.2B, respectively, representing about a 50% increase in each case over the year earlier. Also in 2005, the market for biofuels reached $15.7B, up about 15% from 2004. Clean Edge expects that spending for biofuels, wind power, solar power, and fuel cells will quadruple by 2015. Some entrepreneurs claim that these projections are overly conservative.

This report reviews the status of energy technology development by both large and small companies, with a particular focus on the role of entrepreneurial efforts. Since the mid-1990s and especially in the past five years, existing players in the energy field have been joined by over one hundred new companies seeking to commercialize technologies in virtually every aspect of the energy market. Just as U.S. universities and national laboratories lead the world in research that generates scientific breakthroughs, U.S. entrepreneurs and technology companies are leaders in creating innovative commercial products.

Over the past thirty years, new technologies in the information technology and telecommunications fields (e.g., the Internet) have been transformed from Government-funded, university-based research projects into mainstream consumer products. In many cases, the vital link in this process has been entrepreneurial innovation backed by venture capital. Entrepreneurs have also changed the face of the pharmaceutical industry through biotechnology startups in the 1980s and 1990s. Today, PCAST notes a similar enthusiasm among venture capitalists for advanced energy technologies. This suggests that rapid change could occur in the energy sector as it has for other high-technology fields.

In the United States, venture capital (VC) investment in clean energy reached nearly $1B in 2005 (Table I-1) and is on a trajectory to more than double that level in 2006. Section III of this report highlights a number of entrepreneurial companies engaged in commercializing energy technologies. Several products from these companies have recently become available on the market, while others have not yet emerged.

Table I-1. Venture Capital Investment in Clean Energy Technology Companies

Investors warm to clean energy

Venture capitalists are putting more money into energy technology companies in the United States

Year	Millions of dollars invested in energy technology	Percentage of total venture funding
2001	$468	2.3%
2002	$566	2.7%
2003	$547	3.0%
2004	$716	3.3%
2005	$917	4.2%

Source: Clean Edge 2006

A recent book notes the possibility (though far from certain) that “the pace of technological change in the energy, environmental, and closely related sectors (e.g., automotive and electric power) will become more revolutionary than evolutionary, thereby unleashing dramatic transformations in industrial practice and consumer behavior” (Tester et al. 2005). This report intends to highlight the potential for such a change in these sectors as a result of entrepreneurial and private-sector innovation.

The report is divided into five main sections. The present section describes global and national trends in energy supply, consumption, and emissions, highlighting the need for innovative technologies that could make a significant difference in the Nation's energy picture. Section II provides an overview of advanced technologies by sector — electricity generation, transportation, energy storage, and energy efficiency. Section III focuses on efforts by start-up companies to commercialize promising innovations. Section IV discusses the roles of the Federal Government, State governments, and universities in fostering innovation through a variety of mechanisms, often in partnership with each other. This section also gives a summary of the Energy Policy Act of 2005. In the concluding section, Section V, PCAST recommends policy steps that could be taken in the near term to help accelerate the development and market adoption of energy technologies over the next twenty-five years. With this report, PCAST hopes to contribute to the existing literature in this area[2] a fresh perspective, practical information, and an enthusiasm for the opportunities for new technology to dramatically change and improve national and global energy systems.

Global and National Energy Trends

The United States has abundant and diverse energy resources. It is the third-largest oil-producing nation, and it has the world's largest coal reserves (EIA-DOE 2004). At the same time, the United States consumes about a quarter of the global energy supply, roughly commensurate with its share of global economic output, and it produces about 22% of the world's carbon dioxide (CO_2) emissions (EIA-DOE 2006c). In 2005, energy-related expenditures represented 8.6% of the U.S. gross domestic product (President 2006b).

Technology has greatly improved the efficiency of energy use. Since 1970, the Nation's energy intensity — the amount of energy consumed per dollar of gross domestic product — has been reduced by 50%[3] (President 2006b). In other words, as a proportion of output, the U.S. economy requires only half the amount of energy that it did thirty-five years ago. As the data will show, however, there remain significant opportunities to further improve the efficiency of the Nation's energy use.

Energy supplies are linked to regional and global markets. The United States depends on imports for about 30% of its primary energy needs and over 60% of its oil requirements (EIA-DOE 2005). Rapid growth in global demand for energy has begun to strain the production capacity of the world's energy suppliers, and this situation is expected to continue. Projections of the Energy Information Administration (EIA) of the U.S. Department of Energy (DOE) indicate that world petroleum demand will increase from the current 82 million barrels per day (mbpd) to 118 mbpd in 2030 (EIA-DOE 2006a). Robust global demand, combined with underinvestment in energy infrastructure, regulatory and trade issues, uncertain market conditions, and the preponderance of nationalized oil company reserves, led to a tripling of crude oil prices from 2001 to 2006. These factors increase the likelihood of a major oil supply disruption, which would have deleterious economic effects. Even moderate increases in energy costs and price volatility can negatively impact economic growth (NEPDG 2001). Therefore, reducing oil use is a critical issue for the Nation and the world.

The breakout of U.S. energy consumption by sector (residential, commercial, industrial, transportation, and electric power sectors) is depicted in Figure I-1. This graphic shows that the largest U.S. energy feedstock is oil, two-thirds of which is consumed in the transportation sector, while electricity and natural gas are the

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[2] Other publicly funded energy reports that discuss a wide range of advanced technologies include PCAST 1997, PCAST 1999, NRC 2001a, NEPDG 2001, PCAST 2003, WGA-CDEAC 2006, and UK-DTI 2006.

[3] Researchers estimate that one-third of the reduction in energy intensity has been due to increased energy efficiency; the remainder is attributed to shifts in economic activity toward less energy-intensive sectors (President 2006b).

dominant sources of power and heat for residential, commercial, and industrial facilities. Figure I-1 also shows the input energy sources used to produce electricity. In 2004, U.S. electricity was generated from coal (50%), nuclear power (20%), natural gas (18%), hydropower (7%), and oil (3%), with biomass, geothermal energy, wind, solar energy, and other sources making up the balance (2%)[4] (EIA-DOE 2006a).

Two observations can be made from Figure I-1 that illustrate the complex energy challenges that the United States faces. First, it is evident that most energy losses (indicated by grey lines) result from electricity generation and transportation; in these sectors, only a minor portion of the input energy results in useful work. This suggests that there are significant opportunities to improve the efficiency of today's power plants and vehicles. Second, it is clear that the Nation's economy is heavily dependent on oil and natural gas. Because the greatest reserves of oil and gas are overseas, cost-effective alternatives are needed.

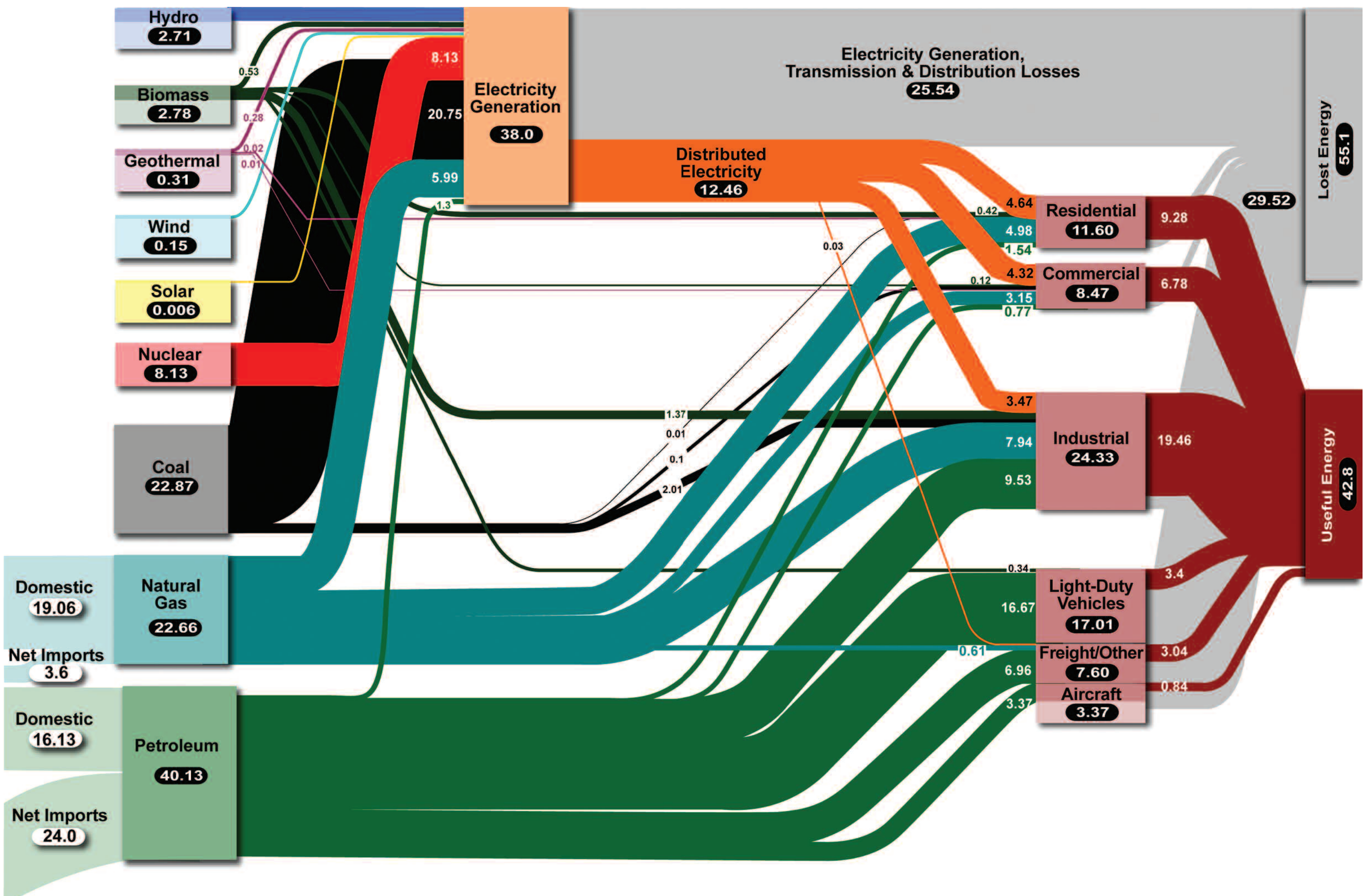
The environmental impact of refineries, power plants, and energy users on air quality, water resources, wildlife and aquatic habitats, and the global climate is another serious concern. In addition to regulated pollutants, fossil fuel combustion generates greenhouse gas emissions that are believed to contribute to global climate change (NAS 2001). Figure I-2 shows the estimated CO_2 emissions in the U.S. economy by primary input fuel — natural gas, coal, and oil. Similar to Figure I-1, the electric power and transportation sectors dominate the total output of CO_2. From 1990 to 2004, total U.S. greenhouse gas emissions rose by 15.8% (EIA-DOE 2005) as the gross domestic product increased by 51% (USDOC-BEA 2005). Without technology improvements beyond baseline assumptions, the EIA projects that annual CO_2 emissions in the United States will increase from 5,900 million metric tons (MMT) in 2004 to 8,114 MMT in 2030 — a 38% increase — as gross domestic product increases by 116% (EIA-DOE 2006a). Meanwhile, world CO_2 emissions are projected to increase over 60% from 27,044 in 2004 (EIA-DOE 2006c) to 43,700 MMT in 2030 (EIA-DOE 2005). To change these outcomes, cost-effective energy systems are needed that can provide transportation, electricity, and other energy services with significantly reduced greenhouse gas emissions.

The similarity between Figures I-1 and I-2 suggests that reductions in fossil fuel use could contribute to improving energy security as well as to reducing greenhouse gas emissions. As this report will describe, both objectives could be achieved by large-scale use of alternative sources of energy (e.g., biomass, nuclear, solar, and wind energy) as well as other advanced technologies for transportation (e.g., hybrid electric vehicles), electricity generation (e.g., coal gasification), and electricity use (e.g., efficient buildings and appliances).

The electric power sector accounts for the largest portion of CO_2 emissions as well as most of the increase in U.S. demand for natural gas since 1990. In business-as-usual projections, natural gas imports from outside North America will increase four-fold by 2030. Conventional coal power will grow its share to 57% of the U.S. electricity mix, from 50% today (EIA-DOE 2006a). Meanwhile, renewable electricity generation is projected to play only a small role. The EIA projects that in 2030, conventional hydroelectric power will contribute 5.1% of U.S. electricity generation (compared to 6.8% in 2004), and other renewable sources such as solar, wind, and geothermal energy will account for 4.3% (compared to 2.2% in 2004) of U.S. electricity generation (EIA-DOE 2006a). In the baseline scenario, therefore, the mix of generating sources in 2030 is not much different from that of today. Recent innovations in advanced energy technologies could, however, change this outcome. As will be described in this report, renewable energy, nuclear energy, and coal gasification technologies could substantially increase electricity generation capacity from low-emission sources that do not depend on imported natural gas.

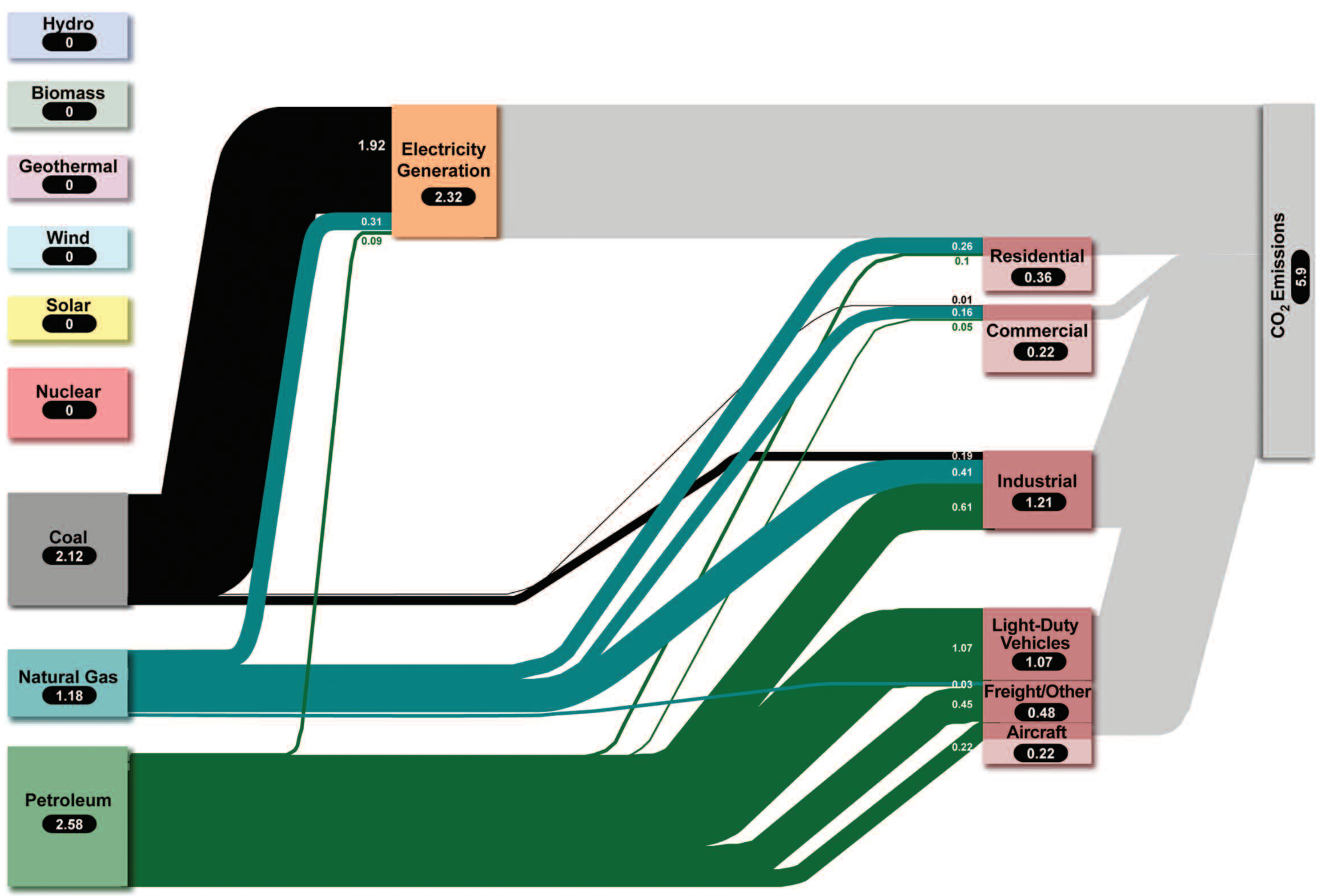
[4] Because of power plant efficiency differences among the different fuel types, the proportions of generated electricity do not exactly match the proportions of input electricity depicted in Figure I-1.

Figure I-1. U.S. Energy Flow Trends in 2005 (units in quadrillion Btus)



Source: LLNL 2006; data is based on EIA-DOE 2006b. If this information or a reproduction of it is used, credit must be given to the University of California, Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include small amounts of electricity imports or self-generation. Nonthermal electric generation sources are represented in thermal energy equivalent terms, so electricity generated from hydro, wind, or solar sources is actually 33% of that shown. Electricity generation, transmission, and distribution losses include fuel and thermal energy inputs for electric generation and an estimated 9% transmission and distribution loss, as well as electricity consumed at power plants. Total lost energy includes these losses as well as losses based on estimates of end-use efficiency, including 80% efficiency for residential, commercial, and industrial sectors, 20% efficiency for light-duty vehicles, and 25% efficiency for aircraft.

Figure I-2. U.S. Carbon Dioxide Emissions from Energy Consumption (units in billion metric tons CO_2)



Source: LLNL 2006; data is based on EIA-DOE 2006b. If this information or a reproduction of it is used, credit must be given to the University of California, Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Annual U.S. energy-related carbon dioxide emissions are shown in units of billion metric tons (gigatons) CO_2 per year. The values shown represent only the carbon dioxide emissions resulting from direct combustion of fossil fuel energy sources (coal, petroleum, and natural gas).

While new energy technologies can help reduce fossil fuel consumption, these fuels will likely remain the dominant sources of global energy for the foreseeable future. Thus, the discovery and use of domestic oil and gas reserves will continue to be vital to the Nation's energy security. While experts provide varying estimates of the useable amount of oil and gas deposits in the world,[5] it is clear that the majority of these resources are in unstable regions. The largest and most easily developed oil reserves are located in the Middle East, and two-thirds of the proven and estimated undiscovered natural gas deposits are in the Middle East and the former Soviet Union states (USGS 2000). Furthermore, 90% of the global oil and gas reserves are controlled by national governments rather than the private sector (BP 2006).

These facts strongly motivate a search for petroleum alternatives. Besides the advanced technologies discussed in this report, synthetic fuels from coal, natural gas, and biomass, as well as unconventional fuels from domestic shale oil and heavy oil, could become economic alternatives to conventional oil if petroleum prices remain above $50 per barrel. Methane hydrates (another type of fossil energy) are available in huge quantities in North America, but economic, technical, and environmental factors will likely prevent commercial development of this resource for at least several decades (NRC 2004a). Although the present report does not discuss these opportunities in detail, the Council recognizes that development of unconventional fossil fuel resources could be a significant contributor to national energy security, especially if the concomitant environmental concerns can be addressed.

National energy challenges are inextricably linked to the global energy situation. In business-as-usual projections, global energy consumption and greenhouse gas emissions will grow significantly. World energy consumption, which doubled between 1970 and 2002, will increase by a further 57% by 2025 (EIA-DOE 2005 and IEA 2006). Most of the growth in demand will be met by increased consumption of coal, oil, and natural gas. Because of rising populations and increased per-capita energy intensity, emerging economies such as China and India will account for nearly two-thirds of projected demand growth (EIA-DOE 2005) over the next two decades. In the baseline case, as noted earlier, world CO_2 emissions will increase from 27,044 MMT per year in 2004 to 43,700 MMT per year in 2030 (EIA-DOE 2005). On current trends, impacts on air quality, water quality, resource availability, land use, and other environmental factors that impact human health and quality of life will reach increasingly unsustainable levels in regions of the developing world. Clearly, advanced technology is needed to slow and ultimately to reverse these trends.

As oil and natural gas prices continue to rise, heavy dependence on fossil fuels will increasingly inhibit the economic growth of developing nations. Advanced technology can help meet energy requirements in these nations while addressing other needs. This report will primarily focus on the potential benefits of technology for electricity generation and transportation, but many secondary benefits could accrue from an improved energy infrastructure. For example, low-cost energy could make water purification systems economically feasible, thereby providing abundant potable water that is essential for social and economic development. Affordable access to modern energy services in developing nations can decrease poverty, increase productivity, and enable greater entrepreneurial activity in rural areas (World Bank 2006).

These global challenges provide motivation for the United States and other developed nations to partner with developing nations to help encourage the adoption of new technologies that can greatly reduce

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[5] EIA, in its 2000 presentation, *Long Term World Oil Supply* (http://www.eia.doe.gov/pub/oil_gas/petroleum/presentations/2000/long_term_supply/index.htm), estimates that recoverable world oil reserves are about 4 trillion barrels of oil (citing USGS 2000), which is equivalent to 130 years of supply at the current rate of world consumption; however, the EIA report acknowledges other estimates as low as 1.5 trillion barrels.

environmental impacts without compromising the economic growth vital to these countries. It also represents an opportunity for domestic energy technology suppliers to capture a nascent overseas market and boost the U.S. manufacturing sector before foreign suppliers do so. The interlinked nature of energy, international trade, and the global environment suggests that efforts to transform energy systems in the United States could also yield substantial environmental and economic benefits, as well as enhanced energy security, for other nations.

Potential Benefits of Technology

Affordable, abundant energy is essential for economic development. Technological advances are enabling the development of new processes that could lower the cost of energy, improve the efficiency of its use, reduce emissions, and make these benefits available to developing and developed economies. Funded in large part by the Federal Government, U.S. researchers are continuing to seek new and better technologies for electric power generation, transportation, and energy-efficient buildings and industrial processes.

This report highlights the fruits of these research investments and the role of newly formed companies in developing and commercializing advanced energy innovations. The report will not pick technology "winners and losers," but will point out additional steps that can be taken to address energy issues. Many emerging technologies could make a significant difference in the next five to ten years, leading to even greater benefits by 2030.

It is important to consider whether successful commercialization of the technologies discussed in this report could significantly change the business-as-usual scenario and lead to a more secure energy future. As a baseline, the EIA *Annual Energy Outlook 2006* projects many trends in energy supply and demand from 2005 to 2030. Highlights from these projections include the following (EIA-DOE 2006a, Figures 3, 5, 52, and 95; EIA-DOE 2006d, Tables 73 and 90):

- U.S. electric power consumption grows 50%, from about 4 trillion kilowatt-hours (kWh) in 2005 to 6 trillion kWh in 2030.
- Nuclear power generation grows 10% in absolute terms from the 2005 level, corresponding to the addition of six new reactors by 2030, but its share of total U.S. electricity declines from 20% to 15%.
- Across all sectors of the economy, energy input from non-hydroelectric renewable resources (e.g., biomass, geothermal, solar, and wind) rises from 3.2 quads to 6.0 quads in 2030, corresponding to an increase from 3% (in 2005) to 4% (in 2030) of total projected U.S. energy consumption.
- In the electric power sector, non-hydroelectric renewable generation in the United States nearly triples in absolute terms, while its share of the total increases from 2.2% in 2005 to 4.3% in 2030.
- Coal-fired power generation, with only a small contribution from coal gasification plants, increases 70%, accounting for 57% of U.S. electricity generation in 2030, up from a 50% share today.
- Electricity produced from natural gas increases 35%, contributing to a four-fold increase in overseas natural gas imports (i.e., from outside North America) to the United States by 2030.
- U.S. oil consumption increases from about 21 million barrels per day (mbpd) in 2005 to 28 mbpd by 2030, while oil imports increase from about 12 mbpd to 17 mbpd.
- Biofuels supply 0.8 mbpd (4% of transportation fuels) in the United States by 2030 compared to 0.3 mbpd today.

- Hybrid electric vehicles comprise about 10% of new U.S. vehicles sales in 2030, compared to about 1% today, while sales of all-electric vehicles and fuel-cell vehicles remain very small.

PCAST members believe that there are numerous opportunities for technology to dramatically change these projections in ways that will increase national energy security and reduce the environmental impact of energy consumption. For example, the following outcomes are not difficult to envision:

- The role of nuclear power could be substantially larger than the EIA baseline. Given the economic, energy security, and (with appropriate storage of waste) environmental benefits of nuclear energy, a reasonable goal is for nuclear power to at least maintain its share of total generating capacity. Based on projected demand (EIA-DOE 2006d, Table 73), this translates to more than 35 new nuclear power reactors by 2030.

- Non-hydroelectric renewable sources such as solar, wind, and geothermal energy could supply 10% or more of total U.S. electricity generation by 2030, which would be far above the level projected by the EIA (EIA-DOE 2006d, Table 89).

- A majority of new coal-fired plants placed in service after 2025 could employ coal gasification technology, amounting to at least 40 full-size (e.g., 800 MW) coal gasification plants.[6]

- Improvements in commercial, residential, and industrial energy efficiency (beyond those assumed in the EIA baseline), including distributed generation, could trim the rate of increase in U.S. electricity demand over the next quarter-century by 10%.

This scenario, which involves an expansion of nuclear power, renewable resources, and coal gasification plants, together with an increase in end-use efficiency and distributed generation capacity, would effectively cut in half the projected growth in power generation from conventional coal and natural gas plants over the next 25 years. Environmental impacts would also be substantially reduced. Reduced demand for natural gas could result in lower and more stable electricity prices and a reduction in overseas natural gas imports. Furthermore, the commercial success of these technologies could enable an even larger transformation of the electric power sector by midcentury.

In the transportation sector, PCAST analysis suggests that an alternative scenario, compared to the EIA baseline, is likewise feasible:

- With a major expansion of biomass feedstocks, cellulosic biofuels production and distribution infrastructure, and biofuel-vehicle compatibility, biofuels could supply on the order of one-third of projected transportation fuel needs by 2030. The parallel expansion of the biobased products industry would also help accelerate this transition.

- Efficient vehicle technologies — potentially including electric- or hydrogen-powered propulsion systems — could be widely deployed, resulting in a 25% reduction in projected transportation fuel demand.

- Synthetic and unconventional fuels derived from domestic resources — especially from coal and shale oil — could supply perhaps 15% or more of transportation fuels with environmentally acceptable processes.

Given these outcomes, alternative fuels and advanced transportation technologies could enable the United States to reduce its oil imports on the order of 70% by 2030, compared to the EIA baseline. With the

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[6]This calculation uses EIA-DOE 2006a (Figure 56) as a baseline. This proposed level of market penetration of coal gasification technology is consistent with that estimated as feasible by a 2004 Booz Allen Hamilton study (DOE-NETL Gasification Technologies Council 2004).

technology opportunities described in this report, therefore, the goals of a dramatic reduction in dependence on foreign sources of energy and a significant improvement in environmental outcomes, with consequent economic benefits to the Nation, are achievable in the 2030 time frame. Furthermore, these technologies could enable other nations to achieve similar energy goals, improving the global environment and long-term energy supplies.

Federal Government Initiatives

Since 2001, the Federal Government has invested nearly $10B to develop cleaner, cheaper, and more reliable alternative energy sources (President 2006a). In his 2006 State of the Union address, President Bush outlined the Advanced Energy Initiative (AEI), which proposes a 22% increase in the Fiscal Year (FY) 2007 budget for clean-energy R&D at DOE. The AEI seeks to improve the Nation's energy security while protecting the environment through greater use of technologies that reduce oil consumption and that generate electricity from clean coal, advanced nuclear power, and renewable resources such as solar and wind energy. The AEI includes the following programs and activities (the requested budget in FY 2007 is shown):

- The **Global Nuclear Energy Partnership** ($250M) proposes new domestic and international waste handling systems that would enable an expansion of clean and safe nuclear power. In related initiatives, the Administration will continue support for (a) the **Nuclear Power 2010** program ($54M) to demonstrate a streamlined licensing process for new plants and otherwise to encourage decisions by U.S. electric utilities to build new "Generation III+" nuclear power plants in the near term; and (b) the **Generation IV Nuclear Energy Systems Initiative** ($31.4M) to develop safer, more reliable, and more-proliferation-resistant "Generation IV" nuclear reactors for deployment by 2030. (The Generation IV initiative has strong components of international research and policy coordination.)
- The **Coal Research Initiative** ($281M) supports development of advanced clean coal technologies such as coal gasification, carbon sequestration, and advanced power turbines.
- **FutureGen** ($54M), a key part of the Coal Research Initiative, supports the partnership between the Federal Government and the private sector to build a demonstration coal gasification plant by 2012 that will capture and store most of its CO_2 output in deep geologic formations.
- The **Solar America Initiative** ($148M, an increase of $65M over FY06) seeks to accelerate the development of low-cost materials for photovoltaic solar cells.
- **Wind Energy** research ($44M, an increase of $5M over FY06) focuses on development of wind turbines that could enable cost-effective wind power generation in areas with only moderate wind speeds.
- The **Biofuels Initiative** ($150M, a $59M increase over FY06) supports development of technologies for cost-effective, biobased fuels such as ethanol from agricultural residues, forest industry by-products, urban wood waste, and perennial grasses.
- **Advanced battery research** ($31M, a $6.7M increase over FY06) seeks to lower the cost of hybrid electric vehicles and to develop new batteries that enable these vehicles to operate on electricity alone for daily commutes.
- The **Hydrogen Fuel Initiative** ($289M, an increase of $53M over FY06) funds research that aims to enable commercially feasible and environmentally attractive fuel cell vehicles, as well as cost-effective production and distribution of hydrogen to fuel these vehicles.

The Administration's Climate Change Technology Program (CCTP), which encompasses programs representing approximately $3B of funding in FY 2007, is the main coordination mechanism for the Federal Government to support research, development, and deployment of technologies that can reduce greenhouse gas emissions, including renewable energy, nuclear energy, efficiency improvements, and carbon sequestration. CCTP includes all DOE programs and activities mentioned above, in addition to programs and activities at eight other Federal agencies. In addition to providing increases in R&D funding, the Administration has established programs for the voluntary reduction of greenhouse gas emissions, including the following:

- **Climate Leaders** is an EPA program representing fifty major companies that inventory their emissions and measure progress toward greenhouse gas reduction goals.
- **Climate VISION** (Voluntary Innovative Sector Initiatives: Opportunities Now) is a joint program of DOE, DOT, USDA, and EPA to encourage broad market penetration of energy efficiency technologies to reduce greenhouse gas emissions.

The Federal Government has also instituted many tax incentives and other measures to encourage commercialization and deployment of renewable energy and energy efficiency technologies. For example, the Energy Policy Act of 2005 (EPAct) provides tax incentives for hybrid and fuel-cell vehicles, residential solar heating systems, efficient building technologies, electricity produced from wind and biomass, and energy produced from landfills, among a host of other alternative energy technologies. These provisions are detailed in Table IV-2. Other examples of foundational legislation are the Biomass Research and Development Act of 2000 that mandated a partnership between DOE and USDA, and the first-ever energy title of the 2002 Farm Bill.

Federally funded basic research has led to the development of many advanced energy technologies described in this report. To ensure continued technological leadership in the world, the President's American Competitiveness Initiative (ACI) commits $5.9B in FY 2007 and more than $136B over 10 years, to increase investments in R&D, strengthen education, and encourage entrepreneurship and innovation. As described in a previous PCAST report (2004), if the Nation is to continue its technology leadership, a knowledgeable workforce will be required. The ACI presents a program for improving the Nation's education system; that program should be strongly supported.

This report focuses on technologies that could make a substantial difference in the Nation's energy systems and infrastructure by 2030. At the same time, PCAST recognizes the value of fundamental research that could yield substantial energy benefits beyond that time frame. In particular, PCAST supports continued, robust funding for the ITER fusion power reactor research initiative, which seeks to demonstrate the scientific and technological feasibility of fusion energy as a clean, virtually unlimited energy source. PCAST also recognizes the long-term potential for biotechnology to create revolutionary new approaches for carbon sequestration and for non-petroleum-based products and processes.

II. Advanced Energy Technology

Emerging technologies could transform today's energy systems and infrastructure in ways that enable cleaner and more efficient use of energy throughout the economy. This would clearly involve a dramatic shift in the energy flows depicted in Figure I-1. Such a change has historical precedent: within just twenty-five years (1970-1995), commercial nuclear power grew from a novelty to a mainstay of the U.S. electricity infrastructure. Today, nuclear energy supplies 20% of the Nation's electricity and an even higher proportion of the base load requirements of the electric grid.

In order to advance the twin goals of energy security and environmental responsibility over the next quarter-century, the U.S. energy infrastructure must shift to new technologies on a scale comparable to the early expansion of nuclear power. In fact, there is some precedent for a large-scale shift from fossil fuel to non-fossil-fuel energy sources, including the following examples:

- Biomass supplies about 20% of Brazil's automotive fuel (Luhnow and Samor 2006).
- Nuclear power provides nearly 80% of electricity consumed in France and 30% of electricity consumed in Japan.
- Wind energy supplies over 20% of electricity consumed in Denmark and about 6% of electricity consumed in Spain and Germany (Graber 2005; German Wind Energy Assoc. 2006).

While each nation has unique economic, geographical, and political features that determine its mix of energy sources, the above examples suggest that mainstream commercial success of advanced energy technologies is feasible. Although the United States already leads the world in production of biofuels and nuclear power and has the third-highest installed capacity of wind turbines, much progress is still needed in these and other technologies to meet national and global energy-related challenges. Therefore, this section reviews technologies that could reduce inefficiencies and carbon emissions in the electric power, transportation, and building sectors, concluding with PCAST's observations on salient opportunities to change the Nation's energy systems by 2030.

Electric Power Generation

Electricity is the dominant source of power for homes, commercial buildings, and many industrial processes. While electricity generation represents only about 40% of total national energy use, electricity accounts for more than 85% of the growth in U.S. energy demand since 1980 (EIA-DOE 2006c). This trend is expected to continue, driven in part by increased energy consumption in the telecommunications and information technology sectors. Today, about 60% of the Nation's gross domestic product derives from industry and services dependent on electricity, up from 20% in 1950 (Huber and Mills 2005). In the future, if electric vehicles become common, transportation systems could also depend heavily on electricity.

The portion of U.S. electricity generation provided by natural gas power plants has grown rapidly in recent decades because of their low capital costs, high efficiency, and relatively clean emissions. For these reasons, natural gas consumption is projected to increase by about 20% over the next decade, and liquefied natural gas imports are projected to increase to 17% of the natural gas supply in the United States by 2030 (EIA-DOE 2006a).

Electricity demand in the United States is expected to increase from about 4 trillion kilowatt-hours (kWh) in 2004 to nearly 6 trillion kWh in 2030, including commercial and industrial generation (EIA-DOE 2006a). To meet this increase in demand and to cover projected plant retirements, the United States will need to add about 350 GW of power generation capacity (EIA-DOE2006d, Table 73), or about 400 coal or nuclear power plants.[7] As described in a previous report of this body (PCAST 2003), the first step to address this challenge is broad deployment of energy efficiency technologies, especially in buildings and the electric grid, in order to slow the rate of demand growth. Second, innovative power generation technologies are needed. In the future, clean and efficient electricity generation could derive from advanced nuclear energy, clean coal power (coal gasification with carbon capture and storage), as well as solar, wind, and other renewable and/or distributed energy resources.

For this discussion, it is useful to define four categories of power sources that supply the electric grid:

1. *Base load generators* handle the constant output required to support the grid throughout the day; these are usually nuclear, coal, or hydroelectric power plants.
2. *Intermediate load generators,* such as natural gas power plants, have higher fuel costs but can be operated as needed to cover grid requirements, which tend to follow daily and seasonal cycles.
3. *Peak load generators,* typically gas turbines or diesel generators, are used only during hours when electrical demand is the highest. Hydroelectric plants can also supply peak load power.
4. Finally, *intermittent generators* supply power that fluctuates according to uncontrollable, natural energy flows; solar and wind energy are examples.

As shown in Figure I-1, electric power generation in the United States depends on a diverse mix of feedstocks, including coal, nuclear energy, natural gas, hydroelectric power, petroleum, and other sources such as biomass, geothermal, wind, and solar energy. Technological advances as well as economic and environmental factors are making new technologies increasingly feasible for commercial deployment. The following paragraphs review the most notable electric power generation technologies under development in universities, the private sector, and Government laboratories.

Advanced Nuclear Energy

Over the next few decades, nuclear power offers perhaps the best opportunity to meet the projected 50% increase in U.S. electricity demand at competitive prices while producing very low atmospheric emissions. In fact, the current operating cost of nuclear power from existing plants is about $0.015 per kWh; unlike fossil-fuel plants, most of the total price of electricity for nuclear power plants is related to up-front capital expenditures (UIC 2006a). Numerous studies show that with improved technology and streamlined approval processes, nuclear plants can be expected to generate power for an amortized cost (including capital expenditures) of between $0.02 and $0.05 per kWh (UIC 2006b), depending on financing, construction costs, and the calculated lifetime of the facility. In general, these studies suggest that next-generation nuclear power plants will be competitive with coal-fired generators and less expensive than natural-gas-fired plants

[7]A typical nuclear plant is about 1 GW capacity; a large coal power plant is about 800 MW capacity.

in the United States (see Table II-1). Furthermore, if CO_2 emissions are regulated in the future, the costs of conventional coal power could increase to $0.05–$0.08 per kWh (IPCC 2005), while the costs of nuclear power plants would not change, because nuclear plants produce almost no atmospheric emissions. Future capabilities of nuclear power, such as efficient hydrogen production, could further enhance its economic and environmental benefits.

Table II-1. Comparison of Generating Costs by Fuel for New Power Plants, over the Expected Life of the Facility

Estimated cost per kilowatt-hour	@5% Discount rate*	@10% Discount rate*
Nuclear	$0.021–$0.031	$0.030–$0.050
Convention coal	$0.025–$0.050	$0.035–$0.060
Natural gas	$0.037–$0.060	$0.040–$0.063

*Discount rate can be defined as the expected rate of return on an investment.

Source: OECD/IEA 2005

Several hurdles must be overcome before nuclear power can be expanded. First, concerns about public safety, and the related financial risks, must be satisfactorily addressed. For this reason, as the nuclear power industry has matured, with help from the Nuclear Regulatory Commission, it has standardized best practices and for the past decade has maintained a consistently improved safety record. Additionally, nuclear engineers have developed new reactors that are simpler, less expensive, and more efficient than existing designs, which date from the 1970s and early 1980s.

Another concern is the safe disposal of nuclear waste. Utilities and the public must have confidence that high-level radioactive waste can be disposed and stored with virtually no risk to human health or to the environment. Currently, however, no permanent repositories have been approved for such waste. Although the Federal Government has selected Yucca Mountain, Nevada, for this purpose, the site has not yet been licensed for use. Based on technical and geologic considerations, the Yucca Mountain site could accommodate all the existing high-level waste as well as that generated by current and proposed nuclear plants for several decades to come (NERAC 2004). Utilities state that resolution of the nuclear waste issue is essential to obtaining approval from public utility commissions for the construction of new nuclear plants. Therefore, PCAST urges the Federal Government to take rapid action to secure appropriate disposition of nuclear waste.

The Administration recently launched the Global Nuclear Energy Partnership (GNEP) initiative, which, among other goals, intends to develop and deploy an advanced nuclear fuel cycle with spent nuclear fuel recycling. In this approach, fast neutron reactors would burn up a large portion of the fission products, reducing the amount of highly radioactive waste by up to 90%, while producing electricity for the grid (USDOE-NE 2003). Spent uranium would be reprocessed to create new fuel for conventional nuclear power plants. A national system for nuclear fuel recycling would support a large increase in nuclear power capacity without requiring a corresponding increase in waste storage facilities.

The GNEP addresses another concern with nuclear energy — proliferation. The use of nuclear energy for civilian purposes has, unfortunately, provided other nations with opportunities to gain access to the materials they need to build nuclear weapons. The GNEP aims to create a new international fuel cycle regime that would support global use of peaceful nuclear power without the need for every state to develop nuclear fuel-processing capability. While a nuclear fuel system of this sort would require time to develop and build, it could address both waste and proliferation objectives.

In conclusion, PCAST views nuclear energy as a mature, low-cost, low-emission source of base load electric power. For these reasons, an expansion of nuclear energy using advanced technologies would contribute to U.S. energy security, environmental stewardship, and a reliable supply of affordable electricity.

Coal Gasification

Integrated gasification, combined-cycle (IGCC) power plants, fueled by coal, may offer an attractive low-carbon option for large-scale power generation from an abundant domestic fuel source. Because IGCC plants use highly efficient gas turbines in tandem with steam turbines, advanced IGCC designs could achieve as high as 50% efficiency,[8] compared to an average 36% efficiency for conventional coal plants built in recent years (USDOE-FE 1999; USDOE-NETL 2004). Further, combining IGCC technology with large, solid-oxide fuel cells could boost output efficiency to over 60% (Gray, Salerno, and Tomlinson 2004). Coal gasification plants could also be used to produce hydrogen for fuel-cell vehicles.

In the IGCC process, coal slurry is gasified and cleaned. The gas stream, with a high content of carbon monoxide and some hydrogen, goes through a process that converts it to a synthetic gas that is rich in hydrogen and CO_2. Regulated pollutants — sulfur, nitrous oxides, and mercury — can be removed relatively easily from the gas stream prior to combustion, thus reducing emission control costs compared to conventional plants. In addition, the IGCC process enables relatively low-cost carbon capture. Carbon dioxide can be separated from the synthetic gas stream, captured, dried, and compressed into a supercritical liquid for underground sequestration in a deep, geologic formation or another form of disposal or use. While carbon capture is most cost-effective when integrated into the plant design, it is also possible to retrofit this capability into an IGCC plant that does not already have it. Even without carbon capture, a coal gasification plant inherently reduces carbon emissions compared to conventional power technology by virtue of its increased efficiency.

Two mid-scale IGCC power generation facilities have been built as part of DOE's Clean Coal Technology Program in Tampa, Florida, and West Terre Haute, Indiana. Additionally, the DOE FutureGen program plans to partner with industry to build a 250-MW IGCC plant by 2012.

Currently, an IGCC power plant is 15–20% more expensive to build than a conventional coal-fired power plant of equivalent capacity. Although this would likely be compensated in the long term by lower fuel costs, utilities and public utility commissions have been reluctant to build IGCC plants because of the higher capital costs and risks associated with a relatively new technology. Given its environmental and efficiency benefits, however, PCAST members believe that deployment of coal gasification plants should be aggressively pursued. If IGCC plants eventually prove capable of achieving efficiencies approaching 70%, as some proponents suggest, the amount of power produced per ton of coal would be approximately double that of today's coal plants. This improvement in efficiency would greatly reduce CO_2 emissions, enable more cost-effective control

[8] Efficiency is defined as the ratio of electrical power output to energy input contained in the pulverized coal feedstock.

of regulated pollutants, and make more efficient use of mined coal. In summary, IGCC technology offers a potentially attractive alternative for large-scale electric power production with low atmospheric emissions.[9]

Renewable Energy Resources: Overview

While solar, wind, and other renewable energy sources are becoming more competitive with fossil-fuel-based electricity generators, especially in distributed applications, several hurdles must be overcome before they can be considered viable replacements for conventional power plants. First, solar cells and wind turbines are intermittent power sources. Converting intermittent generation to constant power requires large energy storage systems, but these are currently too expensive and inefficient for this purpose. Further, renewable power installations and the associated transmission-line corridors can carry high up-front capital costs as well as social and environmental costs. For example, two thousand modern wind turbines — each a quarter the height of the Empire State Building — generate roughly the same delivered power, over the course of a year, as a single coal or nuclear power plant. Siting large numbers of wind, solar, or geothermal generators is a challenge because these energy sources are often most available in remote or pristine areas (Vajjhala 2006). For these reasons, renewable energy technologies are not expected to replace fossil fuel and nuclear plants as the primary source of U.S. base load power over the next few decades.

In some locations, renewable energy sources compare well with conventional sources (which also face economic and environmental trade-offs). As new materials and manufacturing efficiencies drive down costs (as shown in Figure II-1 for PV production), renewable electricity generation will become an increasingly essential element of the national energy system. By 2030, renewable energy could supply 10% or more of the Nation's electricity. This could increase to at least a 20% share by midcentury. Renewable electricity generation could also provide clean power generation for developing nations that are rapidly expanding their electric power infrastructure. To help enable these results, researchers are investigating fundamental breakthroughs in key areas such as materials, manufacturing, energy storage, and system integration, which could lead to renewable energy systems that meet consumer requirements for price, reliability, and power quality. The following paragraphs discuss renewable energy sources in more detail.

Solar Energy

The sun is the primary source of energy for life on earth. The desire to use the sun's energy for human needs is probably as old as mankind. A vast amount of solar energy falls on the earth each day. On a sunny day at the equator, the sun produces about one kilowatt of power per square meter of the earth's surface. DOE estimates that solar PV panels packed into a 100-mile-square area (or 10,000 square miles) of Nevada could theoretically produce enough power to supply the entire electricity demand of the United States (USDOE-EERE Wind and Hydropower Technologies Program 2006). While the "fuel" for a solar power system — the sun's rays — is free, the conversion of those rays to useful power has not been competitive with other power sources for most electric grid applications. New innovations and government incentives, however, are changing the economics of solar power, leading to rapid growth in commercial demand.

Today, solar energy provides about 0.02% of the Nation's grid-connected, utility-supplied electric power.[10] Based on current trends, the EIA projects that this proportion will rise to 0.1% by 2030 (EIA-DOE 2006d,

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[9] PCAST notes that other advanced processes such as oxy-combustion, ultra-supercritical steam cycles, and circulating fluidized bed combustion could also, if incorporated into new commercial plants, significantly boost the average operating efficiency of coal power generation.

[10] The Solar Energy Industries Association (2006) estimates that the United States has 475 MW of installed solar PV capacity, including non-utility-supplied power (e.g., from roof-mounted PV systems). Including these non-utility generators, solar energy accounts for about 0.04% of U.S. electricity.

Supplemental Table 89). With expected technology improvements, however, industry experts project that solar energy capacity could generate 2% or more of the projected 6 trillion kWh of U.S. electricity demand by 2030 (SEIA 2004). Furthermore, if low-cost energy storage becomes available, solar energy systems could supply intermediate load power (i.e., power to the grid whenever needed), opening up a much larger market.

Solar energy installations can be classified as either centralized or distributed power systems. These are described below.

Centralized Solar Power Systems. Centralized solar power plants supply tens or hundreds of megawatts of power to the electric grid during peak hours. These installations are typically located in desert regions, where land and sun are plentiful. Most centralized solar power plants use "concentrating solar power" (CSP) technology. In CSP systems, reflectors concentrate the sun's thermal energy onto a collector, producing steam that drives a turbine generator, which in turn generates electricity. CSP designs include solar troughs, power towers, dish-engine systems, and concentrating photovoltaics.

Solar trough systems reflect the sun's rays onto a long absorber tube containing water or oil, which becomes heated to 400°C and produces steam for electricity generation. Currently, over half of U.S. grid-connected power from solar energy is from a series of trough-style CSP systems in California, rated in total at about 350 MW peak. These systems were built in the 1980s to offset energy costs at State facilities and to demonstrate the capabilities of CSP. Several trough systems have also been installed at remote industrial or government facilities. Levelized electricity costs (including costs of capital plus operations and maintenance) for solar troughs are estimated to be $0.12–0.14 per kWh (USDOE-CFO 2006).

In the power tower design, a field of mirrors focuses sunlight on a tall, central receiver to heat a molten salt fluid to more than 500°C. The largest power tower built to date, in the Mojave Desert, generates 10 MW peak. Design analysis indicates that a power tower on the scale of 100–200 MW would optimize generation costs. Given other efficiency and reliability improvements, power towers of this size might one day be able to supply electricity at an estimated, levelized cost of $0.05 per kWh (Tester et al. 2005).

Dish-engine systems, a more compact type of CSP, use parabolic mirrors to heat an attached receiver to 600–1500°C. The heat is conveyed directly to a heat-engine generator. A dish-engine unit produces only about 25 kW peak, but its small size makes it suitable for distributed applications as well as for clustering in a centralized generating station. Dish-engine demonstrations have generated electricity at an estimated cost of $0.09–0.13 per kWh, but system improvements could reduce this to as low as $0.05 per kWh (Tester et al. 2005). Recently, several partnerships have announced plans to deploy clusters of dish engines in California that, if developed as envisioned, will provide up to 1,700 MW peak generating capacity to the electric grid.

Another type of CSP system is concentrating photovoltaics. In prototype tests, these systems have demonstrated very high output efficiencies by focusing intense light on a specialized solar PV cell. As in conventional PV systems, the solar cell generates electricity directly. Although intial results are promising, researchers have not yet demonstrated the commercial viability of this approach.

The drawbacks of centralized CSP systems include high capital cost as well as the cost and inefficiency of long-distance transmission links to the grid. If new developments address these issues, centralized solar power systems could make a significant long-term contribution to the Nation's electricity needs.

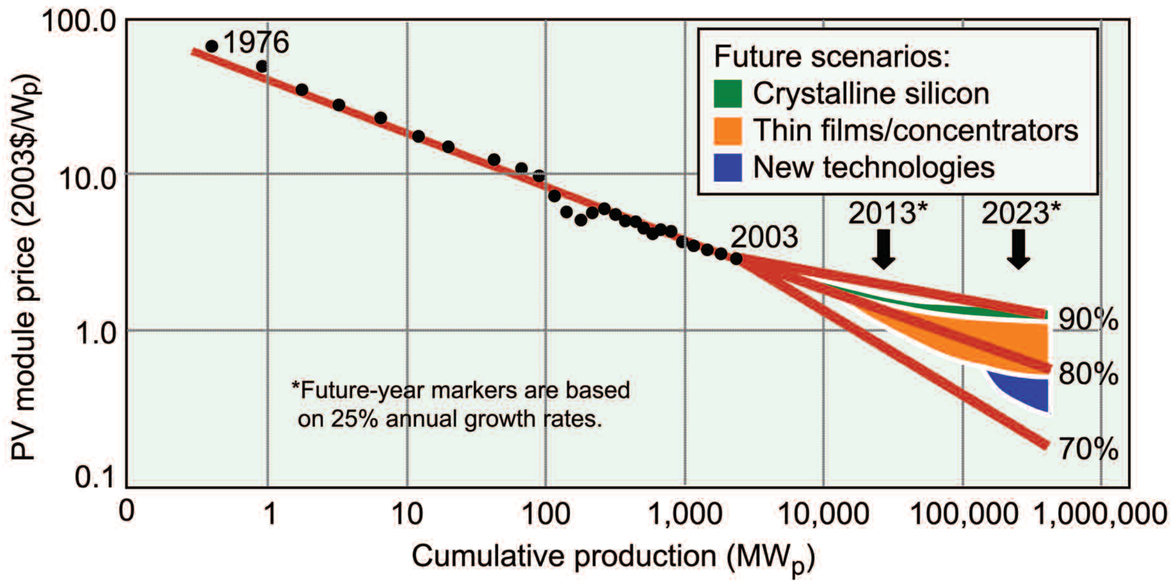
Distributed Solar Power Systems. Distributed solar systems provide electric power directly to a user or electric load. By avoiding transmission and distribution costs, distributed systems offer an attractive economic model for small solar PV systems. In particular, because solar systems generate peak power in the late afternoon, when utilities must rely on expensive peak-load generators, roof-installed PV systems can be cost-effective in some cases. Depending on local utility pricing and Federal and State tax incentives, a PV system might pay back its installed cost in less than ten years.

Most distributed solar power systems use PV devices composed of semiconductor materials to convert solar energy directly to electricity, a technology that was first demonstrated more than 50 years ago. The raw material for conventional PV devices is the same as for most electronics — purified, crystalline silicon (polysilicon). In fact, the Solar Energy Industries Association (2006) estimates that about half of the world's production of polysilicon in 2006 will be consumed by the solar-energy industry. Currently, a global shortage of this feedstock has, at least temporarily, boosted the cost of solar PV production (Bernstein 2006). New capacity and technology coming online in the next year is expected to ease the polysilicon shortage.

Several novel PV designs have been introduced to the market that require little or no polysilicon. "Thin film" technologies, developed in part by DOE, use various combinations of copper, indium, selenium, cadmium, gallium, silicon, and/or other materials to construct very thin semiconductor cells. Examples include cadmium telluride (CdTe), copper indium gallium diselenide (CIGS), nanocrystalline silicon, and amorphous silicon. Another unconventional technology is organic PV cells, which use conjugated polymers, sometimes with light-sensitive dyes, to convert solar energy into electricity. Although thin-film and dye-sensitized cells typically operate below 10% peak efficiency (compared to 18–19% peak efficiency for crystalline silicon PV cells), manufacturers of these devices claim that lower production costs will enable them to compete successfully with conventional PV systems. Thin-film and dye-sensitized PVs, because they are based on flexible substrates, can be manufactured by extremely fast and inexpensive roll-to-roll processes. These PV strips can be embedded even in clothing or on military tents to provide durable, portable sources of power. For these reasons, thin-film PV production, which currently represents only a small fraction of the market, is expected to grow by 70% in 2007 (Clean Edge 2006).

Since 1975, the cost of PV solar cells has been decreasing with a "Moore's law" characteristic, as shown in Figure II-1. Today, the cost of an unsubsidized rooftop PV system with a 30-year life amounts to about $0.20 per kWh (USDOE-CFO 2006). By comparison, retail electricity prices average about $0.08 per kWh in the United States (EIA-DOE 2006a). In some regions, however, the retail price of electricity can rise to as high as $0.25 per kWh, making distributed solar power competitive during peak hours. Some analysts expect PV prices to drop to $0.12 per kWh (including Federal incentives at present levels) within five years (SEIA 2004), which would make solar PV systems economically attractive for mainstream use in areas with high electricity costs.

Figure II-1. Learning Curve for PV Production. A learning curve of 80% (the middle projection) corresponds to a 20% cost reduction for every doubling of cumulative production.



Source: Surek 2005. Reprinted with permission from Elsevier.

Because the initial capital cost of PV systems presents a market barrier for many buyers, novel policies and market instruments are needed to capture the long-term benefit of distributed solar installations. For example, many States require power companies to buy back power produced by distributed solar systems at retail rates. Because consumers who make a capital investment in a PV system can then sell any excess generated power, this policy makes PV systems more economically attractive for residential use. Several home builders now offer energy-efficient homes with solar panels and high-efficiency appliances as an option to buyers. Installing the solar system increases the mortgage payment, but this becomes largely compensated by reduced utility bills.

This confluence of economic and environmental benefits has led to a rapid expansion in the solar PV market. The growth in worldwide solar PV capacity has averaged approximately 35% per year since 1996 (Clean Edge 2006). In the United States, new installations added 150 MW (peak) PV solar capacity in 2005, a 45% increase over the year before (Solarbuzz 2006). Worldwide, the Solar Energy Industry Association (2006) estimates that about 1,500 MW of PV solar panels were installed in 2005, including over 800 MW in Germany and 300 MW in Japan. Clean Edge (2006) forecasts that the total global industry will grow from $11.2B in 2005 to over $50B by 2015.

Many researchers believe that PV-generated electricity could eventually become a huge energy resource for the world. Figure II-1 suggests that, based on continued innovation and manufacturing investments, PV module costs could drop dramatically over the next two decades. A recent DOE report encourages researchers to seek new designs, materials, and concepts that could reduce PV costs by an order of magnitude by 2020 (USDOE-SCI 2005). With such a cost reduction, solar energy would likely emerge as a key component of the U.S. electric power system, especially if it could be combined with cost-effective energy storage.

Wind Energy

Wind turbines at Tehachapi Pass, California.

Extraction of energy from wind has been common since ancient times. In the past few decades, advances in materials, blade design, and electronic controls have enabled wind power to become a commercially feasible resource. Today, a large off-shore wind turbine can generate enough power for a thousand homes.

Wind power currently provides about 0.5% of U.S. electric power, after growing by one-third in 2005.[11] The EIA projects that wind power will provide about 1% of U.S. electricity in 2030 (EIA-DOE 2006d, Supplemental Table 89). If current tax incentives and market trends continue, however, this level could be reached within five years. The National Renewable Energy Laboratory estimates that wind power could eventually supply 20% of the Nation's electricity (Milligan 2006). Already, about 3% of electricity in the European Union is produced by wind power (German Wind Energy Association 2006).

Unlike solar power, many wind power installations are operating profitably; in fact, in some regions of the United States, the cost of wind power has dipped to as low as $0.05 per kWh, not including subsidies (Milligan 2006).[12] In the past two years, wind energy generating capacity has doubled to about 10,000 MW (peak) in the United States (AWEA 2006). Ongoing development of wind turbines for moderate-wind-speed areas could further expand this resource (USDOE-EERE Wind and Hydropower Technologies Program 2004). In addition, many States have mandated a certain percentage of the State's electric power to be derived from renewable sources (see page 59 of this report). In these States, wind is the most common source of non-hydroelectric renewable power generation.

Because wind energy is inherently intermittent, integration with the electric grid becomes more complex as wind power increases its share of electricity generation capacity. Additionally, the siting of wind turbines has proven to be problematic in some areas because of their visual impact, effect on wildlife habitat, and the requirement to build transmission corridors to remote locations. While technology development can mitigate these challenges, PCAST members believe that increased deployment of wind power systems will depend more on State and local zoning and environmental regulations, as well as on Federal policies, than on technology improvements. Given continued tax incentives and a favorable regulatory environment, wind power will likely far exceed EIA projections.

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[11] The United States installed about 2,400 MW (peak) of wind power in 2005, according to the Global Wind Energy Council (2006).

[12] The Federal Government currently provides a 1.9 cent-per-kilowatt-hour tax credit for electricity generated by wind turbines over the first ten years of a project's operations. Unless it is renewed, the tax credit will expire (for new wind turbines) at the end of 2007.

Biopower

Biomass, which includes forest products, logging and urban wood waste, crop residue, solid waste, and landfill gas, can be used to generate electricity. Biomass can be combusted directly to produce steam, co-fired with coal, or gasified to fuel a gas turbine generator or a boiler. For example, a 50-MW biomass gasification plant in Burlington, VT, generates power from waste wood derived from nearby forestry operations (USDOE-EERE Office of the Biomass Program 2005). Currently, biomass feedstocks supply 1.5% of U.S. electricity, and the EIA projects that this proportion will grow to 2.2% by 2030[13] (EIA-DOE 2006d, Table 89). A more substantial expansion of biopower will require breakthroughs in the cost and efficiency of gasification systems and the economic feasibility of dedicated energy crops. Another challenge is that biopower generating stations must be located near feedstock suppliers, such as farms. If, as suggested later in this report, biofuels for transportation are widely commercialized, then biorefineries could be designed to produce both fuels and electricity, optimizing use of the biomass feedstock.

Geothermal Energy

Geothermal systems produce electricity using heat from deep in the earth's crust. For example, hot underground aquifers in the western United States produce steam that can be used directly in a low-pressure steam turbine. Geothermal energy can provide base load electric power, heat for buildings, or energy for residential heat pumps. Currently, geothermal resources provide about 0.4% of the Nation's power, and the EIA projects that this will increase to about 1% by 2030 (EIA-DOE 2006a).

A geothermal field along the border of Sonoma County and Lake County, California.

Researchers are investigating ways to improve the feasibility of extracting geothermal energy from hot, impermeable rock that exists in many parts of the United States at a depth of two to five miles. This would involve drilling deep wells and circulating water (or some other heat-exchange fluid) in order to absorb the heat, which then would be used to create steam to drive a turbine generator. Government studies estimate that geothermal resources at such depths far exceed the total energy consumption of the United States. Further research is needed to determine how much of this resource could be used commercially in the next few decades (GEA 2006). Internationally, Iceland is a significant example of large-scale geothermal use; over half of its total energy requirement is supplied by geothermal energy, primarily for heating (WRI 2003). By comparison, the United States uses over four times more geothermal energy than Iceland, mostly for electricity generation. Research

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[13] The EIA analysis includes wood and other biomass feedstock used in both the electric power sector and the commercial and industrial sector (i.e., in generators not attached to the grid), and municipal solid waste and landfill gas.

efforts should continue to develop these resources, because they contribute to base load power supplies while producing few carbon emissions.

Hydroelectric Power

The flow of water from higher to lower elevations, a cycle that is sustained by solar evaporation and atmospheric precipitation, is widely used to drive turbines that generate electricity. Although the basic principle is similar to that of the ancient water wheel, the scale of many modern hydroelectric power plants is huge. For example, the Three Gorges station in China has a generating capacity seventeen times larger than a nuclear power plant.

Currently, hydroelectric power supplies about 7% of the electricity in the United States. Though subject to seasonal fluctuations, hydroelectric plants serve as a highly reliable and clean power source on the grid. The ability to expand the use of hydroelectric power is, however, limited by a variety of environmental and social factors. Hydropower dams inundate low-lying areas and impact fish migration, water supplies, and aquatic ecosystems. Additionally, up-front capital costs for a large hydropower station are very high.

For these reasons, the EIA does not expect hydroelectric power to grow in the United States for the foreseeable future. By 2030, the EIA projects that hydroelectric power will account for about 5% of U.S. electricity generation. On the other hand, some analysts believe that small hydroelectric power plants, which use the flow of stream water without the need for dams or reservoirs, might be suitable for some areas. A recent DOE report estimates that development of small hydropower resources could provide 3% of U.S. power needs (USDOE-EERE Wind and Hydropower Technologies Program 2006).

Ocean Energy

Inventors have devised various methods to harness the energy in the ocean, including wave power, ocean thermal energy, and tidal energy. Wave power systems involve floats and buoys that drive turbines, pumps, or motors to produce electricity. Compared to solar and wind generators, wave systems can generate consistently high power from relatively small units. Because most wave power demonstrators have been damaged by rough seas, however, entrepreneurs and researchers are focused on improving durability. Researchers envision “wave parks” of floating buoys several miles off-shore, covering a small portion of the Nation’s coastline, which could supply perhaps 1–2% of the Nation’s electricity. Some experts believe that wave power could eventually supply 10% of the world’s electricity needs (World Energy Council 2001). The long-term potential of this technology justifies continued research.

Two other ocean energy technologies could contribute to global power needs. Ocean thermal energy conversion (OTEC) systems use the heat differential between the upper and lower depths of the ocean to create steam, which drives an electric generator and provides desalinated water. OTEC systems are most suitable for equatorial waters, particularly in locations where fresh water is not abundant. For example, the U.S. Navy is working with a private developer to build a 7-MW OTEC power/desalination plant for its Diego Garcia Base in the Indian Ocean.

Tidal energy systems, appropriate for areas with a high range of tides, use a dam with a sluice that opens during high tide and closes during low tide to direct the water to a hydroelectric generator. La Rance tidal energy station in France generates 240 MW during its low-tide power cycle. Although there are very few suitable locations in the United States, researchers have identified a number of bays and inlets in Canada, South America, Asia, and northern Europe for which tidal energy would be an economic option.

Distributed Generation

Small, modular electricity generators can supply a building or manufacturing plant with clean, reliable, and high-quality power for primary or backup supply. Distributed generation technologies generally improve the energy efficiency of a power system both because the generators are highly efficient (especially when used to co-generate heat) and because they avoid the transmission and distribution losses associated with utility-supplied power. Technologies for distributed electricity generation include stationary fuel cells, gas microturbines, combined heat and power systems, wind turbines, solar cells, and small biopower units.

Stationary fuel cells incorporate a reformer that accepts natural gas, propane, kerosene, or gasified biomass as the input fuel. The fuel cell combines hydrogen from the input fuel with oxygen to generate electricity at efficiencies up to 60%. With waste heat recovery, the total system efficiency can reach 70%. Hundreds of these systems have been installed to provide distributed power to commercial buildings. With an inherently high operating efficiency, these systems generate much lower carbon emissions than grid-based power producers. Further technical innovations are needed, however, to reduce cost and improve durability. Continued technical progress could make stationary fuel cell systems, as well as other distributed generation technologies, broadly competitive as efficient, on-site power sources for commercial (and perhaps residential) buildings.

Carbon Sequestration and Management

Power plants generate undesirable greenhouse gases as well as EPA-regulated pollutants. Most power plants require flue-gas scrubbers or other equipment to remove sulfur dioxide, nitrogen oxides, and mercury emissions from exhaust gases. Carbon emissions are also a growing concern, and new technical measures are required to address this concern. As Figure I-2 shows, almost 40% of the CO_2 generated by fossil fuels in the United States is a by-product of electricity generation.

If CO_2 emissions were regulated, coal gasification plants with IGCC technology could provide a feasible option for capturing carbon. It is estimated that IGCC carbon capture and underground sequestration would add about two cents per kWh to the cost of electricity generation (IPCC 2005). Much of this cost increment results from the energy losses incurred in the removal and processing of the carbon. To demonstrate the effectiveness of the IGCC process with carbon capture and storage technology, DOE has established the FutureGen partnership with private sector utilities to build a 250-MW coal gasification plant that will produce near-zero emissions.

An option to reduce the majority of CO_2 emissions from existing plants is to retrofit them with carbon capture equipment. Entrepreneurs are developing commercial systems that use absorbers at the exhaust of a coal plant to remove carbon from the flue gas streams with a chemical process. Once captured, the carbon could be sequestered in a geologic formation — such as a saline aquifer, salt cavern, or other subterranean cavity — or used in a marketable product.

For carbon sequestration, a key research issue is to ensure that the stored CO_2 will not leak into the atmosphere, either as a slow migration or as a sudden release, which could be dangerous. Researchers are working to characterize and identify desirable sequestration sites. The potential capacity for geologic storage of carbon emissions from coal power plants within the United States has not yet been determined, but it is probably the equivalent of a century or more of storage for all carbon emissions from U.S. coal plants (USDOE-FE 2005).

Another option for disposing of captured carbon is to use it in products such as building materials, fuels, packaging, or carbonation. Already, CO_2 is used in many locations to boost the productivity of oil wells through enhanced oil recovery. In these approaches, profitable processes compensate for the cost of capturing the carbon. There are two challenges associated with this approach. First, CO_2 users must be located near the power plants that produce and capture the emissions. Second, the volumes of CO_2 produced by the electric power sector far exceed the capacity of current markets to use it. Still, such opportunities could be essential to the economic development of carbon sequestration and should be explored. Advanced concepts such as biological conversion of CO_2 into fuels also merit research efforts to investigate their feasibility on a large scale.

Transportation

The Nation's transportation systems consume two-thirds of the total U.S. oil supply, slightly more than the amount of U.S. oil imports. Both the Federal Government and the private sector have a strong interest in opportunities to boost alternative fuels and more efficient transportation systems. As described below, PCAST has concluded that a significant transition to advanced fuel and vehicle technologies will become increasingly feasible. Widespread adoption of new technologies — biofuels, unconventional fossil fuels, electric propulsion, and other efficient vehicle technologies — could reduce the Nation's dependence on foreign oil by perhaps 70% by 2030, compared to EIA projections.

Renewable fuels such as ethanol and biodiesel could displace a significant portion of the petroleum used by cars and trucks. Cellulosic biofuel refineries, which require much less fossil fuel input than today's ethanol processes, are nearing commercialization. The economics of biofuels appear compelling and should remain so as long as the price of oil remains above $40 per barrel. Though biofuels currently represent only about 2% of U.S. transportation fuels, this proportion could rise dramatically in coming decades. Based on an analysis of available lands, a recent Federal report (USDA/DOE 2005) estimates that crop residues, logging residues, wood waste, and new plantings of perennial grasses could produce over a billion tons per year of biomass. With a biomass production and conversion infrastructure on this scale, biofuels could eventually provide 30% or more of U.S. transportation fuels (USDA/DOE 2005). Even in the near term, biofuels offer a feasible opportunity to displace a portion of the Nation's oil consumption in a more environmentally responsible way.

About 8% of the Nation's oil is used for aviation (EIA-DOE 2006b). Because of severe constraints on the energy density of aircraft fuel, the aviation sector will likely maintain its exclusive reliance on fossil-based fuels for the foreseeable future. Similarly, heavy-duty vehicles, which account for about 20% of transportation fuel consumption (EIA-DOE 2006b), have unique operational factors that limit the value of alternative fuels and drive systems. Biodiesel is probably viable only as a niche product, because production above perhaps a billion gallons per year (0.3% of U.S. oil consumption) would compete with the food supply (USDA/DOE 2005). For aviation and heavy-duty applications, therefore, unconventional fossil fuels may be the best alternative to petroleum. PCAST estimates that by 2030 a combination of coal-derived fuels, tar sands, and shale oil could replace one-third of the projected diesel and jet fuel supply using advanced, environmentally acceptable processes to convert these feedstocks into fuels.

Electric drive technologies could significantly reduce oil dependence by shifting the primary fuel source from petroleum to electricity generated from coal, natural gas, nuclear, and renewable feedstocks. For example, electric-powered mass transit systems such as light rail trains offer an efficient alternative to automobiles for commuting within and between metropolitan areas. Additionally, improvements in the cost and energy density of storage devices such as batteries and supercapacitors could, in the near term, enable commercially attractive "plug-in" hybrid vehicles that operate on battery power alone for everyday trips. Eventually, this could lead to mainstream use of all-electric propulsion systems, which are already commercially available in specialty vehicles that can travel up to 250 miles on a single charge. Beyond 2020, hydrogen fuel cell vehicles may become competitive with conventional vehicles. PCAST analysis indicates that a combination of these technologies could save as much as 2 million barrels per day of oil by 2030.

The electric motor will not soon displace the internal combustion engine, so other efficient vehicle technologies are needed. Today's conventional vehicles convert only about 20% of the energy in the fuel to power at the wheels. Efficient vehicle technologies, such as clean diesel engines, lightweight materials, low-friction tires, electric accessories, and turbochargers, could significantly improve fuel economy with no compromise in vehicle performance or functionality. While the EIA projects a 17% increase in the overall efficiency of the light-duty vehicle fleet by 2030 (EIA-DOE 2006a), PCAST members believe that technology advances could boost average vehicle efficiency by at least twice that much in the same time frame, leading to a 10–15% reduction in projected U.S. transportation fuel demand. The following paragraphs discuss transportation technologies in more detail.

Biofuels

The market competition between gasoline and biofuels dates to the early days of the automobile. Henry Ford originally designed the Model T to run on ethanol (Ford Motor Co. 2006), but oil became the preferred fuel for automobiles because of its lower cost. Today, it appears that biofuels — which include ethanol, various other alcohol-based fuels, pyrolysis oils, gasification fuels, and biodiesel — offer an excellent opportunity to reduce the Nation's dependence on oil. Ultimately, cellulosic biomass, including crops, grasses, wood products, and agricultural waste, could supply enough biofuels to replace a large portion of U.S. oil imports and significantly reduce projected greenhouse gas emissions from the transportation sector. Cellulosic conversion technologies are still in late stages of development, however, and less sophisticated technologies dominate the market.

In the United States, virtually all ethanol to date has been made from corn. Corn-based ethanol use has increased substantially in the United States, primarily as a blending agent to relieve smog in metropolitan areas. Since 1976, automobile manufacturers have warranted all passenger cars and light trucks for E10 fuel, which is a mixture of 90% gasoline and 10% ethanol. E10 is commonly used in many regions throughout the United States.

Fuels containing greater than 10% ethanol content can only be used in vehicles with upgraded engine components. Vehicles with these upgrades, which usually involve no extra cost to the consumer, are known as flex-fuel vehicles (FFVs). FFVs can run on either gasoline or E85, which is a blend of 85% ethanol and 15% gasoline. As a result of Federal incentives, about six million FFVs are in operation in the United States. Because many vehicle owners do not realize that their vehicles have flex-fuel capability, auto manufacturers have recently increased advertising of this feature. Domestic automakers have also announced plans to increase the percentage of FFVs to as much as 50% of production by 2012. A significant challenge is that most FFV drivers buy only gasoline, because few E85 fuel pumps exist outside the Midwestern States. The EPAct provides incentives for fueling station owners to add E85 capability.

Ethanol from corn has so far been the most successful renewable fuel in the United States, but improvements are needed. DOE estimates that corn ethanol produces about 36% more energy than it consumes in fossil fuels (e.g., natural gas used to produce fertilizer, fuel for harvesting and transportation, and energy used in the ethanol refinery) (USDOE-SCI/EERE 2006). The corn ethanol process uses only the starch, which is a small portion of the harvested crop. This limits the maximum potential of corn. Ethanol production consumed 20% of the 2005-2006 corn harvest, and this amount could double over the next five years. Besides affecting the food supply, increased demand for corn may raise concerns about impacts on soil erosion, nutrient runoff, and water use.

Ultimately, cellulosic biofuels could supply much larger quantities of fuel compared to corn ethanol. Cellulosic ethanol yields as much as ten times more energy output than fossil fuel input. This is because cellulosic conversion makes use of the cellulose and hemicellulose that comprise most of the plant material. If cellulosic technologies are perfected, a wide range of feedstocks could be used to produce biofuels, including perennial crops such as switchgrass and miscanthus, and grain crops such as corn, wheat, and soybeans. Crop residues, from rice and wheat stalks to corn husks, could also be used to the extent that the residues exceed what is needed for sustainable use, an amount that varies widely according to crop, region, and farm management practice. Cellulosic biomass could also be derived from paper pulp waste, logging residue, urban wood waste, and other organic materials.

Besides production efficiency improvements and feedstock diversity, cellulosic biofuels would reduce environmental impacts compared to corn ethanol. Optimized perennial grasses can greatly increase ethanol production per acre compared to corn ethanol, so land use would be much less of a constraint. Perennials require much less water and fertilizer and cause less soil erosion than do grain crops. Further, a recent meta-analysis estimated that cellulosic ethanol could reduce net CO_2 emissions by 85% compared to gasoline, whereas today's corn ethanol reduces CO_2 emissions by only 13% (Farrell et al. 2006).

Although no commercial-scale cellulosic ethanol refineries have been completed, several are in planning or early construction stages. Research, development, and commercialization efforts are focused on increasing crop yields, developing enzymes that can efficiently break down biomass feedstocks into sugar for fermentation, improving pretreatment and distillation processes, and optimizing biorefinery designs.

While cellulosic ethanol currently has the most interest among entrepreneurs and investors, other biofuels could eventually become more successful. A variety of processes have been developed to produce fuels from biomass, including thermal processes (gasification and Fischer-Tropsch synthesis), biological processes (fermentation), pyrolysis (anhydrous heating), transesterification (which produces biodiesel), and others. Researchers are developing production processes for methanol, butanol, dimethyl ether, propanol, heptanol, pyrolysis oils, and other biofuels that could offer efficiency and cost benefits compared to corn ethanol. BP and DuPont recently launched a joint venture to commercialize butanol as a fuel produced from sugar beets (Chase 2006). Butanol offers the advantage that its energy content is about the same as gasoline (by comparison, a gallon of ethanol has only two-thirds the energy content of the same amount of gasoline). Like other biofuels, butanol requires further development to demonstrate its commercial feasibility.

In order to optimize performance and cost within standard specifications, biofuels are often blended in varying proportions with petroleum products and, in some cases, with other biofuels. Because many of these fuels and processes have only been demonstrated on a small scale, it is not yet clear which blend of biofuels might offer the best alternative to gasoline and diesel. Key factors include cost, energy density, octane rating, storage and handling issues, and safety. Because FFVs are currently designed to operate only on gasoline or ethanol, other biofuels might require further flexibility in engine design. Therefore, PCAST encourages collaboration between biofuel producers, fuel suppliers, auto manufacturers, and standards organizations to ensure maximum fuel flexibility and efficiency at minimum cost to consumers.

For freight trucks and other heavy-duty vehicles, biodiesel from vegetable oils and cooking grease offers a viable alternative to conventional diesel fuel. Diesel engines can operate with up to a 20% blend of bio-derived diesel mixed with standard diesel fuel. Biodiesel blends are available today at hundreds of service stations.

Until large-scale refineries are completed, the costs and benefits of converting cellulosic biomass into fuels will not be fully understood or optimized. Nevertheless, some preliminary conclusions can be made. The following are some typical questions and answers regarding cellulosic ethanol; many of these conclusions would apply to other biofuels as well.

- **How many tons of biomass can be produced per acre of land annually?** Estimates range from five to twenty tons per acre. Variables include the quality of the land, type of biomass, cultivation methods, and environmental conditions. Biomass yields in excess of ten dry tons per acre, even on land that is not considered prime farmland, will likely be feasible in the near future as new bioengineering capabilities are employed. For example, switchgrass is a deep-rooted perennial that can sustain itself on lands that would not be considered acceptable for most food crops. Neutered versions of switchgrass, which do not reproduce from seeds, are being developed that can produce ten tons of biomass per acre while requiring much less fertilizer and water than what is used by food crops.
- **How many gallons of ethanol can be obtained from each dry ton of biomass?** Most experts estimate that the yield will be between 80–120 gallons per dry ton.
- **How expensive will it be to transport feedstock to the refinery?** High biomass yields per acre are critical to maintaining low transportation costs. For example, if the yield per acre is 10 tons of biomass, the ethanol yield would be around 1,000 gallons per acre (which is at the low end of ultimate expectations). This implies that a 100-million gallon refinery would require 100,000 acres to grow its feedstock. In a best case scenario, this could mean transporting material an average of about 10 miles, which would translate to a cost of about $0.25 per gallon of ethanol. If the yield per acre were only five tons, 200,000 acres of land would be required to grow the energy crop, and transportation costs would rise by at least 50%.
- **How costly will it be to convert feedstock to sugar and to ferment and distill the sugar into ethanol?** The refinement of biomass to ethanol requires first breaking down the feedstock material into sugars through a process known as hydrolysis. The sugars can then be fermented to produce ethanol. Cost-effective hydrolysis of cellulosic biomass requires special enzymes. Largely through DOE sponsorship, researchers have recently developed enzymes for hydrolyzing switchgrass and wheat at a cost of under $0.20 per gallon. Optimized enzymes will need to be developed for many other biomass feedstocks. In addition, researchers are investigating plant varieties that lend themselves more easily to hydrolysis. This is an area where there will undoubtedly be considerable progress in coming years.

An ethanol production facility in Missouri (left). Emily Heaton, Manager of Energy Crop Product Development at Ceres, Inc., stands next to a field of miscanthus on the Caveny farm in central Illinois (right). The biomass shown is one year's growth; scale markings are in feet. (Courtesy of John Caveny)

- **How would the ethanol be transported to its point of use?** While there is some controversy on this point, most experts agree that today's pipelines will not be suitable for transporting ethanol without an expensive upgrade, although pipelines may be able to handle other biofuels. Current cost estimates assume that the ethanol will be shipped by truck or rail to distribution points.

- **What will be the environmental impact of significant increases in crop production for fuel?** Most crops require fertilizer, pesticides, and herbicides, which can lead to nutrient runoff into waterways and contamination of surface groundwater. Increased water use can stress local aquifers. Additionally, if not properly managed, growing food crops can lead to soil erosion. Perennial crops such as switchgrass use much less fertilizer, pesticides, and water than annual crops, but large-scale plantings would likely involve land-use changes that could impact biodiversity and the availability of lands for recreational activities. These issues need to be carefully evaluated and managed.

- **How soon will cellulosic ethanol be commercially feasible?** DOE projects that the finished product cost of ethanol will be reduced from about \$2.25 per gallon today to about \$1.10 per gallon by 2020 (DOE-EERE Office of the Biomass Program 2005). Some entrepreneurs believe that costs below \$1.50 per gallon will be achieved before 2010 for widely available, domestic feedstocks.

Corn ethanol can provide significant near-term benefits. For example, in the United States, about one-third of gasoline sold is E10, which reduces smog-forming emissions in metropolitan areas. If E10 were used throughout the United States, ethanol production would increase from its current level of nearly 6 billion gallons to about 14 billion gallons. Given EIA projections that gasoline consumption will increase from 139 billion gallons in 2006 to 153 billion gallons in 2012 (EIA-DOE 2006d, Table 10), an 8 billion gallon increase in ethanol output by 2012 could replace 57% (by volume) of the expected increase in annual gasoline consumption over that time period.

While this report focuses on opportunities to reduce oil use in the transportation sector, it should also be noted that 25% of oil consumption in the United States is for the manufacture of chemicals, plastics, hydraulic fluids, pharmaceuticals, and other industrial products (EIA-DOE 2006d, Table 10). Biomass feedstocks can supply the raw materials for processes and products that replace petroleum. For example, corn starch can be used to produce bioplastics. Soybeans are used to produce a polymer for carpet backings. Research programs in DOE and USDA seek to expand the range of products derived from organic materials. A large market for these products could accelerate private investment in biorefineries and contribute significantly to rural jobs and income.

In 2007, the Indianapolis 500 motor race will be fueled by ethanol.

Expanded use of biofuels can also support international development objectives. Biofuels from energy crops could become an important export commodity for developing nations. Additionally, widespread adoption of cellulosic biofuels would benefit the global environment because of the low-net-carbon emissions over the full cycle of crop growth, harvesting, production, and use of biofuels.

PCAST has concluded that of all the emerging technologies studied in this report, biofuels offer the greatest promise for advancing, in the relatively near term, the twin goals of reducing oil dependence and significantly reducing carbon emissions from the transportation sector. As electric-drive vehicles become more common, they could also have a significant impact on national energy security, but those developments are not as imminent. A major shift toward biofuels would be a welcome change in the Nation's energy use.

Synthetic Fuels

Chemical processes can convert coal (or natural gas) to liquid fuels. Following the invention of the Fischer-Tropsch process in Germany in the 1920s, coal-to-liquid (CTL) fuels have been proven to be a commercially viable alternative to petroleum. Sasol, a South African company, provides almost 30% of that country's liquid fuel needs through coal conversion. In a high-oil-price scenario, the EIA projects that CTL and gas-to-liquid fuels could provide 32% of the U.S. distillate fuel supply, displacing nearly 2 million barrels per day of oil (EIA-DOE 2006a).

Conventional CTL processes require more energy and produce more carbon emissions than do the petroleum refining processes. Cleaner, more efficient CTL processes have been developed but have not yet been demonstrated on a commercial scale. One concept that might prove attractive in the future is an integrated energy complex that accepts biodegradable waste, energy crops, and coal as input, captures carbon in the conversion process, and produces a commercially optimal combination of synthetic fuels, hydrogen, electric power, process heat, and petrochemicals. A portion of the captured carbon could be used in the manufacture of saleable products. Whether or not this concept becomes reality, more flexible energy production and distribution systems that make use of feedstocks other than petroleum will be needed in coming decades to meet domestic and global energy needs.

Efficient Vehicle Technologies

As shown in Figure I-1, only about 25% of the energy input to the transportation sector is converted to useful work. Over the years, many efforts have been undertaken to improve transportation efficiency. Between 1979 and 1985, largely as a result of the improvements in automobile performance mandated by the government's Corporate Average Fuel Economy (CAFE) standards, per capita oil consumption in the United States fell from a high of 31 barrels per year to just under 25 barrels per year. New technologies such as closed-loop carburetor control contributed to this improvement. Today, many cost-effective vehicle efficiency technologies have become available to manufacturers, but over the past decade these have mostly been applied to boosting vehicle performance and weight rather than fuel economy (USEPA-OTAQ 2006). Hybrid electric systems are widely available, currently used in about 1% of new cars and trucks, but there are many other options available for increasing vehicle fuel efficiency.

One of the most effective means of improving a vehicle's fuel economy is to reduce its weight. A 10% reduction in a vehicle's weight can yield a 6% improvement in fuel economy, assuming other features of the vehicle remain unchanged. Virtually every component in a vehicle is a candidate for replacement or redesign with lighter materials. Iron and steel, because they are inexpensive, easily formed and joined, and recyclable, remain the dominant structural materials in new vehicles, comprising approximately 64% of their weight. With new materials and process technologies, manufacturers could switch to high-strength steel, aluminum, or magnesium which, because of their superior strength and stiffness, offer 25% to 50% weight savings with equivalent strength compared to conventional steel. Increasingly, these lightweight materials are being used in vehicle engines, bodies, and chassis, and they will become more common as the associated casting and metal-working technologies develop. Polymers and carbon fiber composites can also provide up to 50% weight savings relative to steel, while improving manufacturability and safety. Nevertheless, high-strength composites have yet to be broadly adopted by industry because of the high cost and limited availability of materials, complex manufacturing processes, and operator training requirements. Researchers are developing advanced process technologies that can help address these issues.

Diesel engines offer another opportunity to improve vehicle efficiency by as much as 30%. While most heavy-duty vehicles have diesel engines, these have not been popular for cars and light trucks in the United States. In Europe, half of all new passenger vehicles are diesel fueled, but they do not meet U.S. air quality standards. Additionally, diesel engines are more expensive than gasoline engines, and diesel fuel is not as widely available as gasoline. Technology improvements could resolve these issues and enhance the commercial prospects of diesel automobiles. In fact, several manufacturers have announced plans to introduce luxury cars in the U.S. market with clean diesel engines that meet EPA air quality standards and provide improved fuel efficiency.

Automakers have developed a number of other vehicle technologies that can enable significant improvements in fuel efficiency, assuming constant performance. These include continuously variable transmission, engine supercharging and turbocharging, variable valve timing, cylinder deactivation, aerodynamic design, integrated starter/generator, and low-resistance tires. Many of these technologies are already available in some production vehicles. Integration into a wider range of models would likely be welcomed by consumers, especially if the price of gasoline remains high. Analysis by the National Research Council (2002) indicates that various combinations of available technologies could reduce the fuel consumption of an average vehicle by about one-third at an estimated production cost of several thousand dollars.

Next-generation vehicle efficiency technologies include cam-free valve actuation, variable compression ratio, intake valve throttling, and 42-volt electrical systems. Many of these have been demonstrated in specialty vehicles and could be incorporated into mainstream cars and trucks in the next few years.

Researchers are also aiming to improve the traditional internal combustion engine. For example, homogenous charge compression ignition is a concept that could enable a diesel-like engine to combine high efficiency with very low emissions. Also, thermoelectric materials are being developed that can generate electric power from the waste heat of an engine. Solid-state thermoelectric devices built from nanoscale superlattice materials have demonstrated 20–30% energy recovery efficiency, which could enable up to a 10% improvement in vehicle fuel economy. New types of thermoelectric devices might boost heat recovery efficiency even further.

Advanced Hybrid Electric Vehicles

Hybrid electric vehicles (HEVs) are capable of storing the vehicle's braking energy, as well as excess energy from the engine, in a battery pack. In conventional HEVs, the internal combustion engine supplies all of the energy for powering the vehicle. New technologies could change this paradigm. With expected cost reductions in energy storage, "plug-in hybrids" could become widely available. These vehicles would be charged at home and driven for a short range — perhaps twenty miles — on pure electric power, after which the vehicle would operate like a regular HEV. Further advances in energy storage could extend the electric range of plug-in hybrids to forty miles or more, which would enable most daily trips to be powered by electricity alone (USDOT-BTS 2005). The gasoline engine would then be used only for longer driving distances.

Successful commercialization of plug-in hybrids could ultimately lead to mainstream commercialization of vehicles fueled only by electricity, which is produced from mostly domestic sources. Because of the high efficiency of an electric propulsion system, the cost per mile of powering a vehicle with electricity is much lower than with gasoline. Plug-in hybrids and electric vehicles (EVs) would normally be charged during off-peak hours, when spare electricity generation capacity is available. For this reason, a major expansion of the electric power infrastructure will probably not be needed to support these vehicles until there are tens of millions of plug-in hybrids and EVs in the United States (EPRI 2005). Eventually, plug-in hybrids and EVs might even become an integral part of the grid, supplying energy during peak demand periods and storing power during off-peak hours. This would reduce peak generating capacity requirements and would increase the value of off-peak generation from intermittent renewable sources such as wind power. Another potential benefit of EVs is that emissions from power plants are more easily captured than are vehicle emissions.

Solid-state headlights using light-emitting diodes (in development) could improve vehicle efficiency. (Courtesy of Visteon Corporation)

In the 1990s, General Motors developed and marketed an electric vehicle, named the EV1, which had a maximum 120-mile range using nickel metal hydride batteries. Recently, entrepreneur-led companies (e.g., Tesla Motors, AC Propulsion, Phoenix Motorcars, and Hybrid Technologies) have introduced EVs that use longer-range, lithium battery technologies. For example, Tesla Motors produces a high-performance roadster that it claims can travel up to 250 miles on a single charge. Because of their high prices, small interiors, and long charge times, today's EVs are mostly aimed at niche markets. Fundamental challenges in battery cost, cycle life, size and weight, and charging requirements must be overcome before EVs will be practical and affordable for most consumers. In the meantime, moderate improvements in energy storage may enable affordable plug-in hybrid vehicles. Advanced energy storage could also contribute to the commercial feasibility of hydrogen fuel cell vehicles, which will likely require batteries or supercapacitors to minimize the size and cost of the fuel cell stack.

Fuel Cell Vehicles

Fuel cells convert a fuel, such as hydrogen, to electricity, which can be used to drive an electric motor in a vehicle. Fuel cells produce no emissions and provide very efficient energy conversion. For these reasons, even accounting for the production of hydrogen, use of fuel cell vehicles would reduce fossil fuel consumption and carbon emissions relative to conventional vehicles. Fuel cell vehicles might offer better performance and range than EVs, because hydrogen can be stored at greater energy densities than can electricity in present-day batteries. For a vehicle with a 300-mile range, however, hydrogen storage systems remain too expensive, large, and heavy. Additionally, fuel cell vehicles do not yet meet requirements for cost, performance, and durability. The cost of production and distribution of hydrogen is another challenge. As part of the President's Hydrogen Fuel Initiative, DOE is funding research to improve these parameters. DOE and industry teams are conducting a test of sixty fuel cell vehicles with driving ranges between 120 and 225 miles, operated and fueled under real-world conditions. In the near term, fuel cells may become cost-competitive for portable electronics and for stationary power applications such as commercial office buildings.

Transportation Summary

The transportation sector of the economy is likely to undergo fundamental changes over the next twenty-five years. Given expected technology advances, the U.S. transportation fuel supply could shift from only 3% nonpetroleum fuels today to a much larger percentage of biofuels, such as ethanol and biodiesel, by 2030. Ultimately, biofuels could displace over one-third of transportation fuel. Unconventional fossil fuels, such as coal-to-liquid fuels, could displace a large portion of conventional diesel fuel. Additionally, it is likely that the internal combustion engine will be assisted or even replaced by electric-drive systems. Even without an electric drive, efficient vehicle technologies could raise average light-duty vehicle efficiency by at least 35%. Altogether, successful commercialization of these technologies could reduce projected oil imports by as much as 70% by 2030.

Energy Storage

The availability of high-capacity, low-cost energy storage would make many advanced technologies more attractive to a broad market. Solar and wind systems with sufficient amounts of energy storage could provide power on demand. EVs could replace gasoline-fueled vehicles for many consumers. Parked EVs could even plug in and provide distributed energy storage to the electric grid, reducing peak-load generating requirements.

High-capacity energy storage is not yet economical for most applications. The most common electric energy storage device is the battery. In the past decade, research and development efforts have roughly doubled the performance of batteries (NRC 2004b). Although they remain too expensive and bulky for many transportation and electric power applications, work is ongoing to address these barriers. Other energy storage technologies are also available or in development, including supercapacitors, kinetic energy systems (e.g., flywheels), chemical energy storage (e.g., hydrogen), thermal energy storage, and potential energy storage.

The development of new battery, supercapacitor, and related technologies could change the economics of distributed or even grid-based generation systems that use solar and wind energy. In combination with efficient energy storage, renewable energy systems could store and dispatch electricity over a period of hours, providing load-leveling capacity as needed by electric grid managers. With this capability, renewable energy could reliably supply intermediate load power for the grid.

Advanced Batteries

A battery uses an electrochemical reaction to produce electrons, which power the electric circuit connected to its terminals. The voltage at these terminals is a function of the electrode and electrolyte materials within the battery. The very first batteries were constructed of layers of zinc, paper soaked in salt water, and silver — the so-called voltaic pile. Lead acid batteries, invented in the early 20th century, still power the engine starter on virtually all automobiles.

Advanced chemistries and electrode structures are improving the cost and performance of batteries. Most HEVs use nickel metal hydride (NiMH) batteries. Lithium-ion batteries are commonly used in portable electronics such as cell phones, laptops, and digital cameras. Lithium-ion batteries have captured about 75% of the rechargeable battery market, despite their significant (roughly 80%) cost premium over NiMH batteries. The advantages of lithium-ion technology over NiMH are its more than double energy storage capacity and its 80% lighter weight in a comparably sized battery package.

Several companies are developing lithium battery packs suitable for HEVs. Eventually, these could enable commercially feasible plug-in hybrids. The standard Toyota Prius has a 1.2 kWh NiMH battery pack that retails for $3000 and provides a pure-electric range of about three miles (although the vehicle software does not allow the battery to operate without the engine for this distance). At this price, a plug-in hybrid with a 20-mile pure-electric range would require a $20,000 battery pack. Using the best available technology today, this battery pack would weigh at least 200 pounds, would require several hours to fully charge, and might need replacement several times over the life of the vehicle (USDOE-EERE Office of FreedomCAR and Vehicle Technologies 2006). Other technical challenges for vehicle battery packs include durability and safety (USDOE-NREL 2006). Research is needed, therefore, to develop more cost-effective and practical energy storage. Major improvements in battery technology could ultimately lead to mainstream commercial development of all sorts of EVs.

Supercapacitors

A supercapacitor (also known as an ultracapacitor) combines charge storage on conductors with electrochemical storage. Attractive features of supercapacitors include rapid charge and discharge, high efficiency, high power density, and long life. These characteristics are excellent for handling transient power flows, such as supplying acceleration energy and storing regenerative braking energy in an HEV.

Today's supercapacitors are generally much larger in size than batteries with similar storage capacity, and thus are not suitable for plug-in hybrids or EVs. By exploiting nanoscale material characteristics and novel electrolytes, however, researchers are developing high-energy supercapacitors that may become a competitive option for vehicular energy storage. Supercapacitors could enable an all-electric vehicle to be fully charged in under ten minutes, compared to a full-charge time of several hours for the best batteries available today. Additionally, supercapacitors are being designed to augment the performance of batteries in stationary, uninterruptible power supplies.

Flywheels

Flywheel systems store kinetic energy by accelerating a rotating mass to a very high speed. Flywheels can provide regenerative braking in vehicles as well as load-leveling for large mechanical systems. Advanced flywheels, which use composite materials and magnetic bearings, can provide energy densities equivalent to NiMH batteries. Compared to batteries, flywheels provide longer life, less susceptibility to temperature differences, greater transient power, shorter recharge times, and more reliable charge measurements. Prototype flywheel systems have been developed for electric and hybrid vehicles, but cost and safety issues have prevented widespread commercialization of this technology.

Hydrogen

Hydrogen is the most common element in the universe, but it does not exist on Earth in pure form. Thus, energy is required to extract hydrogen for use as an "energy carrier." Hydrogen can be used as a fuel for fuel cell vehicles or stationary fuel cells. Hydrogen fuel cells produce electricity with only water and heat as by-products. Fuel cells do not emit smog-producing pollutants such as nitrogen oxides. Some experts envision an energy infrastructure in which hydrogen and electricity serve as energy carriers for most applications. In this scenario, hydrogen would supplant petroleum as the dominant transportation fuel and would provide distributed power and heating for residential and commercial buildings, displacing natural gas. This outcome would yield significant energy security and environmental benefits if the hydrogen is derived from renewable sources, nuclear energy, or coal gasification plants with carbon capture and storage, all of which produce very low atmospheric emissions.

Future technology could enable new means of hydrogen production. Some advanced nuclear reactors operate at temperatures sufficiently high (up to 1,000°C) to enable efficient production of hydrogen from water. Researchers are also investigating photoelectrochemical processes that could use sunlight to convert water directly into hydrogen and oxygen. In addition, coal gasification power plants could produce hydrogen and electricity simultaneously (Bylinsky 2005).

Fuel cell vehicles will require a cost-effective, high-density hydrogen storage system. Existing storage technologies, which involve either compressed or liquefied hydrogen, are not yet able to meet market requirements for cost, energy density, reversibility (ability to easily absorb and release hydrogen), and long-term storage. Thus, researchers are investigating new materials such as carbon-based or other porous solids, metal hydrides, and chemical hydrides that could improve these parameters. Chemical hydrides, such as sodium borohydride or organic liquids, would react in the vehicle fuel tank to provide hydrogen when needed, leaving a by-product that could be retrieved and recycled at fueling stations or at a central plant. To date, however, none of these options meets all of the criteria for a commercially viable fuel cell vehicle, so DOE has established an aggressive research program to improve hydrogen storage cost and performance.

Hydrogen as a fuel appears to hold great promise because of its availability and its potential environmental benefits. Efforts should continue to develop low-cost production, storage, and distribution of hydrogen. PCAST also recommends that studies be funded to confirm the current understanding that the release of large amounts of hydrogen into the atmosphere would not have deleterious effects.

Thermal Energy Storage

Because 40% of the primary energy produced in the United States is consumed as heat in buildings and industrial processes, and because sunlight provides a widely available but intermittent form of heat, thermal storage can expand opportunities for solar energy use. For example, large-scale thermal storage can be provided by heat reservoirs of crushed rock, adobe, or concrete. Thermal storage can also be used in small applications such as solar water heating or refrigeration powered by off-peak electricity. Another type of thermal energy storage has been designed specifically for concentrating solar power systems. Because most CSP designs use a high-temperature heat transfer fluid such as steam, oil, or molten salt, an auxiliary reservoir could store the heated fluid to produce electricity (via a turbine generator) at a later time, as needed by the electric grid. This would significantly improve the economic value of CSP generators. Overall, thermal energy storage technologies merit further investigation to evaluate their feasibility for commercial use.

Potential Energy Storage

Pumped hydroelectric power and compressed air systems provide storage of potential energy for electric utilities. They are typically used in conjunction with low-cost generators such as nuclear power plants, which have a very low marginal cost of generation during off-peak hours. Potential energy storage systems contribute to the efficiency of the electric grid by consuming excess power generated during off-peak hours in order to augment the utility's reserve of intermediate and peaking load power, which otherwise would be provided by high-cost generators during daytime hours. In theory, potential energy systems could also be used to capture and smooth the variable power generated by wind farms, improving the value of these intermittent sources.

Several dozen pumped hydroelectric systems in the United States supply, in total, up to 5,500 MW of electric power during peak hours. An example is the Helms hydroelectric facility in California, which is operated by the Pacific Gas & Electric Company (PG&E). Water flows through the generators during the day to produce power for PG&E to dispatch to the grid. At night, when demand for electricity slackens, water is pumped back to the top of the dam using power from PG&E's Diablo Canyon nuclear facility. The next day, the water is released once again to generate power.

Compressed air systems, of which only one is currently operational in the United States (rated at 110 MW for six hours), store high-pressure air in an underground rock or salt cavity. When needed, the air is released to drive a gas turbine generator, in a cycle similar to pumped hydroelectric power systems.

Energy Efficiency

Figure I-1 indicates that the Nation's energy system produces 42.8 quads (quadrillion Btus) of useful energy while creating 55.1 quads of lost energy. Based on these numbers, less than half of U.S. primary energy consumption is reaching the actual, intended end uses (e.g., hot water, light bulbs, power at the wheels of a vehicle, etc.). This is mainly due to low conversion efficiencies in electric power generation and the transportation sector. As discussed above, emerging technologies could improve these factors by 2030. New technologies could also improve energy efficiency in buildings, the electric grid, and industrial processes, which would reduce the demand for electricity as well as avoid the energy losses in power generation, transmission, and distribution that would otherwise be incurred to supply that power.

Building Efficiency Technologies

The building sector is the largest consumer of energy in the United States in terms of combined end-use and loss estimates. As shown in Figure I-1, residential and commercial buildings consumed 20.1 quads in 2005, or 21% of U.S. total energy consumption. Most of this energy was in the form of electricity. With the associated power generation losses, the building sector is actually responsible for 40% of the Nation's energy use and about 40% of U.S. CO_2 emissions (USDOE-EERE 2006). The carbon emissions in the building sector result primarily from fossil fuel combustion in electricity generation and heating.

Large-scale deployment of new technologies for efficient lighting, appliances, and building heating and cooling systems could significantly reduce electricity consumption in buildings. Partially as a result of these technologies, residential energy use per U.S. household has already declined by 17% since 1980 (USDOE-EERE 2006). For typical buildings, further energy reductions of 30% — along with financial savings after a pay-back period — are readily achievable with current technology (USEPA 2005). Over the past two decades, there have been a number of market successes in this arena, largely driven by Federal Government efficiency standards, including efficient refrigerators, "low-E" windows, electronic lighting ballasts, and high-efficiency furnaces. More successes are needed; as shown in Table II-2, over half of all appliances sold do not meet high-efficiency standards.

Several improved building technologies have been recently commercialized. More efficient window technologies are effective at insulating buildings during both summer and winter. Compact fluorescent lights, green building design tools, super-efficient heating units and air conditioners, passive solar lighting using fiber optics, and PV panels doubling as roof tiles are becoming widely available. Building-related innovations still in development include solid-state lighting, electrochromic windows, and solid-state refrigeration systems.

Market dispersion and fragmentation are key challenges for the buildings sector. Market forces operate imperfectly, and a cost-effective decision by normal standards may not be perceived as such by the builder and/or consumer. For example, efficient window technologies and efficient systems for air conditioners and boilers are often not specified by the architect or builder, even though the payback period may be only a few years, because the builder does not benefit directly from the buyer's long-term cost savings. An accelerated depreciation schedule for these technologies could help market acceptance. In most instances, however, the most effective policy tool has been for local building codes to call for energy-efficient design features in new and remodeled buildings. PCAST encourages State and local governments to consider opportunities to update building codes to incorporate energy-saving designs and products that will benefit both consumers and the Nation.

An earlier PCAST report (2003) praised the Energy Star program for alerting consumers to the lifetime cost of operating many household appliances and building materials. PCAST maintains its conclusion that Energy Star

Table II-2. North America Major Appliance Market, in million units

	2002	2003	2004	2005	2006	2007	2008
All Major Appliances							
Washing Machines	8.5	8.9	9.1	9.4	9.7	9.9	10.1
Fridge/Freezers	13.6	13.9	14.3	14.6	14.9	15.2	15.7
Dishwashers	6.7	6.9	7.2	7.4	7.6	7.8	7.9
Air Conditioners	6.3	8.5	8	7.8	8	7.9	8
Total	**35.1**	**38.2**	**38.6**	**39.2**	**40.2**	**40.8**	**41.7**
Low-Efficiency Appliances							
Washing Machines	7.3	7.2	6.9	6.5	6.0	5.3	4.6
Fridge/Freezers	10.5	10.1	9.7	9.0	8.2	7.3	6.5
Dishwashers	3.5	3.3	3.2	3.1	2.9	2.8	2.5
Air Conditioners	5.1	6.4	5.4	4.7	4.2	3.6	3.2
Total	**26.4**	**27.0**	**25.2**	**23.3**	**21.3**	**19.0**	**16.8**
High-Efficiency Appliances							
Washing Machines	1.2	1.7	2.2	2.9	3.7	4.6	5.5
Fridge/Freezers	3.1	3.8	4.6	5.6	6.7	7.9	9.2
Dishwashers	3.2	3.6	4.0	4.3	4.7	5.0	5.4
Air Conditioners	1.2	2.1	2.6	3.1	3.8	4.3	4.8
Total	**8.7**	**11.2**	**13.4**	**15.9**	**18.9**	**21.8**	**24.9**
Total, Major Appliances	**35.1**	**38.2**	**38.6**	**39.2**	**40.2**	**40.8**	**41.7**
% High Efficiency	24.8%	29.3%	34.7%	40.6%	47.0%	53.4%	59.7%

Source: Power Integrations, Inc., based on IMS Research data

contributes greatly to consumer awareness and suggests that the program expand its scope until all items that consume power or that affect power consumption carry an Energy Star rating.

Advanced Electric Grid

Over 5% of the electricity generated by power plants in the United States is lost in the Nation's transmission and distribution systems (USCCTP 2006). The heavily burdened power infrastructure in some regions also increases the risk of blackouts. Researchers are seeking to address these issues. For example, power transmission lines may be fabricated from carbon nanotubes with extremely low electrical resistance. High-voltage DC systems could boost the efficiency of long-distance power transmission and relieve congestion in the grid. Ceramic-core conductors and, eventually, high-temperature superconductors could replace standard transmission cables to relieve localized distribution bottlenecks. Also, improved software could optimize the flow of electricity between generators and loads in order to minimize power losses. Each of these innovations has the potential to improve the reliability and efficiency of the Nation's electricity transmission and distribution systems.

Courtesy of the National Science Foundation. Photo credit: Institut de Recherche d'Hydro-Québec

More effective use of renewable energy sources could augment conventional power generation capacity. For example, communication and control systems could improve the grid's ability to accept power from solar and wind generators, fuel cells, and other distributed energy sources. Increased use of net metering and time-of-use pricing could further improve the economics of distributed electricity generation. Many of these advanced technologies have been commercially demonstrated, so the current focus of the Federal and State governments is on policies to encourage deployment. Because these opportunities were examined by the 2003 PCAST report, this report will not discuss them in further detail.

Industrial Efficiency Technologies

The industrial sector is the most diverse energy-consuming sector in terms of both the types of energy services required and the mix of energy sources used to provide those services. On an end-use basis, the industrial sector accounts for about one-third of U.S energy consumption (including 37% of natural gas demand) and for 30% of greenhouse gas emissions (EIA-DOE 2006a). Over three-quarters of industrial energy is consumed by the heavy manufacturing sectors, including chemicals, petroleum refining, forest products (paper and wood products), primary metals (e.g., steel, aluminum, and castings), and nonmetallic minerals (e.g., cement and glass). The high intensity of energy use in these industries demands low-cost and efficient manufacturing processes to ensure that they can compete in the world market.

Advanced industrial technologies include waste heat recovery, combined heat and power, intelligent sensors and controls, and ultra-high-efficiency, low-emission burners. Several potentially transformational technologies are entering the marketplace, including cokeless ironmaking, isothermal aluminum melting, and laser-based sensors. Next-generation technologies under development include high-efficiency boilers, advanced paper drying, high-temperature and corrosion-resistant materials, alternative chemical processes, and submerged combustion melting. Additionally, fuel-switching technologies such as gasification could improve the flexibility of manufacturers to adapt to dynamic energy prices and supply issues. In general, these technologies could boost energy efficiency and reduce emissions while improving the competitiveness of the industrial sector.

PCAST Observations

This section has described a wide range of advanced energy technologies. Innovations in these areas present significant opportunities to reduce the vulnerability of the United States to energy disruptions and to contribute to a cleaner environment. In the view of PCAST, the most salient points from this section are as follows:

- **Electricity generation** is and will continue to be an important driver of the economy. Projected demand increases will require substantial growth in U.S. electricity generation capacity. Demand could further increase in the future if electric vehicles are widely commercialized. Advanced nuclear power technology presents a low-cost opportunity to produce large amounts of electricity with very low life-cycle emissions. Uranium fuel is readily available. Therefore, PCAST supports a renewed effort to develop nuclear power as a primary source of energy, with a goal at least to maintain its current share of national generating capacity over the next 25 years, leading to a more significant expansion of nuclear energy by 2050.

- **Non-hydroelectric renewable energy sources** are growing in their ability to compete with fossil-fuel-based electricity generation, especially in distributed applications. While renewable sources will not likely become a primary source of grid-based electricity in the next few decades, they could help to meet demand growth. With improved energy storage technologies, renewable generation (other than hydroelectric power) could supply 10% or more of U.S. electricity by 2030 and at least 20% by 2050. A key issue for renewable electricity sources, which often are best sited in remote areas, is access to transmission and distribution networks.

- **Biofuels** offer a near-term opportunity to significantly reduce the Nation's dependence on foreign sources of oil and thus to enhance national energy security. Croplands and forests, as well as lands not particularly well suited for food crops, need to be developed to grow biomass. Biofuel distribution issues must be resolved. Cellulosic conversion technologies need to be demonstrated for many feedstocks on a commercial scale. With these changes, biofuels could displace perhaps a third of transportation fuels by 2030.

- **Electric propulsion systems with advanced energy storage** could enable mainstream commercialization of plug-in hybrids and all-electric vehicles. This would be a key step in a large-scale shift of the Nation's primary energy sources from petroleum to electricity produced from clean, domestic feedstocks.

- By means of the above advances, together with coal gasification and carbon sequestration technologies, the ability to significantly **reduce greenhouse gas emissions** in a cost-effective manner appears to be on the horizon. Every effort should be made to encourage the adoption of systems to control greenhouse gas emissions.

- Finally, an examination of the Nation's energy production and use shows that **energy efficiency is a critical issue.** Many new technologies that improve building and industrial efficiency are coming to market. The Federal Government should expand policies to encourage faster adoption of these systems and components. Lighting, appliances, and HVAC systems are particularly well suited for upgrades to higher-efficiency products. Altogether, improvements in commercial, residential, and industrial energy efficiency could trim the projected rate of increase in U.S. electricity demand between 2006 and 2030 by at least 10%.

III. The Roles of Emerging Technology Companies

Introduction

In the information technology and biotechnology sectors, entrepreneurial companies have demonstrated a remarkable ability to convert fundamental research breakthroughs into marketable products. Many successful companies in these sectors received their first outside investment from a venture capitalist (VC). VCs often respond to an emerging trend by funding startup companies that seek to capture a new market with innovative products.

Recently, private equity firms and VCs have become very active in the energy sector. Entrepreneurs have launched over 100 companies in virtually every area of the energy sector, especially in renewable energy, fuel cells, and energy storage. Many of these companies have based their innovative products on the results of Government-sponsored research performed at public and private research institutions.

VC investment in advanced energy technologies is growing rapidly. In 2005, nearly $1B was invested in energy startups by VCs, in addition to $1.6B of investments in corn ethanol refineries by private equity firms. In 2006, VC energy investments are expected to more than double the 2005 level.

This section describes emerging (mostly U.S.-based) technology companies and their activities in many of the major technology areas identified in Section II. PCAST recognizes that any such review will inevitably be incomplete because of the number of new companies established each month, the diversity of technologies involved, and the incomplete knowledge of the authors. Nevertheless, the Council felt that providing specific examples of startup companies would be the best way to convey the enthusiasm for a new energy paradigm that has inspired many of these entrepreneurial efforts.

Solar Energy

Distributed solar power systems and their related components have attracted intense interest among entrepreneurs and private equity investors, resulting in many new developments and ideas. As discussed in the previous section, PCAST members do not believe that solar power will provide the bulk of the Nation's electrical energy requirements in the next few decades, but the level of entrepreneurial activity suggests that solar power, particularly for distributed applications, will continue to grow at a rapid rate — perhaps over 50% per year — in the near term. Thus, predicting its ultimate place in the electricity generation hierarchy is difficult.

Table III-1 lists some of the newly formed companies that are active in the solar power field (see Appendix A for further details). While many established companies (some of which are included in the text but not in the lists) also manufacture solar cells and systems, the new companies claim to offer PV cells with better conversion efficiencies and lower costs as a result of improved component design and production processes. Besides production of the cell itself, solar PV systems involve raw materials manufacturing, module assembly, inverter and power electronics manufacturing, and system installations. Both entrepreneurial and established companies are commercializing innovations that can improve one or more of these steps, as described in the following paragraphs.

Innovation Examples

Recent innovations may overcome the technical and business hurdles that have constrained solar PV market growth thus far, including the large capital costs for production capacity, manufacturing process limitations, the high cost of polysilicon and other critical feedstocks, and overall PV system cost and reliability. Based on new products in the pipeline, some startup companies believe that within five years solar power will be able to compete directly with utility-supplied power at 10 cents per kWh. In addition to system cost, entrepreneurs are focused on improving PV efficiency, which determines the maximum power of an installation of a given size, and product aesthetics, which influence consumer acceptance of solar PV systems. Specific innovations include

- **High efficiency.** Silicon-based solar cells with efficiencies as high as 22% are now being shipped by companies such as SunPower of San Jose, CA. For organic solar cells, Konarka Technologies and Solaris Nanosciences are working together to develop nanoscale metallic structures that increase efficiency by enhancing the absorption of photons.
- **Improved aesthetics.** HelioVolt has developed methods to apply a thin-film copper indium selenide solar cell coating to steel, metal, polymer roofing material, or architectural glass in order to custom-manufacture a variety of building materials with integrated PV capability. SunPower has developed an interconnect method that eliminates all protruding wires and connections from the surfaces of PV panels.
- **Low cost.** Many startup companies are exploring novel manufacturing techniques to reduce production costs and increase throughput while improving average cell efficiency. Evergreen Solar uses a novel manufacturing technique in which a thin sheet suitable for a PV substrate is continuously drawn from a silicon melt. This process minimizes silicon waste and boosts the efficiency of the PV cell. Miasolé, Energy Conversion Devices (ECD Ovonics), Innovalight, Nanosolar, and other companies have adapted roll-to-roll technology from the printing industry in order to manufacture thin-film solar PVs. This approach involves depositing nanoscale “silicon ink” or other materials onto flexible substrates so as to produce the desired characteristics.

Other solar PV cell technologies that are being commercialized include advanced thin-film alloys, multijunction concentrator cells, and novel quantum-effect devices. Which of these emerging products will achieve market success remains to be seen. The number of small enterprises competing in this field encourages the conclusion that distributed-power solar cells will eventually become a major source of electrical power for many applications.

Entrepreneurs are also developing concentrating solar power systems for both distributed and utility-scale power generation. For example, Energy Innovations, SolFocus, Solaria, and Pacific SolarTech are testing

Table III-1. Examples of Entrepreneurial Companies Developing Solar Energy Technologies

Company	Business or Products Offered
Advent Solar	Back-contact, ultra-thin silicon PV cells
Akeena Solar	Solar electric system installation
Amonix, Inc.	Utility-scale, concentrating PV systems
Atlantis Energy Systems, Inc.	PV roofing slates and PV glass laminates
CaliSolar, Inc.	PV cells from "dirty silicon"
DayStar Technologies	High-throughput manufacturing of thin-film PV "foil"
DEERS	Novel financing for roof-mounted solar systems
Energy Innovations	Roof-mounted or portable concentrating solar power systems
Energy Photovoltaics, Inc.	Amorphous silicon, thin-film PV modules
Entech Solar Inc.	Fresnel-lens-based PV systems for terrestrial and space applications
Evergreen Solar	PV modules based on low-cost "string-ribbon" manufacturing
Global Solar Energy, Inc.	Thin-film PV products to power portable electronics
HelioVolt Corp.	Rapid manufacturing of thin-film PV cells
Innergy Power Corp.	Integrated battery / PV solar modules
Innovalight, Inc.	Solvent-based "silicon nanomaterial" PV manufacturing
Konarka Technologies, Inc.	Nanostructured polymer PV cells
Miasolé	High-throughput thin-film PV manufacturing
Nanosolar, Inc.	High-throughput thin-film PV manufacturing
Nanosys, Inc.	Nanostructured polymer PV cells
Pacific SolarTech	Distributed and utility-scale concentrating PV systems
Powerlight Corp.	Roof-mounted and utility-scale PV systems
Practical Instruments, Inc.	Roof-mounted concentrating PV modules
Prism Solar Technologies, Inc.	"Holographic" concentrating PV modules
Silicon Genesis Corp.	Silicon-on-insulator process for high-performance PV
SkyBuilt Power	Mobile PV power stations
Solaicx	Low-cost, high-performance silicon PV wafers
Solargenix Energy LLC	Solar energy systems for commercial buildings and large-scale generation
Solaris Nanosciences Corp.	Dye-sensitized solar cells
SolFocus, Inc.	Roof-mounted concentrating PV systems
Solyndra	Thin-film PV cells
Stellaris Corp.	Integrated products with concentrating lenses on thin-film PV
SunPower Corp.	Roof-mounted PV modules
Stirling Energy Systems, Inc.	Concentrating solar dish-engine units for distributed or centralized power
Suncat Solar	Silicon PV modules
XsunX, Inc.	Thin-film solar PV cells integrated into building systems

concentrating PV generators. These products, which may soon be commercially available, could provide distributed power to large commercial buildings such as warehouses and retail stores.

In 2005, three solar PV companies — Q-Cells, SunPower, and Suntech Power — raised a combined $800M through public stock offerings. This level of support is undoubtedly influencing other investors to consider solar energy as an investment opportunity.

Biofuels

Recent investment activity in biofuels has been stimulated by the increase in oil prices as well as by the EPAct requirement that manufacturers blend at least 7.5 billion gallons of ethanol into U.S. fuels by 2012. As long as the price of oil remains above $40 per barrel, investors will likely continue to fund biofuel technology development.

Investors and large agribusinesses regard many feedstocks besides corn — such as switchgrass, miscanthus, wood, and waste products — to be potentially attractive sources of biomass. These groups are funding entrepreneurs with expertise in plant genomics, ethanol conversion processes, and distribution technology. Table III-2 lists some of the new companies in these areas (see Appendix B for additional information). There seems to be little question that biofuels are positioned for significant growth in the near future.

Biodiesel production, which is currently approaching 100 million gallons per year, has also attracted entrepreneurs and private equity investors. Biodiesel is a viable substitute for conventional diesel (petroleum distillate). Market challenges include the high cost of vegetable oil, which is the primary feedstock for biodiesel, and the competition with plantings of other food crops. These issues will likely prevent expansion of biodiesel production beyond a billion gallons per year, or roughly 0.3% of U.S. oil consumption (USDA/DOE 2005). Nevertheless, investors seem undeterred and, as seen in Table III-2, many biodiesel investments are being made.

The economics and commercialization of biofuels are heavily dependent on the price of oil. If the price of oil remains high, ethanol and biodiesel production will grow and become increasingly competitive. Currently, reformulated gasoline suppliers in metropolitan areas are increasing demand for ethanol, mostly for blending in E10 to meet clean air regulations. As a result, the price of the ethanol has not had to compete with the price of the fuel it replaces, and, in most places, ethanol is priced higher than gasoline. With ample availability of E85, however, consumers could compare the price of E85 at the pump against the price of conventional gasoline and make a choice. Investors in ethanol for this larger market believe that they will be able to compete as long as oil is priced above $40 per barrel. DOE estimates that by 2020, cellulosic ethanol might be produced for as low as $1.10 per gallon (USDOE-SCI/EERE 2006). (By comparison, the average production cost — not including distribution costs — of Brazil's cane-sugar-based ethanol is estimated to be about $0.75 per gallon.) It appears reasonable to expect E85 to become competitive with gasoline on a national scale within the next decade.

In the short term, the commercialization of E85 is hampered by both supply and distribution issues. The current limitations on ethanol supply could be resolved by reducing tariffs on imported ethanol from Brazil and other countries while the domestic infrastructure is built up to meet demand. On the distribution side, as mentioned earlier in this report, the EPAct includes incentives to expand the availability of E85 at fueling stations.

Table III-2. Examples of Entrepreneurial Companies Developing Biofuels Technologies

Company	Business or Products Offered
Abengoa Bioenergy Corp.	Cellulosic and corn (using entire kernel) ethanol refineries
Agrivida, Inc.	Optimized corn varieties for cellulosic ethanol production
Altra, Inc.	Ethanol and biodiesel production
American Biodiesel LLC	Biodiesel production
Amyris Biotechnologies, Inc.	Synthetic biology for high-performance biofuels
Aventine Renewable Energy, Inc.	Corn ethanol production
Badger State Ethanol LLC	Corn ethanol production
BioEnergy International LLC	Thermal gasification of waste for co-production of electricity, biofuels
Bioengineering Resources, Inc.	Thermal gasification of waste for co-production of electricity, biofuels
Bixby Energy Systems, Inc.	Biomass combustion products for industrial and residential heating
Celunol Corp.	Ethanol from agricultural waste and other cellulosic biomass
Ceres, Inc.	Optimized plant varieties for cellulosic ethanol production
ClearFuels Technology, Inc.	Fuels (ethanol, methanol, hydrogen) from agricultural crop waste
Codexis, Inc.	Biological catalysts — enzymes or fermentation strains
Diversa Corp.	Enzymes and small molecules with agricultural applications
Dogwood Energy LLC	Small- and industrial-scale ethanol and biodiesel production
Dyadic International, Inc.	Enzymes to convert biomass into biofuels
Ethanol Boosting Systems LLC	Ethanol fuel injection system to boost engine efficiency
Galveston Bay Biodiesel LP	Biodiesel fuels for off-road or on-road diesel engines
Hawkeye Renewables	Corn ethanol production
Iroquois Bio-Energy Co., LLC	Corn ethanol production
Mascoma Corp.	Improved enzymes, microbes, and processes for cellulosic ethanol
Methanotech, Inc.	Methanol production from biomass
NatureWorks, LLC	Polymers from renewable resources rather than petroleum materials
Novozymes, Inc.	Enzymes for making ethanol from corn stover
Seattle Biodiesel	Biodiesel production
ORYXE Energy Intl., Inc.	Biodiesel and petroleum additives
Pacific Ethanol, Inc.	Corn ethanol production and saleable by-products
Synthetic Genomics, Inc.	Optimized microorganisms for ethanol and hydrogen production
VeraSun Energy Corp.	Corn ethanol production
White Energy, Ltd.	Corn ethanol production

Innovation Examples

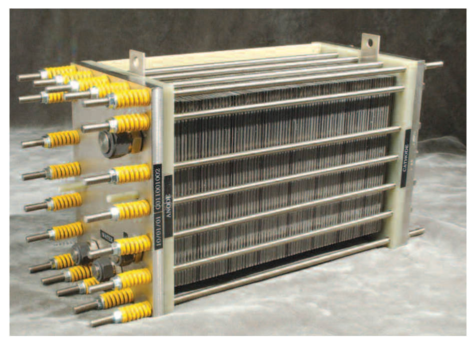
Ceres, Inc., of Thousand Oaks, CA, recently announced a collaboration with The Samuel Roberts Noble Foundation to develop and commercialize new and advanced biomass crops for ethanol production. Ceres is a plant biotechnology company that uses genomics to create unique plant varieties for conversion to biofuels.

Diversa, a San Diego-based enzyme manufacturer, has partnered with Syngenta to develop “enzyme cocktails” that can rapidly hydrolyze (break down into sugar) the cellulosic material in corn and corn stover (the remainder of the corn plant). Celunol Corporation of Dedham, MA, has engineered microorganisms that can ferment the entire range of sugars resulting from hydrolysis, significantly increasing the efficiency of ethanol production. Besides these companies, many other biofuel technology companies, such as those listed in Table III-2, have been established to compete in the huge transportation fuels market.

Fuel Cells

The potential benefits of fuel cells have generated much interest among major corporations as well as entrepreneurs. In the past decade, automotive and fuel cell companies have invested billions of dollars in an aggressive bid to move toward commercialization of hydrogen fuel cell vehicles. General Motors, Ford, DaimlerChrysler, Toyota, Honda, Nissan, Hyundai, and other manufacturers fund R&D to reduce the cost and improve the durability and cold-start capability of fuel cells. These R&D programs are funded either internally or in partnership with major fuel cell suppliers, such as United Technologies Corporation and Ballard Power Systems, and/or with the Federal Government. Several other companies, such as Hydrogenics, IdaTech, Nuvera Fuel Cells, and Plug Power, have been manufacturing mid-sized fuel cells for a number of years. Recent entrepreneurial efforts, on the other hand, are largely focused on small fuel cells for portable applications.

Innovation Examples



A stationary fuel cell manufactured by Plug Power. (Courtesy of Plug Power, Inc.)

Some of the new companies participating in the fuel cell market are listed in Table III-3 (see Appendix C for further information). Jadoo Power provides fuel cell systems for portable power applications such as video cameras and scooters. Using hydrogen stored in metal hydride canisters, these systems extend battery life with less weight than traditional batteries. Neah Power Systems has developed a porous silicon membrane for a direct methanol fuel cell. The design uses etching techniques derived from the semiconductor industry to increase the reaction surface area, thus boosting the power density to enable a long-life, cost-effective replacement for a laptop battery. Microcell builds miniature fuel cells out of extruded, cylindrical microfibers that integrate the electrocatalyst layers, the membrane electrolyte, and the current collectors. This design enables high-volume manufacturing, high power density, and customizable form factors.

Plug Power, IdaTech, and Hydrogenics have developed proton exchange membrane (PEM) fuel cells for stand-alone electric generators as well as for backup power for telecommunication systems. Nuvera Fuel Cells, Ballard Power Systems, Hydrogenics, and Oorja Protonics have designed PEM fuel cells to replace battery systems in forklifts, which could be a first step toward larger vehicle applications.

Hoku Scientific has developed microporous materials for the gas diffusion layer of a PEM fuel cell membrane, enabling it to maintain hydration at higher operating temperatures. PolyFuel has developed membranes based on a hydrocarbon (rather than a fluorocarbon) polymer that is lighter, cheaper, and more durable over a wide

Table III-3. Examples of Entrepreneurial Companies Developing Fuel Cell Technologies

Company	Business or Products Offered
Ardica Technologies	Micro fuel cells for portable electronics
Bloom Energy	Solid-oxide, regenerative fuel cells for load-leveling for renewable sources
CellTech Power, Inc.	Solid-oxide fuel cells with a broader range of input fuels
Enerage, Inc.	Micro fuel cells for portable electronics
Franklin Fuel Cells, Inc.	Solid-oxide fuel cells
HyEnergy Systems, Inc.	Hybrid battery/fuel cells for portable electronics
HyRadix, Inc.	Hydrogen reforming from natural gas
Jadoo Power	Portable fuel cell power systems
Lilliputian Systems, Inc.	Micro fuel cells for portable electronics
Microcell	Cylindrical PEM fuel cells for multiple applications
Neah Power Systems, Inc.	Micro fuel cells for portable electronics
Oorja Protonics	Micro fuel cells for portable electronics
PolyFuel	Nanostructured fuel cell membranes
Protonex Technology Corp.	Portable fuel cell power systems
ReliOn, Inc.	Modular, portable fuel cell power systems
TesSol, Inc.	Fuel cell test equipment
Trulite, Inc.	Chemical-hydride hydrogen fuel packs for portable fuel cells

range of operating temperatures. These advances could enable automotive manufacturers to develop more practical automotive fuel cell engines.

Acumentrics is developing solid oxide fuel cells (SOFCs) for use as small auxiliary power units for heavy trucks, military, or communications applications, using microtubular fuel cells that optimize power density and reduce cost. Bloom Energy (formerly Ion America) manufactures stationary SOFC systems for residential or back-up power applications that can be fueled with either natural gas or low-quality (inexpensive) ethanol.

Energy Storage

The importance of advancing energy storage technology can hardly be overemphasized. Emerging companies recognize that improved energy storage would significantly help the commercial feasibility of renewable power sources such as solar, wind, and wave energy. Specifically, large, affordable energy storage systems could enable renewable generators to meet intermediate load requirements; that is, excess energy could be captured and dispatched to the electric grid at later times as needed. In the transportation sector, low-cost, high-energy batteries or supercapacitors could enable commercially feasible “plug-in” hybrid vehicles or even all-electric vehicles (See Table III-5 for examples of new electric vehicle companies). The development of acceptable energy storage products for these applications would likely initiate a dramatic shift in the Nation’s electric power and transportation infrastructure.

Table III-4. Examples of Entrepreneurial Companies Developing Energy Storage Technologies

Company	Business or Products Offered
A123 Systems	Lithium-ion batteries using nanoscale materials
Cymbet Corp.	Thin-film batteries for direct integration into ICs or electronics
EEStor, Inc.	Supercapacitors with multilayer ceramics
Firefly Energy, Inc.	Lightweight, composite lead-acid batteries
PowerGenix	Rechargeable nickel-zinc batteries
SCI Engineered Materials, Inc.	Lithium, thin-film batteries
Solicore, Inc.	Ultra-thin lithium polymer batteries for portable electronics
Zinc Matrix Power, Inc.	Rechargeable silver-zinc batteries

As Table III-4 shows, a number of entrepreneurs are entering the energy storage field (see Appendix D for more information). Typically, these new companies develop their first products for small electronic devices such as portable computers and cell phones, for which consumers are willing to pay a premium for small, long-lasting, fast-charging batteries. Virtually all of the companies reviewed in this section have plans to scale up their technologies for larger applications such as vehicles and renewable power conversion. In addition, some companies have found interest in their technologies from the military. PCAST's review suggests that with the success of ongoing technology development, there will be a sharp increase in the production of advanced batteries in the near future — albeit from a modest revenue base today.

Innovation Examples

A123, a Massachusetts-based company, is working on lithium-ion battery technology for portable, electric tools, as well as for cars and light trucks. A123 claims to have resolved the problem of high-temperature failure that has previously inhibited the use of lithium batteries in some high-power applications.

Zinc Matrix Power is a California-based company that has developed a rechargeable zinc silver battery. Portable electronics are its first market, but Zinc Matrix is developing automotive applications with the expectation that its technology will be even more suitable for large systems.

EEStor is a Texas-based company working in the supercapacitor field. Company leaders believe that through their use of nanotechnology, they can produce a storage device that has the energy density of a battery while being capable of a very short (six-minute) recharge cycle.

Related Innovations

Besides the technologies in the above categories, there are many other innovations that could, if successfully commercialized, improve the efficiency and environmental performance of electric power and transportation systems. Some of the emerging companies actively working on related technologies are shown in Table III-5 (see Appendix E for additional information).

Carbon Sequestration and Management

Several companies are developing technologies for diverting carbon and other chemicals captured from the flue gas of power plants to the manufacture of marketable products. Skyonic is currently testing technology on an operating power plant. So far, its system has demonstrated the capability of removing well over 80% of CO_2 emissions while producing a profitable product. Skyonic reports that its technology can be retrofitted onto existing coal-fired plants. While some details of startups in this area are confidential at this writing, it is clear that a successful system with these capabilities could provide a cost-effective solution, at least in limited quantities, to the difficult problem of carbon sequestration.

Table III-5. Examples of Entrepreneurial Companies Developing Other Energy Technologies

Company	Business or Products Offered
AC Propulsion Inc.	Electric vehicles
AquaEnergy Group, Ltd.	Ocean wave energy systems
Clipper Windpower, Inc.	Wind power generation
Clean Energy Systems, Inc.	Syngas combustion for clean coal power
Commuter Cars Corp.	Electric vehicles
EnerNOC, Inc.	Demand response and energy management systems
Fat Spaniel Technologies, Inc.	Real-time energy monitoring for residential and commercial buildings
Gaia Power Technologies, Inc.	Demand response and energy management systems
Greenfuel Technologies Corp.	Algae bioreactors that convert smokestack CO_2 into fuels
GridPoint, Inc.	Energy management appliances for power reliability and energy efficiency
Hi-Z Technology, Inc.	Small-scale power generation from thermoelectric devices
Home Comfort Zones, Inc.	Residential temperature control and energy management
Hybrid Technologies, Inc.	Electric vehicles
NanoSteel Co.	High-strength, nanocrystalline microstructures
Ocean Power Technologies, Inc.	Ocean wave energy for electrical power for utility-scale grid applications
Pentadyne Power Corp.	Flywheel power systems for power quality and power recycling
Phoenix Motorcars, Inc.	Electric vehicles
Powerspan Corp.	Integrated air pollution controls for coal-fired power plants
Skyonic Corporation	Capture of CO_2 and regulated pollutants from coal power plants
SmartSpark Energy Systems, Inc.	Energy management and power conversion for distributed solar power
Southwest Windpower, Inc.	Wind turbine generators for distributed power
SpectraSensors, Inc.	Sensors for environmental monitoring
STM Power, Inc.	Distributed power generators using Stirling-cycle engines
Tellurex Corp.	Small-scale power generation, cooling, and heating using thermoelectrics
Tesla Motors, Inc.	Electric Vehicles
Universal Electric Vehicle Corp.	Electric vehicles
WebGen Systems	Software for energy conservation and control in commercial buildings
Wilson TurboPower, Inc.	Distributed power generators using microturbines with heat regeneration
WOW Energies	Waste-heat turbine generators

Lightweight Materials

As a result of research advances in nanostructured materials, experts believe that major improvements in the strength-to-weight ratio of materials will soon be commercially feasible. For example, using nanoscale fabrication processes, the NanoSteel Company has demonstrated a large improvement in the strength-to-weight ratio of steels. Vermont Composites produces strong and lightweight carbon-fiber components for the Chevrolet Corvette; these components incorporate several manufacturing innovations in tool design and vehicle specifications.

Solid-State Energy Recovery

Nanostructures are ideal candidates for highly efficient thermoelectric energy conversion. Hi-Z Technology and Tellurex are developing thermoelectric power generation technologies for use in recovering waste heat from industrial processes, co-generation systems, and vehicle engines. Their innovations include the use of tunneling, thin-film, and superlattice structures, low-dimensional thermoelectrics, and nanoscale materials.

Synthetic Fuels

Several small enterprises are commercializing technologies that could produce synthetic fuels from gasification of coal or biomass with improved efficiency, lower cost, and reduced emissions compared to existing processes (such as the commercial-scale, coal-to-liquids production facilities in South Africa). These entrepreneurs believe that the low cost and great abundance of coal and biomass in the United States offer an opportunity for development of a large synthetic fuels industry, if environmental issues can be properly addressed.

Energy Management and Power Conversion

Entrepreneurs have developed innovative products for distributed electric power management and control. Some of these systems are designed to improve the quality, reliability, and efficiency of utility-supplied power to a building or manufacturing facility. Other systems of this type provide an interface between renewable or distributed generation sources and the electric grid. For example, because solar PV cells generate DC power, the PV output must be converted to high-quality AC power before it can supply the electric grid or standard loads. Similarly, wind turbines, wave energy generators, fuel cells, and microturbines all require costly power converters in order to supply a standard AC output. Innovative designs can reduce the size and cost of these power converters while improving system efficiency and input/output power quality. Small companies in energy management and power conversion include Fat Spaniel Technologies, GridPoint, SatCon Technology, SmartSpark Energy Systems, and WebGen Systems.

IV. The Innovation Ecosystem

Overview

The United States leads the world in science and technology. U.S. R&D funding from the Government and the private sector comprises over 30% of total global spending on R&D (Duga and Studt 2005). Economists estimate that since World War II, technology innovations have been responsible for one-third to one-half of the Nation's economic growth and at least two-thirds of its improved productivity (Tassey 1999). While innovations in the energy sector have accounted for only a small portion of this effect, the recent, rapid rise of entrepreneurial interest in advanced energy technologies suggests that a major shift to cleaner and more efficient energy systems may become feasible in the near future.

Entrepreneurs and the private sector represent just one component of the "innovation ecosystem." Innovation typically results from dynamic, complex interactions among the private sector, the Federal Government, State governments, universities, and the marketplace (PCAST 2004). For example, successful commercial products often derive in part from basic research conducted at universities or national laboratories under the sponsorship of the Federal Government or a State government. This section will explore the interactions that have developed among these stakeholders to foster innovation.

The Federal Role

The Federal Government enables energy technology innovation in a variety of ways, including research funding, partnerships with industry, small-business grants, the national laboratory system, and tax and regulatory policies. Each of these mechanisms has played a major role in the development of the Nation's current energy infrastructure and will likely continue to enable essential improvements in its energy systems.

Basic and Applied Research

The U.S. Federal Government is the largest source of funding for fundamental research in the world. Federally funded research has contributed to a number of important advances in energy technology, including nuclear power, solar PV cells, and efficient windows and lighting. Federal agencies that support the physical sciences include NSF, NIST, NASA, DOD, and DOE. These agencies together provide about $13B each year for research related to the physical sciences. In addition to basic research, DOE and other agencies fund applied R&D and efforts to commercialize advanced energy technologies. DOE funds programs that cover almost every technology area described in this report. Besides DOE's support of energy R&D (see Table IV-1), a number of other agencies also provide significant funding for energy technology development. For example, in FY2006, enacted funding for energy-related technologies that help address the risk of climate change, as reported in the U.S. Climate Change Technology Program Strategic Plan (2006), was as follows: USDA ($47.8M), DOD ($70.6M), DOT ($1.4M), NASA ($104.4M), and EPA ($108.6M). Additionally, USDA has long provided capital for the build-out of new energy systems in rural America.

Table IV-1. DOE Research and Development Budget Overview ($ millions)

	FY 2006 Estimate	FY 2007 Request
Office of Science (SC)	$3,596.4	$4,101.7
Select SC programs		
High Energy Physics	$721.0	$775.1
Nuclear Physics	$368.0	$454.1
Biological & Environmental Research (BER)	$591.0	$510.3
Basic Energy Sciences (BES)	$1,138.0	$1,421.0
Advanced Scientific Computing Research (ASCR)	$235.0	$318.7
Science Laboratory Infrastructure (SLI)	$43.0	$51.0
Fusion Energy Sciences	$290.0	$319.0
Science Program Direction	$164.0	$171.0
Energy Efficiency & Renewable Energy (EERE)	$1,173.8	$1,176.4
Office of Electricity Distribution & Energy Reliability (OE)	$161.9	$124.9
Fossil Energy R&D (FE)	$841.6	$648.9
Nuclear Energy Science and Technology (NE)	$535.7	$632.7

Source: USDOE-CFO 2006

Government-Industry Partnerships

Federal agencies have established voluntary government-industry partnerships that strengthen information sharing and collaboration among stakeholders. For example, in the FreedomCAR and Fuel Partnership, DOE and other agencies work with manufacturers and suppliers to coordinate precompetitive, cost-shared research. As another example, the EPA's Methane-to-Markets and Climate Leaders programs work with private entities to develop and implement strategies and goals for greenhouse gas emissions reductions.

Small Business Grants

The Federal Government recognizes the important role of entrepreneurs and small businesses in the Nation's economy and in the innovation ecosystem. To encourage small businesses to engage in research that supports national goals and has potential economic value, each year a portion of the Federal budget for research and development is set aside for the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs. Both programs are targeted at small businesses; however, the STTR program requires partnering between a small business and a nonprofit research institution. In 2004, the most recent year for which data are available, over 6300 SBIR awards were funded, totaling more than $2 billion. In the same year, nearly 850 STTR awards were made for a total of more than $200 million. The SBIR and STTR programs are managed within the participating Federal agencies, which solicit programs in topical areas related to each agency's mission. Under these programs, several agencies are funding small businesses for energy technology research, and a number of the companies listed in the appendices to this report have received Federal funding from these programs.

DOE National Laboratories

Solid-state lighting developed at Sandia National Laboratories. (Courtesy of J. Simmons)

The DOE national laboratories are government-owned, contractor-operated (GOCO) organizations that serve as centers of world-class scientific and technology expertise to support national goals. DOE provides oversight of 18 national labs of this type, including (among others) Argonne National Laboratory (NL), Idaho NL, Lawrence Berkeley NL, Lawrence Livermore NL, Los Alamos NL, Oak Ridge NL, Pacific Northwest NL, Sandia NL, and the National Renewable Energy Laboratory, in addition to several labs operated directly by DOE, such as the National Energy Technology Laboratory. The national labs address a wide range of issues that require collaboration among diverse scientific disciplines. For example, basic research on nanoscale materials could involve experts in many disciplines, including chemistry, materials science, computational mathematics, biology, and physics. Subsequently, this interdisciplinary collaboration might yield nanomaterials breakthroughs that lead to innovative technologies in energy storage, fuel cells, solid-state lighting, solar photovoltaics, biofuels, and other applications. The national labs often work closely with universities and industry to share results and to collaborate on research activities that will yield new technologies with energy, economic, and defense-related benefits for the Nation.

Tax and Regulatory Policy

The Federal Government establishes tax and regulatory policies that encourage consumer and private-sector purchases and the use of alternative energy technologies that are not cost-competitive without subsidies. Many such policies were implemented or extended in the EPAct, as shown in Table IV-2. In addition to the EPAct and related legislation that preceded it, Congress has instituted several regulatory programs that encourage the use of energy-efficient or alternative energy technologies. These include regulations on vehicle efficiency, biofuels production, and flex-fuel vehicles.

Vehicle Fuel Efficiency. Corporate Average Fuel Economy (CAFE) regulations were first enacted by Congress in 1975. Periodically, the DOT National Highway Traffic and Safety Administration (NHTSA) revises fuel economy standards for light trucks. In March 2006, NHTSA issued its CAFE rule for light trucks — pick-ups, sport utility vehicles (SUVs), and minivans — for model years 2008–2011. Also, as part of this rule, NHTSA will transition the CAFE regulatory system for light trucks to the use of size-based standards, which will essentially require smaller vehicles to be more fuel efficient than larger vehicles. This encourages fuel-efficiency improvements that do not compromise safety (NRC 2002). The rule also increases CAFE standards for light trucks from the current 21.6 mpg to a target of 24 mpg by 2011, and closes the loophole that has exempted very large SUVs from CAFE regulation. The Administration has also requested Congress to grant it the authority to reform the CAFE standard for passenger cars (which has been fixed at 27.5 mpg since 1990).

Biofuels Production. Since 1979, the Federal Government has provided a tax incentive for production of ethanol used as a motor fuel. In that year, Congress established a 5.2 cent-per-gallon tax exemption for gasohol (generally the same as E10, 10% ethanol and 90% gasoline). Because this provision reduced Federal gasoline tax receipts, which are used largely for the Highway Trust Fund, Congress decided in 2004 to make the incentive a production tax credit instead of a fuel tax exemption. The American Jobs Creation Act of 2004 (PL 108-357) established the Volumetric Ethanol Excise Tax Credit (VEETC), which provides ethanol blenders/retailers with $0.51 credit per gallon of pure ethanol, most of which is blended with gasoline to make E10. This incentive expires in 2010. PL 108-357 also established a biodiesel tax credit of up to $1.00 per gallon. As shown in Table IV-2, the EPAct extended the biodiesel tax credit until 2008. The EPAct also established a renewable fuels mandate that requires domestic production of 7.5B gallons of ethanol by 2012.

Flex-Fuel Vehicles. Under the Energy Policy and Conservation Act of 1975, automotive manufacturers earn credits towards their CAFE requirements for each manufactured alternative fuel vehicle, including FFVs (which can operate on E85 or gasoline). The FFV credit effectively amounts to an artificial increase of a vehicle's fuel economy by a factor of 1.6 for CAFE purposes. The benefit is capped at a 1.2 mpg increase in the overall calculation of a manufacturer's average vehicle fuel economy each year. The FFV credit, which involves no direct cost to consumers, is the primary reason that there are currently about six million FFVs in the United States.

Table IV-2. Selected Provisions of the Energy Policy Act of 2005

Federal Energy Use

EPACT Section #	Selected Provisions (not including research and development authorizations)
203	Requires the Federal government to purchase at least 3% of its electric power from renewable energy sources, increasing to 5% in 2010 and 7.5% in 2013.
204	Sets a goal to install solar systems in 20,000 Federal buildings by 2010, including at least 150 MW of PV solar over five years (authorized $50M each year for FY06-FY10).
211	Sense of Congress that the Sec. of Interior should seek to approve 10,000 MW of electricity generation from renewable energy sources (other than hydroelectric power) on Federal lands by 2015.

Renewable Energy

EPACT Section #	Selected Provisions (not including research and development authorizations)
1335 1337	Establishes a solar energy tax credit for homeowners and businesses for up to 30% of the cost of installing a solar PV or hot water system (capped at $2000) in 2006 or 2007.
1301	Extends the renewable energy production tax credit for two years for qualifying facilities: solar, wind, biomass, geothermal, landfill gas, irrigation, refined coal, hydroelectric power, and trash combustion facilities.
1303	Provides for up to $800M in renewable energy bonds; creates a new category of tax credit bonds, the Clean Renewable Energy Bonds (CREBs).
1703	Authorizes a loan guarantee program for advanced energy technologies, including renewable energy systems.

Biofuels

EPACT Section #	Selected Provisions (not including research and development authorizations)
208	Establishes the Sugar Cane Ethanol Program in EPA; authorizes $36M to study the potential for domestic production of ethanol from sugar cane.
210	Authorizes $50M for each of FY06-FY16 for grants for production in rural communities of biofuels or heat or power from biomass.
942	Establishes a program of production incentives for cellulosic biofuels, authorized $250M, with the goal of achieving 1 billion gallons of annual, domestic, cellulosic ethanol production by 2015.
946	Directs the Sec. of Agriculture to competitively award demonstration grants for cellulosic biomass innovations in feedstock preparation and harvesting.
1342	Establishes a 30% tax credit for the cost of installing clean-fuel refueling equipment (e.g., pumps for E85 ethanol or B20 biodiesel), effective through 2010.
1345 1347	Extends the $1.00 per gallon tax credit for certain types of biodiesel until 2008, and provides an additional 10 cent-per-gallon tax credit for small producers of biodiesel and ethanol.
1501	Mandates an increase to 7.5 billion gallons of ethanol annual production by 2012 and a minimum 250 million gallons of cellulosic ethanol annual production by 2013.
1510	Establishes a loan guarantee program for producers of ethanol (and commercial by-products) from cellulosic biomass and municipal solid waste.
1512	Authorizes grants to producers of cellulosic ethanol, up to $100M in FY06, $250M in FY07, and $400M in FY08.

Hybrid Electric and Alternative Fuel Vehicles

EPACT Section #	Selected Provisions (not including research and development authorizations)
706	Authorizes $40M (over four years) in DOE grants for demonstration of flex-fuel or hybrid vehicles.
712	Establishes a grant program to subsidize acquisition of hybrid, alternative fuel, or fuel cell vehicles by State and local governments.
915	Establishes a program, authorized $21M, to seek secondary uses in utility and commercial applications for refurbished hybrid electric vehicle batteries.
1341	Establishes substantial tax credits for hybrid, clean diesel, and alternative fuel vehicles (other than ethanol-fueled).
1703	Authorizes a loan guarantee program for advanced energy technologies, including production facilities for fuel efficient vehicles.

Hydrogen and Fuel Cells

EPACT Section #	Selected Provisions (not including research and development authorizations)
743	Authorizes $25M for demonstration of fuel-cell-powered school buses.
745	Authorizes $315M for deployment of fuel-cell systems in trucks and locomotives to provide auxiliary power and thus reduce engine idling.
782	Authorizes $95M for Federal and State procurement of fuel-cell vehicles and hydrogen fuel systems.
783	Authorizes $345M for Federal procurement of stationary, portable, and micro fuel cells.
805	Authorizes $200M in FY07, increasing to $250M in FY10, for R&D on hydrogen production, distribution, and storage. It also authorizes $160M in FY07, increasing to $200M in FY10, for R&D on fuel cells.
808	Authorizes $1.3B over five years for demonstrations of fuel cells and hydrogen production technologies.
1703	Authorizes a loan guarantee program for advanced energy technologies, including hydrogen fuel cell systems.

Nuclear Energy

EPACT Section #	Selected Provisions (not including research and development authorizations)
602	Extends until 2025 Price Anderson indemnification of nuclear power plants against nuclear incidents.
634	Directs the Secretary of Energy to conduct two demonstrations of the commercial production of hydrogen at existing nuclear power plants; authorizes $100 million.
638	Authorizes standby support for delays for new construction of up to a total of six reactors.
641	Authorizes $1.25B over 10 years for a prototype Next-Generation Nuclear Plant Project that produces electricity and hydrogen, sited at Idaho National Laboratory.
1306	Allows establishment of a production tax credit for six new advanced nuclear power plants, 1.8 cents per kWh for 8 years.
1703	Authorizes a loan guarantee program for advanced energy technologies, including advanced nuclear power plants.

Energy Efficiency and Buildings Technologies

EPACT Section #	Selected Provisions (not including research and development authorizations)
102	Mandates that Federal buildings reduce their consumption of energy per square foot by 2% per year beginning in 2006, and 20% by 2015, compared to energy use per square foot in 2003.
103	Requires, by 2012, all Federal buildings to have electricity meters, and to the extent practical, advanced meters for hourly tracking of electricity consumption.
104	Requires (with some exceptions) that Federal agencies purchase Energy Star or FEMP-designated energy-efficient products, including air conditioners.
107	Authorizes $6M for FY06-FY08 for the General Services Administration to establish an Advanced Building Efficiency Testbed program.
109	Requires revised standards for Federal buildings such that, where practical, they are designed to use 30% less energy than current international building standards would imply.
122	Authorizes $500M in FY06, $600M in FY07, and $700M in FY08 for weatherization assistance, to improve the energy efficiency of homes of low-income owners (up to $3000 per dwelling — Sec. 206).
124	Authorizes $50M for each of FY06-FY09 for State-run energy-efficient appliance rebate programs.
135	Establishes energy efficiency standards for 15 new products, including commercial HVAC and refrigeration units, and amplifies the existing Energy Star program.
1331	Provides tax deductions for construction of energy-efficient (50% of ASHRAE standard) commercial buildings.
1332	Provides tax deductions for construction of energy-efficient (50% of ASHRAE standard) homes.
1333	Provides tax credits for purchase and installation of energy-efficient windows, insulation, doors, roofs, and heating and cooling equipment in homes, of up to $500, between January 1, 2006 and December 31, 2007.
1334	Provides up to $75M in tax credits for individual consumer purchases of energy-efficient appliances, including refrigerators, dishwashers, and clothes washers.

Electricity Grid

EPACT Section #	Selected Provisions (not including research and development authorizations)
1221	Grants the Secretary of Energy siting authority for interstate electric transmission facilities.
1223	Directs the Federal Electric Reliability Commission to encourage the use of advanced electric transmission technologies.
1224	Authorizes $10M in each of FY06-FY12 to provide a 1.8 cent-per-kWh payment (up to 10 million kWh per year) to operators of qualifying advanced power system technology facilities.
1251	Requires all electric utilities to provide net metering service to customers upon request.
1252	Requires all electric utilities, by Feb. 2007, to offer customers the option of using a time-based rate schedule ("smart metering"), either a time-of-use, critical-peak, or real-time pricing system.
1703	Authorizes a loan guarantee program for advanced energy technologies, including (among others) efficient electrical generation, transmission, and distribution technologies.

Clean Coal

EPACT Section #	Selected Provisions (not including research and development authorizations)
411	Authorizes loan guarantees for IGCC plants with carbon sequestration and co-generation of hydrogen.
421 1307	Provides $800M for a 20% investment tax credit for IGCC coal plants and $500M for a 15% tax credit for other clean-coal technology construction or deployment investments.
1703	Authorizes a loan guarantee program for advanced energy technologies, including (among others) advanced fossil energy technologies, coal gasification plants, carbon sequestration technologies, and pollution control equipment.

Source: Energy Policy Act of 2005 (PL 109-58)

The Role of States

States have become major contributors to the development and deployment of renewable energy technologies. States use several policy measures for this purpose, including regulatory measures (e.g., renewable portfolio standards), clean energy funds (e.g., tax credits and production incentives), support for R&D, and indirect tax incentives. Virtually every State uses at least one of these mechanisms to encourage greater use of renewable resources for electricity generation or vehicle fuels.

Twenty States have established a renewable portfolio standard (RPS). An RPS prescribes the minimum amount of renewable energy resources to be included in a State's electricity resources portfolio by a certain date. Utilities can meet this requirement by building renewable power generation capacity or by purchasing renewable power from other providers. Typically, a State tailors its RPS according to its unique needs, energy resources, and policy objectives. Based on implied market volume, the RPS requirements in California and Texas are by far the most significant among the State RPS programs (Union of Concerned Scientists 2006). In total, by 2017, existing State RPS programs are projected to result in an additional 31,000 MW of renewable power generation, equivalent to about 3% of current U.S. electricity generation capacity (Rabe 2006).

Several States have instituted renewable fuels mandates. One of the first States to actively promote biofuels was Minnesota, which has consumption mandates for ethanol and biodiesel.

Another important mechanism in many States is a clean energy fund, which can include production incentives, grants and buy-down programs, long-term contracts, debt financing, and risk insurance. States with the largest clean energy funds are shown in Table IV-3. Based on capacity obligated (which includes the results of past-year investments), the most significant State programs of this type are in California, Pennsylvania, New York, Minnesota, Oregon, and Illinois. California, for example, has committed $3B over the next 10 years to add 3,000 MW of solar PV capacity on residential homes.

Many States also contribute to energy research and development conducted at State universities and in the private sector. For example, the New York State Energy Research and Development Authority (NYSERDA) administers 2,700 clean-energy and energy-efficiency projects. One of these was a study to evaluate the potential for geothermal resources in upstate New York (NYSERDA 2004). These projects are funded primarily by a surcharge on electricity and natural gas bills from State utilities, which, according to NYSERDA, amounts to about $0.70 per New York resident per year.

Some States offer indirect tax incentives for clean energy installations, such as property tax reductions for homes with solar PV panels, corporate tax reductions for capital investment in renewable energy systems, and recruitment incentives to attract renewable energy equipment manufacturers (IREC 2006). Sixteen States provide excise tax exemptions or producer credits for ethanol fuel. In all of these ways, States are a key factor in the rapid growth of the renewable energy market.

The Role of Universities

Universities form an essential link between government and private industry in the development and commercialization of new energy technologies. Universities foster innovation in numerous ways. These

Table IV-3. Funding for Renewable Energy Projects in Selected States

Project Location	# of Projects	Funding Originally Obligated	Funding Currently Obligated	Capacity Obligated (MW)	Capacity Cancelled (MW)	Capacity Pending (MW)	Capacity On-Line (MW)
CA	60	$243,573,376	$189,970,791	1,291.5	64.5	748.5	478.5
IL	5	$8,425,000	$8,425,000	112.5	0.0	6.0	106.5
MA	5	$32,756,736	$32,756,736	52.3	0.0	49.0	3.3
ME	1	$5,600,000	$5,600,000	19.0	0.0	19.0	0.0
MN	147	$107,679,545	$107,679,545	253.3	1.7	35.3	216.3
NH	1	$2,720,000	$2,720,000	50.0	0.0	50.0	0.0
NJ	6	$17,782,026	$14,682,026	38.9	21.0	6.9	11.0
NY	11	$25,560,000	$10,460,000	316.1	266.5	8.0	41.6
OR	4	$3,800,000	$3,800,000	122.0	0.0	6.0	116.0
PA	10	$27,292,000	$21,442,000	386.6	39.6	204.5	142.5
Total	**250**	**$475,188,683**	**$397,536,097**	**2,642.2**	**393.3**	**1,133.2**	**1,115.6**

Source: CESA 2006

include support for fundamental research, high-level initiatives, regional partnerships, and campus-affiliated research parks.

Fundamental Research

Basic research investigates the materials, catalysts, biological structures, physical and chemical mechanisms, and analytical tools that can lead to new energy technologies. In 1942, Enrico Fermi demonstrated the first self-sustaining nuclear chain reaction, a precursor to today's nuclear power plants, at the University of Chicago. Today, university researchers are exploiting opportunities to design and control new structures and processes at the nanoscale. These advances could help accelerate commercialization of solar energy, advanced batteries, hydrogen fuel cells, biofuels, and other energy technologies.

The Bayh-Dole Act of 1980 (PL 96-517, Patent and Trademark Law Amendments Act of 1980) allows universities to retain ownership of patents and copyrights resulting from Federally financed research, with the right to license that intellectual property to industry. This has encouraged the growth of basic and applied research in fields that are linked to high-technology markets, such as biotechnology and information technology (NRC 2001a). As described below, a number of universities are now expanding their research capabilities in energy-related fields. University research has already enabled major advances in biofuels, advanced batteries, solar PV, fuel cells, and other areas.

University Initiatives

Many universities have established high-level, multidisciplinary initiatives that aim to coordinate diverse research efforts and cross-cutting competencies to address national and global energy and environmental challenges. The following are some representative examples:

- The **University of California, Berkeley,** and Lawrence Berkeley National Laboratory have launched an initiative known as Helios. Drawing on cutting-edge research in nanoscience and synthetic biology, the initiative explores technologies that can convert sunlight into a transportation fuel. The Helios effort will be complemented by other UC Berkeley research programs in electricity generation, transmission, storage and end-use efficiency. One example is the CITRIS (Center for Information Technology Research in the Interest of Society) project to use wireless sensor networks for demand response, which can reduce peak demand for electricity.
- The **University of California, San Diego,** Center for Energy Research provides a venue for interdisciplinary interactions among faculty, researchers, students, and the public in order to promote energy research and education. Research areas include fusion energy, clean combustion, and bioenergy. The center also serves as a focal point for studies of the socio-economic and environmental aspects of energy production and use.
- The **Georgia Tech** Strategic Energy Initiative supports energy technology development, assessments, demonstration projects, and policy guidance. The initiative coordinates interdisciplinary research projects on strategically selected technologies, such as enabling ethanol production from southern yellow pine and evaluating the optimal sizes of wind turbine rotor blades.
- The **Massachusetts Institute of Technology (MIT)** Energy Research Initiative intends to coordinate development of research programs, curricula, and campus infrastructure to better achieve the world's energy goals in a sustainable manner. As part of this effort, MIT plans to establish a new interdepartmental laboratory for sustainable energy research and education.
- The **Purdue University** Energy Center at Discovery Park hosts over 75 researchers, scientists, engineers, political scientists, and economists in a multidisciplinary environment. Research topics include solar, wind, and bio-based energy, advanced batteries, nuclear reactor design, hydrogen production and fuel cells, clean coal, and socio-economic and political issues associated with energy.
- The **Stanford University** Global Climate & Energy Project, with support from ExxonMobil, General Electric, Schlumberger, and Toyota, funds research into novel, cost-effective energy technologies and system solutions that could reduce greenhouse gas emissions. Sponsors have committed to invest $225M in this project over ten years.
- The **University of Minnesota** Initiative for Renewable Energy and the Environment coordinates applied research, demonstration projects, and science-based public policy on renewable energy alternatives. Research currently funded under this initiative includes a project to improve the yield and genetic benefits of hybrid poplar trees and a project to improve solar thermal heating systems.
- The **University of Southern California** Future Fuels and Energy Initiative seeks to reduce global reliance on fossil fuels by researching alternative fuels and by considering the social, economic, environmental, and policy issues that arise when new energy and fuel standards are developed.

Regional Partnerships

An ideal environment for innovation is a local or regional clustering of strong R&D centers, high-technology manufacturing, appropriately educated and skilled workers, and supportive government policies (PCAST 2004). In many regions of the United States, universities partner with State and local governments, national laboratories, and the private sector to accelerate development of technologies in key areas, including energy. These collaborations help to bridge the gap between basic research and market commercialization. The following are examples of these partnerships:

- **The Microproducts Breakthrough Institute** of the Oregon Nanoscience and Microtechnologies Institute (ONAMI) involves Oregon State University, Portland State University, the University of Oregon, the State of Oregon, and the Federally funded Pacific Northwest National Laboratory. The partnership seeks to advance micro- and nanoscale technologies and manufacturing, including those related to energy. For example, the partnership has developed a process for small-scale production of biodiesel that could enable farmers to economically convert soybeans to fuel on their farms.
- **The Renewable and Sustainable Energy Initiative**, led by the University of Colorado at Boulder, builds collaboration among the National Renewable Energy Laboratory, Colorado School of Mines, Colorado State University, and the University of Colorado at Denver. The initiative has organized a symposium and "seed grant" competition to inspire innovative research in sustainable energy technology, as well as research on related policy and legislative issues; social, cultural, and philosophical dimensions; and economic aspects of energy.
- **The Tennessee Valley Corridor Initiative** is a collaboration between the University of Tennessee, Oak Ridge National Laboratory, East Tennessee State University, University of Alabama-Huntsville, Virginia Tech University, and other Federal, State, and nonprofit institutions in the region. The partnership coordinates research and commercialization efforts in areas of shared expertise, including biofuels, electric vehicles, and hydrogen-powered vehicles.
- **The Wright Fuel Cell Group** is a collaboration of five Ohio academic institutions, a broad coalition of industrial companies, and private nonprofit organizations. The goal of the center is to establish Ohio as an international leader in fuel cell research and innovation. The State of Ohio Third Frontier Commission has awarded $1.6M to the Wright Fuel Cell Group as part of a larger 10-year, $1.6B initiative to expand Ohio's high-tech research capabilities.

Research Parks

Many universities operate or work closely with entrepreneurial incubators and research parks to help promising research developments make the often difficult transition to market. These organizations provide startup companies with the resources to commercialize research breakthroughs by supplying financial assistance, business connections, mentorship, and facilities. They also provide assistance with technical assessment, product development, intellectual property protection, and marketing.

Novel models for commercialization continue to be developed, with many universities now supporting joint ventures, licenses, and spin-off company development. The following are some examples of university-based research parks and incubators that are known to PCAST:

- The Austin Technology Incubator and IC² Institute have initiated the University of Texas **Clean Energy Incubator** to help develop startup companies with innovative energy technologies. Companies that have emerged from this effort include MicroDynamo, which markets a device that uses human energy to recharge batteries, and Austin Biofuels, which produces biodiesel from vegetable oils.

- The **Deshpande Center for Technological Innovation** at the MIT School of Engineering partners with investors and industry to commercialize innovations in the energy field and other areas. Recent innovations emerging from this effort include solar PV systems with integrated power inverters, cost-competitive electrode assemblies for fuel cells, and low-emission compression-ignition engines.

- Over 30 companies have been established with support from EnterpriseWorks, an incubator in the **University of Illinois Research Park**; these include SmartSpark Energy Systems, which builds high-efficiency power converters that can interface between most types of energy sources and loads.

- The **UC Berkeley Lester Center for Entrepreneurship & Innovation** oversees the UC Berkeley Business Plan Competition among other activities designed to promote the transformation of innovative ideas into viable businesses. An alternative energy company, Aurora Biofuel, won the 2006 Business Plan competition. Aurora Biofuel has developed a technology that it claims can produce biodiesel with yields up to 125 times greater than current production methods, at half the cost.

- The **Massachusetts Technology Transfer Center** at the University of Massachusetts works with regional research institutions to promote new ventures in various areas, including energy. Millitech, Inc., a company that specializes in millimeter-wave technology that can be used to monitor power plant energy consumption, emerged from the Center, as did Konarka, a world leader in the field of low-cost PV cells.

- **Ohio University's Innovation Center** business incubator has produced, among other companies, Third Sun Solar & Wind Power, which installs renewable power systems for individuals, businesses, and institutions.

- The **Georgia Tech VentureLab**, part of the Enterprise Innovation Institute, has supported several energy-related companies; these include WiSPI, which develops methanol-based fuel cells that can be placed on silicon chips to make self-powered, wireless sensors; Ajeetco, which uses high-efficiency polycrystalline silicon films to create large PV solar panels; and Plum Combustion, which has developed a novel method to combust fuel in engines and gas turbines with very low nitrogen oxide emissions, which could eliminate the need for expensive catalysts.

Universities support innovation through their unique capacities in education, workforce development, knowledge-creation, technology transfer, and commercialization. They contribute resources, collaboration mechanisms, and a research and intellectual-property infrastructure that help drive innovation in energy technologies.

V. Summary and Recommendations

The ancient Chinese proverb attributed to Confucius states, *A journey of a thousand miles begins with a single step*. It would be easy to look at the vast field of energy and conclude that changing it is too complex a task. As this report has shown, however, not only a single step but many steps already are being taken to move toward the goals of improved national energy security, environmental stewardship, and economic well-being. As the report also highlights, reaching these goals will take a long and sustained effort over the next few decades. Therefore, this report concludes with recommendations that PCAST believes will help the Nation to make substantial progress by 2030. The recommendations are specifically focused on actions that can be implemented immediately. Many of these recommendations encourage incentives for the private sector to accelerate commercialization of energy technologies that, if successful, could dramatically change today's energy systems and infrastructure on a national and global scale.

Recommendations for Federal Energy Policy

Overarching Recommendations

1. **Increase Federal support for science and technology research and development.** Many of the advanced energy technologies described in this report have originated, at least in part, from Federally funded research. The President's American Competitiveness Initiative supports future innovation by proposing to double funding for NSF, NIST, and the DOE. Meanwhile, in order to accelerate the near-term commercialization of energy technologies, the President's Advanced Energy Initiative proposes a 22% increase in clean energy research and development funding in DOE in FY 2007. PCAST recommends that Congress fully fund these initiatives and consider funding for an expanded Advanced Energy Initiative research effort in future years, including at the USDA.

2. **Promote EPAct 2005 incentives.** Financial support measures targeted to assist commercialization — low-interest loans, tax incentives, capital contributions, and price subsidies, among others — are in many cases vital to bringing new energy technologies to market. The Energy Policy Act of 2005 (EPAct) established incentives for virtually every area of energy technology (see Table IV-2). DOE, USDA, and other agencies have taken significant steps to implement these provisions. PCAST recommends that DOE and USDA promote these incentives as currently targeted and report back on whether they are having the desired effect or whether modifications are necessary. If ongoing monitoring shows that goals are being reached sooner than the Act anticipated, PCAST recommends moving up the timelines and making the goals more aggressive. Also, some of the EPAct incentives expire in 2007 and 2008; those that have proven to be successful should be extended.

3. **Support State initiatives.** Individual States are funding many programs to improve the competitiveness and availability of renewable energy resources for their businesses and residents. These programs tend to focus on resources that are most readily available in each State, such as hydroelectric, geothermal, biomass, wind, wave, or solar energy. Because States and their public utility commissions have the ultimate authority for most decisions related to the electric power infrastructure, the Federal Government

should work with the States to expand successful programs and encourage the States to cooperate with each other on “best practices” developed through these projects.

4. **Position the Federal Government as an early adopter of new technology.** The Federal Government is both a large producer and a large user of the Nation’s energy resources. Therefore, the Federal Government should expand its role as an early adopter in order to demonstrate the commercial feasibility of advanced energy technologies. PCAST suggests that the Federal Government redouble its efforts to implement EPAct provisions of this type.

Electric Power Generation

As stated earlier, domestic electricity demand is expected to rise by 50% over the next quarter-century. This has two policy implications. First, the overall energy efficiency of the electric power sector must be improved. In an earlier report (PCAST 2003), this Council recommended policy actions, several of which have been implemented, to reduce inefficiencies in the Nation’s electricity generation and transmission infrastructure. Complementing this, the present report includes a discussion of the need to improve the energy efficiency of end-use applications. Even with improved efficiency, however, a substantial increase in electricity generation capacity will be needed. Non-hydroelectric renewable energy can be an important contributor to U.S. power generation by 2030, but more new capacity will likely be supplied by fossil fuel and nuclear power plants. Thus it is crucial to accelerate deployment of next-generation nuclear and coal gasification plants, which can help achieve both economic and environmental goals.

5. **Expand nuclear energy as a clean, base-load power source.** Nuclear energy has the potential to be the lowest-cost source of electric power (OECD/IEA 2005), and it produces very low life-cycle emissions. The EPAct legislation provides incentives to encourage utilities to work with the Federal Government to reinvigorate the domestic nuclear industry. PCAST recommends that the Federal Government use its best efforts to ensure that the risk insurance and other incentives outlined in the EPAct are taken up by utilities so that new nuclear plants can contribute to the electric grid beginning in 2015, as the first step in a significant expansion in nuclear power capacity. PCAST further recommends that Congress increase the scope of the production tax credit for advanced nuclear power plants beyond the EPAct-specified 6,000 megawatt capacity limit. The goal for the Nation should be to add at least 36,000 megawatts of new nuclear generation capacity by 2030.[14]

6. **Resolve the nuclear waste containment issue.** New reactor designs and reprocessing technologies that are under consideration could reduce the amount of high-level waste generated by nuclear plants, but they will not eliminate it. In order to expand nuclear energy capacity, the nuclear industry needs assurance that a permanent waste disposal site exists. All stakeholders need to work together to ensure that the proposed underground waste facility at Yucca Mountain, NV, is established as soon as possible.

7. **Build coal gasification plants instead of natural gas facilities.** The EPAct provides incentives for the construction of high-efficiency, low-emission coal gasification power plants. PCAST recommends that the Federal Government use its best efforts to maximize the value of these incentives for public utilities. States should be encouraged to establish energy policies that support national energy security objectives rather than depending solely on “least cost” parameters. Based on existing trends, most new electric power capacity will be supplied by natural gas plants and conventional coal plants, leading to an

[14] This figure is based on maintaining a constant proportion of U.S. electricity generation from nuclear energy (EIA-DOE 2006d, Table 73).

increase in overseas natural gas imports and greenhouse gas emissions. Through its higher generating efficiency, coal gasification technology could make better use of the Nation's huge domestic coal reserves while reducing energy losses and carbon emissions compared to conventional coal plants. This technology also enables relatively low-cost carbon capture. With the benefit of several commercial-scale demonstrations over the next decade, next-generation coal gasification plants could become competitive with conventional power plants, reducing the need for new natural gas plants to supply clean base load power (NRC 2003). Thus, the Federal Government should work with the States, taking full advantage of the EPAct incentives, to encourage deployment of coal gasification power plants.

8. **Improve the efficiency of legacy electric power plants.** Current regulations inhibit utilities from making needed improvements to old power plants. These regulations should be modified to allow utilities to improve the efficiency and environmental performance of legacy coal plants without incurring an onerous economic penalty, as long as the upgraded power plants will produce fewer emissions per megawatt of generation capacity than they would without the upgrades.

9. **Support renewable energy plans.** Many States have incentive programs to increase the percentage of their grid power requirements supplied by renewable sources. These programs focus on utility-scale projects (defined as 1 megawatt output or more); to date, over $475M has been obligated for some 18 different projects, mostly involving wind energy. These programs, together with State renewable portfolio standards, could help increase the level of renewable electricity generation substantially over the next two decades. The DOE should be tasked to track these programs and to encourage broader use of those approaches that are showing the most promise. Additionally, the Federal Government should aggressively pursue, and consider increasing, the EPAct goal for at least 10,000 megawatts of non-hydroelectric renewable generation capacity to be approved for siting on Federal lands by 2015.

10. **Reduce regulatory barriers to installation of renewable distributed generation technologies.** Today, grid interconnection and net metering rules vary by State, and even by utility or other electric service provider within a State, resulting in a patchwork of requirements across the United States. Some States do not even have regulatory interconnection standards. This inconsistency creates high barriers to penetration of renewable distributed generation technologies (such as solar photovoltaic cells) into the U.S. market. Therefore, the Federal Government should work with State governments and utility regulators to facilitate the broad adoption of consistent interconnection and net metering standards, which would create a more predictable and consistent business environment for technology suppliers and project developers. The Federal Government should also examine access to transmission lines for new renewable electricity providers, especially in rural areas.

Transportation

Increasing concerns about energy security provide a strong motivation for the United States to reduce its requirement for imported oil. This goal can be achieved by developing new domestic oil fields, competitive alternative fuels, and vehicles with higher fuel efficiency. Currently, most entrepreneurial activity in this area is aimed at biofuels or efficient vehicle propulsion systems. The following recommendations could facilitate commercialization of these technologies.

11. **Encourage industry to expand the availability of biofuels and flex-fuel vehicles.** The Administration should convene a roundtable of stakeholders, including automakers, energy companies, fuel distributors,

and fleet managers, to develop a private-sector roadmap with specific commitments to increase the nationwide availability of biofuels and the percentage of flex-fuel vehicles (FFVs) among new car offerings. The stakeholders should also collaborate on fuel and vehicle standards that maximize market efficiencies and biofuel flexibility.

12. **Increase the supply of E10 and other biofuel blends.** The EPAct established or extended several incentives for the production of ethanol. E10, which contains 10% ethanol and 90% gasoline, helps reduce smog formation and has provided a major market for ethanol producers. PCAST suggests that the Administration encourage broader use of E10, as well as higher-percentage blends of ethanol (or other biofuels), in order to surpass the EPAct goal of 7.5 billion gallons of ethanol by 2012. For example, use of 10% ethanol in all transportation fuel would equate to 12–14 billion gallons of biofuels. Widespread use of richer biofuel blends could increase ethanol use far beyond this level.

13. **Eliminate the ethanol import tariff for E85 applications.** The EPAct provides incentives for distributors of E85, a fuel containing 85% ethanol and 15% gasoline. Some private companies considering distribution of E85 are hindered by the current lack of a reliable and cost-competitive supply of ethanol. Thus, PCAST supports opening the biofuels market so that the import of foreign sources of ethanol (primarily from Brazil) for E85 would be permitted without a tariff. This should be viewed as part of an integrated industrial development and trade strategy.

14. **Modify the Volumetric Ethanol Excise Tax Credit (VEETC) to match competitive realities.** Currently, blenders of E10 and E85 fuels are granted tax incentives based on the amount of ethanol they bring to market. This incentive effectively reduces the cost of producing these fuels. Competitive considerations, however, would suggest that as the price of oil rises, the need for a tax incentive decreases; conversely, as the price for oil decreases, the need for a subsidy increases. PCAST recommends that these realities be placed into the regulations such that the VEETC slides from high to low as the price of oil moves from low to high. If set at appropriate levels, this change in the VEETC would help lower the price at which biofuels are competitive with gasoline. Additionally, States should consider taxing fuels on the basis of energy content rather than volume; most States currently tax fuels by volume, which effectively penalizes E85, because it contains only about 75% of the energy per gallon as in gasoline. PCAST recognizes that the timing of these types of changes is critically important and should be weighed with long-term investment horizons in mind. The current ethanol industry has only recently experienced strong growth, compared to the decades of profitability for the petrochemical industry with its multiple historical

subsidies. Over the next several decades, the Nation — and the world — may be similarly building out a new biofuels industry; therefore, changes to the current tax structure should be carefully phased in.

15. **Identify lands suitable for energy crop production.** Several different crops capable of yielding in excess of 10 tons of biomass per acre are under consideration for use as energy feedstocks. Suitable lands for perennial grasses — potentially the largest source of biomass — could come from the Conservation Reserve Program or other Federally managed lands. An inventory of Federal lands suitable for conversion to energy crops would help expedite the shift to large-scale production of biomass for energy. PCAST recommends that USDA be tasked to specifically identify lands most suitable for energy crop production.

16. **Support cellulosic biomass conversion technologies.** PCAST endorses the recently announced roadmap for developing cellulosic ethanol (USDOE-SCI/EERE 2006) and encourages the DOE and USDA to also consider the potential of other biofuels such as butanol, methanol, and others, as well as the suite of biobased products. Given recent progress in developing cost-effective enzymes and improved biomass yields, large-scale production of cellulosic biofuels appears feasible by 2015.

17. **Encourage production of FFVs.** For many years, automobile manufacturers in the United States have been providing flex-fuel capability for a small percentage of their new cars and light trucks, enabling these vehicles to operate on either E85 or gasoline. To enhance future flexibility, PCAST suggests that the Federal Government use its influence to encourage vehicle manufacturers to rapidly provide flex-fuel capability in as many models as possible. FFVs give consumers a choice of fuels and create much-needed competition in transportation fuels. This recommendation could be implemented in part through the industry roundtable described in recommendation #11.

18. **Expand use of E85 in Federal Government vehicles.** The Energy Policy Act of 1992 requires Federal agencies, with certain exceptions, to purchase alternative fuel vehicles for 75% of their fleet vehicles. Many agencies purchase FFVs to comply with this requirement, but E85 has often not been available for their use. Last year, the EPAct instituted a requirement that Federal agencies use E85 in all FFVs unless a waiver is granted by DOE. PCAST recommends that this provision be applied aggressively in order to expand ethanol availability by providing a growing market.

19. **Review CAFE standards regularly and make needed reforms.** Corporate Average Fleet Economy (CAFE) standards on passenger cars have not been updated for more than 15 years, even though many efficient vehicle technologies have become available. Therefore, PCAST recommends that Congress pass legislation to give the U.S. Department of Transportation (DOT) the flexibility both to set passenger car fuel economy regulations and to structure the program to be consistent with the revised light truck CAFE program. DOT should also be made responsible for reviewing the standards at least every three years in order to assess the feasibility of further increases in the CAFE standards.

20. **Modify CAFE regulations to encourage non-fossil-fuel use.** The CAFE program should be modified to further encourage deployment of FFVs. Although FFVs currently receive CAFE credits, these incentives are capped at a relatively low percentage of new vehicle production. Therefore, the CAFE incentives should be restructured to encourage a larger percentage of the fleet to have flex-fuel capability. Additionally, plug-in hybrids, which are expected to be commercially available in the next few years, should be granted targeted CAFE credits to encourage their manufacture.

Energy Storage

It is difficult to overstate the importance of energy storage. The efficiency and cost-competitiveness of renewable electricity generation and alternative-fuel vehicles could be significantly improved by the availability of low-cost, high-capacity storage. For example, because solar and wind power generation is intermittent — the sun and the wind are not constantly available — these systems require energy storage if they are to serve as a reliable supply of electricity throughout the day. In the transportation sector, advanced energy storage technology could enable affordable family-sized vehicles that travel 200 miles or more on a single, rapid battery charge. Low-cost energy storage could also improve the commercial feasibility of hydrogen fuel cell vehicles. Therefore, PCAST makes the following recommendations.

21. **Support research on nanomaterials for energy storage applications.** The National Nanotechnology Initiative is to be commended for supporting research that is advancing understanding of nanomaterials broadly, including for energy storage applications. Progress toward improved energy storage systems will depend on continued strong support for research on novel nanoscale and nanostructured materials. Promising technologies should be identified and targeted to receive support for further development and prototyping in order to expedite technology transfer to and application by the private sector.

22. **Encourage the manufacture of energy storage products in the United States.** The manufacture of most batteries has moved offshore. Energy storage should be considered a key sector for the Federal Government to target with domestic manufacturing incentives. Such incentives could encourage the growth of an energy storage “ecosystem” spanning from materials development to the manufacture of finished products, helping to ensure that the United States leads in this core area of energy technology.

23. **Initiate a basic research initiative on next-generation energy storage technology.** The Federal Government should initiate significant funding for basic research to investigate radically new chemistries and concepts for electrochemical or electric storage, with the goal of achieving an order-of-magnitude improvement in cost and energy density compared to today’s lithium battery technology.

End-Use Energy Efficiency

While several recommendations above relate to improving the efficiency of the electric power and transportation sectors, there are also significant opportunities to improve "end-use" efficiency in the residential, commercial, and industrial sectors. Building and appliance efficiency improvements can reduce consumer costs and, on a national scale, yield a substantial reduction in primary energy input (e.g., coal, natural gas, and nuclear energy), including energy used for power generation and transmission.

24. **Expand the Energy Star program as broadly as possible.** The Energy Star program, managed by the U.S. Environmental Protection Agency, helps to raise public awareness of the “after purchase” costs of energy for many products. To the degree possible, all products that impact energy, from kitchen appliances to windows to automobiles, should carry an Energy Star rating. The EPA should update each standard regularly to ensure that it is stretching the private sector to integrate the latest energy efficiency technologies that can provide economic benefits to consumers.

25. **Encourage mainstream use of energy-efficient and renewable energy technologies in buildings.** Consumers and businesses are increasingly interested in owning their own distributed energy systems, which often use photovoltaic solar cell or fuel cell technology. The EPAct offers incentives to consumers

and businesses to install solar and other efficient systems, but these products are often not available as an integrated option for new homes or commercial buildings. Thus, in order to expand adoption of economically attractive and energy-efficient systems for homes and commercial office space, the Administration should encourage greater collaboration between stakeholders in this sector, including builders, trade associations, labor unions, State and local regulators, realtors, lenders, investment bankers, pension funds, appraisers, insurers, consumer groups, and utilities. A strong collaboration among these stakeholders could help overcome the market barriers — including a lack of information, outdated codes and standards, high transaction costs, and fragmented procedures and regulations — that inhibit the use of commercially available technologies that provide financial, energy, and environmental benefits.

26. **Establish programs to install efficient lighting.** Dramatic improvements have been made in the efficiency of household and commercial lighting. The transition to these new technologies, however, has been uneven — moving quickly in some applications such as traffic lights, but more slowly, for example, in the residential market. Besides assigning Energy Star ratings to all lighting products, the Federal Government (as mandated in the EPAct) should lead the way by switching most of its lighting to efficient bulbs, in order to demonstrate their value while helping to reduce manufacturing costs by increasing the volume of these products. Consumer incentives for installing high-efficiency lighting should be retained and, if appropriate, expanded.

27. **Set standards to improve motor-driven appliance efficiency.** Mandatory Federal standards for the efficiency of residential heating, ventilation, and air conditioning (HVAC) units increased by 30% in January 2006, as part of the National Appliance Energy Conservation Act. Additionally, the EPAct establishes an HVAC maintenance consumer education program and mandates an increase in the efficiency of commercial HVAC units by 2010, in addition to new standards for 14 other product categories. Still, some appliance efficiency standards in Europe and Japan remain stricter than those of the United States, suggesting that further increases in the minimum efficiency requirements may be economically feasible. The Federal Government should consider raising appliance efficiency standards based on the availability of improved technologies, such as low-cost brushless DC motors for efficient HVAC units.

Each stage of the energy infrastructure — the production, storage, transportation or transmission, conversion, and use of energy — involves unique technologies. Clearly, no single silver bullet can meet all the Nation's energy needs in a cost-effective and environmentally responsible way. Rather, the technologies mentioned in these recommendations and in the balance of this report must be considered as potential contributors to a long-term shift from heavy dependence on fossil fuels to more efficient, clean, and domestically available technologies such as renewable energy and nuclear power. This report has highlighted new ideas stirring in universities, government laboratories, and private enterprises that could dramatically change the Nation's energy infrastructure and systems by 2030. PCAST's recommendations consist of near-term opportunities for the Federal Government to encourage development of these technologies in order to advance national and global energy goals.

Closing Thoughts

A wide range of activities is underway in large and emerging growth companies, in universities, and in Government research facilities to develop and commercialize clean and efficient energy technologies. In recent years, entrepreneurs and private-sector leaders have substantially increased investment in technology innovations that, if successfully commercialized, could increase the Nation's energy supply, ensure its competitiveness, and improve U.S. energy security through greater reliance on home-grown solutions, while reducing local and global environmental impacts. New concepts for vehicles, fuels, power generation, and buildings could yield substantial benefits in the near term and enable significant changes in the Nation's energy infrastructure by 2030. Internationally, commercial success of these technologies could transform the efficiency and cleanliness of energy production and use in both developing and developed nations, and encourage greater international collaboration and trade in advanced energy systems.

Following widespread adoption of many of these technologies, perhaps by midcentury, the Nation's energy supply picture would look considerably different than Figure I-1. Nuclear, coal gasification, and renewable energy technologies would play a major role in electricity generation. Imports of natural gas would fall to negligible levels. Most vehicles would be powered by biofuels, electricity, or hydrogen instead of petroleum. Energy efficiency technologies would improve the efficiency of the electricity grid and energy use in homes, businesses, and factories. Lightweight materials and other improvements would double average vehicle fuel efficiency. Unconventional fossil fuels would provide a major portion of the fuel consumed by heavy-duty vehicles and aircraft. Efficient, electric-powered mass transit systems would be used by many commuters. As a result of all these factors, U.S. demand for oil would fall dramatically as a proportion of economic output, as would energy losses and greenhouse gas emissions at all stages of energy production and use. Furthermore, commercial acceptance of these technologies would likely occur on a global scale, resulting in significant energy and environmental benefits for the world. In this report, PCAST has highlighted opportunities to address vital, energy-related needs and has recommended steps that the Federal Government could take to further accelerate commercial development of these promising technologies.

Appendix A. Examples of Entrepreneurial Companies Developing Solar Energy Technologies

Company Name and Location	Web site	Business or Products Offered
Advent Solar Albuquerque, NM	http://www.adventsolar.com	Back-contact, ultra-thin silicon PV cells
Akeena Solar Los Gatos, CA and Fairfield, NJ	http://www.akeena.net	Solar electric system installation
Amonix, Inc. Torrance, CA	http://www.amonix.com	Utility-scale, concentrating PV systems
Atlantis Energy Systems, Inc. Sacramento, CA	http://www.atlantisenergy.org	PV roofing slates and PV glass laminates
CaliSolar, Inc. Sunnyvale, CA	http://www.calisolar.com	PV cells from “dirty silicon”
DayStar Technologies Halfmoon, NY 12065	http://www.daystartech.com	High-throughput manufacturing of thin-film PV “foil”
Developing Energy-Efficient Roof Systems (DEERS) Ripon, CA		Novel financing for roof-mounted solar systems
Energy Innovations Pasadena, CA	http://www.energyinnovations.com	Roof-mounted or portable concentrating solar power systems
Energy Photovoltaics, Inc. Princeton, NJ	http://www.epv.net	Amorphous silicon, thin-film PV modules
Entech Solar, Inc. Keller, TX	http://www.entechsolar.com	Fresnel-lens-based PV systems for terrestrial and space applications
Evergreen Solar Marlboro, MA	www.evergreensolar.com	PV modules based on low-cost “string-ribbon” manufacturing
Global Solar Energy, Inc. Tucson, AZ	http://www.globalsolar.com	Thin-film PV products to power portable electronics
HelioVolt Corp. Austin, TX	http://www.heliovolt.com	Rapid manufacturing of thin-film PV cells

Company Name and Location	Web site	Business or Products Offered
Innergy Power Corp. San Diego, CA	http://www.innergypower.com	Integrated battery / PV solar modules
Innovalight, Inc. Santa Clara, CA	http://www.innovalight.com	Solvent-based "silicon nanomaterial" PV manufacturing
Konarka Technologies, Inc. Lowell, MA	http://www.konarkatech.com	Nanostructured polymer PV cells
Miasolé San Jose, CA	http://www.miasole.com	High-throughput thin-film PV manufacturing
Nanosolar, Inc. Palo Alto, CA	http://www.nanosolar.com	High-throughput thin-film PV manufacturing
Nanosys, Inc. Palo Alto, CA	http://www.nanosysinc.com	Nanostructured polymer PV cells
Pacific SolarTech Fremont, CA	http://www.pacificsolartech.com	Distributed and utility-scale concentrating PV systems
Powerlight Corp. Berkeley, CA	http://www.powerlight.com	Roof-mounted and utility-scale PV systems
Practical Instruments, Inc. Pasadena, CA	http://www.practical-instruments.com	Roof-mounted concentrating PV modules
Prism Solar Technologies, Inc. Stone Ridge, NY	http://www.prismsolar.com	"Holographic" concentrating PV modules
Silicon Genesis Corp. San Jose, CA	http://www.sigen.com/	Silicon-on-insulator process for high-performance PV
Skybuilt Power Arlington, VA	http://www.skybuilt.com	Mobile PV power stations
Solaicx Santa Clara, CA	http://www.solaicx.com	Low-cost, high-performance silicon PV wafers
Solargenix Energy LLC Raleigh, NC	http://www.solargenix.com	Solar energy systems for commercial buildings and large-scale generation
Solaris Nanosciences Corp. Providence, RI	http://www.solarisnano.com/index.php	Dye-sensitized solar cells

Company Name and Location	Web site	Business or Products Offered
SolFocus, Inc. Palo Alto, CA	http://www.solfocus.com	Roof-mounted concentrating PV systems
Solyndra Santa Clara, CA	http://www.solyndra.com	Thin-film PV cells
Stellaris Corp. Lowell, MA 01853	http://www.stellaris-corp.com	Integrated products with concentrating lenses on thin-film PV
SunPower Corp. Sunnyvale, CA	http://www.sunpowercorp.com	Roof-mounted PV modules
Stirling Energy Systems, Inc. Phoenix, AZ	http://www.stirlingenergy.com	Concentrating solar dish-engine units for distributed or centralized power
Suncat Solar Phoenix, AZ		Silicon PV modules
XsunX, Inc. Aliso Viejo, CA	http://www.xsunx.com	Thin-film solar PV cells integrated into building systems

Appendix B. Examples of Entrepreneurial Companies Developing Biofuel Technologies

Company Name and Location	Web site	Business or Products Offered
Abengoa Bioenergy Corp. Chesterfield, MO	http://www.abengoabioenergy.com	Constructing cellulosic and corn (using entire kernel) ethanol refineries
Agrivida, Inc. Cambridge, MA	http://www.agrivida.com	Optimized corn varieties for cellulosic ethanol production from corn stover
Altra, Inc. Los Angeles, CA	http://www.altrabiofuels.com	Ethanol and biodiesel production
American Biodiesel LLC Toledo, OH	http://www.americanbiodiesel.net	Biodiesel production
Amyris Biotechnologies, Inc. Emeryville, CA	http://www.amyrisbiotech.com	Synthetic biology for high-performance biofuels
Aventine Renewable Energy, Inc. Pekin, IL	http://www.aventinerei.com	Corn ethanol production
Badger State Ethanol LLC Monroe, WI	http://www.badgerstateethanol.com	Corn ethanol production
BioEnergy International LLC Norwell, MA	http://www.bioenergyllc.com/	Thermal gasification of organic waste for co-production of electricity and biofuels
Bioengineering Resources, Inc. (BRI Energy) Fayetteville, AR	http://www.brienergy.com	Thermal gasification of organic waste for co-production of electricity and biofuels
Bixby Energy Systems, Inc. Rogers, MN	http://www.bixbyenergy.com	Biomass combustion products for industrial and residential heating
Celunol Corp. Dedham, MA	http://www.celunol.com	Ethanol from agricultural waste and other cellulosic biomass
Ceres, Inc. Thousand Oaks, CA	http://www.ceres-inc.com	Optimized plant varieties for cellulosic ethanol production
ClearFuels Technology, Inc. Aiea, HI		Fuels (ethanol, methanol, hydrogen) from agricultural crop waste

Company Name and Location	Web site	Business or Products Offered
Codexis, Inc. Redwood City, CA	http://www.codexis.com	Biological catalysts — enzymes or fermentation strains
Diversa Corp. San Diego, CA	http://www.diversa.com	Enzymes and small molecules with agricultural applications
Dogwood Energy LLC Tullahoma, TN	http://www.dogwoodenergy.com	Small- and industrial-scale ethanol and biodiesel production
Dyadic International, Inc. Jupiter, FL	http://www.dyadic-group.com	Enzymes to convert biomass into biofuels
Ethanol Boosting Systems LLC Cambridge, MA	http://www.ethanolboost.com	Ethanol fuel injection system to boost engine performance and efficiency
Galveston Bay Biodiesel, LP Houston, TX	http://www.galvestonbiodiesel.com	Biodiesel fuels for off-road or on-road diesel engines
Hawkeye Renewables Iowa Falls, IA	http://www.hawkrenew.com	Corn ethanol production
Iroquois Bio-Energy Co. Hebron, IN		Corn ethanol production
Mascoma Corp. Cambridge, MA	http://www.mascoma.com	Improved enzymes, microbes, and processes for cellulosic ethanol production
Methanotech, Inc. Pasadena, CA	http://www.methanotech.com	Methanol production from biomass
NatureWorks LLC Minneapolis, MN	http://www.natureworksllc.com	Polymers from renewable resources rather than petroleum materials
Novozymes, Inc. Davis, CA	http://www.novozymes.com	Enzymes for making ethanol from corn stover
Seattle Biodiesel Seattle, WA	http://www.seattlebiodiesel.com	Biodiesel production
ORYXE Energy, International, Inc. Irvine, CA	http://www.oryxe-energy.com	Biodiesel and petroleum additives
Pacific Ethanol, Inc. Fresno, CA	http://www.pacificethanol.net	Corn ethanol production and saleable by-products

Company Name and Location	Web site	Business or Products Offered
Synthetic Genomics, Inc. Rockville, MD	http://www.syntheticgenomics.com	Optimized microorganisms for ethanol and hydrogen production
VeraSun Energy Corp. Brookings, SD	http://www.verasun.com	Corn ethanol production
White Energy, Ltd. Dallas, TX	http://www.white-energy.com	Corn ethanol production

Appendix C. Examples of Entrepreneurial Companies Developing Fuel Cell Technologies

Company Name and Location	Web site	Business or Products Offered
Ardica Technologies San Francisco, CA	http://www.ardica.com	Micro fuel cells for portable electronics
Bloom Energy (formerly Ion America) Sunnyvale, CA	http://www.bloomenergy.com/	Solid-oxide, regenerative fuel cells for load-leveling for renewable sources
CellTech Power, Inc. Westborough, MA	http://www.celltechpower.com	Solid-oxide fuel cells with a broader range of input fuels
Enerage, Inc. Arcadia, CA	http://www.enerage.com	Micro fuel cells for portable electronics
Franklin Fuel Cells, Inc. Malvern, PA	http://www.franklinfuelcells.com	Solid-oxide fuel cells
HyEnergy Systems, Inc. Austin, TX		Hybrid battery/fuel cells for portable electronics
HyRadix, Inc. Des Plaines, IL	http://www.hyradix.com	Hydrogen reforming from natural gas
Jadoo Power Folsom, CA	http://www.jadoopower.com	Portable fuel cell power systems
Lilliputian Systems, Inc. Woburn, MA		Micro fuel cells for portable electronics
Microcell Raleigh, NC	http://www.microcellcorp.com	Cylindrical PEM fuel cells for multiple applications
Neah Power Systems, Inc. Bothell, WA	http://www.neahpower.com	Micro fuel cells for portable electronics
Oorja Protonics Menlo Park, CA	http://www.oorjaprotonics.com	Micro fuel cells for portable electronics
PolyFuel Mountain View, CA	http://www.polyfuel.com	Nanostructured fuel cell membranes

Company Name and Location	Web site	Business or Products Offered
Protonex Technology Corp. Southborough, MA	http://www.protonex.com	Portable fuel cell power systems
ReliOn, Inc. Spokane, WA	http://www.relion-inc.com	Modular, portable fuel cell power systems
TesSol, Inc. Bryan, TX	http://www.fideris.com	Fuel cell test equipment
Trulite, Inc. Orem, UT	http://www.trulitetech.com	Chemical-hydride hydrogen fuel packs for portable fuel cells

Appendix D. Examples of Entrepreneurial Companies Developing Energy Storage Technologies

Company Name and Location	Web site	Business or Products Offered
A123 Systems Watertown, MA	http://www.a123systems.com	Lithium-ion batteries using nanoscale materials
Cymbet Corp. Elk River, MN	http://www.cymbet.com	Thin-film batteries for direct integration into ICs or electronics
EEStor, Inc. Cedar Park, TX	http://www.EEstor.US	Supercapacitors with multilayer ceramics
Firefly Energy, Inc. Peoria, IL	http://www.fireflyenergy.com	Lightweight, composite lead-acid batteries
PowerGenix San Diego, CA	http://www.powergenix.com	Rechargeable nickel-zinc batteries
SCI Engineered Materials, Inc. Columbus, OH	http://www.superconductive comp.com	Lithium, thin-film batteries
Solicore, Inc. Lakeland, FL	http://www.solicore.com	Ultra-thin lithium polymer batteries for portable electronics
Zinc Matrix Power, Inc. Camarillo, CA	http://www.zmp.com	Rechargeable silver-zinc batteries

Appendix E. Examples of Entrepreneurial Companies Developing Other Energy Technologies

Company Name and Location	Web site	Business or Products Offered
AC Propulsion Inc. San Dimas, CA	http://www.commutercars.com	Electric vehicles
AquaEnergy Group, Ltd. Mercer Island, WA	http://aquaenergygroup.com	Ocean wave energy systems
Clipper Windpower, Inc. Carpinteria, CA	http://www.clipperwind.com	Wind power generation
Clean Energy Systems, Inc. Rancho Cordova, CA	http://www.cleanenergysystems.com	Coal power plants with zero atmospheric emissions, using oxy-combustion and carbon capture
Commuter Cars Corp. Spokane, WA	http://www.commutercars.com	Electric vehicles
EnerNOC, Inc. Boston, MA	http://www.enernoc.com	Demand response and energy management systems
Fat Spaniel Technologies, Inc. San Jose, CA	http://www.fatspaniel.com	Real-time energy monitoring for residential and commercial buildings
Gaia Power Technologies, Inc. New York, NY	http://www.gaiapowertech.com	Demand response and energy management systems
Greenfuel Technologies Corp. Cambridge, MA	http://www.greenfuelonline.com	Algae bioreactors that convert smokestack CO_2 into fuels
GridPoint, Inc. Washington, DC	http://www.gridpoint.com	Energy management appliances for power reliability and energy efficiency
Hi-Z Technology, Inc. San Diego, CA	http://www.hi-z.com/	Small-scale power generation from thermoelectric devices
Home Comfort Zones, Inc. Beaverton, OR	http://www.homecomfortzones.com	Residential temperature control and energy management
Hybrid Technologies, Inc. Las Vegas, NV	http://hybridtechnologies.com	Electric vehicles
NanoSteel Co. Providence, RI	http://www.nanosteelco.com	High-strength, nanocrystalline microstructures

Company Name and Location	Web site	Business or Products Offered
Ocean Power Technologies, Inc. Pennington, NJ	http://www.oceanpower technologies.com	Ocean wave energy for electrical power for utility-scale grid applications
Pentadyne Power Corp. Chatsworth, CA	http://www.pentadyne.com	Flywheel power systems for power quality and power recycling applications
Phoenix Motorcors, Inc. Ontario, CA	http://61.218.37.153/	Electric vehicles
Powerspan Clean Energy Technology Portsmouth, NH	http://www.powerspan.com	Integrated air pollution controls for coal-fired power plants
Skyonic Corp. Austin, TX	http://www.skyonic.com	Capture of CO_2 and regulated pollutants from coal power plants; conversion of CO_2 into products
SmartSpark Energy Systems, Inc. Champaign, IL	http://www.smartsparkenergy.com/	Energy management and power conversion for distributed solar power
Southwest Windpower, Inc. Flagstaff, AZ	http://www.windenergy.com	Wind turbine generators for distributed power
SpectraSensors, Inc. San Dimas, CA	http://www.spectrasensors.com	Sensors for environmental monitoring
STM Power, Inc. Ann Arbor, MI	http://www.stmpower.com	Distributed power generators using Stirling-cycle engines
Tellurex Corp. Traverse City, MI	http://www.tellurex.com	Small-scale power generation, cooling, and heating using thermoelectric devices
Tesla Motors, Inc. San Carlos, CA	http://www.teslamotors.com	Electric vehicles
Universal Electric Vehicle Corp. Thousand Oaks, CA	http://www.universalelectric vehicle.com	Electric vehicles
WebGen Systems Cambridge, MA	http://www.webgensystems.com	Software for energy conservation and control in commercial buildings
Wilson TurboPower, Inc. Woburn, MA	http://www.wilsonturbopower.com	Distributed power generators using microturbines with heat regeneration
WOW Energies Sugar Land, TX	http://www.wowenergies.com	Waste-heat turbine generators

Glossary

AC	alternating current
ACI	American Competitiveness Initiative
AEI	Advanced Energy Initiative
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
B20	A fuel blend containing 20% biodiesel and 80% diesel (by volume).
Barrel	A unit of volume equal to 42 U.S. gallons.
Base load	The minimum amount of electric power delivered or required over a given period of time at a steady rate.
Base load generator	An electric power plant, usually housing high-efficiency steam-electric units (e.g., with heat supplied by nuclear power or coal combustion), which is normally operated to take all or part of the minimum load of a system, and which consequently produces electricity at an essentially constant rate and runs continuously. These units are operated to maximize system mechanical and thermal efficiency and minimize system operating costs.
Biodiesel	Any liquid biofuel suitable as a diesel fuel substitute or diesel fuel additive or extender. Biodiesel fuels are typically made from oils such as soybeans, rapeseed, or sunflowers, or from animal tallow. Biodiesel can also be made from hydrocarbons derived from agricultural products such as rice hulls.
Biofuels	Liquid fuels and blending components produced from biomass (plant) feedstocks, used primarily for transportation.
Biomass	Organic, non-fossil material of biological origin constituting a renewable energy source.
British thermal unit	The quantity of heat required to raise the temperature of 1 pound of liquid water by 1°F at the temperature at which water has its greatest density (approximately 39°F).
Btu	British thermal unit
CAFE	Corporate Average Fuel Economy
Carbon sequestration	The fixation of atmospheric carbon dioxide in a carbon sink through biological or physical processes.
CCTP	Climate Change Technology Program
CdTe	cadmium telluride

CIGS	copper indium gallium selenide
CITRIS	Center for Information Technology Research in the Interest of Society
CO_2	carbon dioxide
CPG	concentrating PV glazing
CREBs	Clean Renewable Energy Bonds
CSP	concentrating solar power technology
CTL	coal-to-liquid fuels
DC	direct current
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
E10	A fuel blend containing of 10% ethanol and 90% unleaded gasoline (by volume).
E85	A fuel blend containing 85% denatured ethanol and 15% gasoline (by volume).
EIA	The Energy Information Administration, an independent agency within DOE that develops surveys, collects energy data, and analyzes and models energy issues. EIA must meet the requests of Congress, other elements within DOE, the Federal Energy Regulatory Commission, the Executive Branch, and its own independent needs, and it must assist the general public and other interest groups without taking a policy position. See more information about EIA at http://www.eia.doe.gov/neic/aboutEIA/aboutus.htm.
Electric generator	A facility that produces only electricity, commonly expressed in kilowatt-hours (kWh) or megawatt-hours (MWh). Electric generators include electric utilities and independent power producers.
Electric power	The rate at which electric energy is transferred. Electric power is measured by capacity and is commonly expressed in megawatts (MW).
Electric power grid	A system of synchronized power providers and consumers connected by transmission and distribution lines and operated by one or more control centers. In the continental United States, the electric power grid consists of three systems: the Eastern Interconnect, the Western Interconnect, and the Texas Interconnect. In Alaska and Hawaii, several systems encompass areas smaller than the State (e.g., the interconnect serving Anchorage, Fairbanks, and the Kenai Peninsula; individual islands).
Electric power plant	A station containing prime movers, electric generators, and auxiliary equipment for converting mechanical, chemical, and/or fission energy into electric energy.
Electric power sector	An energy-consuming sector that consists of electricity only and combined heat and power plants whose primary business is to sell electricity, or electricity and heat, to the public.

Electric utility	A corporation, person, agency, authority, or other legal entity or instrumentality aligned with distribution facilities for delivery of electric energy for use primarily by the public. Included are investor-owned electric utilities, municipal and State utilities, Federal electric utilities, and rural electric cooperatives. A few entities that are tariff-based and corporately aligned with companies that own distribution facilities are also included.
Electricity demand	The rate at which energy is delivered to loads and scheduling points by generation, transmission, and distribution facilities.
Electricity generation	The process of producing electric energy or the amount of electric energy produced by transforming other forms of energy, commonly expressed in kilowatt-hours (kWh) or megawatt-hours (MWh).
EPA	U.S. Environmental Protection Agency
EPAct	Energy Policy Act of 2005
Ethanol	A clear, colorless, flammable oxygenated hydrocarbon (CH_3-CH_2OH). Ethanol is typically produced chemically from ethylene, or biologically from fermentation of various sugars from carbohydrates found in agricultural crops and cellulosic residues from crops or wood. It is used in the United States as a gasoline octane enhancer and oxygenate (blended up to 10 percent concentration). Ethanol can also be used in high concentrations (E85) in vehicles designed for its use.
EV	electric vehicle
FEMP	The Federal Energy Management Program within DOE.
FFV	flex-fuel vehicle
Flex-Fuel Vehicle	A vehicle that can operate on: (1) alternative fuels (such as E85) (2) 100-percent petroleum-based fuels (3) any mixture of an alternative fuel (or fuels) and a petroleum-based fuel. Flexible fuel vehicles have a single fuel system to handle alternative and petroleum-based fuels. Flexible fuel vehicle and variable fuel vehicle are synonymous terms.
Fuel cell	A device capable of generating an electrical current by converting the chemical energy of a fuel (e.g., hydrogen) directly into electrical energy. Fuel cells differ from conventional electrical cells in that the active materials such as fuel and oxygen are not contained within the cell but are supplied from outside. It does not contain an intermediate heat cycle, as do most other electrical generation techniques.
FY	fiscal year
GNEP	Global Nuclear Energy Partnership
GOCO	government-owned, contractor-operated

Greenhouse gases	Those gases, such as water vapor, carbon dioxide, nitrous oxide, methane, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride, that are transparent to solar (short-wave) radiation but opaque to long-wave (infrared) radiation, thus preventing long-wave radiant energy from leaving Earth's atmosphere. The net effect is a trapping of absorbed radiation and a tendency to warm the planet's surface.
Grid	The layout of an electrical distribution system. See electric power grid.
Gt	gigaton
GW	gigawatt
HEV	hybrid electric vehicle
HVAC	heating, ventilation, and air conditioning
Hybrid electric vehicle	An electric vehicle that either (1) operates solely on electricity, but contains an internal combustion motor that generates additional electricity (series hybrid); or (2) contains an electric system and an internal combustion system and is capable of operating on either system (parallel hybrid).
IC	integrated circuit
Industrial sector	An energy-consuming sector that consists of all facilities and equipment used for producing, processing, or assembling goods. The industrial sector encompasses the following types of activity: manufacturing; agriculture, forestry, fishing and hunting; mining, including oil and gas extraction; and construction. Overall energy use in this sector is largely for process heat and cooling and powering machinery, with lesser amounts used for facility heating, air conditioning, and lighting. Fossil fuels are also used as raw material inputs to manufactured products.
IGCC	Integrated gasification-combined cycle technology used for production of electricity from coal. In this process, coal, water, and oxygen are fed to gasifier, which produces syngas. This medium-Btu gas is cleaned (particulates and sulfur compounds removed) and is fed to a gas turbine. The hot exhaust of the gas turbine and heat recovered from the gasification process are routed through a heat-recovery routed through a heat-recovery generator to produce steam, which drives a steam turbine to produce electricity.
Intermittent generator	An electric generating plant with output controlled by the natural variability of the energy resource rather than dispatched based on system requirements. Intermittent output usually results from the direct, non-stored conversion of naturally occurring energy fluxes such as solar energy, wind energy, or the energy of free-flowing rivers (that is, run-of-river hydroelectricity).
kWh	kilowatt-hour
Low-E windows	low-emissivity windows; new window technology that lowers the amount of energy loss through windows by inhibiting the transmission of radiant heat while still allowing sufficient light to pass through.

mbpd	million barrels per day
MMT	million metric tons
NASA	National Aeronautics and Space Administration
NHTSA	National Highway Traffic and Safety Administration, within the DOT.
NiMH	nickel metal hydride
NIST	National Institute of Standards and Technology, within the U.S. Department of Commerce.
NL	National Laboratory
NOx	nitrous oxide
NRC	National Research Council, a part of the National Academies.
NSF	National Science Foundation
NYSERDA	New York State Energy Research and Development Authority
OECD	Organisation for Economic Co-operation and Development
OTEC	ocean thermal energy conversion
PCAST	President's Council of Advisors on Science and Technology
Peak load	The maximum demand for electricity during a specified period of time; peak demand.
Peak load generator	An electric power plant usually housing old, low-efficiency steam units, gas turbines, diesels, or pumped-storage hydroelectric equipment normally used during the peak-load periods.
PEM	proton exchange membrane (or sometimes, polymer electrolyte membrane)
PL	Public Law
Power plant	See electric power plant.
PV	photovoltaic
quad	quadrillion Btus
R&D	research and development
RPS	renewable portfolio standard
SBIR	Small Business Innovation Research programs
SOFC	solid oxide fuel cell; a fuel cell, mainly for stationary applications, that has an electrolyte of solid-oxide (ceramic) material, which enables operation at high temperatures (e.g., 800 – 1000°C).

STTR	Small Business Technology Transfer programs
USDA	U.S. Department of Agriculture
Utility	See electric utility.
VC	venture capitalist
VEETC	Volumetric Ethanol Excise Tax Credit

Source for definitions: Energy Information Administration glossary, http://www.eia.doe.gov/glossary/

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President's Council of Advisors on Science and Technology • November 2006

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