America's Energy Future: Technology and Transformation

This report from the National Academy of Sciences and National Academy of Engineering assesses the potential over the next two to three decades of a range of technologies to increase sustainability, support long-term economic prosperity, promote energy security, and reduce adverse environmental impacts. The report finds that, with a sustained national commitment, the United States could achieve considerable energy-efficiency improvements, acquire new sources of energy supply, and effect substantial reductions in greenhouse gas emissions through the accelerated development and deployment of a portfolio of existing and emerging energy-supply and end-use technologies. Actions taken between now and 2020 to develop and demonstrate the viability of several key technologies will, to a large extent, determine the nation's energy options for many decades to come.

Energy has always played a critical role in our country's national security, economic prosperity, and environmental quality. Growing concern about America's dependence on vulnerable sources of imported oil and in the future, natural gas, the volatility of energy markets, increasing worldwide demand for energy, and concerns about climate change have sparked a national and political interest in the country's energy future. In the face of these issues, the United States must consider how to provide sufficient, affordable, and sustainable supplies of energy.

Fossil fuels currently dominate the United States' energy landscape, providing more than 85 percent of the United States' energy supply (see Figure 1) and 21 percent of world energy and consumption. For transportation, the United States is almost completely dependent upon petroleum, of which 56 percent is imported. United States fossil energy

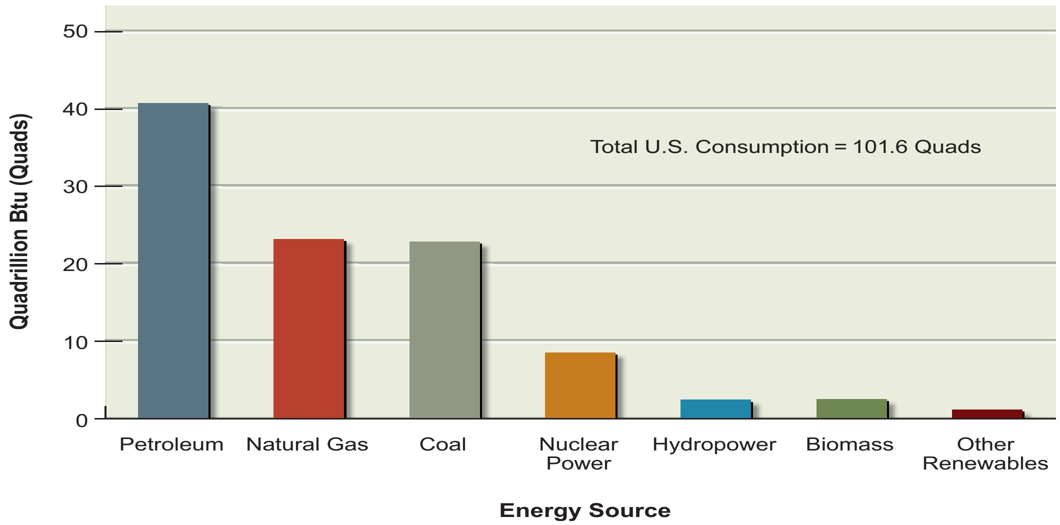

Figure 1: America's energy use in 2008. Source: Energy Information Administration, 2008

consumption generates about 6 billion tons of carbon dioxide (CO_2)—a major greenhouse gas—emissions, accounting for about a quarter of the world's total CO_2 emissions annually.

Market forces have, for the most part, guided the development of the current United States energy system. But to date, they have undervalued the changes necessary for movement toward sustainable energy supply and use, such as the environmental costs of burning fossil fuels and dependence on imported fuels. Decisions about future energy options require technology choices that involve a complex mix of scientific, technical, economic, social, and political considerations. A key message from *America's Energy Future* is that a suite of current and emerging technologies have the potential to move the nation towards a more secure and sustainable energy system.

America's Energy Future addresses the relative costs, environmental impacts, and barriers to widespread deployment of existing and emerging energy-supply and end-use technologies. An accelerated deployment effort from now until 2035 is compared against the Energy Information Administration's (EIA's) "business-as-usual" reference case.

Energy Efficiency

Increased adoption of energy-efficiency technologies is the nearest-term and lowest-cost option for moderating our nation's demand for energy, especially over the next decade. The potential energy savings available from the accelerated deployment of existing energy efficiency technologies in buildings, industry, and transportation sectors could more than offset projected increases in United States energy consumption through 2030.

Buildings, which use 73 percent of electricity and 40 percent of all U.S energy consumed, have the greatest potential for increases in efficiency (see Figure 2). By 2030, using currently available or emerging efficiency technologies in buildings could lower energy use by 25 to 30 percent compared to predictions reflected in the EIA reference case, even with expected growth in consumer demand. This reduction would eliminate the need to build any new electric power generating plants before 2030 except to address regional supply imbalances, replace obsolete generating assets, or substitute more environmentally benign electricity sources. Replacing incandescent lamps with compact fluorescent and new solid state (light emitting

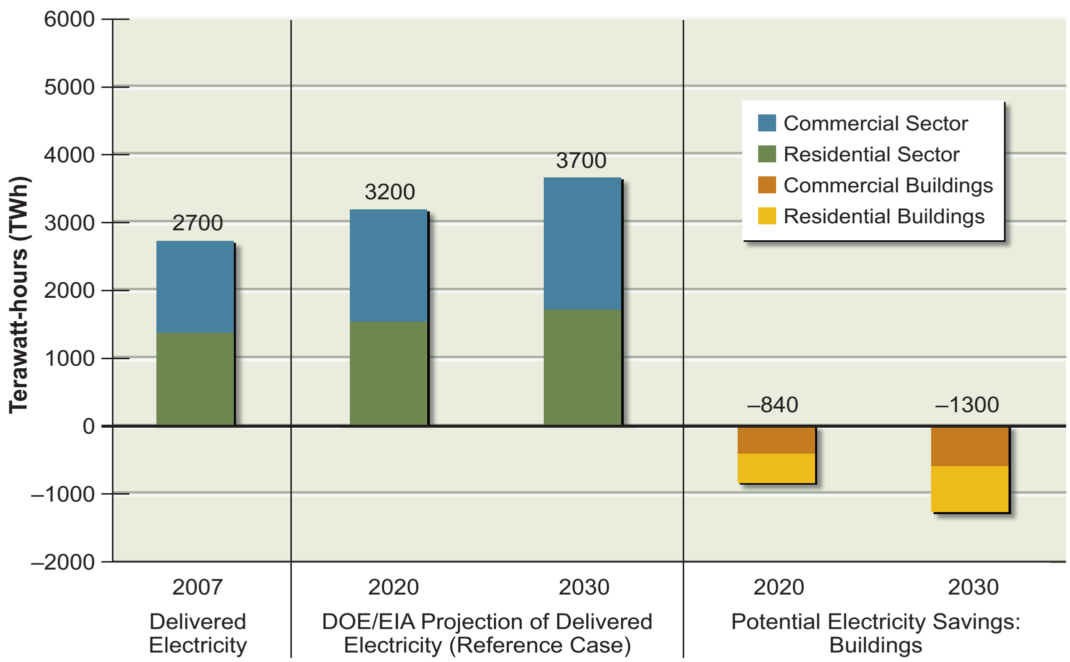

Figure 2: The 2007 U.S. delivered energy, used mainly in buildings, is on the left. The building sector's projected electricity consumption in 2020 and 2030 is in the middle. The sector's potential savings with an accelerated deployment of efficiency technologies is on the right.

diode) lamps alone could reduce buildings' electricity use by 12 percent.

Many building efficiency technologies represent attractive investment opportunities with a payback period of two to three years. While lack of information and capital discourages consumers and businesses from using these technologies, setting efficiency standards, incorporating efficiency into building codes, labeling product efficiency, and promoting consumer awareness could dramatically increase adoption of these measures.

The industrial and transportation sectors could also significantly increase their energy efficiency. The industrial sector could reduce its energy use by 14 to 22 percent by 2020, compared to the expected trend reflected in the EIA reference case. It could expand the use of available systems that both produce electricity and recover waste heat, along with other specific process technologies. In transportation, technologies that increase the efficiency of light-duty vehicles (cars and sport utility vehicles [SUVs]) could allow the new vehicle fleet to exceed 35 miles per gallon average by 2020. This 40 percent increase in fuel economy over today's average of 25 miles per gallon would offset the predicted increase in fuel demand absent such improvements. To achieve these savings, vehicle manufacturers must use new technology to increase fuel economy rather than vehicle size or power. Increased use of plug-in electric hybrid vehicles, which rely partly on electricity for fuel, and battery electric vehicles could also appreciably reduce gasoline use. These vehicles could begin to make a large impact beyond 2020 but their market success critically depends on development of batteries with much higher performance and lower costs than are currently available. In addition, fuel cell vehicle technology improvements could pave the way for large-scale deployment in the period 2035-2050. Medium and heavy duty vehicles, such as tractor trailers, could also experience a 10 to 20 percent reduction in fuel use by 2020 compared to projections. Using rail for freight shipping could also reduce that sector's fuel use, because it is ten times more efficient in terms of energy use than trucking.

New Supplies of Electricity

Although most electricity is produced by burning conventional fossil fuels (over 70 percent in the United States), several non-traditional sources of electricity have the potential to significantly change the supply mix during the next two to three decades. They can reduce greenhouse gas emissions substantially but will likely cost consumers more than current sources (see Figure 3).

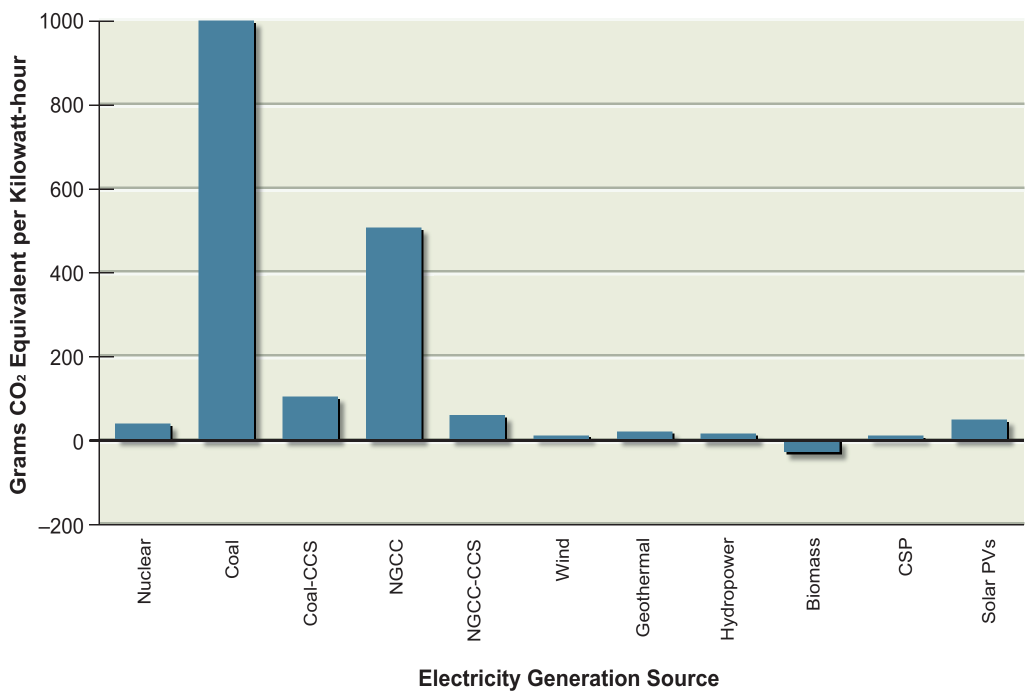

Figure 3: The potential range of greenhouse gas emissions for new sources of electricity. NGCC is natural gas combined cycle technology, CCS is carbon capture and storage, CSP is concentrating solar power, and PV is photovoltaic.

Coal-fired power plants currently generate about half of the electricity consumed in the United States. Domestic coal reserves are sufficient for continued use of coal in power generation for more than a century, including accommodation of substantial growth in electricity use. But these plants produce a significant amount of CO_2, and future controls placed on greenhouse gas emissions may limit their use unless the CO_2 is captured and stored. Carbon capture and storage (CCS) technology captures and injects CO_2 into secure rock formations, such as oil and gas reserves, deep saline aquifers, and deep coal beds. This technology has the potential to considerably reduce the amount of CO_2 emissions to the atmosphere from coal-fired plants. Current geological surveys suggest that there are enough places near major CO_2 producers to store decades worth of emissions. Refitting existing coal-fired power plants with CCS could reduce their CO_2 emissions by as much as 50 percent, while new plants could eventually produce 90 percent less CO_2. The potential exists to replace or refit all of America's coal-fired power plants with CCS plants by 2035, albeit at considerably increased cost relative to existing plants. However, to demonstrate the reality of this potential at acceptable cost, public and/or private entities need to construct 15 to 20 demonstration plants, new and retrofitted, with a variety of fuels (natural gas, biomass, and different types of coal), technologies, and carbon capture and storage strategies by 2020. These plants are needed to demonstrate that this technology can be safely deployed at the scale required in a variety of geological formations. It will take decades to achieve deep reductions in the electricity sector. The urgency of getting started on the demonstration to clarify future deployment options cannot be overstated.

Nuclear power currently supplies about 19 percent of United States electricity production. It has substantial potential for continuing to contribute a significant fraction of United States electric power generation, but realizing that potential requires upgrading existing plants to increase their generating capacity as well as constructing new ones. Upgrading existing nuclear power plants could supply almost as much additional electricity by 2020 as new plants at less than a third of the cost. To prove nuclear power's future commercial viability in the United States, construction of about five evolutionary nuclear plants in the United States (using today's technology) will be necessary during the next decade. If these initial plants meet cost, schedule, and performance targets, three to five new plants could be constructed annually during the period from 2020 to 2035. Such an expansion would significantly increase the nation's energy supply diversity, fulfilling electricity demand that coal with CCS and renewable sources will be unlikely to meet during that time frame. Barriers to developing nuclear power in the United States include high capital costs, a possible regulatory bottleneck for applications, and public concerns.

Renewable energy sources, such as wind, solar, hydropower, geothermal, and biopower, also have a significant role to play in the nation's future electricity system. Conventional hydropower produces 6 percent of America's electricity, but its environmental impacts will probably limit its expansion. Although non-hydropower renewable sources produce only 2.5 percent of the United States' electricity, use of both wind and solar power has

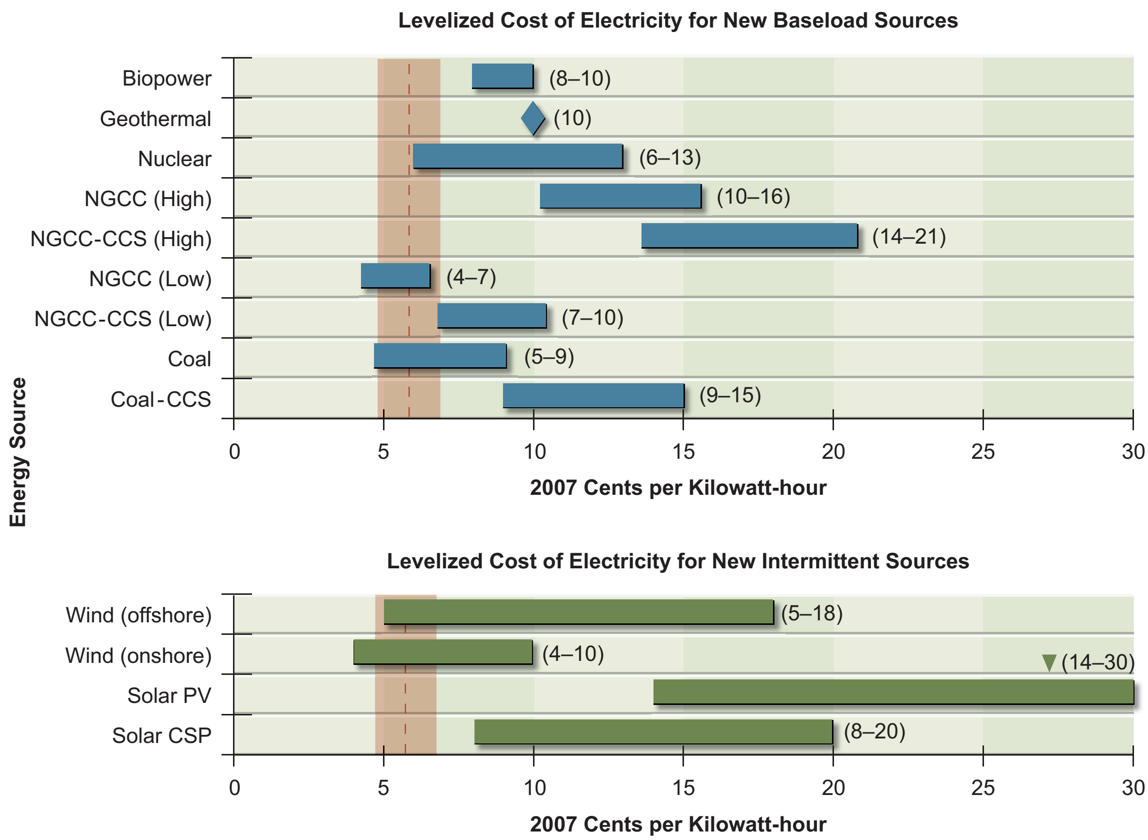

Figure 4: The potential range of costs for new sources of electricity. These estimated costs include plant construction, financing, operations, fuel, and decommissioning, but not transmission or distribution. The dotted red line represents the average wholesale price for electricity in 2007, which is not expected to change significantly through 2030. NGCC is natural gas combined cycle technology, CCS is carbon capture and storage, PV is photovoltaic, and CSP is concentrating solar power. Those prices with (low) indicate potential prices with a low price for natural gas and those with (high) indicate potential prices with a high price for natural gas.

grown dramatically in the last decade. Overall, solar power has the most resource potential in the United States, followed by wind. Aside from higher cost relative to traditional alternatives, neither has any technical constraints on expansion. Together, they could realistically provide 10 percent of the country's electricity by 2020 and 20 percent by 2035. By 2035, the amount of energy provided by renewables could exceed the amount supplied by nuclear or coal with CCS. To achieve this potential, however, policies are needed to help the price of renewable sources compare favorably to current sources. Also, because renewable energy sources are intermittent and geographically distributed, their large-scale use will require an expansion of and investment in electric power transmission and distribution. Fast-responding back-up electricity generation will be needed as well. If electricity generation from renewable resources is able to expand beyond 20 percent of total generation, advanced electricity storage technologies will also be necessary.

Electricity costs from coal plants with CCS, evolutionary nuclear plants, offshore wind plants, and concentrating solar power plants will probably be substantially higher than current electricity production costs (Figure 4). In addition, concerns about land use, water use, and potential health effects may limit the use of some technologies, such as CCS and nuclear power. To minimize costs and risks, the nation should develop a diverse portfolio of alternative electricity supply technologies. Of particular significance in fashioning this portfolio is determining the viability of CCS or evolutionary nuclear plants in the United States. The range of options will be quite

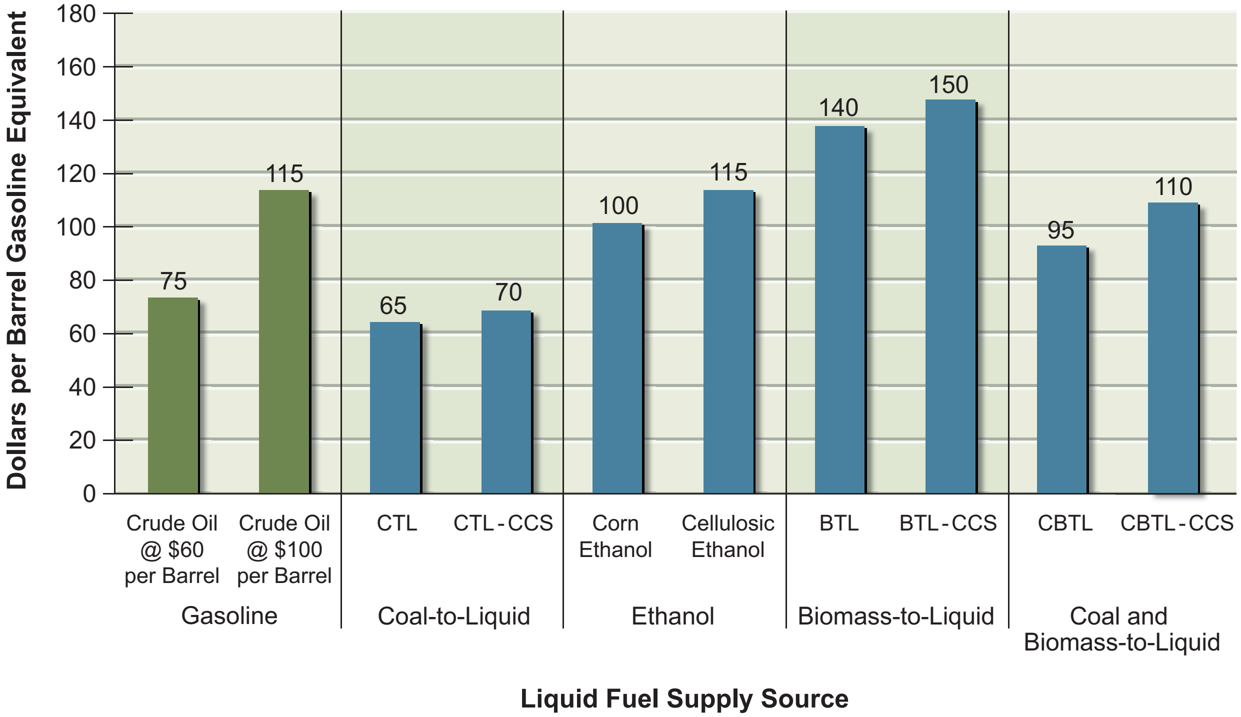

Figure 5: This graph illustrates the predicted future prices for a number of liquid fuels feedstocks. CTL is coal-to-liquid feedstocks, BTL is biomass-to-liquid feedstocks, and CBTL is coal-and-biomass-to-liquid feedstocks. CCS stands for carbon capture and storage. These estimated costs are in 2007 dollars and rounded to the nearest $5.

different without such a determination and nothing is gained by delays in completing the necessary demonstration efforts for both technologies.

The Electric Grid

The nation's electric power transmission and distribution network urgently needs to be upgraded to improve reliability, increase security, and expand the use of energy efficiency technologies. The current electric grid, an amalgamation of outdated technologies, is vulnerable to outages from natural and human causes. Much of the technology to update the grid exists now and can help consumers save energy, improve information to operators, incorporate renewable energy, and accommodate plug-in electric hybrid and battery electric vehicles. The grid could be completely modernized and expanded in 20 years and it is estimated that the benefits will significantly outweigh the costs. Carrying out modernization and expansion simultaneously has the additional benefits of further lowering costs and more rapidly implementing modifications. Completing these changes concurrently would cost $250 billion less than carrying them out separately. However, this conversion will be expensive and involve resolution of many policy issues as well as legislative and regulatory changes to encourage investment.

Alternative Liquid Transportation Fuels

Petroleum is an indispensable transportation fuel today and will continue to be for many decades. Improving vehicle efficiency is the best near-term option for reducing petroleum use but, in addition, some fuel substitutions may be available after 2020 (see Figure 5).

To reduce the United States' dependence on imported petroleum, converting coal and biomass into liquid fuels could provide significant domestic sources of transportation fuel. Although coal-to-liquid fuel technology is being demonstrated outside the United States, the conversion process produces twice as much CO_2 as petroleum. However, coal-to-liquid combined with CCS produces about the same level of CO_2 emissions as petroleum use and could provide up to 25 percent of the current volume of fuel used in United States transportation by 2035. If the United States' production of coal-to-liquid reached a level of 3 million barrels of gasoline equivalent per day by 2035, this would require a 50 percent increase in coal production. It would also require deployment of significant additional infrastructure for coal mining, transportation, coal-to-liquid plants and CCS systems. This increased demand for coal would have a range of environmental impacts and could potentially raise the price of coal, particularly if coal use continues to grow in power generation because of the successful commercialization of CCS.

If during coal-to-liquid conversion, coal is combined with a biomass feedstock and CCS is utilized, liquid fuels can be produced with nearly zero CO_2 lifecycle emissions. Using 60 percent coal and 40 percent biomass, there is the potential to produce 2.5 million barrels per day of fuel, or 20 percent of the volume used in the United States' transportation. However, this level of alternative fuel market penetration relies on aggressive development of CCS and commercial demonstration of the conversion technology.

Cellulosic (non-food biomass) ethanol is another major non-petroleum option, although conversion of cellulosic energy crops has not been demonstrated on a commercial scale. Although biomass is renewable, limited availability of land and water resources would restrict annual output. Using today's agricultural practices, farmers could produce up to 500 million dry tonnes of biomass per year by 2020. If cellulosic ethanol is commercialized and plants are built twice as quickly as corn ethanol plants have been, cellulosic ethanol could provide 0.5 million barrels per day of fuel by 2020. By 2035, it could provide 1.7 million barrels per day, or nearly 20 percent of current light-duty vehicle fuel use.

Achieving a biomass production level of 500 million tonnes per year in the United States and its conversion to liquid fuels would require government incentives to farmers to sustainably grow cellulosic energy crops. It would also require the government provide permits for tens to hundreds of conversion plants and accompanying infrastructure.

Future Barriers and Needs

Many emerging energy demand and supply technologies have significant barriers to their widespread adoption. These barriers vary considerably by technology, including the slow turnover of infrastructure, limited resources, potentially higher costs, concerns about performance, and uncertainty about restrictions on greenhouse gas emissions. As noted earlier, new energy supply options will be more expensive than fuels and electricity have been in recent years. In many cases, significant capital investments will be needed. Investments in the new technologies may be inhibited if investors are uncertain about future energy prices. Policies, such as those that set efficiency standards, support renewable energy, and encourage demonstration of CCS, evolutionary nuclear, and cellulosic ethanol technologies, can help overcome these barriers.

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*Resigned from committee on January 21, 2009

This report brief was prepared by the National Research Council (NRC) based on the committee's report. The NRC appointed the above panel of experts, who volunteered their time for this activity. The NRC study was initiated by the National Academy of Sciences and the National Academy of Engineering and subsequently endorsed by a request from Congress. The committee's report is peer-reviewed and signed off by both the committee members and the NRC.

EXPERT CONSENSUS REPORT

Reports in the National Academies' America's Energy Future Initiative
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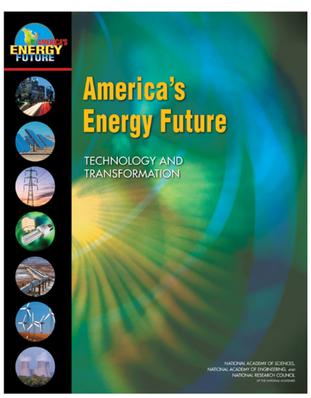
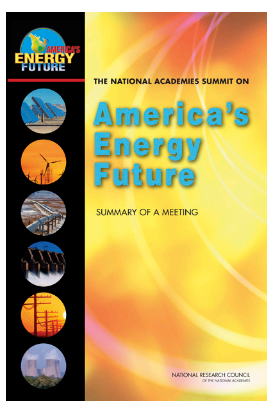
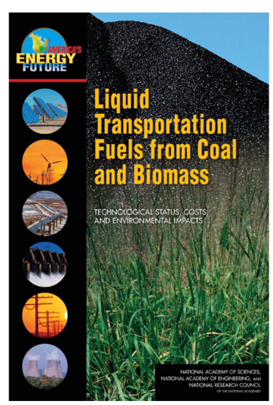
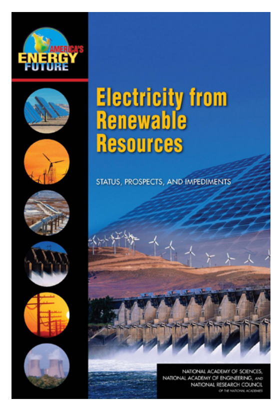
Liquid Transportation Fuels from Coal and Biomass
Electricity from Renewables: Status, Prospects, and Impediments
Real Prospects for Energy Efficiency in the United States









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