What You Need to Know About Energy

DETAILS

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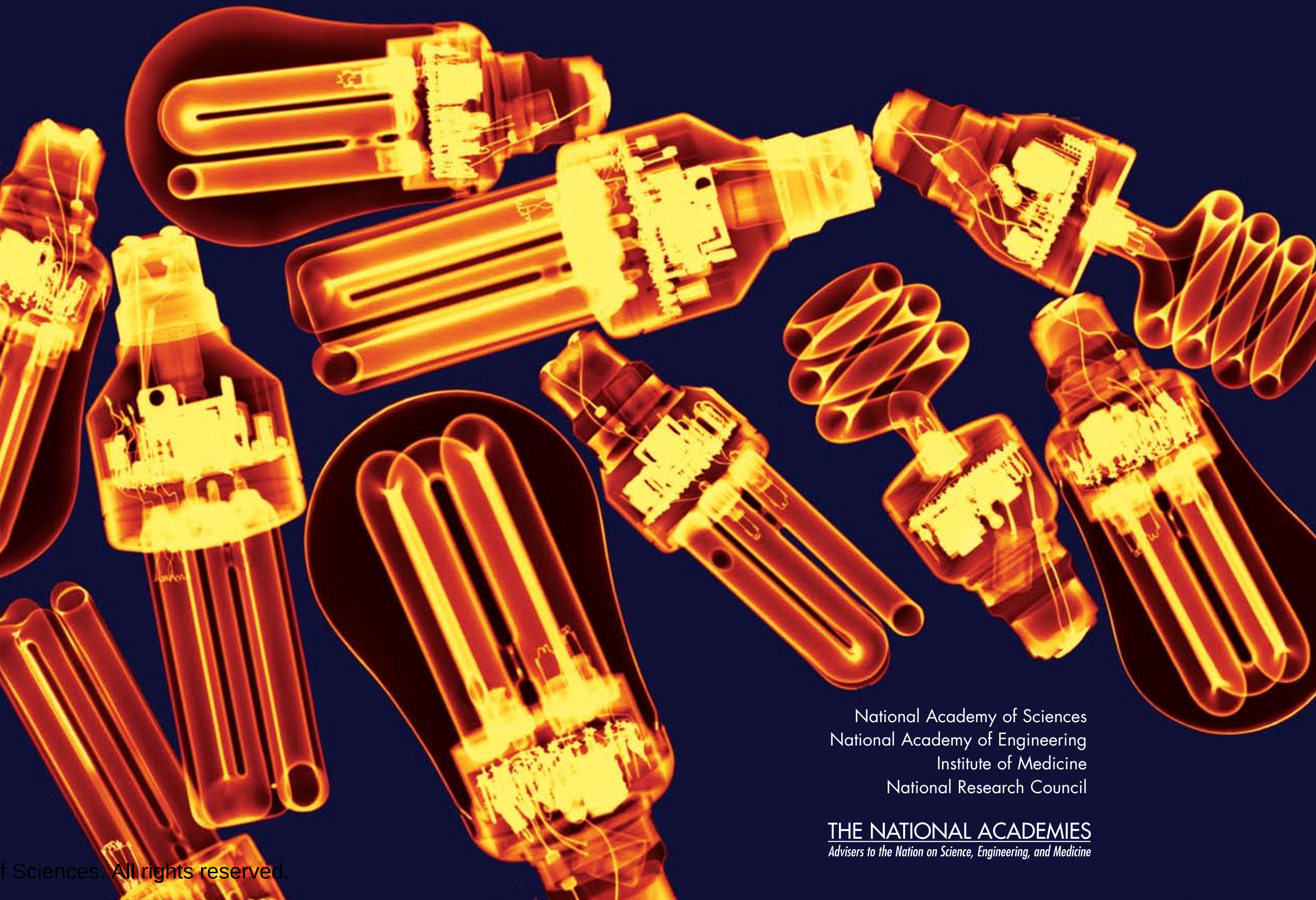

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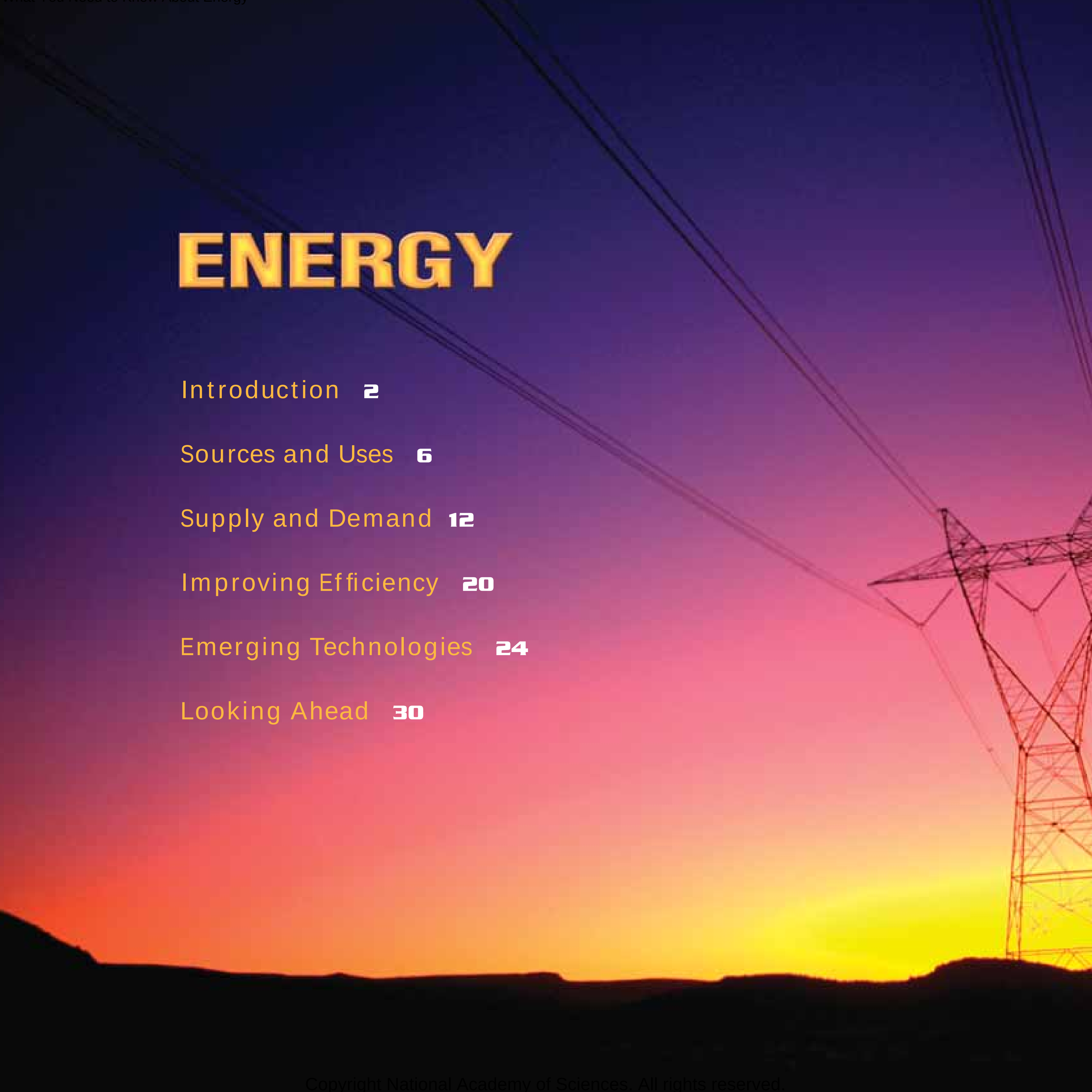

ENERGY

American society, with a standard of living unprecedented in human history, can attribute a large measure of its success to increasingly sophisticated uses of energy. The strength of industry, the speed of transportation, the myriad comforts and conveniences of home and workplace, and the security of the nation all derive from ever more ingenious provision and application of various sources and forms of energy.

The world at night.

But that condition has come at a cost—to irreplaceable resources, to the environment, and to our national independence. Society has begun to question the methods we use to power modern life and to search for better alternatives. As the nationwide debate continues, it is already evident that managing energy use wisely in the 21st century will call for balancing three essential, but quite different, concerns: resources, responsibility, and security.

RESOURCES

Our appetite for energy appears boundless, but traditional supplies are not. We are depleting the planet's finite stores of fossil fuels millions of times faster than they are formed, a situation that cannot continue indefinitely. Eventually we must devise ways to keep resources and consumption in sustainable equilibrium. Addressing the issue of sustainable resources in a nation that gets 85% of its total energy from oil, coal, and gas is a formidable goal, but one that we must pursue rigorously.

RESPONSIBILITY

The combustion of fossil fuels releases carbon dioxide (a major "greenhouse" gas) into the atmosphere, and most climate scientists believe that the buildup of those gases is the primary cause of global warming in recent decades.

Moreover, many uses of fossil fuels, as well as their extraction from the earth, contribute to air pollution and can cause severe damage to our health and the environment. Responsible stewardship of our planet demands that we find new ways to minimize or eliminate those effects. That goal appears attainable, and considerable progress is already evident.

SECURITY

Our society relies on energy that is available when and where it is needed, is generally affordable at stable prices, and can be counted on in the near future. Yet we are dependent on foreign sources for two-thirds of our petroleum supplies as well as many other resources, and the world is an uncertain place. As a result, access to some critical energy sources is beyond our control. Many planners argue that this situation threatens the economic and military security of the nation and urge policies that maximize the use of domestic resources. This is a difficult objective and will likely require many years to address thoroughly.

Meeting all three of these energy concerns will be a long-term process with unknown outcomes. Fortunately, both public and private organizations continue to support substantial energy research. There is also growing technical and financial interest in renewable and sustainable

sources—such as advanced nuclear power, wind power, solar power, and certain biofuels—and in technologies that minimize carbon dioxide emissions and capture the gases in storage areas where they cannot reach the atmosphere.

Such efforts are especially consequential as worldwide consumption trends put increasing pressure on traditional energy sources. In the United States alone, energy consumption is projected to rise 20% above present levels over the next two decades. Worldwide demand is forecast to nearly double by 2030. Much of that growth will be in developing nations—most notably China and India, which between them contain more than one-third of the planet's people—creating unprecedented competition for limited conventional resources.

Whatever happens, three developments are certain. First, fossil fuels will be a major part of the world's energy portfolio for decades to come because no single technology will provide all of tomorrow's energy and because it takes time and money to change the distribution and consumption patterns of large populations. Second, invention and development of more cost-effective, low-carbon energy sources will become progressively more urgent. And third, bringing those new technologies to market in convenient and affordable forms will pose a challenge even more daunting than the research itself.

Meanwhile, as national and international debate on energy grows more intense, Americans increasingly need dependable, objective, and authoritative energy information. We hope this booklet is a step in that direction. In its role as adviser on science and technology policy matters to the federal government, the National Research Council has conducted numerous studies on the topic of energy. Additional studies are in process. The information in this booklet draws on that body of material and on other sources in order to offer a basic toolkit of facts and concepts to use in assessing various energy claims and proposals. (See a complete list of the Research Council's relevant reports on page 31.)

This overview begins with a description of the status of energy in 21st-century America, including the main sources of energy used in the United States and a survey of the nation's energy demand versus the world's available supply. Then it looks ahead to the quest for greater energy efficiency and emerging technologies. Along the way it addresses how social concerns influence our choice of energy options and how those options affect our everyday lives. The goal of this booklet is to present an accurate picture of America's current and projected energy needs and to describe options that are likely to play a significant role in our energy future. No one can afford to remain uninformed about the energy future because we all have a stake in its outcome.

SOURCES AND USES

WE CONSUME ENERGY IN DOZENS OF FORMS.

Yet virtually all of the energy we use originates in the power of the atom. Nuclear reactions energize stars, including our sun. The energy we capture for use on Earth comes largely from the sun or from nuclear forces local to our own planet.

Sunlight is by far the predominant source, and it contains a surprisingly large amount of energy. On average, even after passing through hundreds of kilometers of air on a clear day, solar radiation reaches Earth with more than enough energy in a single square meter to illuminate five 60-watt lightbulbs if all the sunlight could be captured and converted to electricity.

The sun's energy warms the planet's surface, powering titanic transfers of heat and pressure in weather patterns and ocean currents. The resulting air currents drive wind turbines. Solar energy also evaporates water that falls as rain and builds up behind dams, where its motion is used to generate electricity via hydropower.

Most Americans, however, use solar energy in its secondhand form: fossil fuels. When sunlight strikes a plant, some of the energy is trapped through photosynthesis and is stored in chemical bonds as the plant grows. We can recover that energy months or years later by burning wood, which breaks the bonds and releases energy as heat and light. More often, though, we use the stored energy in the much more concentrated forms that result when organic matter,

after millions of years of geological and chemical activity underground, turns into fossil fuels, such as coal, oil, or natural gas. Either way, we're reclaiming the power of sunlight.

The only other original source of energy on Earth's surface is found in more local nuclear reactions, where atoms of radioactive elements such as uranium split apart into smaller atoms and liberate energy in the process. Harnessed as heat, the released energy boils water, producing steam that turns turbines, thereby being converted to mechanical energy that generates electricity. Nuclear energy currently provides 20% of total electricity generation in the United States.

Finally, the heat of Earth's molten interior, itself largely the result of the nuclear decay of radioactive elements, provides geothermal energy. At present, it is chiefly used in only a few places, such as California and Iceland, where proximity to high temperature geothermal fields makes it practical.*

THE HIGH COST OF CHANGE

By the time energy is delivered to us in a usable form, it has typically undergone several conversions. Every time energy changes forms, some portion is "lost." It doesn't disappear, of course. In nature, energy is always conserved. That is, there is exactly as much of it around after something happens as there was before. But with each change, some amount of the original energy turns into forms we don't want or can't use, typically as so-called waste heat that is so diffuse it can't be captured.

Reducing the amount lost—also known as increasing efficiency—is as important to our energy future as finding new sources because gigantic amounts of energy are lost every minute of every day in conversions. Electricity is a good example. By the time the energy content of electric power reaches the end user, it has taken many forms. Most commonly, the process begins when coal is burned in a power station. The chemical energy stored in the coal is liberated in combustion, generating heat that is used to produce steam. The steam turns a turbine, and that mechanical energy is used to turn a generator to produce the electricity.

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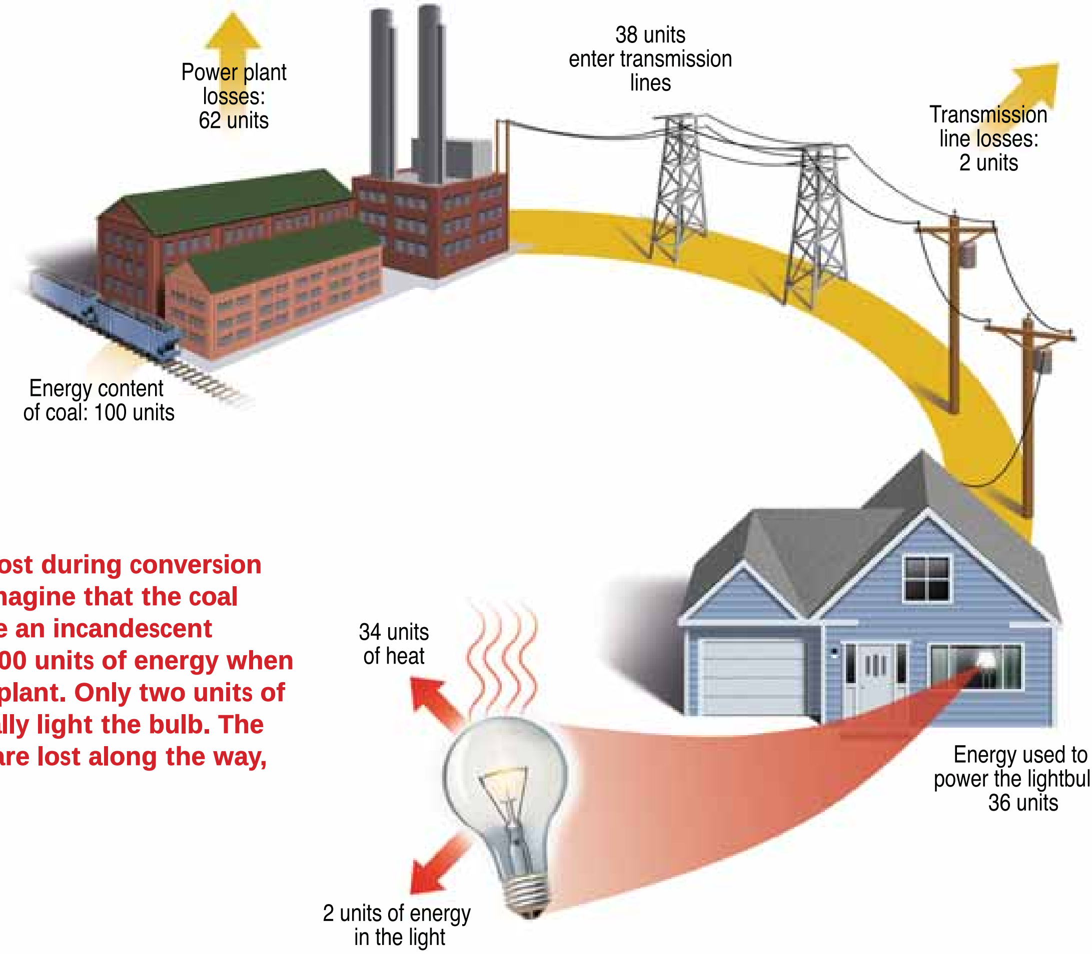
*One exception to the solar and local nuclear origins of Earth's energy promises only an exceedingly small contribution to our total energy picture at present: Some engineers are exploring methods for capturing energy from ocean tides, thus tapping into a gravitational source of energy.



Example of energy lost during conversion and transmission. Imagine that the coal needed to illuminate an incandescent lightbulb contains 100 units of energy when it enters the power plant. Only two units of that energy eventually light the bulb. The remaining 98 units are lost along the way, primarily as heat.

In the process, the original energy has taken on a series of four different identities and experienced four conversion losses. A typical coal-fired electrical plant might be 38% efficient, so a little more than one-third of the chemical energy content of the fuel is ultimately converted to usable electricity. In other words, as much as 62% of the original energy fails to find its way to the electrical grid. Once electricity leaves the plant, further losses occur during delivery. Finally, it reaches an incandescent lightbulb where it heats a thin wire filament until the metal glows, wasting still more energy as heat. The resulting light contains only about 2% of the energy content of the coal used to produce it. Swap that bulb for a compact fluorescent and the efficiency rises to around 5%—better, but still a small fraction of the original.

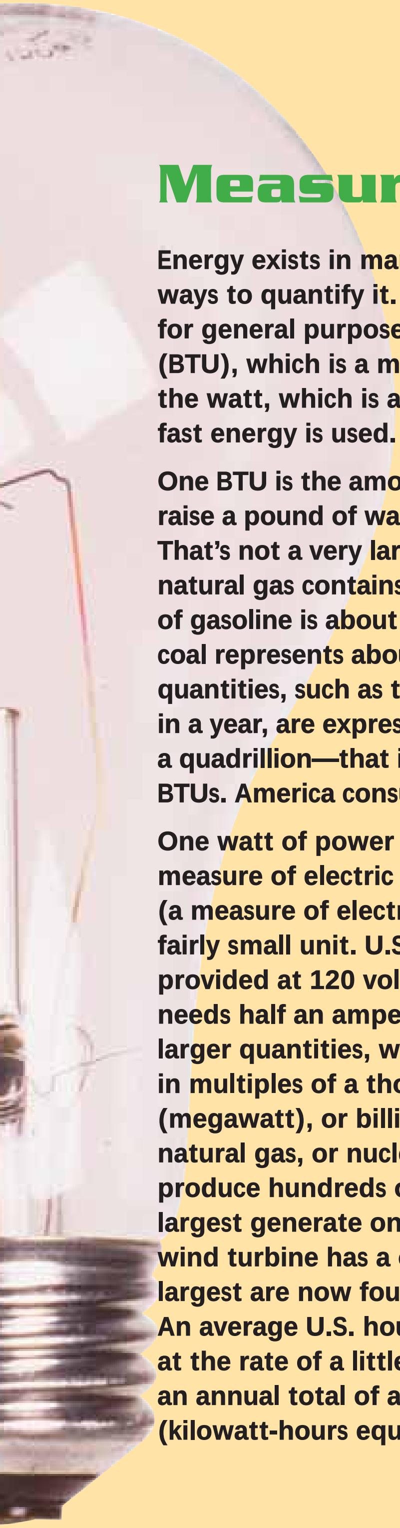
Another familiar form of conversion loss occurs in a vehicle's internal combustion engine. The chemical energy in the gasoline is converted to heat energy, which provides pressure on the pistons. That mechanical energy is then transferred to the wheels, increasing the vehicle's kinetic energy. Even with a host of modern improvements, current vehicles use only about 20% of the energy content of the fuel as power, with the rest wasted as heat.

Electric motors typically have much higher efficiency ratings. But the rating only describes how much of the electricity input they turn into power; it does not reflect how much of the original, primary energy is lost in generating the electricity in the first place and then getting it to the motor.

Efficiencies of heat engines can be improved further, but only to a degree. Principles of physics place upper limits on how efficient they can be. Still, efforts are being made to capture more of the energy that is lost and to make use of it. This already happens in vehicles in the winter months, when heat loss is captured and used to warm the interior for passengers. In natural gas combined cycle, or NGCC, power plants, we now have technology that takes the waste heat from a natural gas turbine and uses it to power a steam turbine, resulting in a power plant that is as much as 60% efficient. Similar technologies are being developed for use in coal power plants.

The energy sources that power our most indispensable devices often reflect convenience as much as efficiency. Energy can take many forms, but modern society prefers those that are easily produced, distributed, and stored. For example, American passenger cars are designed to hold enough onboard energy to travel 300 miles or so at a reasonable rate of speed. That's easy to do with the relatively high chemical energy content of gasoline or diesel fuel, despite the inefficiency of the engines.

If a car is powered by electricity, however, the energy has to be stored in batteries that have a much lower energy density than gasoline does. To carry 300 miles' worth of energy, an electric car would need a lot of very heavy batteries. Furthermore, it is difficult to deliver the energy needed to power an electric car in an acceptably short time. Modern battery-powered



Measuring Energy

Energy exists in many forms, so there are many ways to quantify it. Two of the most widely used for general purposes are the British Thermal Unit (BTU), which is a measure of energy content, and the watt, which is a measure of power, or how fast energy is used.

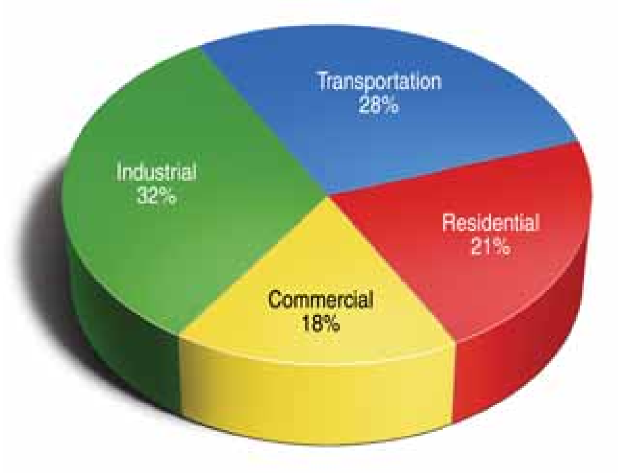
One BTU is the amount of energy needed to raise a pound of water by one degree Fahrenheit. That's not a very large amount. One cubic foot of natural gas contains around 1,000 BTUs. A gallon of gasoline is about 124,000 BTUs, and a ton of coal represents about 20 million BTUs. Enormous quantities, such as total U.S. energy consumption in a year, are expressed in "quads." One quad is a quadrillion—that is, a million billion, or 10^{15}—BTUs. America consumed about 100 quads in 2006.

One watt of power is equal to one ampere (a measure of electric current) moving at one volt (a measure of electrical force). Again, this is a fairly small unit. U.S. household electricity is provided at 120 volts. So a 60-watt lightbulb needs half an ampere of current to light up. For larger quantities, watts are usually expressed in multiples of a thousand (kilowatt), million (megawatt), or billion (gigawatt). A big coal, natural gas, or nuclear electrical plant can produce hundreds of megawatts; some of the largest generate one or more gigawatts. A typical wind turbine has a one megawatt rating, and the largest are now four megawatts when turning. An average U.S. household consumes electricity at the rate of a little more than one kilowatt, for an annual total of about 10,000 kilowatt-hours (kilowatt-hours equal power multiplied by time).

cars charge at a rate roughly a thousand times slower than the rate of refueling with gasoline, meaning overnight charging is required to store enough energy for a day's worth of driving. For most Americans in the fast-paced 21st century, that's an unacceptably long time span.

ENERGY AND THE INDIVIDUAL

Energy trade-offs and decisions permeate society, directly affecting everyday quality of life in many ways. Some effects may be most noticeable at home—or at least in household energy bills due to the rising costs of heating oil and natural gas. Residential energy use accounts for 21% of total U.S. consumption, and about one-third of that goes into space heating, with the rest devoted, in decreasing proportions, to appliances, water heating, and air-conditioning. So our personal preferences



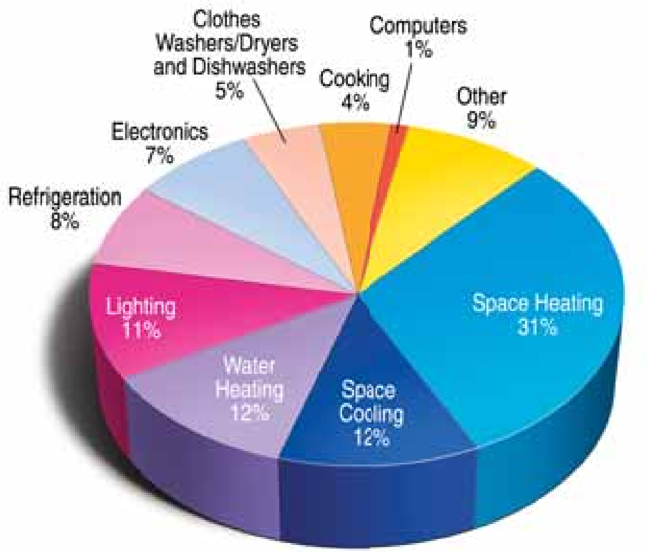
Percentage of energy consumed by each economic sector in the United States in 2006.*

* Percentages do not sum to 100% due to independent rounding.

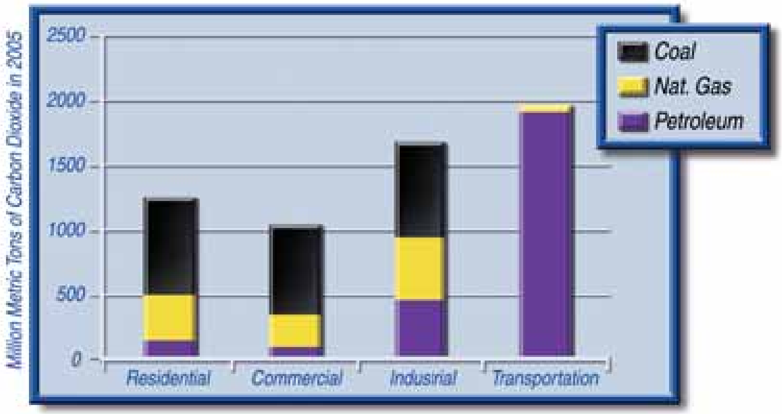
are intimately tied to, and immediately affect, the nation's overall energy budget.

Our individual automotive and public-transit choices also have a substantial impact, because transportation takes up 28% of all U.S. energy consumption (and about 70% of all petroleum use). Even the 50% of total U.S. energy consumption that goes to commercial and industrial uses affects every single citizen personally through the cost of goods and services, the quality of manufactured products, the strength of the economy, and the availability of jobs.

The condition of the environment also holds consequences for all of us. Carbon dioxide (CO_2) concentration in the atmosphere has risen about 40% since the beginning of the industrial revolution—from 270 parts per million (ppm) to 380 ppm—and contributes to global warming and ensuing climate change. At present, the United States emits approximately one-fourth of the world's greenhouse gases, and the nation's CO_2 emissions are projected to rise from about 5.9 billion metric tons in 2006 to 7.4 billion metric tons in 2030, assuming no changes to the control of carbon emissions. Of course this is not just a national concern. Worldwide, CO_2 emissions are projected to increase substantially, primarily as a result of increased development in China and India. Future decisions about whether and how to limit greenhouse gas emissions will affect us all.



Energy usage in the U.S. residential sector in 2006.



CO_2 emissions by U.S. economic sector and energy source in 2005.

Before we can consider ways to improve our energy situation we must first understand the resources we currently depend on, as well as the pros and cons of using each one.

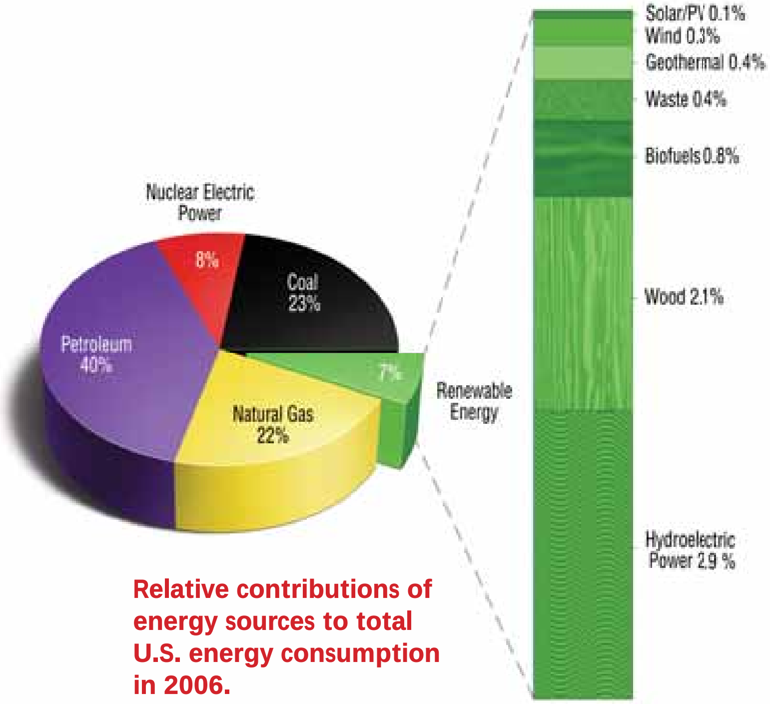
SUPPLY AND DEMAND

TWO PROFOUND QUESTIONS LOOM OVER ALL OTHER ENERGY CONCERNS: Will we have enough affordable energy in the near future? What will we do for the long term?

The answers depend on our inventory of sources. At present, oil accounts for 40% of total energy consumption in the United States. Coal provides 23% and natural gas provides 22% of our energy. Another 8% comes from nuclear power plants. Renewable energy sources round out the roster, accounting for 7% of consumption—mostly as the result of hydropower investments made in the last century and the use of biomass (organic matter such as wood, municipal waste, and agricultural crops) for energy production.

Those sources and their proportions will have to change eventually, since the planet's known supplies of fossil fuels are limited. But during the next couple of decades, the nation's energy menu is unlikely to be substantially different from today's—assuming "business as usual" conditions.

That may be a lot to assume: Energy prices and availability aren't solely determined by the size of the supply. They're also affected by the economy, possible new laws and regulations governing energy choices (such as emissions of carbon dioxide and other gases), worldwide demand, the policies and political stability of petroleum-rich nations, lifestyle



Relative contributions of energy sources to total U.S. energy consumption in 2006.

choices and business decisions, climate change, and the pace of developments in science and engineering. Any of these factors can change in a very short period of time.

Still, if the economy and the inflation rate perform as expected and there are no drastic geopolitical changes or dramatic technological breakthroughs, objective forecasts show that traditional supplies of petroleum, gas, and coal will be adequate to meet expanded demand for decades.

OIL

The United States, with less than 5% of the world's population, is home to one-third of the world's automobiles. Over the next 20 years, the total number of miles driven by Americans is forecasted to grow by 40%, increasing the demand for fuel. Yet there is little that can be done locally to increase the oil supply. U.S. domestic production of crude oil peaked around 1970 at about 9.5 million barrels per day (MBD) and had declined to 5.1 MBD by 2006. Today America imports almost two-thirds of its oil from a handful of nations. The Energy Information Administration (EIA), a U.S. government agency that provides official energy statistics and forecasts, expects U.S. production of oil to remain approximately constant through 2030, while imports are projected to rise gradually to about 70% of consumption.

So the basic question remains: How long can we maintain our petroleum dependency? The EIA cites known conventional oil reserves at more than 1.3 trillion barrels worldwide, and the U.S. Geological Survey estimates that there may be another 600 billion barrels undiscovered to date.

At present, total world consumption is approximately 85 MBD, 21 million of which is used by the United States. The nation's dependency on oil and the rapidly rising demand for oil in other countries, such as China and India, are heightening concern that we will reach a point where the oil supply can no longer be increased to meet projected demand. While this will certainly be true eventually, there is no consensus as to whether we are already entering that period or it is decades away. Pinning down an exact time frame is nearly impossible as estimates

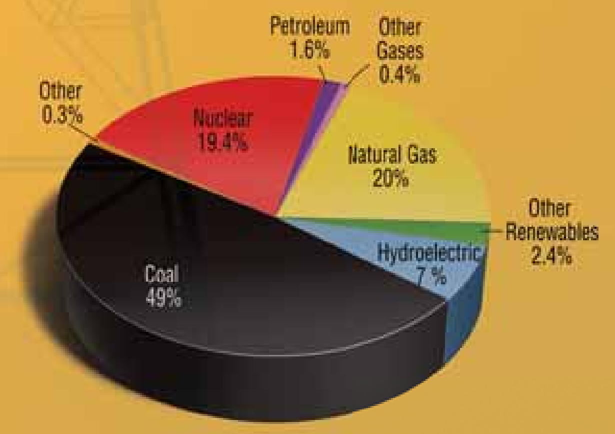
Electricity, the #1 Secondary Source

Electricity can't be pumped out of the ground like oil or captured from moving air like wind energy. So it is called a secondary source of energy, meaning that it is produced by the use of primary energy sources such as coal, natural gas, or nuclear reactions. Electricity plays such an essential role in contemporary America that its supply and demand are often examined separately from the primary sources used to produce it.

Experts predict a 35% increase in demand for electricity by 2030. In practical terms, that means an equivalent increase in demand for coal and gas, at least for the next decade: Electricity generating plants now consume two-fifths of U.S. energy from all sources, including 90% of America's coal and nearly 30% of its natural gas.

There is no immediate way to alter that situation. In the near term, renewable sources such as solar, wind, and geothermal are unlikely to substantially change the mix of our energy supply. (And integrating the energy from many of these renewable energy sources would likely require substantial expansion of the electric transmission system.) While nuclear generation is a zero-atmospheric-emissions alternative that already produces one-fifth of America's electricity, efforts to increase that capacity face two large, though not insurmountable, hurdles: high capital investment costs and resistance from citizens groups that oppose the use and storage of radioactive material.

Getting electric power to consumers may be as much of a problem as generating it. Generating stations usually are built away from load centers because sites are easier to find and fewer people are disturbed by the accompanying noise, emissions, and activity. This power must be delivered by a high-voltage transmission system that has become increasingly stressed in recent years as growing demand has outstripped capacity. Widespread blackouts are possible, as evidenced by the August 2003 disruption to 50 million customers from Ohio to New York and Canada. New transmission lines are difficult to build because of uncertain cost recovery and public opposition. Building small plants near customers, known as distributed generation, may become more important in order to meet demand and maintain reliability.



Energy sources used to generate electricity in the United States in 2006.*

* Percentages do not sum to 100% due to independent rounding.

of the amount of "recoverable" oil available can change depending on new discoveries, technological developments, and price.

Over the past century, dependence on vehicles burning petroleum-based fuels has become a defining component of American life, bringing countless benefits. However, combustion of gasoline and diesel fuel emits carbon dioxide, as well as particulate matter, oxides of nitrogen (a prime component of "smog"), carbon monoxide, and unburned hydrocarbons. Indeed, whenever any fossil fuels are burned, carbon dioxide is released into the atmosphere, where it functions as a heat-trapping greenhouse gas.

Efforts are already well under way to find suitable alternatives to oil. In the short term, the leading liquid substitute is ethanol ("grain alcohol"), now chiefly made from corn. The federal government has an aggressive program to encourage its production. As a result, in 2005 about 4 billion gallons of fuel ethanol mixed with gasoline hit the domestic market. But in the same year, the United States consumed about 140 billion gallons of gasoline and 40 billion gallons of diesel fuel, so ethanol accounted for only a small percentage of the total gasoline pool.

Ethanol raises other concerns. One drawback of corn ethanol production is that it requires a large amount of land and fresh water, along with inputs of fertilizers and energy. This results in potential competition with food sources for land use and fresh water for other industrial and commercial uses. In addition, with current technology, two-thirds of the energy value of corn ethanol is used just to produce the fuel—and most of that energy comes from fossil-fuel-based electricity or heating, offsetting much of the benefit.

NATURAL GAS

Unlike oil, our natural gas comes primarily from North America. The annual volume of consumption is projected to rise from 21.8 trillion cubic feet (TCF) in 2006 to about 23.4 TCF in 2030. New activity in Alaska will supply some of that, but most will likely come from the lower 48 states and the Gulf of Mexico. Although the nation imports less than 3% of its natural gas from outside North America, it is forecast that imports will increase in the next few decades, from 0.5 TCF per year in 2006 to 2.9 TCF per year in 2030. These imports will largely take the form of liquefied natural gas, which is natural gas cooled to its liquid phase, making it easier to transport.

Global consumption of natural gas in 2004 was 100 TCF. Known world reserves of conventional natural gas total about 6,000 TCF, with perhaps another one-tenth of that amount still undiscovered. At that rate, known reserves will be adequate for about 60 years.

Natural gas is often described as "clean burning" because it produces fewer undesirable by-products than gasoline. Like all fossil fuels, its combustion emits carbon dioxide, but at about half the rate of coal.

COAL

America has plenty of coal. Its mines produced 1.2 billion tons in 2006, nearly all of it destined for electricity generation. That was a record year, but it barely scratched the surface of U.S. recoverable coal reserves, which are estimated at about 270 billion tons. More than one-fourth of the total known world coal reserves are in the United States, and supplies are sufficient for hundreds of years at current consumption rates.

Demand is projected to increase by 30% between now and 2030, propelled by rising use of electricity and possibly the expanded use of still-developing technology that converts coal to liquid fuel. Most of the increased supply will probably come from western states, which now provide about six-tenths of the nation’s coal. Wyoming alone accounted for 38% of all domestic coal mined in 2006.

Of all the fossil-fuel sources, coal is the least expensive for its energy content. In 2005, a million BTUs of energy from coal cost approximately $2, compared to $5 for natural gas and $10 for petroleum. However, burning coal in electric power plants is a major source of CO_2 emissions, and its use has repercussions beyond combustion. Mining coal disturbs the land and modifies the chemistry of rainwater runoff, which in turn affects stream and river water quality. Coal-fired power plant emissions include oxides of nitrogen, sulfur dioxide, particulate matter, and heavy metals (such as mercury) that affect air quality and human health, often even hundreds of miles from the power plant. In response to strict environmental laws, “clean coal technologies” are being developed to reduce harmful emissions and improve the efficiency of these plants.

RENEWABLE ENERGY SOURCES

Use of renewable energy sources will increase, in some cases dramatically, over the next two decades. While they may make significant contributions to the energy supply in certain geographic areas, absent major changes in economic, political, or technological factors, they will still provide a small fraction of our overall energy.

Hydropower is unlikely to increase much between now and 2030, but energy from biomass products (which include wood and wood byproducts, municipal waste, methane from landfills, and fuel from agricultural crops) will likely increase more than

60% by 2030. Energy from wind, solar, and other renewable sources is expected to nearly triple. But the net effect of all that activity will probably only raise the total contribution of renewables from 7% of total consumption now to about 8% in 2030.

Hydroelectric production currently accounts for about 2.9% of our total energy production, while geothermal accounts for about 0.4%. Wind and solar-to-electric technologies account for a very small part of our total energy production, but wind, currently assisted by a production tax credit, has been penetrating the market rapidly in the past few years and accounted for almost 1% of the electricity generated in the United States in 2006.

The idea of drawing our energy from sources that are renewable, are independent of foreign nations, and do not emit greenhouse gases has powerful appeal. But capturing these resources is expensive, and many are intermittent, or sporadic, which complicates using them on a large scale. Further development promises reduced costs and improved storage and controls to overcome the intermittency problem.

NUCLEAR FUEL

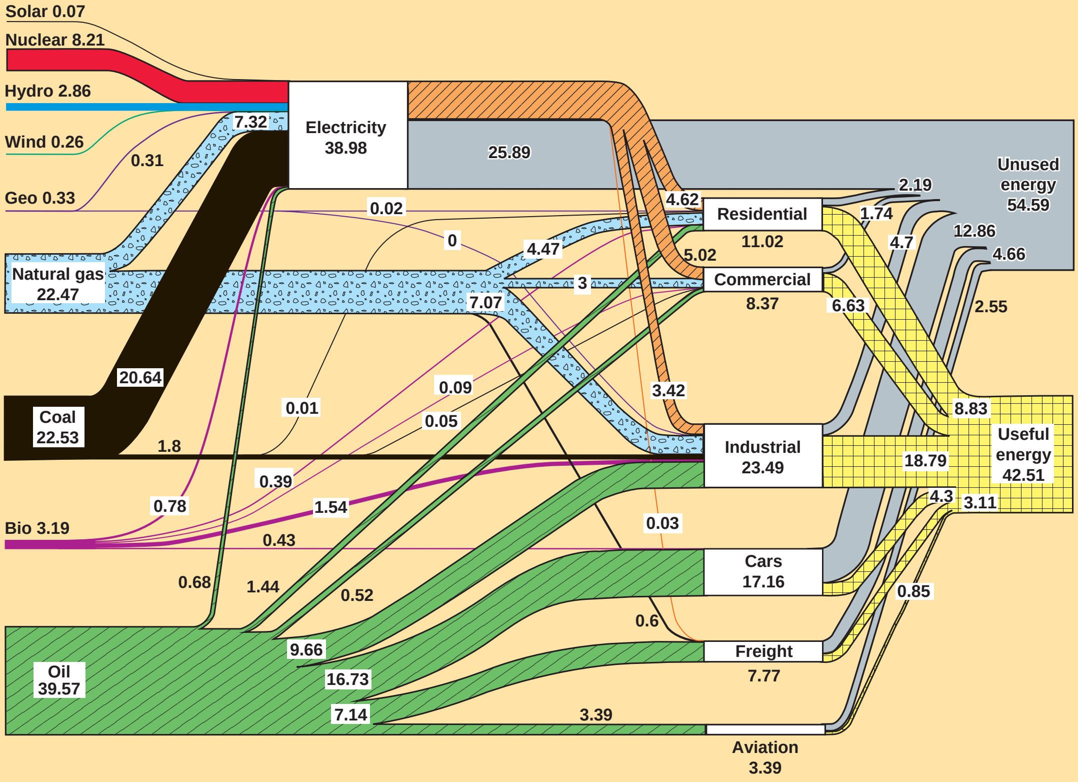
America is unlikely to face problems in obtaining enough uranium ore to meet anticipated demand for several decades. According to government estimates, output from nuclear power plants is expected to increase only 18% by 2030. However, a U.S. nuclear renaissance is possible, and a growing number of nuclear plant design and construction permits have been submitted to the Nuclear Regulatory Commission over the past year. Some countries have successfully embraced nuclear power generation: for example, nuclear power plants produce nearly 80% of all electricity in France. In the United States, the issue prompts considerable debate, including concern over security and arguments about where and how to dispose of nuclear waste. But interest is growing, and nuclear energy may one day play a much larger role in supplying America's electricity.

Even with renewed U.S. interest in nuclear power generation, sufficient uranium supplies will likely be available. According to the Council on Foreign Relations, known worldwide reserves are adequate for about 70 years at current consumption rates and under current policies.

The Flow of Energy

This figure depicts the flow of energy, measured in quadrillion (1 million billion) BTUs, across the energy system of the United States for 2006, based on data from the Energy Information Administration of the U.S. Department of Energy. The chart illustrates the connections between primary energy resources (fossil, nuclear, and renewables), shown at the far left, and end-use sectors categorized into residential, commercial, industrial, and the three principal components of transportation: cars, freight, and aviation. Electricity, a carrier derived from primary resources, powers the sectors to varying degrees and is positioned closer to the middle of the chart to display its inputs and outputs. Note that hydro, wind, and solar electricity inputs are expressed using fossil-fuel plants' heat rate to more easily account for differences between the conversion efficiency of renewables and the fuel utilization for combustion- and nuclear-driven systems. This enables hydro, wind, and solar to be counted on a similar basis as coal, natural gas, and oil. For this reason, the sum of the inputs for electricity differs slightly from the displayed total electricity output.

Estimated Energy Usage in 2006: ~97.1 Quads



Source: LLNL 2008; data is based on DOE/EIA-0384(2006), June 2007. If this information or a reproduction of it is used, credit must be given to the 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. Energy flows for non-thermal sources (i.e., hydro, wind, and solar) represent electricity generated from those sources. 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.

GETTING MORE FOR LESS

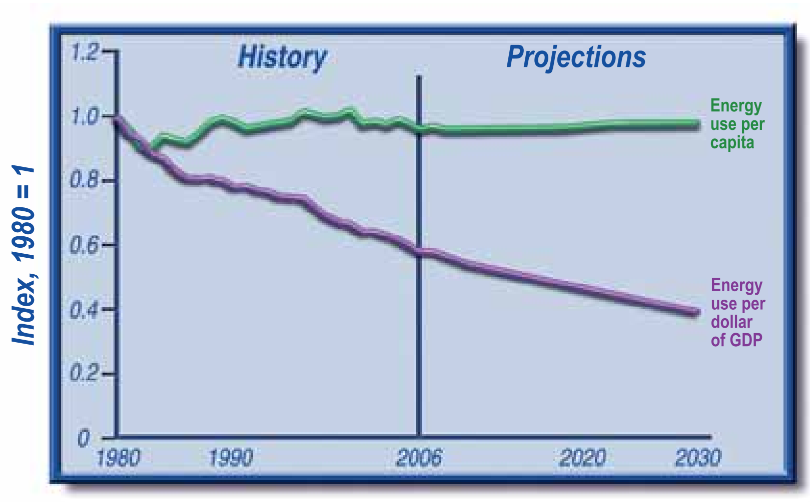
Given the anticipated growth in every U.S. economic sector and in demand for all energy sources, it's natural to wonder how that growth can possibly be sustained. After all, America, with only 5% of the planet's population, already consumes one-fifth of the world's total energy. And other countries are poised to experience increases in energy use as they become more industrialized and improve their standard of living. Can the United States actually meet its growing needs?

It remains to be seen. Yet one important factor is working in our nation's favor. The demand for energy has not been growing as rapidly as the economy, resulting in a significant drop in what is called energy intensity. At present, Americans use about half as much energy per dollar of Gross Domestic Product (GDP)—the total market value of all the goods and services produced in a country during one year—as they did in 1970. Were it not for this development, the U.S. energy bill would be hundreds of billions of dollars per year higher. Energy-efficiency investments and structural shifts in the economy away from energy-intensive industry and toward service and information-based jobs have both contributed to the phenomenon. So have engineering improvements in scores of systems, from automobile engines to building insulation to electric power-generating facilities.

This trend is expected to continue. The EIA projects that by 2030 Americans will be using only slightly more energy per capita than they did in 1980—but less than half as much per dollar of GDP.

Continuing this downward trend in energy intensity depends in part on the nation taking advantage of numerous opportunities for efficiency advances in current technology. Fortunately, recent history provides ample evidence that efficiency research and education can pay enormous dividends.

Energy use per capita and per dollar of GDP from 1980 to 2030.



IMPROVING EFFICIENCY

INCREASING SUPPLY IS NOT THE ONLY ANSWER TO A STABLE ENERGY FUTURE.

Reducing demand through the improved efficiency of devices and procedures achieves the same effect.

The use of electricity is a dramatic example. During the 1970s, total U.S. electrical consumption increased 4.2% per year. In the 1980s, it grew only 2.6% annually, dropping to 2.3% in the 1990s. Current projections are 1.3% per year. That trend is partly a result of ongoing improvements in efficiency.

Similar progress is visible in nearly every sector of the economy as a result of independent technological breakthroughs, directed research, government mandates and incentives, consumer education, or a combination of these elements.

CAFE STANDARDS

One of the most impressive efficiency successes in modern memory is the result of the federal Corporate Average Fuel Economy (CAFE) standards established in 1975. CAFE standards stipulated that the average fuel economy for new passenger cars would be 27.5 miles per gallon (mpg) by model year 1985—up from 18 mpg for model year 1978, an improvement of more than 50%. The U.S. Department of Transportation later stipulated that the average for light trucks would be 20.7 mpg. Automakers complied, dramatically improving the fuel economy of the nation's light-duty vehicle fleet, reducing dependence on imported oil, improving the nation's balance of trade, and reducing CO_2 emissions. Had the CAFE standards not been enacted (and had fuel prices not increased), America's gasoline consumption would now be 14% higher than it is, or about 2.8 million barrels more per day.

In December 2007, Congress passed an updated CAFE law mandating that new cars, SUVs, and light trucks together average 35 mpg by 2020, an increase of 40% from today's 25 mpg average. This legislation will further push technology, leading to greater fuel economy and reducing fuel consumption in the fleet.

Automotive technology also demonstrates how developments and breakthroughs in fields unrelated to energy can have a profound effect on the energy sector. The electronics and computer revolutions of the 1960s and 1970s, which continue to this day, led to the development of very small sensors and computers. In addition, the ability to develop new materials such as catalysts—substances that prompt chemical reactions—led to ways to cut down on the pollutants in automobile exhaust (and in power plants). Putting these technologies together into systems on automobiles has led to more efficient automotive drivetrains, more power, better control, and lower emissions.

The continuing development of electronics, small electric motors, sensors, and computers is also contributing to the advancement of hybrid electric vehicles. Improved understanding of the combustion of fuels in the engine has led to more efficient engine technologies. At present, there are advanced technologies that have the potential to improve vehicle fuel economy substantially, but at a higher cost.

REFRIGERATION

Refrigeration provides another case in which targeted research produced remarkable results: a reduction of more than two-thirds in the energy consumed by the household refrigerator during the past 30 years. In 1974, the average consumption per unit was 1,800 kilowatt-hours per year, and average sizes were increasing as well. At that point, a joint government-industry R&D initiative began looking for more efficient compressors, as well as improvements in design, motors, insulation, and other features.

The effort began to pay off almost immediately. By the early 1980s, electricity consumption per refrigerator had dropped by one-third and new developments kept coming. Even the changeover from ozone-threatening chlorofluorocarbons (CFCs) did not impede progress. Further design enhancements and tighter government standards since 1990 have saved the nation an estimated $15 billion in total electricity costs for home refrigerators over the entire life of the appliances.

LIGHTING

Today there are still enormous opportunities for efficiency gains across a wide range of products and processes. One area regarded as particularly ripe for improvement is lighting, which accounts for 18% of all electricity use in the United States and 21% of the electricity for commercial and residential buildings. Major research efforts are in progress to reduce those costs by using the same technology that now creates the glowing lights on appliances: the light-emitting diode (LED).

LEDs are “solid-state” devices made of materials similar to those in computer chips. They produce illumination by allowing electrons to flow across an electrical junction (the diode) and drop into a lower energy state, releasing the difference as light. LEDs generate relatively little heat, last 100 times longer than an incandescent lightbulb, and convert about 25% to 35% of electrical energy to light, as opposed to about 5% in a conventional incandescent bulb. Additionally, they do not require bulky sockets or fixtures and could be embedded directly into ceilings or walls.

At present, such systems are too expensive for broad commercial use. But if they can be made affordable, the effect will be dramatic. By one expert estimate, widespread use of LEDs would reduce consumption of electricity for lighting by 50%—a savings of about $10 billion a year in the United States. And it would reduce worldwide demand for electricity by 10%, an amount equivalent to about 125 large generating plants.

INDUSTRIAL EFFICIENCY

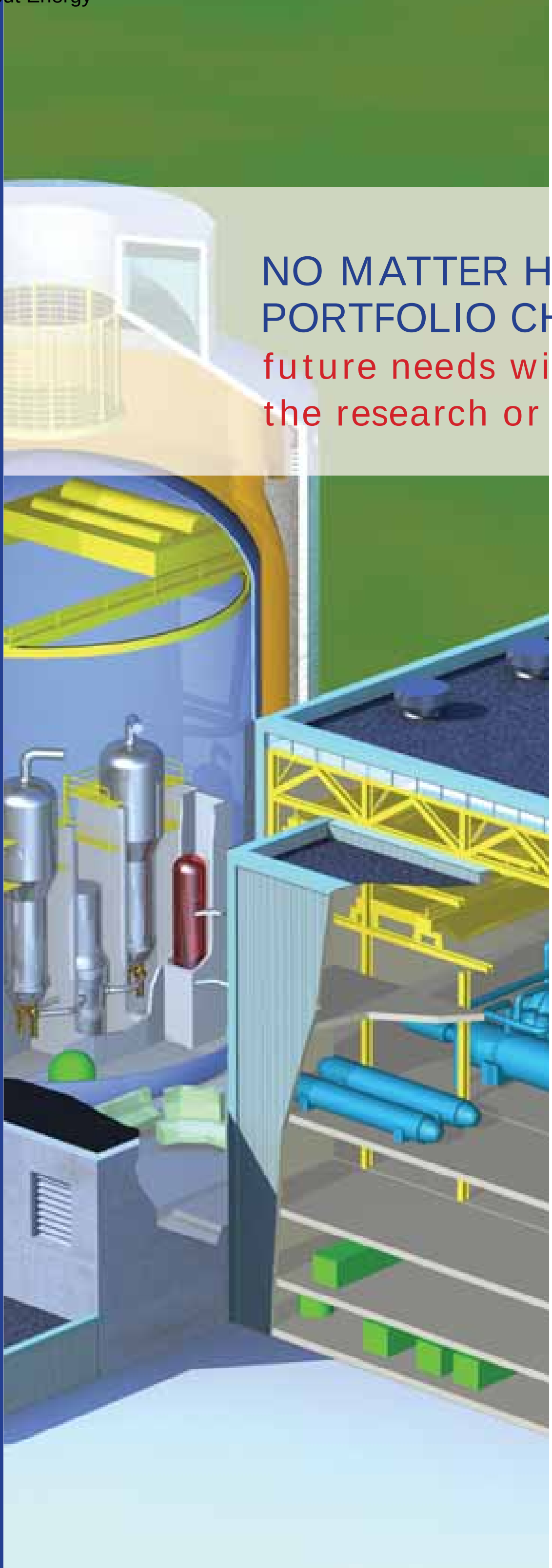
Other researchers are exploring ways to make industrial and manufacturing processes much more efficient. Industry accounts for about 32% of all energy consumption in the United States, and seven energy-intensive industries use three-fourths of that power. As a result, public/private-sector partnerships and research programs are focusing on those areas.

One of the prime targets is the chemical industry, which uses 19% of all fuel consumed in the U.S. industrial sector. In particular, processes used to separate chemicals and to enable chemical reactions are being evaluated for possible savings.

A similar effort is under way in analyzing the energy-intensive forest products industry. Researchers have identified enhanced raw materials, next-generation mill processes, improved fiber recycling, and wood processing as candidates for improvements in efficiency.

Nonetheless, improved energy efficiency alone cannot solve all the nation’s energy problems. Multiple parallel efforts will be needed, and that recognition has prompted intense interest in a wide variety of new technologies.

EMERGING TECHNOLOGIES



NO MATTER HOW THE NATION'S ENERGY PORTFOLIO CHANGES, an increasing share of future needs will be met by technologies now in the research or development stages.

Some will require substantial improvements—or even research breakthroughs—to have a major impact on our energy budget. The following are some of the options.

ADVANCED NUCLEAR FISSION

Although nuclear power plants account for 20% of U.S. electricity generation, no new reactors have come on line since 1996. Designs conceived in the 1990s (so-called Generation III+) may provide significant improvements in economics and safety. Consortia of companies are working with the Nuclear Regulatory Commission to secure federal approval for these types of nuclear power plants, and several utilities recently requested approval of a combined construction and operating license. Generation III+ plants are also under construction in Europe and Asia, with the first scheduled to come on line in 2009 in Finland.

Longer term advances could broaden the desirability and future use of nuclear energy. The U.S. Department of Energy (DOE) has engaged other governments, international and domestic industry, and the research community to develop "Generation IV" systems. The goals of these efforts are to improve the economics, safety, fuel-cycle waste management, and proliferation resistance of nuclear reactors, as well as widen their applications. DOE is pursuing the demonstration of one such design, a very-high-temperature reactor, through its Next Generation Nuclear Plant program, and the facility is scheduled to begin operations by 2021.

SOLAR POWER

Sunlight is Earth's most abundant energy source and is delivered everywhere free of charge. Yet direct use of solar energy—that is, harnessing light's energy content immediately rather than indirectly in fossil fuels or wind power—makes only a small contribution to humanity's energy supply. In theory, it could be much more. In practice, it will require considerable scientific and engineering progress in the two ways of converting the energy of sunlight into usable forms.

Photovoltaic (PV) systems exploit the photoelectric effect discovered more than a century ago. In certain materials, the energy of incoming light kicks electrons into motion, creating a current. Sheets of these materials are routinely employed to power a host of devices from orbiting satellites to pocket calculators, and many companies make roof-sized units for homes and office buildings.

At the present time, however, the best commercial PV systems produce electricity at five to six times the cost of other generation methods. In addition, PV is an intermittent source, meaning that it's only available when the sun is shining. Furthermore, unless PV energy is consumed immediately, it must be stored in batteries or by some other method. Adequate and cost-effective storage solutions await development. One factor favoring PV systems is that they produce maximum power close to the time of peak loads, which are driven by air-conditioning. Peak power is much more expensive than average power. With the advent of time-of-day pricing for power, which is technologically feasible, PV power would be much closer to being economical.

Sunlight can also be focused and concentrated by mirrors and the resulting energy employed to heat liquids that drive turbines to create electricity—a technique called solar thermal generation. Existing systems produce electricity at about twice the cost of fossil-fuel sources. Engineering advances will reduce the cost, but solar thermal generation is unlikely to be feasible outside regions such as the southwestern United States that receive substantial sunlight over long time periods.

ELECTRIC VEHICLES

Many new vehicle technologies have the goal of steering automobiles away from a dependence on fossil fuels. One vision is an all-electric vehicle (EV) that uses no gasoline or diesel fuel and does not emit any CO_2. But affordable and reliable EVs will require advances in energy storage. At present, batteries that store enough electricity to give a vehicle acceptable driving range are expensive, large, and heavy. Yet technology may provide new options. For example, recent advances in nanotechnology, applied to the lithium ion battery, may permit significantly more energy to be stored in a smaller, lighter package.

Tesla Motors' Roadster EV has enough battery power to travel 220 miles. That's still not enough for a long road trip, but it represents significant improvement.

A compromise—plug-in hybrid electric vehicles (PHEVs)—may secure a significant place in the market sooner. PHEVs have conventional gasoline engines as well as batteries that can supply enough energy to travel 10 to 40 miles, depending on the kind of batteries used. They run on electric power until the batteries are discharged, then switch to gasoline for additional range. As of January 2008, no PHEVs were in production. But several major motor companies—including Toyota, General Motors, and Ford—have plans to introduce PHEVs within the next few years.

EV and PHEV batteries are recharged by plugging them into an electricity source while the vehicle is parked. This provides the immediate benefit of shifting some transportation energy demand from onboard petroleum-based fuels to the electrical grid. However, CO_2 emissions would not decline proportionally because about half of the electricity used to recharge the vehicle's batteries is produced at coal-based plants.

WIND ENERGY

This renewable technology, already widely deployed in 36 states and producing almost 1% of America's electricity, uses the wind-induced motion of huge multiblade rotors—sweeping circles in the air 100 yards in diameter—to drive emission-free turbines. But like solar energy, the source is intermittent and currently lacks an economically practical way to store its energy output. In addition, the huge wind

turbines (sometimes grouped into "wind farms" containing hundreds of turbines) can prompt complaints on aesthetic grounds from communities whose sight lines are altered. Current designs can also be a hazard to birds and bats. Wind energy's potential contribution is large, though, and with developments in storage technologies and an expanded and upgraded electrical grid, it could provide a substantial portion of our electricity, especially in some regions.

ADVANCED COAL TECHNOLOGIES

In the endeavor to reduce—or even eliminate—the emission of CO_2 when fossil fuels are burned, coal is a prime target: It accounts for about one-third of the nation's CO_2 emissions. New technologies focus on separating, capturing, and safely storing the CO_2 before it is discharged from the smokestack. Several approaches are possible. One is coal gasification, a process in which coal is converted to a gas (called syngas) before it is burned, making it easier to separate the CO_2 as a relatively pure gas before power is generated. Such Integrated Gasification Combined Cycle, or IGCC, plants are projected to be up to 48% efficient, a significant improvement over current coal-power plants, which are about 38% efficient.

Another option is to burn coal in oxygen instead of air (as is currently done), to reduce the amount of flue gas—essentially exhaust—that must be processed to isolate CO_2. These techniques show promise but require more research and development. They also substantially increase the cost of the electricity produced.

Once CO_2 has been captured, it must be sequestered, or permanently stored. Current options focus on such geological formations as oil and gas reservoirs, unmineable coal seams, and deep saline aquifers, all of which are geologically sealed and unlikely to allow injected CO_2 to escape. While these technologies are very promising, it still must be proven that large quantities of CO_2 can be stored effectively underground and monitored for long periods of time. The methods also must be acceptable to the public and regulatory agencies. Large-scale field trials of prototypes of coal-fueled, near-zero-emissions power plants are needed to test the viability of several of these new clean coal technologies.

FUEL CELLS

For more than 150 years, scientists have known that when hydrogen and oxygen combine to form water (H_2O), the chemical reaction releases electrical energy. (It's exactly the reverse of electrolysis, in which running a current through water separates H_2O into its constituent elements.) Devices that use a controlled combination of the two gases to generate current are called fuel cells. This developing technology underlies the vision of a nationwide "hydrogen economy," in which the only exhaust from fuel-cell-powered vehicles would be water vapor, and America would drastically reduce its dependence on foreign fuel supplies.

There are several significant obstacles to achieving that vision. Present fuel cells are too expensive and unreliable for the mass market. And hydrogen is very difficult to store and transport in a vehicle unless it is compressed to thousands of pounds per square inch (psi). Automotive companies are using containers in their demo vehicles that can store hydrogen at 5,000 to 10,000 psi, but a cost-effective and safe distribution system would have to be put in place before these vehicles could become widely available.

Furthermore, hydrogen (like electricity) is not a primary source of energy but rather an energy carrier. There are no natural reservoirs of pure hydrogen; it must be extracted from compounds such as natural gas or water. And the processes for separating it from these principal sources pose their own challenges. When natural gas (basically methane, a lightweight molecule made of carbon and hydrogen) is exposed to steam under high temperatures in the presence of a catalyst, it frees the hydrogen. However, the process itself also produces substantial amounts of CO_2. Widespread use would require a carbon sequestration scheme. And, of course, hydrogen can be extracted from water by electrolysis. But that takes a lot of electric power. So unless the electricity is generated by nuclear or renewable sources, the environmental advantage of hydrogen is substantially negated.

The federal government, particularly the U.S. Department of Energy, is conducting significant research on fuel cells to accelerate their development and successful introduction into the marketplace. And hydrogen-fuel-cell cars are receiving considerable attention in the press. Some car manufacturers, including General Motors and Honda, are putting a very limited number of these vehicles on the road. There are hydrogen fueling stations in about 16 states, the greatest number being in California. Most of these, though, are small, private facilities intended to support a few experimental vehicles. It will take decades of research and development, as well as changes in the energy infrastructure, before a hydrogen economy on a broad scale can be achieved.

ALTERNATIVES TO CONVENTIONAL OIL

There are several "unconventional" petroleum sources, materials from which oil can be extracted—at a cost. Resources are abundant and could greatly impact the U.S. oil supply in the future. The three largest are oil shale (rock that releases petroleum-like liquids when heated in a special chemical process); tar sands (heavy, thick, black oil mixed with sand, clay, and water); and heavy crude oil (thicker and slower flowing than conventional oil).

The most extensive deposits of all three are in North and South America. A region covering parts of Colorado, Utah, and Wyoming contains oil shale

totaling about three times the proven oil reserves of Saudi Arabia. About two-thirds of the world's supply of tar sands (estimated at 5 trillion barrels, though not all of it is recoverable) is found in Canada and Venezuela. Venezuela also has the largest known reserves of heavy crude oil, estimated at 235 billion barrels.

However, extracting these resources is much more costly, energy intensive, and environmentally damaging than drilling for conventional oil. The processes by which we mine and refine oil shale and tar sands to produce usable oil, for example, involve significant disturbance of the land, extensive use of water (a particular concern in dry regions where oil shale is often found), and potential emissions of pollutants to the air and groundwater. In addition, more energy goes into these processes than into extracting and refining conventional oil, and more CO_2 is emitted. But as conventional oil costs rise, more attention is being focused on alternative sources and on overcoming the challenges associated with their use. Canada already produces more than a million barrels per day of oil from tar sands, and some companies are interested in pursuing oil shale in the United States, probably using below-ground techniques to extract the oil without mining the shale.

BIOFUELS

Fuel derived from plant material, or biofuel, is an appealing renewable alternative to fossil fuels. It is uncertain, though, whether biofuels are ultimately viable in the absence of subsidies. In particular, the prospects for "biodiesel" fuel—a relatively heavy liquid derived from soybean, vegetable, rapeseed, or safflower oils, among others—are considered doubtful. Typically, those oils are already expensive compared to fossil-fuel sources, and there does not appear to be a way to bring the cost down.

As mentioned previously, corn-based ethanol is already offsetting a small amount of fossil-fuel use in vehicles. However, many experts believe that ethanol-based biofuels will not provide much benefit until the conversion technology is fully developed to use cellulose (as found in trees and grasses) for the raw material instead of corn or sugar cane. In fact, the Energy Independence and Security Act of 2007 stipulates that by 2022 the United States must produce 21 billion gallons of advanced biofuels, such as cellulosic ethanol. Research is under way in this field, which could provide a ubiquitous sustainable resource and perhaps take advantage of the existing nationwide infrastructure created for petroleum-based fuel distribution.

Even with this increased focus on biofuels, however, it is uncertain how much projected gasoline consumption can be replaced in the next few decades. Furthermore, biofuels contain carbon, and although they may burn "cleaner" than oil-derived fuels, they would not completely eliminate CO_2 emissions.

Many of these technologies will likely contribute in some way to America's energy sources in the 21st century. But it is impossible to predict how much impact these and other technologies will have on our energy future.

LOOKING AHEAD

The future holds great promise. New discoveries, advanced technologies, and high-tech engineering may transform the energy landscape—and with it the shape of society. Public-private partnerships will play an important role in the development of these new technologies and will increase the chances of their adoption in the marketplace. But our energy makeover will be a very gradual and uneven process. The current energy infrastructure is huge—and hugely valuable. Changing it will and should be a careful, deliberative matter unaffected by sudden popular enthusiasms or technological fads.

One thing is certain: There will be no single “silver bullet” solution to our energy needs. Tomorrow’s energy, like today’s, will come from a robust variety of sources. New devices, processes, and systems will surely be offered, but not every new technology works, and even those that do are not always adopted by consumers. If the history of human ingenuity is a reliable guide, however, America will find ways to flourish on energy that is sustainable, responsible, and secure.

The information in this booklet was derived from data provided by the Energy Information Administration and from the following National Research Council reports. Specific citations can be found in the online version of the booklet at **www.nationalacademies.org/energybooklet.**

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The Environmental Impacts of Wind-Energy Projects **(2007)**

Prospective Evaluation of Applied Energy Research and Development at DOE (Phase Two) **(2007)**

Alternatives to the Indian Point Energy Center for Meeting New York Electric Power Needs **(2006)**

Prospective Evaluation of Applied Energy Research and Development at DOE (Phase One): A First Look Forward **(2005)**

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