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Preface

After the oil shortage in 1972 there was talk about the hydrogen economy as a way to change the energy sources that we use in transport systems. The promise of a hydrogen revolution was exciting to many, but instead of becoming a technology race, it became more of an economics issue since as long as petroleum was available and cheap there was no need to develop a hydrogen technology.

Now, we see much more investment in fuel cell technology, hydrogen fueled vehicles and even hydrogen fuel stations. The technology is being pushed by economics as oil prices continue to rise with dwindling supplies.

Hydrogen fuel cell technology is becoming more economically feasible, but when will it happen on a larger scale? The process of splitting water to produce hydrogen requires that electric power be produced. Can this be done without fossil fuels that generate greenhouse gases by using solar power to generate electricity which can split the water? If we don't use fossil fuels when we make the hydrogen, that's really renewable and non-polluting technology. Applications include automotive transportation and home power. A cylinder of hydrogen could provide power for cell phones and other portable units. Cars may use this technique too or store hydrogen in solid hydrides which would be exhausted and then recharged at a filling station. There are hydrogen filling stations in California and other areas in the United States and Europe.

In 5-10 years hydrogen may begin making inroads replacing petroleum and we can become less dependent on Middle East oil supplies.

A hydrogen economy may require the expenditure of hundreds of billions of dollars for an entirely new energy infrastructure of pipelines, fueling stations and power sources. This will come from public and private money.

At the headquarters of Plug Power in Latham, NY stationary hydrogen fuel cell units are manufactured for backup power applications. A hydrogen fueling station has been co-developed with Honda engineers. It contains a miniature chemical plant in the form of a steam reformer that extracts hydrogen fuel from natural gas. Besides refueling vehicles, the system feeds some of the hydrogen into a fuel cell stack to produce power for the headquarters building, which is also warmed in part by waste heat generated by the unit. The fuel dispensing pump is the size of a kitchen stove in the company parking lot and filling a car's hydrogen tank takes about five or six minutes.

A study by GM estimates that $10 billion to $15 billion would pay for 11,700 fueling stations in major urban areas. This would be enough so a driver could always be within two miles of a hydrogen station in these major urban areas with a station every 25 miles along main highways. These hydrogen stations would support about one million fuel cell vehicles.

This filling station along with several dozen others from Europe to California to Japan are the first steps toward the construction of an infrastructure. Soon over 100 hydrogen refueling stations will be operating worldwide, and the California Hydrogen Highway program has a goal of 200 stations.

A National Academy of Sciences committee estimated that the transition to a hydrogen economy could take decades, since tough challenges remain. These include how to produce, store and distribute hydrogen in adequate quantities and at reasonable costs without releasing greenhouse gases.

Hydrogen is also a leak-prone gas that could escape from cars and production plants into the atmosphere, which could set off chemical reactions that generate greenhouse gases. Using fossil fuels to make hydrogen may take more energy that contained in the hydrogen itself.

U.S. industry currently produces 50-60 million tons of hydrogen per year, so there is experience in handling hydrogen. But, 50-60% of the problems with fuel cells have come from impurities in hydrogen purchased from this industry. The purity needs to be improved.

Building a hydrogen infrastructure in the 21st century may be like building railroads in the 19th century or the interstate highway system in the 20th century. There will be a point relatively soon when funding decisions become more important than technology issues.

Today, $12 billion is only a fraction of what cable operators are spending for cable system installations which is close to 100 billion in some cases.

The resolution of technical and market issues will determine when the transportation vehicle of the proposed hydrogen economy, fuel cell automobiles arrive in commercial quantities. The high cost of the precious metal ingredients in fuel cells is one of these issues. Lowering the platinum content includes methods to raise the activity of the catalyst as well as finding a stable catalyst that does not degrade. Avoiding side reactions that contaminate the membrane is another concern.

There also needs to be enough hydrogen onboard to provide a sufficient driving range. Hydrogen is stored in pressure tanks as a highly compressed gas at ambient temperature. Liquid hydrogen systems, which store the fuel at temperatures below –253 degrees C, have also been used in prototype fuel cell vehicles.

Honda's FCX fuel cell car behaves like a gasoline powered vehicle except for the lack of engine noise. GM's HydroGen3 fuel cell vehicle uses a Proton Exchange Membrane (PEM) fuel cell, which is the most popular for use in autos. A PEM fuel cell gets its energy from the chemical reaction between the hydrogen stored onboard the vehicle and oxygen from the air.

One of the biggest challenges for hydrogen fuel cell transportations will be an infrastructure for quick, convenient refueling. As with gasoline, hydrogen storage and fueling facilities will have to meet various local, state and federal codes. Toyota has worked with the city of Torrance, California to build a supporting garage for its FCHV fuel cell cars. Based on the Toyota Highlander, the FCHV has been undergoing real world tests through a lease program at the National Fuel Cell Research Center. Participants use the vehicles for their daily driving.

Honda has built a solar-powered hydrogen station to refuel its FCX fuel cell fleet. Honda has also been testing a Home Energy Station that extracts hydrogen from natural gas, while generating electricity and hot water for home use. But, natural gas jumped from about $5/thousand cubic feet in 1999 to almost $12 in 2006.

Chapter one is an overview of the energy evolution. It introduces the technology and emission issues, safety, and alternative fuels such as natural gas, hydrogen gas, methanol, ethanol and fuel cell power.

Chapter two investigates current environmental issues in the use of energy including carbon accounting and global warming. This chapter outlines the major environmental trends and concerns including Kyoto and global warming, temperature cycles, deforestation and the greenhouse effect.

Alternative fuel programs is the theme of Chapter three. Subjects include hydrogen, methanol, syn gas, biofuels, fueling methods, safety and storage. The chapter ends with a discussion of cost issues.

Chapter four is concerned with hydrogen production and storage choices. Biomass is considered as a source of hydrogen fuel as well as natural gas. Nuclear and renewable are also considered.

Transportation and fuel cells are the main themes of chapter five. Fueling stations are important for any alternative fuel especially hydrogen. Fuel cell advances will also pace hydrogen cars as well as the level of government support. Topics include the auto future, electric cars, revivals, the auto industry, car designs and the impact of mass production. The chapter investigates the impact of auto technology and considers fuel cell electric cars, fuel cell cabs, the fuel cell future and recent advances in fuel cell auto technology.

Chapter six considers the impact of fuel cells on power generation. One concept is to use hydrogen cars as mobile power sources. Other topics include the benefits of fuel cells, coal gasification, solar, wind and nuclear power.

Chapter seven is concerned with heating and cooling energy. Cogeneration is discussed using fuel cells. Other topics include energy management, building automation, limiting demand, load shedding, high efficiency heating and district heating and cooling.

Chapter eight discusses the power and energy and transportation future which includes hydrogen and fuel cells. Related topics involve renewables and solar satellite power. The chapter concludes several possible future scenarios and trends in nuclear power.

Many thanks to Dee who did much to organize the text and get this book into its final form.

Chapter 1

The Energy Evolution

When oil prices increase, the interest in alternatives increases. Recent hydrogen demonstration programs are being conducted by states such as California where the concern of air quality is high which makes finding solutions more urgent.

Alternate energy becomes more popular but major questions remain to be answered on which fuel or fuels will emerge and to what extent alternative sources will replace gasoline as the main product of crude oil.

Oil and other non-renewable fossil fuels are being quickly consumed, which is creating major impacts on air and water pollution as well as concern on global climate change. A shift to zero-carbon emission solar hydrogen systems could fundamentally resolve these energy supply and environmental problems. Hydrogen can be manufactured from water with algae and other microorganism, as well as with any source of electricity. New electrical production options include coal and nuclear power plants or solar technologies, such as photovoltaic, wind and ocean thermal systems.

Civilization has experienced exceptional developments during the last 200 years. This was spurred by the discovery and use of fossil fuels and resulted large productivity gains. Humans now number over 6 billion persons, more than 6 times the population that existed before the discovery of fossil fuels. Even persons with moderate incomes in industrialized countries have, in many aspects, much more disposable energy, more comfortable homes, far better appliances, better health care choices, and more enjoyable living conditions than the most wealthy king or queen that reigned before fossil fuels were exploited. Millions of average citizens regularly drive cars and trucks on improved roadways with sufficient power to comfortably travel 300 miles at 60 MPH. More millionaires and billionaires now exert their economic reigns than at any previous time in history.

Progress was always possible when better tools were invented. Inventions that emphasized lighter, stronger and potentially more useful alloys defined the Iron Age of progress.

New inventions are rapidly progressing that will enable a solar hydrogen society to enter a non-carbon age of material excellence. Renewable energy for this advancement will be converted into safely storable, efficiently transportable, and clean usable hydrogen.

Hydrogen is a universal fuel that could power automobiles, aircraft, spacecraft, power plants and appliances, including gas stoves that can operate on mountain-tops. Since it is a zero-carbon emission fuel, carbon emissions that may effect pollution and global climate change are eliminated. Shifting to hydrogen energy can have a profound positive impact on the Earth's biological systems.

Every product has a basic energy cost and the rising consumption of fossil fuels makes it difficult to predict energy costs in the future. Shifting to hydrogen will reduce future cost and supply uncertainties and significantly improve the U.S. balance of trade.

Many relate hydrogen fuel use, which involves a chemical change, with hydrogen weapons, which involves a thermonuclear reaction. Many people do not realize that most of the passengers and crew of the Hindenburg survived, and that extensive testing and utilization evidence by NASA & BMW show hydrogen to be safer in many ways than gasoline and other petrocarbon fuels when accidents do occur.

HYDROGEN THE BASIC ELEMENT

The chronicle of hydrogen begins with the Big Bang theory of universe creation 15 billion years ago, when hydrogen atoms were first formed. Gravity acted as the primitive force that caused the hydrogen to condense into vast clouds that collapsed into stars, which consume the hydrogen as fuel. When the larger stars with adequate mass no longer have enough hydrogen, a supernova is formed which then transforms into heavier elements. These giant molecular cloud formations, consisting almost entirely of hydrogen, are the most massive objects within galaxies. Gravity eventually causes the hydrogen to compress until it fuses into heavier elements.

Without the energy emitted by the sun, life as we know it could not exist. The primary fuel for the sun and other stars is hydrogen while the force that allows the sun and other stars to burn is gravity. Our sun consumes about 600 million tons of hydrogen every second. As this hydrogen is fused into helium, photons of electromagnetic energy are released and eventually find their way through the earth's atmosphere as solar energy.

This solar energy is the aftermath of nuclear fusion, while nuclear fission occurs in commercial nuclear reactors. Without this energy there would be no life, there would be no fossil fuels or wind or even elements in our world.

Hydrogen was discovered in 1766 when the English chemist Henry Cavendish observed what he called an inflammable air rising from a zinc-sulfuric acid mixture. It was identified and named in the 18th century by Antoine Lavoisier, who demonstrated that this inflammable air would burn in air to form water. He identified it as a true element, and called it hydrogen, which is Greek for water former. Hydrogen is the simplest, lightest and most abundant of the 92 elements in the universe. It makes up over 90% of the universe and 60% of the human body in the form of water. As the most basic element, it can never be exhausted since it recycles in a relatively short time.

Protons and electrons are the basic components of the hydrogen atom and these atoms are the basic building blocks of the other 91 elements that occur naturally. The atomic number of an atom equals the number of protons, hydrogen nuclei, or electrons of the element. Hydrogen with one proton and one electron, has an atomic number of 1. Carbon has six protons and six electrons and an atomic number of 6. The proton's positive electrical charge and the electron's negative charge have a natural attraction for each other.

Hydrogen atoms and other subatomic particles would have continued to expand away from each other from the force of the big bang, but gravity caused these particles to cluster in large masses. As the mass increased, the force of gravity increased and eventually, the force and pressure became great enough for the interstellar clouds of hydrogen to collapse causing the hydrogen and other particles to collide.

These collisions result in high enough temperatures of 45 million degrees Fahrenheit and pressures to fuse the hydrogen into helium and the birth of a star takes place. As the star feeds on this supply of hydrogen, four hydrogen nuclei are fused into one heavier helium nucleus.

The heavier helium atoms form a dense, hot core. When the star has consumed most of its hydrogen, it begins to burn or fuse the helium, converting it to carbon and then to oxygen.

The more massive a star is, the higher the central temperatures and pressures are in the later stages. When the helium is consumed, the star fuses the carbon and oxygen into heavier atoms of neon, magnesium, silicon and even silver and gold. In this way, all the elements of the earth except hydrogen and some helium were formed billions of years ago in stars.

The transition from nonrenewable fossil fuel should consider the development of technologies that can use the available energy of the sun. It is reasonable to assume that solar energy will eventually serve as a primary energy source. As we attempt to use solar energy to replace the use of fossil and nuclear fuels, this relationship between solar energy and hydrogen returns and one may not effectively work without the other.

Hydrogen is the most abundant element in the universe and our sun alone consumes 600 million tons of it each second. Unlike oil, widespread underground reservoirs of hydrogen are not to be found on earth. While hydrogen is the simplest element and most plentiful gas in the universe, it never occurs by itself and always combines with other elements such as oxygen and carbon. The hydrogen atoms are bound together in molecules with other elements and it takes energy to extract the hydrogen.

Hydrogen is not a primary energy source, but it can be used like electricity as a method of exchange for getting energy to where it is needed. As a sustainable, non-polluting source of power hydrogen could be used in many mobile and stationary applications. As an energy carrier, hydrogen could increase our energy diversity and security by reducing our dependence on hydrocarbon-based fuels.

HYDROGEN CHARACTERISTICS

Hydrogen is different than other energy options like oil, coal, nuclear or solar. Solar technology is renewable, modular and generally pollution free, but it has some disadvantages, such as not always being available at the right time.

Hydrogen and electricity are complementary and one can be converted into the other. Hydrogen can be viewed as a type of energy currency that does not vary in quality depending on origin or location. A molecule of hydrogen made by the electrolysis of water is the same as hydrogen manufactured from green plant biomass, paper, coal gasification or natural gas.

Hydrogen is a primary chemical feedstock in the production of gasoline, fuel oils, lubricants, fertilizers, plastics, paints, detergents, electronics and pharmaceutical products. It is also an excellent metallurgical refining agent and an important food preservative.

Hydrogen can be extracted from a range of sources since it is in almost everything, from biological tissue and DNA, to petroleum, gasoline, paper, human waste and water. It can be generated from nuclear plants, solar plants, wind plants, ocean thermal power plants or green plants.

When hydrogen is burned in a combustion chamber instead of a conventional boiler, high-pressure superheated steam can be generated and fed directly into a turbine. This could cut the capital cost of a power plant by one half. While hydrogen is burned, there is essentially no pollution. Expensive pollution control systems, which can be almost one third of the capital costs of conventional fossil fuel power plants are not required. This should also allow plants to be located closer to residential and commercial loads, reducing power transmission costs and line losses.

Since hydrogen burns cleanly and reacts completely with oxygen to produce water vapor, this makes it more desirable than fossil fuels for essentially all industrial processes. For example, the direct reduction of iron or copper ores could be done with hydrogen rather than smelting by coal or oil in a blast furnace. Hydrogen can be used with conventional vented burners as well as unvented burners. This would allow utilization of almost all of the 30 to 40% of the combustion energy of conventional burners that is lost as vented heat and combustion by-products.

ENERGY CARRIERS

Hydrogen is known as a secondary energy carrier, instead of a primary energy source. Energy is needed to extract the hydrogen from water, natural gas, or other compound that holds the hydrogen. This portrayal is not precise because it assumes solar, coal, oil or nuclear are primary energy sources, but energy is still expended to acquire them. Finding, extracting and delivering the so-called primary energy sources requires energy and major investments before they can be utilized. Coal and natural gas are closer to true primary energy sources since they can be burned directly with little or no refining, but energy is still needed to extract these resources and deliver them to where the energy is needed. Even when extensive drilling for oil is not required from shallow wells or pools, energy is still needed for pumping, refining and delivery.

Many environmental problems are the result of finding, transporting and burning fossil fuels. But, when hydrogen is used as a fuel, its by-product is essentially water vapor. When hydrogen is burned in the air, which contains nitrogen, nitrogen oxides can be formed as they are in gasoline engines. These oxides can almost be eliminated in hydrogen engines by lowering the combustion temperature of the engine. Some tests have shown that the air coming out of a hydrogen fueled engine is cleaner than the air entering the engine. Acid rain, ozone depletion and carbon dioxide accumulations could be greatly reduced by the use of hydrogen.

After it has been separated, hydrogen is an unusually clean-energy carrier and clean enough for the U.S. space shuttle program to use hydrogen-powered fuel cells to operate the shuttle's electrical systems while the by-product of drinking water is used by the crew.

Hydrogen could be an alternative to hydrocarbon fuels such as gasoline with many potential uses, but it must be relatively safe to manufacture and use. Hydrogen fuel cells can be used to power cars, trucks, electrical plants, and buildings but the lack of an infrastructure for producing, transporting, and storing large quantities of hydrogen inhibit its growth and practicality. Although the technology for electrochemical power has been known since 1839, fuel cells are still not in widespread use. The electrochemical process allows fuel cells have few moving parts. Air compressors are often used to improve the efficiency although there are compressor-less designs.

Fuel cells operate like batteries expect that they combine a fuel, usually hydrogen, and an oxidant, usually oxygen from the air, without combustion.

HYDROGEN PRODUCTION

Hydrogen can be obtained from natural gas, gasoline, coal-gas, methanol, propane, landfill gas, biomass, anaerobic digester gas, other fuels containing hydrocarbons, and water. Obtaining hydrogen from water is an energy intensive process called electrolysis, while hydrocarbons require a more efficient reforming process.

Hydrogen may be produced by splitting water (H_2O) into its component parts of hydrogen (H_2) and oxygen (O). Steam reforming of methane from natural gas is one way to do this. It converts the methane and other hydrocarbons in natural gas into hydrogen and carbon monoxide using the reaction of steam over a nickel catalyst. Another method is electrolysis which uses an electrical current to split water into hydrogen at the cathode

(+ terminal) and oxygen at the anode (– terminal). Steam electrolysis adds heat to the process and this heat provides some of the energy needed to split water and makes the process more energy efficient. When hydrogen is generated from renewable sources, its production and use becomes part of a clean, natural cycle.

Thermochemical water splitting uses chemicals and heat in several steps to split water into hydrogen and oxygen. Photolysis is a photoelectrochemical process that uses sunlight and catalysts to split water. Biological and photobiological water splitting use sunlight and biological organisms. Thermal water splitting uses a high temperature of 1000°C. Biomass gasification uses microbes to break down different biomass feedstocks into hydrogen.

Some of the first life forms on Earth were photosynthetic algae that existed about 4 billion years ago. Hydrogenase is an enzyme that can be used in extracting hydrogen from carbon. Chlorophyll uses sunlight to extract hydrogen from water. In the future, developments in Microbiology, Molecular Biology and Nanotechnology are expected to allow biological hydrogen production systems to be fully realized.

Cost is one hurdle that is keeping hydrogen from being more widely as a fuel. Many changes in the energy infrastructure are needed to use hydrogen.

Electricity is required for many hydrogen production methods and the cost of this electricity tends to make hydrogen more expensive than the fuels it would replace.

Another matter is hydrogen's flammability since it can ignite in low concentrations and can leak through seals. Leaks in transport and storage equipment could present public safety hazards. Gasoline transport and storage presents similar public safety hazards. Older gasoline storage tanks at filling stations have leaked and contaminated groundwater at many locations. A leaking pipeline contaminated the soil under a California coastal town and required demolition and rebuilding of the town in order to replace the soil.

STORAGE AND TRANSPORTATION

Hydrogen can be stored and transported as a compressed gas, a cryogenic liquid or in solids. Liquid hydrogen is closer to gasoline in the areas of volume and vehicular weight. In commercial aircraft, the takeoff weight could be reduced by 40 percent. Hydrogen can be transported in underground pipelines, tanker trucks or ships. Hydrogen pipelines can carry both gaseous and liquid hydrogen.

Although it may be difficult, more cooperation is required between vehicle manufacturers, fuel producers, and the government. The infrastructure for the production and delivery of the fuels can evolve as needed with free market forces providing most of the momentum. But, there will need to be a coordination of selections of fuels and the adjustments needed to run those fuels.

A combination of available alternative fuels should evolve with the most likely choices affected by a number of technical, political and market factors. In order to allow a wider application of alternative fuels, a number of obstacles have to be overcome. These include economic, technological, and infrastructural issues. In the past, gasoline has been plentiful and has had a significant price advantage compared to other fuels. This could change quickly and alternative fuels would need to become more commonplace.

COST ISSUES AND SUSTAINABLE ENERGY

Accountants and economists commonly consider the cost of a barrel of oil or a ton of coal or a therm of natural gas to be the taking cost and the replacement cost is neglected. If the replacement cost of oil is used to establish the cost of gasoline at the pump, cars would be much more fuel-efficient. If we valued the replacement cost of energy, natural gas would not have been vented for decades from oil fields.

When the external costs of using fossil and nuclear fuels, including environmental regulations and health care costs are factored into the price of gasoline products, hydrogen becomes one of the least expensive fuels. Many believe that the legislative trigger mechanism for the hydrogen economy is the passage of a Fair Accounting Act that will insure that hydrogen will be the least expensive fuel.

Society must become more sustainable to conserve the resources that make humans productive. A more complete economic analysis and accounting would stimulate improved efficiency for economic development and promote a future with sustainable prosperity.

The problems of expanding demands for diminishing resources have been important in modern struggles for more oil resources. In World

War II Japan and Germany needed access to oil. Limiting this access was part of the Allied efforts to end World War II. There have been more recent struggles to control the Organization of Petroleum Exporting Countries (OPEC) and other oil rich areas, including the pathways from foreign oil fields to markets.

The opportunities to harness solar, wind, wave, falling water and biomass-waste resources are projected to exceed any wealth created by the exploitation of oil. Progressing past the Oil Age means an important economy of wealth expansion from energy-intensive goods and services with renewable energy.

As energy-efficient technologies help to release us from fossil fuels, consumers will have a wider and more diverse set of energy sources, the economy will be more robust and the world more stable.

Carbon reinforced products that require less energy to produce and that are ten times stronger than steel, lighter than aluminum, and that conduct more heat than copper can be increasingly used to reduce the weight of vehicles, improve the performance of appliances and tools and increase the efficiency of heat-transfer systems. Other forms of carbon will provide super semiconductors and advanced optics.

Hydrogen powered transportation equipment can use stronger, lighter more compact energy storage tanks made of carbon. Aircraft, ships and buildings can use new forms of carbon materials that are much stronger, more corrosion resistant, and that will withstand higher temperatures than steel.

A BIOMASS FUTURE

One fuel alternative involves the more widespread use of biomass produced fuels. More efficient biomass conversion techniques would help make biofuels more cost-competitive. Land availability and crop selection are major issues in biomass fuel usage. Biomass alternatives can be expected to grow to a significantly larger scale for providing fuel.

Land availability may not be a major problem, but land use issues need to be coordinated. The long-term production of biofuels in substantial quantities will require a number of changes. Grain surpluses will not provide sufficient feedstocks for the fuel quantities needed. Producers will need to switch to short-rotation woody plants and herbaceous grasses, these feedstocks can sustain biofuel production in long-term, substantial quantities. The increased use of municipal solid waste (MSW) as a feedstock for renewable fuels is also likely to grow.

In spite of significant problems, many are optimistic about the role of biomass for alternative fuels in the future. The U.S. Department of Energy believes that biofuels from nonfood crops and MSW could potentially cut U.S. oil imports by 15 to 20%. Ethanol industry members believe that the capacity for producing that fuel alone could be doubled in a few years and tripled in five years.

METHANOL

Methanol, which is also known as wood alcohol, is a colorless and odorless liquid alcohol fuel that can be made from biomass, natural gas, or coal. It is the simplest alcohol chemically and it may be used as an automobile fuel in its pure form (M100), as a gasoline blend of typically 85% methane to 15% unleaded gasoline (M85). It is also used as a feedstock for reformulated gasoline. M100 or pure methanol may be used as a substitute for diesel. In M85, the gasoline is added to color the flame of burning fuel for safety reasons and to improve starting in cold weather.

Methane has an invisible flame and can be explosive in a closed space such as a fuel tank although it is less flammable than gasoline and results in less severe fires when ignited. Colorants may be added to help identify the flame and baffles or flame arresters at the opening of the tank can be used to repress the accidental ignition of methanol vapors.

One of the considerations regarding the use of methanol as a fuel is that it emits higher amounts of formaldehyde, which is a contributor to ozone formation and a suspected carcinogen, compared to gasoline. Proponents of methanol dispute this, saying that one-third of the formaldehyde from vehicle emissions actually comes from the tailpipe, with the other two-thirds forming photochemically, once the emissions have escaped. They state that pure methanol vehicles produce only one tenth as much of the hydrocarbons that are photochemically converted to formaldehyde as do gasoline automobiles.

If methanol utilization is to be increased, production needs to become more efficient and the infrastructure improved to make it more competitive. A major source of methane has been natural gas, since this has been the most economical source. Although the United States has both natural gas and coal, these are both nonrenewable resources.

Biomass can be a renewable feedstock for methane. Biomass feedstocks for methane production include crop residues, municipal solid waste (MSW), and wood resources. Biomass resources for the production of alcohol fuels are estimated at about 5 million dry tons per day which could provide 500 million gallons of methanol per day.

In the 1990s the U.S. methanol industry was producing almost 4 million gallons of methanol per day. Only a third of this was used as fuel for transportation and much of it was converted to MTBE. Methanol is also popular in high-performance racing because of its octane-enhancing qualities.

California has more than 1,000 methanol vehicles including cars, trucks, and buses on the road in a state program with auto manufacturers and oil companies. New York City also uses buses that run on methanol. Arizona Checker Leasing uses methanol vehicles with a fleet of 450 M85 fuel flexible vehicles.

ETHANOL

Ethanol, or grain alcohol, is an alcohol fuel widely used as automotive fuel. It can be made from a variety of feedstocks, mainly grains, forest resides, and solid waste. It can be used in its pure form, but is more widely used in a blended form. Gasoline blends (90% gasoline/10% ethanol) have been widely used in many areas of the country. Ethyl tertiary butyl ether (ETBE) is a feedstock for reformulated gasoline based on ethanol.

In the early 1990s, almost 8% of the gasoline sold in the United States was an ethanol mixture with 850 million gallons of ethanol produced each year. About 95% of this was from the fermentation of corn. Most of this was used as a gasoline additive to produce the 10% ethanol/90% gasoline mixture called gasohol. About 30% of the nation's gasoline had some alcohol in it. Most ethanol use in the United States was in the Midwest, where corn and grain crops were used as feedstocks.

In 1979 only 20 million gallons of ethanol were being produced in the United States each year. By 1983, this had jumped to 375 million gallons annually and by 1988 to almost 840 million gallons annually. More than sixty ethanol production facilities were operating by 1993 in the United States in twenty-two states. Farm vehicles were being converted to ethanol fuel and demonstration programs were underway for testing light-duty vehicles.

The nation's first E85 (85% ethanol) fueling station opened in La Habra, CA in 1990, operated by the California Renewable Fuels Council.

METHANOL AND ETHANOL PRODUCTION

In the 1920s the catalytic synthesis of methanol was commercialized in Germany. Even before that, methane was distilled from wood, but this pyrolysis of wood was relatively inefficient.

Ethanol saw several spikes of popularity during the last century, notably during the world wars when petroleum demand soared. In more recent decades, the use of alcohol fuels has seen rapid development.

The use of MTBE occurred quickly after the first MTBE plant was built in Italy in 1973. Its use then spread through Europe and by 1980, Europe was producing almost 90 million gallons per year. This reached 300 million gallons per year by the end of 1990. In the U.S. MTBE production began in the early 1980s and reached more than a billion gallons by 1987.

Methanol and ethanol are alcohol fuels that can be produced from various renewable sources. Alcohol fuels are converted from biomass or other feedstocks using one or several conversion techniques. Both government and private research programs are finding more effective, less costly methods of converting biomass to alcohol fuels. Methanol was originally a by-product of charcoal production, but today it is primarily produced from natural gas and can also be made from biomass and coal.

When methanol is made from natural gas, the gas reacts with steam to produce synthesis gas, a mixture of hydrogen and carbon monoxide. This then reacts with a catalytic substance at high temperatures and pressures to produce methanol. The process is similar when methanol is produced by the gasification of biomass. The production of methanol from biomass or coal can cost almost twice as much as production from natural gas.

Most of the ethanol in the United States has been made from fermenting corn. Dry-milling or wet-milling can be used. In dry-milling, the grain is milled without any separation of its components. The grain is mashed and the starch in the mash is converted to sugar and then to alcohol with yeast. In wet-milling, the corn is first separated into its major components, the germ, oil, fiber, gluten and starch. The starch is then converted into ethanol. This process produces useful by-products such as corn gluten feed and meal. The only other country with a significant production of ethanol is Brazil which makes its fuel from sugar cane.

Considering the full production cycle, methanol from biomass emits less carbon dioxide than ethanol from biomass. This is because short rotation forestry, the feedstocks of methanol, requires the use of less fertilizer and diesel tractor fuel than the agricultural starch and sugar crops which are the feedstocks of ethanol.

The more widespread use of ethanol could have some safety benefits since ethanol is water soluble, biodegradable, and evaporates easily. Ethanol spills tend to be much less severe with an easier clean up than petroleum spills.

When agricultural surplus was used for the production of ethanol in the United States, it provided economic benefits to farmers and to the farming economy. In 1990, almost 360 million bushels of surplus grain were used to produce ethanol. In that year, it is estimated that ethanol production increased farm income by $750 million while federal farm program costs dropped by $600 million and crude oil imports fell by over forty million barrels.

A major drawback of ethanol compared to methanol is its price which can be almost twice as much as methanol. But, both methanol and ethanol, as liquids, can use established storage and distribution facilities.

Although most ethanol is now produced from corn, research has been done on producing this type of alcohol fuel from cellulosic biomass products including energy crops, forest and agricultural residues, and MSW, which would provide much cheaper feedstocks. The process of chemically converting these cellulosic biomass feedstocks is more involved and until this process can be simplified the price of ethanol will remain high.

FUEL ALCOHOL GROWTH

Fuel alcohol programs have been appearing in more and more countries. Energy independence, low market prices for sugar and other food crops, and large agricultural surpluses have been the main reasons for these programs. Countries with fuel alcohol programs are in Africa and Latin America, along with the United States and a few other countries.

When fuels are produced from biomass, there is job creation in agriculture and related industries. Expanded production can also increase exports of by-products such as corn gluten meal from ethanol.

Brazil has been the major producer of ethanol in the world and began to make ethanol from sugar cane in 1975. By the 1990s, more than 4 million cars were using ethanol.

The ethanol used in Brazil is a mixture of 95% ethanol and 5% water. A small amount (up to 3%) of gasoline is also used. Almost 90% of new cars in Brazil run on this mixture. The rest operate on a 20% ethanol/80%

gasoline mix. The production of this ethanol requires about 1% of Brazil's total farmable land. Sugar cane can be grown nearly year-round in Brazil but the program has required government assistance. These subsidies for the production of ethanol from sugar cane have totaled several billion dollars. Also, Brazil's program has not been able to supply enough fuel and in order to meet consumer demand, the Brazilian government has been forced to import ethanol to meet the demand.

REFORMULATED GASOLINE

Reformulated gasoline is an alternative fuel that does not require engine modifications. It is used mainly because its effectiveness in reducing tailpipe emissions. Reformulated gasoline was qualified under the Clean Air Act to compete with other alternatives as an option for meeting lower emission standards. The formula can vary by region and season, but reformulated gasoline usually has polluting components like butane, olefins, and aromatics removed. An octane-enhancer like methyl tertiary butyl ether (MTBE) has also been added. This can reduce carbon monoxide, hydrocarbons and nitrogen oxides and improve combustion efficiency. MTBE was widely used in California, Arizona, and Nevada, but was phased out after it was found to contaminate water supplies.

ARCO has marketed a reformulated gasoline, EC-1 Regular (emission control-1), for older vehicles without catalytic converters, in southern California. These older vehicles were only a small segment of the total car and truck population in the region but produced about a third of the air pollution. ARCO has also marketed a premium reformulated gasoline, EC-Premium. The EPA estimated that the ARCO reformulated gasolines reduced air pollution by almost 150 tons a day in southern California.

NATURAL GAS

Natural gas is found in underground reservoirs and consists mainly of methane, with smaller amounts of other hydrocarbons such as ethane, propane, and butane along with inert gases such as carbon dioxide, nitrogen, and helium. The composition varies, depending on the region of the source.

As an engine fuel, natural gas can be used either in a compressed form as compressed natural gas (CNG) or in a liquid form as liquefied natural gas (LNG). The major difference between compressed natural gas and more conventional fuels is its form. Natural gas is gaseous rather than liquid in its natural state.

The United States has been a major producer and user of natural gas, but only a few percent of annual production is used for vehicles, construction and other equipment including power generation. Compressed natural gas has been used in about 30,000 vehicles in the United States, which includes school buses, delivery trucks, and fleet vehicles. Worldwide, about a million vehicles in thirty-five countries operate on natural gas. Some of the countries where natural gas is widely used include New Zealand, Italy and countries of the former Soviet Union. Vehicles that operate on liquid natural gas have also been used in taxis in Korea and Japan.

Most of the 300 NG filling locations in the United States are used by private fleets, but about one-third are open to the public. This fuel is more appropriate for fleet vehicles that operate in limited geographical regions and that return to a central location every night for refueling.

In 1991 the California Air Resources Board certified a compressed natural gas (CNG) powered engine as the first alternative fueled engine certified for use in California. The board also sponsored a program to fuel school buses with CNG. While CNG has been used for fleet and delivery vehicles, most tanks hold enough fuel for a little over 100 miles.

While natural gas has been plentiful, supplies are limited and increased demand has caused the cost to increase. Besides the range limitation, natural gas vehicles can cost more due to the need to keep the fuel under pressure. The weight and size of the pressure tank also reduces storage space and affects fuel economy.

NATURAL GAS VEHICLES

Most gasoline-powered engines can be converted to dual-fuel engines with natural gas. The conversion does not require the removal of any of the original equipment. A natural gas pressure tank is added along with a fuel line to the engine through special mixing equipment. A switch selects either gasoline or natural gas/propane operation. Diesel vehicles can also be converted to dual-fuel operation.

Natural gas engines can use lean-burn or stoichiometric combustion. Lean-burn combustion is similar to that which occurs in diesel engines, while stoichiometric combustion is more similar to the combustion in a gasoline engine.

Compressed natural gas has a high octane rating of 120 and produces 40 to 90% lower hydrocarbon emissions than gasoline. There are also 40 to 90% lower carbon monoxide emissions and 10% lower carbon dioxide emissions than gasoline.

Natural gas can also be less expensive than gasoline on a per gallon-equivalent. Maintenance costs can also be lower compared to gasoline engines since natural gas causes less corrosion and engine wear.

The larger, heavier fuel tank that is used has a limited range of about 100 miles. Refilling takes two to three times longer than refilling from a gasoline pump. Some slow fill stations can take several hours and the limited availability of filling stations can be a problem.

ALTERNATIVE FUEL COSTS

Cost differences between gasoline and most alternative fuels are a barrier to wider use of these fuels. Conversion technologies may become more efficient and more cost-competitive over time, but as long as gasoline prices remain relatively low, alternative fuels will not become cost-competitive without government help, in the form of subsidies or tax credits. However the cost difference between untaxed renewable fuels and taxed gasoline can be rather small. In the early 1990s, methanol was about $0.75 per gallon without federal or state tax credits.

The cost of wood-derived ethanol dropped from $4.00 to almost $1.10 before any tax credits. The federal government provided a tax credit of $0.60 per gallon, which was further subsidized by some states with an additional $0.40 per gallon. These tax credits allowed ethanol to be competitive with gasoline.

A comparison of the per gallon costs of methanol, ethanol and gasoline requires multiplying the gallon cost by the number of gallons needed for the same distance as gasoline. Methanol's energy density is about half that of gasoline, so it takes about two gallons of methanol to get the same amount of power as one gallon of gasoline. A gallon of ethanol contains about two-thirds the energy as a gallon of gasoline.

Most of the initial interest in alternative fuels started after the oil crisis in the 1970s. It has grown more recently by concerns about supply interruptions, high prices, air quality and greenhouse gases.

GOVERNMENT ACTIONS

The U.S. has seen legislation on cleaner-burning gasoline substitutes, gasoline enhancers and more efficient automobiles. This includes the 1988

Alternative Motor Fuels Act (AMFA) and the 1990 amendments to the Clean Air Act (of 1970).

The AMFA had demonstration programs to promote the use of alternative fuels and alternative-fuel vehicles. The act also offered credits to automakers for producing alternative-fuel vehicles and incentives to encourage federal agencies to use these vehicles.

The 1990 amendments to the Clean Air Act covered a range of pollution issues. New cars sold from 1994 on were required to emit about 30% less hydrocarbons and 60% less nitrogen-oxide pollutants from the tailpipe than earlier cars. New cars were also to have diagnostic capabilities for alerting the driver to malfunctioning emission-control equipment. In October 1993 oil refiners were required to reduce the amount of sulfur in diesel fuel. Starting in the winter of 1992/1993, oxygen was added to reduce carbon monoxide emissions to all gasoline sold during winter months in any city with carbon monoxide problems. In 1996 auto companies were to sell 150,000 cars in California that had emission levels of one-half compared with the other new cars. This was increased to 300,000 a year in 1999 and in 2001 the emission levels were reduced by half again. Starting in 1998 a percentage of new vehicles purchased for centrally fueled fleets in 22 polluted cities had to meet tailpipe standards that were about one-third of those for passenger cars.

If alternative fuels are to be more widely used, changes must take place both in fuel infrastructure, storage and engine technology. Infrastructural changes will improve the availability of alternative fuels. This may be done by the modification of existing filling stations and by establishing a distribution system that is as efficient as the current gasoline system.

FUEL SWITCHING

Technological changes in the manufacture of power sources are required if they are to run on alternative fuels. The development of alternative fuels depends on automotive manufacturers making alternative fuel engines available while fuel suppliers produce and distribute fuels for these vehicles. Flexible fuel vehicles (FFVs), which are also known as variable fuel vehicles, (VFVs) are designed to use several fuels. Most of the major automobile manufacturers have developed FFV prototypes and many of these use ethanol or methanol as well as gasoline.

More flexible-fuel vehicles are available as manufacturers move away from single-fuels to several fuels. This is also true in many power plants today. Dual-fuel or flexible-fuel vehicles are now used to some degree around the world. A dual-fuel boiler for a turbine generator or an engine to drive a generator might operate on natural gas, fuel oil, gasoline or an alternative fuel. Typically, boilers or engines will switch between a liquid or gaseous fuel. Cars, trucks, and buses that use both gasoline and compressed natural gas have been in use in northern Italy.

Flexible-fuel engines are able to use a variable mixture of two or more different fuels, as long as they are alike physically, in usually liquid form.

Vehicles with flexible-fuel engines are not in widespread use. There are about 15,000 M85 methanol vehicles in operation in the U.S. While methanol vehicles can provide greater power and acceleration but they suffer from cold starting difficulties. Cold starting problems can occur with these fuels in their pure form, but the addition of a small percentage of gasoline eliminates this problem. Both methanol and ethanol have a lower energy density than that of gasoline and thus more alcohol fuel is needed to provide the same energy.

The costs for near alcohol automobiles will be very close to the cost of a gasoline automobile. FFVs are expected to cost slightly more. The EPA estimates that with the necessary adjustments, the savings and costs will balance out. The increased costs necessary for fuel tank adjustments and to compensate for cold-start problems could be balanced out by the smaller, lighter engines that these cars can have because of their increased efficiency.

CARBON EXCHANGE

When fuels are derived from biomass, the net increase in carbon dioxide emitted into the atmosphere is usually considered to be neutral or even negative since the plants used to produce the alcohol fuel have reabsorbed the same or more carbon than is emitted from burning the fuel. The net effect may not be as favorable when the carbon dioxide emitted by equipment for the harvesting of the biomass feedstocks is considered in the balance. Much of this depends on the differences in equipment, farming techniques and other regional factors.

USING HYDROGEN

Before wide-scale use of hydrogen becomes a reality in transportation, researchers must develop new technologies that can use hydrogen that is stored or produced, as needed, onboard vehicles.

Hydrogen internal combustion engines can be used to convert hydrogen's chemical energy to electricity using a hydrogen piston engine coupled to a generator in a hybrid electric vehicle.

Onboard reforming for fuel cells depends on catalytic reactions to convert conventional hydrocarbon fuels, such as gasoline or methanol, into hydrogen that fuel cells can then use to produce electricity to power vehicles.

The FreedomCAR Partnership to develop fuel-cell-powered vehicles commits the U.S. Department of Energy toward a hydrogen-based energy system by making fuel-cell-powered vehicles available in 2010. The FreedomCAR program is also sponsoring investigation of ultralight materials including plastics, fiberglass, titanium, magnesium, carbon fiber and developing lighter engines made from aluminum and ceramic materials. These new materials can reduce power requirements and allow other fuels and fuel cells to become popular more quickly.

When hydrogen is used as fuel, the main emission from fuel cells is potable water. Even when using hydrocarbons as fuel, these systems offer substantial reductions in emissions. Honda's FCX fuel cell vehicle carries 156.6 liters of compressed hydrogen (about 3.75 kilograms) in two aluminum tanks. The fuel cell's peak output is 78 kilowatts which drives the electrical motor that moves the vehicle. An ultra-capacitor acts as a reservoir when the electrical load during acceleration exceeds the energy produced by the fuel cell. The ultra-capacitor offers quicker and higher voltage discharges and recharges than nickel-hydride batteries which are also used for this purpose. The batteries are slower to charge but hold it longer.

Solid oxide fuel cell (SOFC) systems can reach electrical efficiencies of over 50% when using natural gas, diesel or biogas. When combined with gas turbines there can be electrical efficiencies of 70%, for small installation as well as large. In a fuel cell system, these efficiencies can be kept at partial loads as low as 50%. Conventional technologies must run at close to full load to be most efficient.

NO_x and SO_x emissions from SOFC systems are negligible. They are typically 0.06-g/kWhe and 0.013-g/kWhe (kilo-watt hours electrical).

SOFCs also produce high-quality heat with their working temperature of 850°C. This makes combined heat and power production possible with SOFC systems. The total efficiency can then reach 85%. Advanced conventional cogeneration of heat and power can reach total efficiencies up to 94% with electrical efficiencies over 50%. This occurs only at full load. A high electrical efficiency is preferred over heat efficiency, since this results in a higher energy with the initial energy source better utilized, in terms of practical end-use.

Fuel cell systems are modular like computers which makes it possible to ramp up generating facilities as needed with sections in an idle mode when full capacity is not needed. The capacity is easily adjusted, as the need arise.

Hydrocarbons such as natural gas or methane can be reformed internally in the SOFC, which means that these fuels can be fed to the cells directly. Other types of fuel cells require external reforming. The reforming equipment is size-dependent which reduces the modularity.

Fuel cell cars must be able to drive hundreds of miles on a single tank of hydrogen. Honda's prototype fuel cell car had a range of 190 miles in 2004. It stored a little more than 3 kilograms of hydrogen at 4,400 psi. This gave it a mile/kg efficiency of 51 city and 46 highway. The 2005 model had an improved fuel cell and was rated at 62 city and 51 highway. A gallon of gasoline contains about 2,600 times the energy of a gallon of hydrogen, but a kilogram of hydrogen has almost exactly the same chemical energy as a gallon of gasoline.

An experimental Honda fueling station in the Los Angeles area produces about 1/2-kg of hydrogen per day, about 3.5-kg. It uses 700 square feet of solar panels to produce 6 kilowatts of power to electrolyze water.

If hydrogen cars are to travel 300 miles on a single tank, they will have to use compressed hydrogen gas at very high pressures, up to 10,000 pounds per square inch. Even at this pressure, cars would need large fuel tanks.

Liquid hydrogen may be a better choice. The GM liquid-fueled HydroGen3 gets about 250 miles on a tank about twice the size of a typical gasoline tank.

Cars and light trucks produce about 20% of the carbon dioxide emitted in the U.S., while power plants burning fossil fuels are responsible for more than 40% of CO_2 emissions. Fuel cells can be used to generate electricity for homes and businesses.

HYDROGEN AND GLOBAL WARMING

Hydrogen fuel cells do not emit carbon dioxide, but extracting hydrogen from natural gas, gasoline or other products requires energy and involves other by-products. Obtaining hydrogen from water through electrolysis consumes large amounts of electrical power. If that power comes from plants burning fossil fuels, the end product can be clean hydrogen, but the process used to obtain it can be polluting.

After the hydrogen is extracted, it must be compressed and transported, if this equipment operates on fossil fuels, they will produce CO_2. Running an engine with hydrogen extracted from natural gas or water could produce a net increase of CO_2 in the atmosphere.

FUEL CELL APPLICATIONS

Fuel cells seem like an energy user's dream: an efficient, combustion-less virtually pollution-free power source, capable of being sited in downtown urban areas or in remote regions, that runs almost silently and has few moving parts. Based on an electrochemical process discovered more than 150 years ago, fuel cells supplied electric power for spacecraft in the 1960s. Today they are being used in more and more distributed generation applications to provide on-site power and waste heat in some cases for military bases, banks, police stations and office buildings from natural gas.

Fuel cells can also convert the energy in waste gases from water treatment plants to electricity. In the future, fuel cells could be propelling aircraft, automobiles and allowing homeowners to generate electricity in their basements or backyards.

While fuel cells operate much like a battery, using electrodes in an electrolyte to generate electricity, they do not lose their charge as long as there is a constant source of fuel.

Fuel cells to generate electricity are being produced by companies such as Plug Power, UTC, FuelCell Energy and Ballard Power Systems. Most of these are stationary fuel cell generators. Plug Power has hundreds of systems in the U.S. including the first fuel-cell-powered McDonald's. The installed fuel cells have a peak generating capacity of about 100 megawatts, which is only 0.01% of the nearly one million megawatts of total U.S. generating capacity.

The fuel cells used in the space program in the 1960s and 1970s were very costly at $600,000-kW. Although some of this cost can be attributed to the high reliability manufacturing required for space application. The cost was far too high for most terrestrial power applications.

During the past three decades, major efforts have been made to develop more practical and affordable designs for stationary power applications. Today, the most widely deployed fuel cells cost about $4,000 per kilowatt compared to diesel generator costs of $800 to $1,500 per kilowatt. A large natural gas turbine can be even less.

Many specialty products are designed for specific applications. One power system from a California company called HaveBlue is designed for sailing yachts. The system includes solar panels, a wind generator and a fuel cell. The solar panels provide 400 watts of power for the cabin systems and an electrolyzer for producing hydrogen from salt or fresh water. The hydrogen is stored in six tanks in the keel. Up to 17 kilograms of hydrogen is stored in the solid matrix metal hydride tanks which replace 3,000 pounds of lead ballast. The wind generator has an output of 90 watts under peak winds and starts producing power at 5 knots of wind. The fuel cell produces 10 kilowatts of electricity along with steam which is used to raise the temperature of the hydrogen storage tanks. A reverse-osmosis water system desalinates water for cabin use and a deionizing filter makes pure water for fuel cell use.

Other applications include fuel cell-powered forklifts that are being used in a General Motor's plant in Oshawa, Ontario, Canada. The Hydrogenics forklifts have a 5000 pound lift capacity and are perfect for indoor facilities, such as factories and warehouses, since they produce no significant exhaust emissions, and are quite and offer significant operational advantages over battery-powered forklifts such greatly reduced recharge times.

This project was partially funded by the Sustainable Development Technology Canada foundation which was created by the Canadian government to develop and demonstrate clean technologies that address climate change as well as clean air, water and soil quality. Also involved are the Canadian Transportation Fuel Cell Alliance and FedEx Canada, Deere & Co. and the NACCO Materials Handling Group which assisted in the integration of the fuel cell systems into the forklifts. The forklift and refueler project will also be used for FedEx operations in the greater Toronto area.

The fuel cell power pack includes the fuel cell power module, an ultracapacitor storage unit, hydrogen storage tanks, thermal management and power electronics and controls. Hydrogenics' HyPM 10 Proton Exchange Membrane (PEM) fuel cells are used. The power pack is 33 inches long x 40 inches wide x 24 inches high. The low-pressure cell is rated 10-kW net continuous power at 39 to 58 Vdc with a maximum system efficiency of 56%.

The HyPM 10 fuel cell is fueled by hydrogen. The low-pressure design ensures quiet operation while maintaining high performance. The four-wheel forklift uses regenerative braking. Electric energy is stored in Maxwell Technologies' Boostcap ultracapacitors.

Ultracapacitors have demonstrated a higher recovery of energy from braking than batteries. They are also lighter, have a longer life and are better for the environment. When used with fuel cells in stop-and-go mobility applications such as forklifts, ultracapacitors provide a burst of power for lifting acceleration and enable regenerative braking. A small 12-volt battery is also included to start up the fuel cell.

Since these forklifts had previously been powered by heavier batteries, one issue in the modification was weight. The fuel cell power pack itself was relatively easy to integrate into the equipment since it was smaller and lighter than the lead acid battery system. But, since the battery provided part of the counterbalance, additional weight was added to provide enough stability for the forklift.

The fuel cell is supplied with hydrogen from a Hydrogenices HyLyzer hydrogen refueling station. The HyLyzer produces hydrogen by the hydrolysis of water using electricity. Depending on the size of the HyLyzer, the unit can produce up to 65-kg of hydrogen daily. The HyLyzer refueling station can refuel a forklift in less than two minutes, much less than batteries can be changed or recharged. The forklift's 4 pound hydrogen storage capacity is enough for up to eight hours of operation.

The modular design of the HyPM fuel cells allows scaling for higher power requirements using a variety of configurations, such as series and parallel systems. Potential applications for the technology include vehicle propulsion, auxiliary power units (APU), stationary applications including backup and standby power units, combined heat and power units and portable power applications for the construction industry and the military.

HYDROGEN-POWERED AIRCRAFT

The hydrogen economy may be the solution to most of the hydrocarbon problems of today's oil dependent transport systems. Hydrogen-powered aircraft could reduce greenhouse gas and nitrous oxide pollution from jet engines while being more efficient than present jet fuels.

Fuel cells have to compete with the turbine, in installed cost as an aircraft power plant. A study by the U.K.'s Cranfield University concluded that fuel cells are still too heavy for propulsion. A large aircraft requires many megawatts, generated by at least two turbine engines weighing about 3,900-kg (8,600lb) each. Today's fuel cells that generate 1,000-kW weight over 3,200-kg each.

A major question for autos has been if the user generates hydrogen on board or obtains it from a hydrogen refinery. This question also applies to aviation. Do you have a reformer on the aircraft, or do you generate the hydrogen at a central location? Both have advantages. Reforming on board allows the hydrogen to be transported in a form that is easy to move, such as methanol, natural gas and gasoline. The disadvantage is that having reformers on vehicles is not as efficient as central generation. But, how would the hydrogen be produced centrally? A gas- or coal-powered power plant produces more carbon dioxide, defeating the one object of using hydrogen. Nuclear power is a low carbon cost option, but faces political opposition. Renewable energy sources, such as solar power, wind and wave power, have been proposed as sources of power for electrolysis. But renewable technology is not mature enough to supply all the power required.

Hydrogen and oxygen storage is another issue. There are significant mass impacts for the pressure vessels needed which are insulated to stop boil off.

Hydrogen aircraft have been studied by NASA. This involved a fuel-cell-powered aircraft the size of a Boeing 737 in its Revolutionary Aeropropulsion Concepts program. The hydrogen 737 would use a solid oxide fuel cell (SOFC) for power.

Boeing will test a SOFC auxiliary power unit (APU) in one of its 737s. The APU is 45% efficient in turning hydrogen into electricity. In contrast, a gas turbine is 15% efficient. The APU will use a reformer to process jet fuel to obtain the hydrogen needed. Boeing hopes that by 2010, the technology will be mature enough to offer the APU on future versions of its 787 Dreamliner.

The 787 Dreamliner will use 20% less fuel than the comparably sized 767. A completely new manufacturing process is used with sections of the fuselage produced around the world and then flown to the assembly plant in Everett, Washington in a special 747 large cargo freighter. The body uses composite fibers of carbon graphite held together by epoxy for 50% of the overall fuselage. The engine is a super efficient General Electric GEnx with all composite fan case and blades as well as nozzles. It operates at lower temperatures with few hydrocarbon emissions.

In the time frames considered for the introduction of hydrogen-powered aircraft, renewable energy could be a viable option. Even if renewable energy was available for centralized production, the hydrogen would require a method of transport to the aircraft. Hydrogen can be piped, but gaseous hydrogen molecules are able to pass through solids, even stainless steel. In addition hydrogen makes steel brittle and more susceptible to fracture. An option is to store the hydrogen in a medium that releases it when heated. Research on this has focused on hybrids and pure carbon, or carbon nanotubes doped with metals, but there is a weight penalty. Liquid hydrogen is the way to store the volume needed for an aircraft according to the United Nations' International Energy Agency's hydrogen program.

NASA is focusing on liquid-hydrogen power as part of its Vehicle Systems program. This includes a zero-emissions hydrogen-powered fuel-cell aircraft with cryogenic electric motors in the wing.

The European Union has similar goals and in 2002 it completed a 3-year Fifth Framework program called Liquid Hydrogen-Fueled Aircraft Systems Analysis, also known as Cryoplane. It involved 35 organizations across the EU and assessed practical solutions for the introduction of hydrogen aircraft. Computer models were used for fuel system simulation and aircraft propulsion systems. Defining the airport infrastructure for fuel production and distribution was also a major component. Since 2002, the EU has continued its study in hydrogen fuel and aviation with its Helicopter Occupant Safety Technology Application (HELISAFE) project.

A Sustainable Fuel project is researching the use of a sustainable biomass fuel source for aviation that can be integrated into the existing infrastructure. It aims to create a safe and economical way of supplying hydrogen fuel.

NASA and the California-based company AeroVironment built the Helios solar-powered remotely operated aircraft. Helios had a 235-kg nonregenerative fuel cell, but crashed into the Pacific in 2003 before it could use power from the fuel cell after breaking up in turbulence. AeroVironment achieved a major milestone more recently when it successfully flew the world's first fuel cell-powered unmanned air vehicle (UAV). The aircraft was a scale model of the planned Global Observed high-altitude long-endurance UAV and it was the first powered flight of its kind. The flight lasted 1 hour and used a proton exchange membrane cell with platinum catalyst. The Global Observer would use fuel cells and fly for more than a week at 65,000 feet (19,800m). Israel Aircraft Industries is working on mini-UAV applications where flight times last for 4 hours initially and then later 8 hours.

Boeing's fuel-cell-powered manned glider is being developed by the U.S. company's Spanish operation with Intelligent Energy, a U.K. company, providing the fuel cell. A 50-kW proton membrane exchange fuel cell has been installed with a battery hydride in the glider to demonstrate the technology.

MATERIALS RESEARCH

Areas of research under way in Europe and the USA include weight-reducing materials, increasing power-to-weight density, lower cost materials, reducing complexity, minimizing temperature rise, streamlining manufacturing processes and designing for mass production and lower unit costs.

Low-cost material programs include the European Union's $54 million sixth framework research program on nanotechnologies and nanosciences, knowledge-based multifunctional materials, new production processes and devices. In partnership with the European Space Agency (ESA), the 5-year project seeks to find catalysts less expensive than platinum, which is used widely in fuel cells. As an alternative to platinum, nickel, cobalt and copper alloys are a possible solution.

HYDROGEN IN ICELAND

Iceland's hydrogen fueling station near Reykjavik is used by a small fleet of fuel cell buses. The hydrogen is produced on site from electrolyzed tap water. The Iceland New Energy consortium includes auto manufacturers, Royal Dutch/Shell and the Icelandic power company Norak Hydro. It has plans to convert all of Iceland to hydrogen. Almost 75% of Iceland's present electricity comes from geothermal and hydroelectric power. In the U.S. only about 15% of grid electricity comes from geothermal and hydroelectric sources, while 71% is generated from fossil fuels. Only 16 hydrogen fueling stations are planned to allow Icelanders to refuel fuel cell cars around the country.

At almost 90 times the size of Iceland, the U.S. could start with about 1,500 fueling stations. This assumes that the stations are placed to properly cover the entire U.S. with no overlap. The Department of Energy's hydrogen-production research group expects that a fourth to a third of all filling stations in the U.S. would be needed to offer hydrogen before fuel cells become viable as vehicle power. California has its Hydrogen Highway Project with 150 to 200 stations at a cost of about $500,000 each. These would be situated along the state's major highways by 2010. There are over 100,000 filling stations in the U.S. The Center for Energy, Environmental and Economic Systems Analysis at Argonne National Laboratory near Chicago estimates that building a hydrogen economy would take more than $500 billion.

Oil companies are not willing to invest in production and distribution facilities for hydrogen fueling until there are enough hydrogen cars on the road. Automakers will not produce large numbers of hydrogen cars until drivers have somewhere to fill them up.

President George W. Bush pledged to spend $1.2 billion on hydrogen yet the Department of Energy spends more on nuclear and fossil fuel research than on hydrogen. The government's FreedomCAR program, funds hydrogen R&D in conjunction with American car manufacturers. The program requires that the companies demonstrate a hydrogen-powered car by 2008 and many have done so.

Efforts continue to improve fuel cell technology and utilization which should reduce costs. The General Motors fuel cell program aims at having a commercial fuel cell vehicle by 2010. Volume production of fuel cell cars should reduce costs, but one Department of Energy projection with a production of 500,000 vehicles a year still has the cost too high.

A potential problem with the proton exchange membrane (PEM) fuel cell, which is the type being developed for automobiles is life span. Internal combustion engines have an average life span of 15 years, or about 170,000 miles. Membrane deterioration can cause PEM fuel cells to fail after 2,000 hours or less than 100,000 miles.

Ballard's original PEM design has been the prototype for most automobile development. This has been the basic design that has been used to demonstrate fuel cell power in automobiles. But, it may not be the best architecture and geometry for commercial automobiles. The present geometry may be keeping the price up. Commercial applications require a design that will allow economies of scale to push the price down.

HYDROGEN SOURCES

A study by the Massachusetts Institute of Technology and Harvard University, concluded that hydrogen produced by electrolysis of water will depend on low cost nuclear power. Nuclear power can produce hydrogen without emitting carbon dioxide into the atmosphere. Electricity from a nuclear plant could electrolyze water splitting H_2O into hydrogen and oxygen. However that nuclear power can create long-term waste problems.

Performing electrolysis with renewable energy, such as solar or wind power eliminates pollution problems of fossil fuels and nuclear power. However, current renewable sources only provide a small portion of the energy that is needed for a hydrogen fuel supply. From 1998 to 2003, the generating capacity of wind power increased 28% in the U.S. to about 6,500 megawatts, enough for less than 2 million homes. Wind is expected to provide about 6% of the nation's power by 2020. The University of Warwick in England estimates that converting every vehicle in the U.S. to hydrogen would require the output of a million wind turbines which could cover half of California. Solar panels would also require huge areas of land, but huge tracts of land are available in the southwest, a region ideally suited for solar production.

Water sources could be another problem for hydrogen production, particularly in sunny regions that are well-suited for solar power. A study by the World Resources Institute in Washington, D.C. estimated that obtaining adequate hydrogen with electrolysis would require more than 4 trillion gallons of water yearly. This is equal to the flow over Niagara Falls every 90 days. Water consumption in the U.S. could increase by about 10%.

HYDROGEN LEAKAGE

Hydrogen gas is odorless and colorless. It burns almost invisibly and a fire may not be readily detected. Compressed hydrogen gas could be ignited with the static discharge of a cell phone. But, an accident may not cause an explosion, since carbon fiber reinforced hydrogen tanks are nearly indestructible. There is always the danger of leaks in fuel cells, refineries, pipelines and fueling stations.

Hydrogen is a gas, while most of our other fuels are liquids and easily spread over the ground or other objects. Hydrogen gas will rise into the atmosphere.

In a high-pressure gas or cryogenic liquid hydrogen fuel distribution the hydrogen is such a small molecule that it tends to leak through the smallest of cracks.

A leaky infrastructure could alter the atmosphere according to researchers from the California Institute of Technology and the Jet Propulsion Laboratory in Pasadena, CA. They used statistics for accidental industrial hydrogen and natural gas leakage which were estimated at 10 to 20% of total volume. Extending these estimates to an economy that runs on hydrogen results in four to eight times as much hydrogen in the atmosphere. The Department of Energy's Office of Energy Efficiency and Renewable Energy thinks these estimates are much too high. But, more hydrogen in the atmosphere will combine with oxygen to form water vapor and create more clouds. This increased cloud cover could alter the weather more and affect global warming.

ELECTRIC AND HYBRID AUTOS

When electric vehicles emerged after the 1973 Arab oil embargo, small companies like Linear Alpha produced conversions. Sebring-Vanguard made its CitiCar and was able to sell all it could make for a short time, but sales dropped when gas prices dropped and the gas lines disappeared. One of the more affordable of the electric cars during this time was the Danish-made Kewet El-Jet I. It sold for about $18,000 fully loaded while other EVs started at $25,000. But, instead of a standard metal body, there was a fiberglass box and performance was slow and noisy, while most electrics are very quiet. Ron Kaylor, Jr., was an electrical engineer from Menlo Park, CA, who started building electric cars in the early 1960s. He specialized in VW Beetle conversions using motors from F-100 fighter planes. In the early 1970s, he offered his Kaylor Hybrid Module that provided VW electric cars with a 400-mile range.

Hybrid conversions have not been common, since they are twice as complex as electric conversions. But in 1979, Dave Arthurs of Springdale, Arkansas, spent $1,500 converting an Opel GT into a hybrid that got 75 miles-per-gallon, using a 6-horsepower lawn mower engine, a 400-amp electric motor and a bank of 6-volt batteries. Dave Arthurs continued building hybrids into the 1990s. One of these conversions was a 99 miles-per-gallon Toyota pickup which used a 9-horsepower diesel engine.

In California one of the larger electric car builders was U.S. Electricar in the 1970s. It converted the Renault LeCar to electric power and by 1994, the company went public, with 300 workers in three plants. Its Los Angeles factory converted Geo Prizms and Chevy S-10 pickups, but by 1995 the company had large losses and complaints of defective cars.

The Solectria Company started on a small-scale in 1989 selling solar panels, electric motor controllers, and converters to college electric vehicle racing teams. This led to electric conversions on compact cars and pickup trucks but even their most basic conversion was $33,000 and most sales were to utilities and government agencies.

Solectria even had government contracts from the Defense Advanced Research Projects Agency (DARPA) and won a bid to build a lightweight Sunrise EV. But, just as Solectria was looking for a partner, the auto companies' own electric programs were being launched. Major automakers had their own designs in cars like the GM EV1. The Sunrise did not make it into production and only a few prototypes were built. Solectria did go on to build the Force EV, which is a converted Chevrolet Metro and the company was involved in the GM CitiVan, which was an urban delivery vehicle.

Many firms were hopeful that they could compete with Detroit, but Solectria had to price its Force EV based on a fully equipped Chevrolet Metro that the company had to buy at retail from a local dealer. It took Solectria seven years of building this car before it was able to buy engineless cars from GM.

By the late 1990s, it was clear that only the big automakers could make the electric car really happen. But, these were the same companies that had disdained electric cars earlier. GM once sued California in the U.S. District Court in Fresno to block imposition of the state's zero-emissions rules. These regulations would require automakers to build thousands of electric vehicles using rechargeable storage battery technology. But, the auto industry contended that conventional, electric-powered cars were too expensive and too limited in range to be profitable.

Of the 300 million cars in the United States, only a few thousand were highway capable electric vehicles and some of these were conversions. Most dealerships do not put much effort in marketing alternative fuel vehicles because of the limited demand. Battery electric cars suffered from their limited range and lack of charging stations. They were only marketed in a few states with very limited advertising. Even with this limited effort and low expectations, the resulting sales were disappointing. Honda discontinued its EV Plus program and by the spring of 1999, after three years on the market, GM had leased only 650 EV1s and 500 S-10 electric pickups. Toyota's RAV4 EV was marketed since the end of 1997 and only sold 500 vehicles by 1999. Ford sold about 450 Ranger electric pickups in the same time period and only about 250 leases were signed for the EV Plus. In 10 years EV maker Solectria sold only 350 converted cars and trucks. Many companies choose to lease vehicles to commercial fleets to limit their risk from limited sales.

The hydrogen economy could arrive by the end of the next decade or closer to mid-century. But, interim technologies will play a critical role in the transition. One of the most important of these technologies is the gas-electric hybrid vehicle, which uses both an internal combustion engine and an electric motor. Electronic power controls allow switching almost seamlessly between these two power sources to optimize gas mileage and engine efficiency. U.S. sales of hybrid cars has been growing and 2005 saw the first hybrid SUVs, Ford Escape, Toyota Highlander and Lexus RX400h. Hybrid sales are expected to rise as gasoline prices continue to increase.

OIL SUPPLIES

A National Energy Policy Report that was released in 2001 predicted that U.S. requirements for burning 20 million barrels of oil each day will continue to increase and that increases in U.S. dependence on imported supplies of oil will reach two-thirds by 2020. Also, the Persian Gulf countries will be the main source for this amount of oil and the U.S. trade imbalance will continue to grow.

U.S. dependence upon imported oil could grow faster depending on oil availability. The petroleum reserves in the U.S. could be depleted more rapidly but U.S. reserves, which were once about as large as Saudi Arabia's, have been depleted to the point where some believe that we now have less than 3% of the world's remaining oil reserves. The U.S. uses oil at a rate that amounts to more than 25% of the world's production, but both U.S. and world reserves have been growing as improved recovery techniques are applied to older fields.

Iraq has oil reserves of about 110 billion barrels which is second only to Saudi Arabia. Russia has about 50 billion barrels and the Caspian states another 15 billion. Iraq is one oil producer that could substantially increase oil production to meet the growing world demand in highly populated countries.

U.S. oil production peaked in 1970 and the peak of world oil production has been predicted to occur from 2005 to 2036. For 100 years Americans have enjoyed relatively inexpensive gas, diesel fuel and petroleum products. As recently as the 1990s, gas prices were below one dollar per a gallon. Now, prices seem to be rising most of the time along with the cost of a barrel of oil.

When prices do drop, they never seem to return to the previous low price. As prices rise and fall, the trend is still upwards. There are even rumors that oil production in Saudi Arabia has already peaked and output may soon decline as worldwide demand increases.

Many believe in a simple solution: increase exploration and drilling in other areas. There may be as much as 270 billion barrels of oil in the Caspian Sea region, a part of the former Soviet Union. To use this oil we would have to deal with countries in an unstable area. The U.S. would also compete against other nations of the world, all of which are thirsty for oil which is also essential for the production of food and the manufacture of many products. Beyond these problems is a rapidly growing world population and an area with contested borders and conflicting political and religious ideologies.

In 1956 a well-known geophysicist, M. King Hubbert predicted that U.S. oil production would peak in 1970 as it did. In 1969 Hubbert predicted that world oil production would peak in 2000. Some suggest that the peak is occurring now. Official USGS studies place the peak in 2036.

No new U.S. oil refineries have been built since 1970 for a variety of reasons, and giant oil tankers are being retired without replacement. The oil companies have not been investing in refineries because of environmental regulations, and they have been able to increase refinery capacities, but that is nearing its end.

The environmental restrictions of the EPA have limited the construction of new refineries. These restrictions are now being relaxed and the construction of new refineries may begin.

The present refining and delivery system for gasoline is stretched thin. Sudden events, such as Hurricane Katrina, can result in shortages causing price jumps around the country. Hubbert's prediction is frequently challenged. The world seems so vast that there must be more oil, but oil is a finite resource that will run out some time. If we prepare for other forms of energy, that transition will be smoother. If we are unprepared there may be armed conflicts over oil resources. The remaining oil supplies should be used wisely and alternative sources of energy need to be developed.

U.S. STRATEGIC PETROLEUM RESERVES

The U.S. Strategic Petroleum Reserve (SPR) is the largest stockpile of government-owned emergency crude oil in the world. Established after the 1973-74 oil embargo, the SPR provides the President with a response option if a disruption in commercial oil supplies endanger the U.S. economy. It also allows the United States to meet part of its International Energy Agency obligation to maintain emergency oil stocks, and it provides a national defense fuel reserve. The Energy Policy Act of 2005 directs the Secretary of Energy to fill the SPR to its authorized one billion barrel capacity.

Since the early 1900s, the Naval Petroleum Reserves program has controlled oil bearing lands owned by the U.S. government. The program was intended to provide U.S. naval vessels with an assured source of fuel. The Naval Petroleum Reserves operated three major oil fields located in California and Wyoming.

The government also held oil shale lands in Utah and Colorado that were opened to development during the 1980s as an alternate source of fossil fuels. In 1996 Congress authorized the divestment of several Naval Petroleum and Oil Shale Reserves properties.

Today, the Naval Petroleum Reserves manages closeout activities for the Elk Hills Naval Petroleum Reserve No. 1, located in California, and coordinates public and private initiatives related to oil shale demonstration and development programs from its headquarters in Washington, D.C.

NAVAL PETROLEUM & OIL SHALE RESERVES

For most of the 20th century, the Naval Petroleum and Oil Shale Reserves served as a contingency source of fuel for the Nation's military. All that changed in 1998 when Naval Petroleum Reserve No. 1, known as Elk Hills, was privatized, the first in a series of major changes that leaves only two of the original six federal properties in the program.

Since the early 1900s, the government-owned petroleum and oil shale properties were envisioned as a way to provide a reserve supply of crude oil to fuel U.S. naval vessels in times of emergencies. The Reserves were mostly undeveloped until the 1970s, when the country began looking for ways to enhance domestic oil supplies. In 1976, Congress passed the Naval Petroleum Reserves Production Act authorizing commercial development of the Reserves. Crude oil and natural gas from the Reserves were sold by DOE at market rates.

One of the largest of the federal properties, the Elk Hills field in California, opened for production in 1976 and became the highest production oil and natural gas field in the lower 48 states at one point. In 1992, the field produced its one billionth barrel of oil. It was only the thirteenth field in U.S. history to reach this number and while managed by the DOE, Elk Hills generated over $17 billion in profits for the U.S. Treasury.

The sale of Elk Hills was the nation's largest public divestiture. In 1996, Congress decided that the properties no longer served the national defense purposes as envisioned in the early 1900s, and authorized steps towards divestment or privatization.

In 1998, the Department of Energy and Occidental Petroleum Corporation concluded the largest divestiture of federal property in the history of the U.S. government. This completed a process that began in 1995 when the Clinton Administration proposed selling Elk Hills. The divestment removed the federal government out of the business of producing oil and gas at Elk Hills.

In 1995 the Clinton Administration proposed placing the federally-owned Elk Hills Naval Petroleum Reserve on the market as part of its efforts to reduce the size of government and return inherently non-federal functions to the private sector. In 1996, the Congress passed and the President signed the Defense Authorization Act for Fiscal Year 1996 containing authorization to proceed with the sale. In 1998 the Department of Energy sold Elk Hills to Occidental Petroleum for $3.65 Billion.

The Department of Energy also transferred two of the Naval Oil Shale Reserves in Colorado to the Department of the Interior's Bureau of Land Management. Like other federally owned lands, these properties are offered for commercial mineral leasing, primarily for natural gas production and future petroleum exploration.

The DOE still retains oversight of two Naval Petroleum Reserve properties and one technology testing center: Teapot Dome Naval Petroleum Reserve #3 in Wyoming and a small stripper well oil field with 540 wells. The Rocky Mountain Oilfield Testing Center identifies and resolves technical and environmental issues associated with the production, distribution and use of the nation's energy resources. It was established in 1994 and is the only oil field testing center in the United States.

In 2001, the DOE returned the undeveloped Naval Oil Shale Reserve #2 in Utah to the Northern Ute Indian Tribe in the largest transfer of federal property to Native Americans in the last century.

OIL SHALE

It is generally agreed that worldwide petroleum supply will eventually reach its productive limit, peak, and begin a long term decline. One of the alternatives is the Nation's untapped oil shale as a strategically located, long-term source of reliable, affordable, and secure oil. The extent of U.S. oil shale resources, which amounts to more than 2 trillion barrels, has been known for a century. In 1912, the President established the Naval Petroleum and Oil Shale Reserves. There have been several commercial attempts to produce oil from oil shale, but these have failed because of the lower cost of petroleum at the time. With future declines in petroleum production, market forces are expected to improve the economic viability of oil shale.

Commercializing the vast oil shale resources could greatly add to the country's energy resources. Shale oil could have an effect similar to the 175 billion barrels of oil from Alberta tar sands to Canada's oil reserves. As a result of the commercial effort, oil from tar sand production now exceeds one million barrels per day. Oil shale in the United States is as rich as tar sand and could become a vital component in America's future energy security.

POWER INDUSTRY TRENDS

In Texas, TXU is making a $10 billion investment for future power needs by creating a new renewable company for the electric power needs of a growing Texas market. It plans to provide lower-cost, secure and stable power with new consumer and business service offerings, and a voluntary emissions reduction program. The new investments will provide more reliable electricity thereby reducing dependence on natural gas, as well as create jobs and lower emissions.

Texas is expected to add almost 6 million residents in the next decade. At the same time, electric power reserve margins in Texas are compressing rapidly and are expected to fall below reliable levels by 2010.

Texas uses natural gas for most of its power generation. Over 70 percent of the state's generation capacity depends on natural gas for fuel, compared to the U.S. average of 45 percent. This presents real challenges with natural gas prices increasing. Many believe the low gas prices of the 1990s will not return. Imports of natural gas are increasing and over the next few decades imports are expected to increase five-fold.

The $10 billion invested in modern technologies should provide near-term solutions to meet Texas' growing need for power. It should increase energy reliability and independence by expanding reserve margins and diversifying supply. Overall, the plan should add an estimated 10 percent to the power supply, enough to serve 6.5 million homes. This should be adequate to meet demand through 2015.

There will be eleven new generation units at nine existing TXU Power sites. The new units are expected to be operational by 2010. By using TXU's existing sites, rail facilities and other infrastructure, the cost of the new units should be 3/4 the cost of a typical new development. The selected sites will provide maximum leverage to existing infrastructure while minimizing costs and allowing a more efficient construction timeline. To reduce engineering, procurement, and construction costs, TXU will work with exclusive partnerships with Bechtel Power and Fluor Corp.

TXU is also launching a new company, TXU Renew, to double its renewable energy power by 2011. TXU Renew will invest in renewable power facilities bringing TXU's total renewable energy to 1,400-MW with enough wind energy to power almost 275,000 homes. TXU will also invest up to $2 billion in the development and commercialization of integrated gasification combined cycle (IGCC) technology.

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Chapter 2

Energy and Changes in the Environment

The spread of economic development has pushed the use of automobiles to all parts of the modern world. The bulk of industrialized nations including Japan, Britain, Germany, France and others have seen great increases in energy use. At the end of the 20th century, the U. S. used more energy per capita than any other nation, twice the rate of Sweden and almost three times that of Japan or Italy. In 1988, the United States, with only 5% of the earth's population, consumed 25% of all the world's oil and released about a fourth of the world's atmospheric carbon.

When the earth was formed about 4.5 billion years ago, 95% of the atmosphere consisted of carbon dioxide. The emergence of plant life changed the atmosphere since plants, through the process of photosynthesis, absorb carbon dioxide. Carbon from the atmosphere was absorbed into the vegetation and when the vegetable matter died, it decomposed, and formed coal and oil. This dropped the carbon dioxide in the atmosphere to less than 1%.

Industrialization and the burning of fossil fuels reverses this process. Instead of being absorbed out of the air, carbon is extracted from the ground and sent into the atmosphere.

A major surge in U.S. energy consumption occurred between 1930 and the 1970, rising by 350% as more oil and natural gas was used for industrial, agricultural, transportation and housing needs. Oil and natural gas contain less carbon than coal or wood, but the demand for energy soared as the nation's economy grew and consumers became more affluent. By 1950, Americans drove three-quarters of all the world's automobiles and they lived in larger energy consuming homes with relatively inefficient heating and cooling systems. Appliances were also increasing which boosted power needs. Energy consumption slowed in the 1970s and 1980s, as manufacturers designed more efficient appliances.

Private cars began to command American transportation and more roads were needed. In the early 1930s, the National Highway Users

Conference, also known as the highway lobby, became one of the most powerful groups in Washington. In the years following World War II, the interstate highway system was to become a major achievement. When GM President Charles Wilson, became Secretary of Defense in 1953, he proclaimed that a new road system was essential to U.S. security needs. Congress approved the $25 billion Interstate Highway Act of 1956 and the highways expanded.

The interstates in turn encouraged more single-family homes which had to be reached by private cars. Since the mid-1950s, cities like Phoenix, Arizona, have grown from 15-20 to over 200-400 square miles. From 1965 to 1990, the greater New York City area grew by 61% from 1965 to 1990, while adding only 5% to its population. From 1970 to 1990, the greater Chicago area grew by more than 46% in land area, but its population increased by only 4%.

From 1970 to 1999 vehicle-miles of travel more than doubled while average miles per vehicle increased a little more than 20% (See Tables 2-1a and 2-1b).

Table 2-1a. Motor Vehicle Distance Traveled
Vehicle miles of travel (billions)

	Total	*Cars*	*Buses*	*Vans pickups SUVs*	*Trucks*
1970	1110	920	4.5	123	62
1980	1527	1122	6.1	291	108
1990	2144	1418	5.7	575	146
1991	2172	1387	5.8	649	150
1996	2486	1470	6.6	817	183
1999	2691	1589	7.7	901	203
2003	2891	1661	6.8	998	216

THE EARTH AS A GIANT GREENHOUSE

The greenhouse effect relates to the increased warming of the earth's surface and lower atmosphere that occurs from increased levels of carbon dioxide and other atmospheric gases. This is similar to the glass panels

Table 2-1b. Motor Vehicle Distance Traveled
Average miles per vehicle (1,000)

	Total	*Cars*	*Buses*	*Vans pickups SUVs*	*Trucks*
1970	10.0	10.0	12.0	8.7	13.6
1980	9.5	8.8	11.5	10.4	18.7
1985	10.0	9.4	7.5	10.5	20.6
1990	11.1	10.3	9.1	11.9	23.6
1991	11.3	10.3	9.1	12.2	24.2
1995	11.8	11.2	9.4	12.0	26.5
2003	12.2	11.2	10.3	11.5	27.3

of a greenhouse where the heat is let in through the glass but most of it is prevented from escaping. If the earth did not act like a giant greenhouse, temperatures at the earth's surface would be about 35°C (60°F) colder than they are, and life on earth would be much different.

These greenhouse gases might be affected by human actions. A rise in temperature of about 5°C (9°F) in the next fifty years would be equal to a rate of climate change almost ten times faster than the average observed rate of change. Temperature changes of this magnitude could transform patterns of rainfall, drought, growing seasons and sea level.

The greenhouse effect is a well known theory. Fourier's concept of planetary energy balance began the current understanding of the greenhouse effect, which depends on the principle of an energy balance of the asymmetric influence of the atmosphere on incoming light versus outgoing infrared.

The sun is the main source of the earth's climate has surface temperatures of about 6,000°C (10,800°F) which produce radiant energy at very short wavelengths. Almost half this energy reaches the earth's surface.

Particles and gases in the earth's atmosphere absorb about 25% of this energy and 25% is reflected back to space by the atmosphere, mostly from clouds. About 5% of the incoming solar radiation is reflected back to space from the surface of the earth, mostly from bright regions such as deserts and ice fields. A 1-square-meter surface (39 inches by 39 inches), placed above the atmosphere will collect about 1,370 watts of radiant power. This radiant power is known as the solar constant even though it varies by a few tenths of a percent over 11-year-long sunspot cycles. Since the sun does not shine all the time on every square meter of the earth, the actual amount of incoming energy is about 340 watts per square meter.

Since the earth has temperature, it emits radiant energy called thermal radiation or planetary infrared radiation. Measurements by satellites show an average radiant emission from the earth of about 240 watts per square meter. This is equivalent to the radiation that a black body would emit if its temperature is at –19°C (–3°F). This is also the same energy rate as the solar constant averaged over the earth's surface minus the 30% reflected radiation. This shows that the amount of radiation emitted by the earth is closely balanced by the amount of solar energy absorbed and since the earth is in this state of balance, its temperature will change relatively slowly from year to year.

If more solar energy is absorbed than infrared radiation emitted, the earth would warm and a new equilibrium would appear. But, if the earth had more clouds, it would reflect more solar radiation and absorb less. This would have a cooling effect on the planet, lowering the amount of infrared radiation that is escaping to space to balance the lower amount of absorbed solar energy. The earth's radiant energy balance today is 240 watts per square meter.

The amount of energy the earth absorbs from the sun is the same amount it radiates back to space on average over the 500 trillion square meters of surface area. Satellites above the earth's atmosphere can measure the outgoing thermal radiation and show this balance to a high degree of precision.

An average of temperature records on the earth's surface over a year indicates that the earth's average surface temperature is about 14°C (57°F). But, the earth's 240 watts per square meter of thermal infrared radiation as measured by satellite is equivalent to the radiation emitted by a black body whose temperature is about -19°C (-3°F), not the 14°C (57°F) average measured at the earth's surface. The 33°C (60°F) difference between the apparent temperature of the earth as seen in space and the actual temperature of the earth's surface is attributed to the greenhouse effect.

The solar heat absorbed by the atmosphere and the earth's surface goes back into the atmosphere through the evaporation of water. Thermals are formed by the heating of air in contact with a warm surface and the upward emission of energy.

The trace gases in the earth's atmosphere are only a few percent of its composition but they make the planet livable. They absorb radiant energy at infrared wavelengths much more efficiently than they absorb radiant energy at solar wavelengths, thus trapping most of the radiant heat emitted from the earth's surface before it escapes.

THE GREENHOUSE CYCLE

Greenhouse gases include water vapor, carbon dioxide (CO_2) and other particles such as water droplets in clouds. They absorb infrared energy and also give it off. The infrared radiation is emitted upward cooling the planet and maintaining a balance with incoming sunlight. Some of it goes back to the earth's surface creating the greenhouse effect. This downward reradiation warms the earth's surface and makes it 33°C (60°F) warmer.

In the greenhouse analogy, gases and clouds in the earth's atmosphere allow a larger amount of the sun's shorter wavelength radiation in while allowing the longer wavelength infrared radiation to escape to space. This theory has been tested with millions of measurements in the atmosphere, space and laboratories.

Over 4 billion years ago the heat from the sun was about 30% less powerful than it is today. A number of elements, including carbon and oxygen, condensed to form the earth and as the earth's crust cooled and hardened, hot gases from the interior were ejected including carbon dioxide.

The amount of carbon dioxide in the atmosphere then has been estimated to be many times greater than today. This explains how the earth's climate was warm enough for liquid water and the life that evolved from it about 4 billion years ago. As life on earth evolved, the solar output increased and photosynthetic organisms used much of this carbon dioxide.

CO_2 is a major factor in the cycles that built up our mineral resources. Fossil fuels developed over several hundred million years during the Phanerozoic era. There was abundant life for about 600 million years.

The richest fossil fuel deposits are thought to occur at times when the earth was much warmer and contained much more CO_2 than today.

During the last 2 million years, the permanent polar ice descended and most of the evidence indicates that CO_2 levels decreased compared to the times when dinosaurs lived. Gas bubbles found in ancient ice in Greenland and Antarctica indicate that during the end of the last great ice age, 10,000 to 20,000 years ago, CO_2 levels were about 2/3 of what they are today.

After the last ice age (5,000-9,000 years ago) the summers were about 2°F warmer than today and the CO_2 concentrations grew to preindustrial levels. Since then, there has been a 25% increase in CO_2. The burning of organic matter may be a large part of this increase. As CO_2 goes into the atmosphere at a much higher rate than it can be withdrawn or absorbed by the oceans or living plants, there is a CO_2 buildup and this could be one of the controls moderating the climate.

GREENHOUSE GASES

Carbon dioxide is not the only greenhouse gas that humans have been changing. Methane is another important greenhouse gas. It has increased in the atmosphere by almost 100% since 1800 but has been stable or even seen a slight decrease since 1990. See Table 2-2.

Methane is produced by biological processes where bacteria have access to organic matter such as marshlands, garbage dumps, landfills and rice fields. Some methane is also released in the process of extracting coal or transporting natural gas.

Methane is 20-30 times as effective at absorbing infrared radiation as CO_2. But, it is not as important in the greenhouse effect since the CO_2 percentage is much greater in the earth's atmosphere. Chlorofluorocarbons (CFCs) are even more effective greenhouse gases, but are only a small part of the CO_2 greenhouse gases. CFCs are involved in the depletion of stratospheric ozone.

Ozone is a form of oxygen (O_3), where three oxygen atoms combine into one molecule. Ozone has the property of absorbing most of the sun's ultraviolet radiation. It does this in the upper part of the atmosphere, called the stratosphere, which is about 6 to 30 miles (10-50 kilometers) above the earth. This absorption of ultraviolet energy causes the stratosphere to heat up. Life on earth has been dependent on the ozone layer shielding us from harmful solar ultraviolet radiation. Ozone is part of the greenhouse effect, although it is not as important as CO_2 or methane. Ozone in the lower atmosphere can cause damage to plant or lung tissues and is a pollutant in photochemical smog.

Table 2-2. Emission of Greenhouse Gases

Type and Source	*Unit*	*1990*	*1995*	*1997*	*1999*
Carbon dioxide					
Carbon content, total	Mil. metric tons	1,350.5	1,434.7	1,505.2	1,526.8
Energy sources	"	1,325.0	1,404.7	1,474.3	1,495.0
Methane					
Gas total	"	31.74	31.18	30.11	28.77
Energy sources	"	11.94	11.38	11.03	10.58
Landfills	"	11.40	10.63	9.97	9.11
Agricultural sources	"	8.29	9.03	8.98	8.96
Nitrous oxide, total	"	1,168	1,257	1,226	1,224
Agriculture	"	844	859	865	870
Energy sources	"	211	269	269	279
Industrial sources	"	96	111	74	57
Chloroflurocarbons(CFCs)	"	202	102	51	41
CFC-11	"	54	36	25	24
CFC-12	"	113	52	23	14
CFC-113	"	26	9	0.5	0.5
Other CFCs	"	9	5	0.5	0.5
Halons	"	2.8	2.9	3.0	3.0
Hydrofluorcarbons					
HFC-23	"	3.0	2.0	3.0	3.0
HFC-125	"	0.5	0.5	0.9	1.3
HFC-134a	"	1.0	14.3	23.5	30.3
HFC-143a	"		0.1	0.3	0.7
Perfluocarbons	"	3	2	3	2
CFC-4	"	3	2	2	2
CF-2 F-6	"	1	2	2	2
C-4 F-10	"	.5	.5	.5	.5
Sulfur hexafluoride	"	1	2	2	1

Other greenhouse gases, include nitrous oxide (laughing gas), carbon tetrachloride, and several other minor gases. The collective greenhouse effect of these gases is estimated to add 50-150% to the increase in greenhouse effect expected from CO_2 alone.

The American Automobile Manufacturers Association, which merged into the International Alliance of Automobile Manufacturers claims that today's automobiles are up to 96% less polluting than cars 35 years ago but automobiles still produce a quarter of the carbon dioxide generated annually in the United States.

GLOBAL WARMING

Carbon dioxide, in combination with other greenhouse gases such as methane and ozone, can trap the sun's heat. In the century from 1890 to 1990, the average surface temperature of the earth increased by 0.3 to 0.6 degrees Celsius. This temperature rise, which has lengthened the growing season in parts of the northern hemisphere, may have occurred naturally, although such a change would be notable.

The global warming issue has become a major concern. But, it was not that long ago that global cooling was being promoted. During the 1970s, several extreme weather events, including freezing conditions in Florida, produced fears over decreasing temperatures. In 1974, the CIA even issued a report claiming that decreases in temperature could affect America's geopolitical future.

In the 1980s, the focus shifted to global warming, as a result of the unusual drought and heat wave of 1988. Climate scientist James Hansen reported to Congress that he was 99% sure that the greenhouse effect was contributing to global warming. This fueled a growing apprehension over rising temperatures that had the attention of the media and the public.

Environmentalists obsessed over the role of modern life in global warming used this attention to push goals such as improving air quality and preserving forestland. Some studies indicate that human influence accounts for 75% of the increase in average global temperature over the last century, but others argue that up to nine other factors are more important than human activity and Mars and Venus are also experiencing warming trends.

Changes in global ocean currents or in the amount of energy emitted by the sun could be a major part of the change. Most of industry including the oil, gas, coal and auto companies see the problem as a theory in need of more research, but many cry for serious action to reduce fossil fuel use.

Most scientists do not debate whether global warming has occurred, they accept it, but the cause of the warming and future projections about the results is questioned. The proposed National Energy Policy Act of 1988, called for controls on industrial and agricultural emissions producing greenhouse gases. They were:

1. Regulations to ensure energy efficiency.
2. Controls on deforestation.
3. Curbs on population growth.
4. Increased funding for energy alternatives, including safer nuclear power.

In the early 1990s, the Information Council on the Environment, which was a group of coal and utility companies, used a public relations firm to push global warming as theory. The U.S. auto industry has also played a role. Much lobbying took place to depose global climate change and fight legislation on fuel economy which is an important agent in carbon emissions.

REDUCING HYDROCARBON EMISSIONS

A global accord on reducing hydrocarbon emissions was reached at the 1992 Early Summit in Brazil. Great Britain and Germany came close to meeting their 2000 targets while the U.S. fell short of its goal by 15 to 20%.

In 1997 an international agreement on global warming was signed by 150 countries in Kyoto, Japan. It required a major reduction in automobile exhaust emissions while greenhouse gases were to be reduced to 7% below 1990 levels by 2012. The Kyoto Protocol was adopted at the urging of international environmental groups that demanded reductions in carbon dioxide and other gases. The treaty would require disproportionate cutbacks by U.S. companies and the U.S. Senate voted 95 to 0 to reject it. With Russia's accession in 2004, an international treaty that may have threatened U.S. industry with stiff regulations moved closer to global ratification.

Meeting the Kyoto goals could have a major impact on the electric power and auto industries and many believed the economy would suffer greatly. Developing countries like China and India would be exempt from the reduction of carbon dioxide emissions. China and India have plans to build over 600 coal-fired plants. The emissions of these plants would be 5 times the total saving of Kyoto.

Tightening the corporate average fuel economy (CAFE) standard for cars and trucks would be one requirement since a 12-mile-per-gallon car or truck emits four times as much carbon dioxide as a 50-mile-per-gallon subcompact. The auto industry has always resisted attempts to tighten CAFE and certain vehicles like SUVs and pick-up trucks are not subject to CAFE standards.

The average fuel economy has declined since 1988, as the auto industry moved away from fuel-efficient smaller vehicles and pushed more profitable trucks and SUVs. In 1970 the average miles per gallon (mpg) for autos was 13.5, by 1999 the mpg was 21.4, but annual fuel consumption (afc) in billions of gallons increased from 92.3 to over 160. During this time the mpg for vans, pickups and SUVs went from 10 to 17.1 but the afc went from 12.3 to 52.8. The mpg for vans, pickups and SUVs was actually slightly higher in 1993 at 17.4 before the larger SUVs appeared. (See Tables 2-3A and 2-3B)

Table 2-3a. Domestic Motor Fuel Consumption

	All Vehicles	*Average annual % change*	*Cars*	*Vans pickups SUVs*	*Busses*	*Trucks (billion gallons)*
1970	92.3	4.8	67.8	12.3	0.8	11.3
1975	109.0	2.5	74.3	19.1	1.1	14.6
1980	115.0	-5.9	70.2	23.8	1.0	20.0
1990	130.8	-0.8	69.8	35.6	0.9	24.5
1991	128.6	-1.7	64.5	38.2	0.9	25.0
1993	137.3	3.3	67.2	42.9	0.9	26.2
1995	143.8	2.1	68.1	46.6	1.0	29.0
1997	150.4	2.0	69.9	49.4	1.0	29.9
1999	160.7	3.4	73.2	52.8	1.1	33.4
2003	169.6	.5	74.8	56.3	1.0	37.6

The Coalition for Vehicle Choice (CVC) is a lobbying group sponsored by carmakers, which has pushed to rescind the CAFE standards. The CVC has stated that CAFE causes 2,000 deaths and 20,000 injuries every year by forcing people into smaller cars. The auto industry has questioned the science behind global warming and claimed there are not enough facts to allow a judgment.

Table 2-3b. Domestic Motor Fuel Consumption (Average miles per gallon)

	All Vehicles	*Cars*	*Vans pickups SUVs*	*Busses*	*Trucks (billion gallons)*
1970	12.0	13.5	10.0	5.5	5.5
1975	12.2	14.0	10.5	5.8	5.6
1980	13.3	16.0	12.2	6.0	5.4
1990	16.4	20.3	16.1	6.4	6.0
1991	16.9	21.2	17.0	6.7	6.0
1993	16.7	20.6	17.4	6.6	6.1
1995	16.8	21.1	17.3	6.6	6.1
1997	17.0	21.5	17.2	6.7	6.4
1999	16.8	21.4	17.1	8.7	6.1
2003	17.6	22.3	17.7	6.9	6.1

Toyota was the first auto company to announce, in 1998, that it was joining others such as British Petroleum, Enron, United Technologies, and Lockheed Martin in an alliance to fight global warming. Toyota is supporting the Pew Center on Global Climate Change, which was started with a $5 million grant from the Pew Charitable Trusts.

DuPont has reduced carbon emissions from its plants in the U.S. and around the world by 67% since the Kyoto treaty appeared. The company believes that these reductions have made their factories more efficient and prepared their businesses for future markets of 2 to 5 decades from the present.

Electric power companies are also making changes. American Electric Power Company, one of the major utility giants in the country, plans to build a $40-billion plant that uses coal gasification. The facility will turn coal into synthetic gas before burning it, sharply reducing emissions including carbon dioxide.

Coal gasification is more costly compared with conventional coal-fired power generation. AEP says it is building a power plant that considers environmental prospects over a 30-year life. General Electric has a partnership with power plant builder Bechtel Group, Inc. to develop a standard commercial design for gasified coal generating systems. GE also acquired a subsidiary of Chevron Texaco that produces synthetic gas by infusing oxygen into the methane found in coal. There has been more focus on coal, the most abundant energy resource in the United States, China and other countries. (See Table 2-4)

Table 2-4. World Coal Production (million of tons)

	1980	*1990*	*1995*	*1999*
World total	4200	5386	5161	4737
China	684	1190	1537	1118
United States	830	1029	1033	1099
India	126	233	298	328
Australia	116	226	267	321
Russia	NA	NA	296	276
South Africa	132	193	227	248
Germany	532	514	274	226
Poland	254	237	220	190
Ukraine	NA	NA	99	91
Korea, North	51	99	107	85
Canada	40	75	83	80

NA-not available

Coal is more polluting than other fuels, but this energy source provides 52% of America's electricity and the worldwide use of coal is expected to grow 40% in the next two decades. The Pew Center on Global Climate Change thinks it is highly unlikely that the world's energy needs can be met without coal. Research and business investment is up in making coal use a cleaner process.

Energy price volatility and uncertainty are also forcing American industry to think more about the diversification of energy sources. Wind power is seeing more use in Europe. Denmark is using the North Sea coastal wind to turn electrical generators. GE's wind energy operations has an order to supply 660 wind turbines to power a 1,000-megawatt generating station in Canada.

Fuel cells are also being used as nonpolluting electrical generators. They may replace batteries in many electronic devices including laptop computers and cell phones.

TEMPERATURE CYCLES

Sulfates found in ice cores occur in a regular pattern throughout 150,000 years of the earth's history. The cycle appears to occur with a shift in the earth's orbit that causes the North Pole to point toward the sun when the earth is closest to it. The ice cores also showed that calcium carbonate seems to have a cyclic pattern. This cycle occurs with the change in the tilt angle of the earth's axis relative to the plane of its orbit. The greater the tilt angle the hotter the seasonal extremes are. Changes in the amount of carbon dioxide directly track the implied temperature changes through the past 150,000 years. The same is true with methane, which is 20-30 times more powerful as a greenhouse gas than CO_2.

Since methane is produced mainly by microbial decomposition of dead organic matter in swamps, bogs and refuse piles, the close correlations between changes in methane, CO_2, and temperature suggest that biological processes are involved.

It can take 500-1,000 years for the surge of warming temperatures that take place as the ice ages vanish to pervade tundra and permafrost. This warming could release methane to the air.

In bog formations extensive quantities of organic matter are stored during glacial periods. These processes could be a critical link in the explanation of large climatic changes that have occurred in the past.

A billion years ago the bacteria and algae of the earth began to build up the oxygen that makes our planet livable. After another billion years, multicelled creatures started to evolve into plants and animals. A hundred million years ago, dinosaurs roamed the earth while the average temperature was 10° to 15°C (18° to 27°F) warmer. During this period, there was no permanent ice at the poles that can be detected from geologic records. As the continents drifted, Antarctica became isolated at the South Pole and India drifted northward crossing the equator and connecting with Asia. The Tibetan plateau rose, and sea level dropped about 1,000 feet. Then, the planet cooled and permanent ice was formed.

The combination of forces that caused these changes is still in question but it involves the stability of the climate. The climate has fluctuated between limits of plus or minus 15°C (27°F) for hundreds of millions of years. These limits are large enough to have a major influence on species' extinction and evolution. A runaway greenhouse effect is thought to have changed Venus where the oceans boiled.

There is almost as much carbon in the atmosphere in the form of CO_2

as there is in living matter, mostly in trees. But, there is several times more carbon in the soils stored as dead organic matter called necromass. Bacteria eventually help to decompose some of this necromass into greenhouse gases such as methane, nitrous oxide (N_2O), and CO_2. The decomposition speeds up if the soil gets warmer, emitting more greenhouse gases and increasing the warming effect.

If global warming raises the temperature of surface waters and carbon dioxide continues to build up in the atmosphere, the carbon dioxide is less soluble in warmer water. The dissolved carbon dioxide can easily move back into the atmosphere unless it is taken up by marine plants or combines with a molecule of carbonate. But, the ocean's supply of carbonate is limited and is replenished only slowly as it is washed into the oceans by rivers that erode carbonate-containing rocks such as limestone. By absorbing two billion tons of carbon from the atmosphere each year, the ocean is depleting its buffer carbonate supply.

Creating carbon sinks includes planting new forests, which the Kyoto climate treaty encourages. In China, the government has planted tens of millions of acres of trees since the 1970s. This was done to control floods and erosion, but one result has been to soak up almost half a billion tons of carbon.

Young trees are hungry for carbon before they mature so one technique is to keep a forest young, by regular thinning. U.S. forests have increased by more than 40% in the last 50 years from 600 billion to nearly 860 billion. Standing timber is increasing at a rate of almost 1% per year in the country.

While all the living matter in the oceans contains only about 3 billion tons of carbon, ten thousand times that amount is dissolved in the oceans, mostly in nonliving form. The carbonate sediments in the continental crust and the ocean floor contain almost 70 million billion tons of carbon. These are huge quantities compared to the atmosphere and living and dead biota.

The ocean's natural uptake of carbon is in decline, scientists the 1980s suggested that large tracts of ocean could have green plants that are the marine equivalent of forests and grasslands. These could be started by treating the oceans with an iron compound. The plant growth would soak up carbon and as the plants died and sank, the carbon in their tissues would remain in the ocean.

Experiments have shown that treating with iron sulfate does cause algae to bloom with patches tens of miles long. But when the extra plants and the animals they nourish die, their remains mostly decay before they have a chance to sink. The carbon dioxide from the decaying nourishes new plants, reducing the need for more carbon from the atmosphere.

CARBON DIOXIDE CONCENTRATION

The concentration of carbon dioxide in the atmosphere is about 360 parts per million. Some believe this could increase another 200 to 600 ppm by the end of the century. It may have been over 300 ppm more than 400,000 years ago with lows around 200 ppm at 350,000, 200, 000 and 30,000 years ago. Between these lows were peaks of 250 to 270 ppm.

The present levels may depend on population, capita consumption of fossil fuel, deforestation and aforestation activities.

The faster the climate warms up, the more likely it is that feedback processes will change the greenhouse gas buildup. There are many that believe that CO_2 and other trace greenhouse gases could double sometime within the next century.

Estimates on fossil fuel growth indicate a 1-2% annual growth rate. This could double the amount CO_2 based on preindustrial levels.

The different greenhouse gases can have complicated interactions. Carbon dioxide may cool the stratosphere which slows the process that destroys ozone. Stratospheric cooling can also create high altitude clouds which interact with chlorofluorocarbons to destroy ozone. Methane may be produced or destroyed in the lower atmosphere at various rates, which depend on the pollutants that are present. Methane can also affect chemicals that control ozone formation.

In the exchange and distribution of carbon, an important process is the uptake by green plants. Since CO_2 is the basis of photosynthesis and more CO_2 in the air means faster rates of photosynthesis. Other factors are the amount of forested and planted areas, and the effects of climate change on ecosystems.

The removal of CO_2 from the atmosphere takes place through biological and chemical processes in the oceans, which may take decades or centuries. Climate changes modify the mixing processes in the oceans.

About the same amount of carbon (almost 800 billion tons) is stored in the atmosphere as is stored in living plant matter on land, mostly in trees. Animals retain a small amount of carbon about 1-2 billion tons and the amount in humans is just a small percentage of this. Bacteria have almost as much weight in carbon atoms as all the animals together and fungi have about half that amount. Dead organic matter, mostly in soils, contains about twice as much carbon as does the atmosphere.

BIOLOGICAL MODERATION

Biological feedback processes can be expected to affect the amounts of carbon dioxide that might be injected into the air over the next century.

As CO_2 increases, green plants could take up more carbon dioxide into plant tissues through photosynthesis reducing slightly the buildup of CO_2. This could moderate some of the greenhouse effect.

However raising the temperature in the soils by a few degrees may increase the activity rates of bacteria that convert dead organic matter into CO_2.

This is a positive feedback loop since warming would increase the CO_2 produced in the soils, further increasing the warming. The EPA thinks there is a real potential for major positive feedback that could greatly increase greenhouse effects. There are more than a dozen biological feedback processes that could affect estimates of the temperature sensitivity to greenhouse gases due to human activities. If all of these operate in unison, it could double the sensitivity of the climatic system to the initial effects of greenhouse gases. This would be a possible but worst case situation. The time frame over which these processes could occur is estimated at several decades to a century or more.

CLIMATE MODELS

Most climate models show a climate in stable equilibrium. If the 1900 condition of 300 parts per million doubles to 600 ppm, most three-dimensional models indicate an equilibrium with an average surface temperature warming of 3.5° to 5°C (5.6° to 9°F). If the carbon dioxide content of the atmosphere doubled in one month, the earth's temperature would not reach its new equilibrium value for a century or more.

If we were able to limit all CO_2 emissions, we could still expect about one degree of warming while the climatic system catches up with the greenhouse gases already released. It is not the global average temperature that is most important but it is the regional patterns of climate change.

Making reliable predictions of local or regional responses requires models of great complexity, but most calculations imply wetter subtropical monsoonal rain belts, longer growing seasons in high latitudes and wetter springtimes in high and middle latitudes. This could result in greater crop yields in some areas.

But, in other areas there could be drier midsummer conditions in the midlatitudes, increased probability of extreme heat waves and an increased probability of fires in drier/hotter regions. Increased sea levels over the next century could also be expected, the estimates here vary from several inches to several feet.

There are potential health consequences for humans and animals in already warm climates with a reduced probability of extreme cold weather in colder areas.

Possible actions could involve attempts to prevent atmospheric changes through limiting emissions. Strict economists favor doing nothing active now, assuming that resources will be used to maximize economic conditions in the future and solutions will eventually develop. Strict environmentalists favor a redistribution of resources to modify costs and incomes.

Developing nonfossil energy sources and improving efficiency in all energy sectors should be viewed as part of a high-priority strategic investment. The mechanisms to accomplish this include research and development on more cost effective solar photovoltaic cells and safer modular nuclear plants and possible tax incentives to reduce fossil fuel emissions. Greenhouse gas buildup is a global problem and is connected to global economic development. It depends on population, resources, environment and economics.

Developed countries are the major producers of CO_2 but global strategies for preventing greenhouse gas buildup require international cooperation between rich and poor nations. The increased burden of debt is a major hurdle in the global development of the third world. It is difficult for countries to invest in expensive energy-efficient equipment when they can barely pay back the interest on loans from other countries. A debt/nature swap has been proposed where underdeveloped countries would provide tracts of forest to developed countries in exchange for forgiving part of their debt. Another approach is to have the World Bank place environmental conditions on its loans.

Population growth rates are another point of dissension between developed and developing countries. Total emission is the per capita emission rate times the total population size. The population growth which is occurring predominantly in the third world will become an important factor.

For the poor of the world, more energy and more energy services can mean an improved quality of life. Energy use can allow services that improve health care, education and nutrition in less-developed nations.

As population or affluence grows, so does pollution. Ultimately the world population should stabilize and future pollution levels should be lower for any per capita standard of consumption. A stable population is a critical part of a sustainable future.

If the buildup of CO_2 and other trace gases is not considered as part of global development, it is unlikely that greater buildup will be prevented, except by great advances in alternative fuel systems and programs to increase energy efficiency.

The world produces about 7.2 billion metric tons of carbon each year in the form of carbon dioxide. The U.S. produces about 1.7 billion tons. (See Table 2-5)

Proposed legislation in 1988 called for a 50% reduction in CO_2 in the United States early in the next century. Our residential and commercial energy use is about 35% of the total energy used. Industrial energy use is about 38% and transportation is about 27%.

Almost 40% of our energy is derived from oil. For the electric utilities about 21% is produced by coal, with about 8% from nuclear, about 23% from natural gas and the rest from hydro and other renewables. This accounts for most of the energy use in the United States.

Since coal is the least efficient fuel, it produces the greatest amount of CO_2 per unit energy. Any increase in the use of coal would substantially increase CO_2 levels. Moving to more natural gas, nuclear, solar, hydro or wind power would decrease CO_2 amounts. The Western Governor's Association in 2004 approved a resolution to increase renewable energy production, which would require 30,000 megawatts to be produced by 2015 and encourage energy efficiency gains of 20 percent by 2020.

Hydrogen could become a major energy source, reducing U.S. dependence on imported petroleum while diversifying energy sources and reducing pollution and greenhouse gas emissions. It could be produced in large refineries in industrial areas, power parks and fueling stations in communities, distributed facilities in rural areas with processes using fossil fuels, biomass, or water as feedstocks and release little or none carbon dioxide into the atmosphere. Hydrogen could be used in refrigerator-

Table 2-5. Carbon Dioxide Emissions from Fossil Fuels
(Millions of metric tons of carbon)

	1990	*1995*	*1999*	*2005*	*2010**
World total	5873	6018	6144	7015	7835
Australia	72	80	94	NA	NA
Brazil	63	74	89	108	139
Canada	128	135	151	158	165
China	617	788	669	889	1131
France	102	101	109	116	120
Germany	NA	239	230	246	252
India	156	224	243	300	351
Indonesia	41	59	64	NA	NA
Iran	56	71	84	NA	NA
Italy	112	118	121	131	137
Japan	269	298	307	324	330
Korea, South	61	103	107	128	144
Mexico	84	88	101	124	145
Netherlands	58	61	64	66	67
Poland	89	83	85	NA	NA
Russia	NA	444	400	NA	NA
Saudi Arabia	59	69	74	NA	NA
South Africa	81	94	99	NA	NA
Spain	62	67	82	NA	NA
Taiwan	32	49	63	NA	NA
Thailand	23	43	45	NA	NA
Turkey	35	51	50	57	66
Ukraine	NA	124	104	NA	NA
United Kingdom	164	153	152	168	177
United States	1355	1430	1520	1690	1809

NA-not available
*projected

sized fuel cells to produce electricity and heat for the home. Vehicles that operate by burning hydrogen or by employing hydrogen fuel cells would emit essentially water vapor.

Micro-fuel cells using small tanks of hydrogen could operate mobile generators, electric bicycles and other portable items. Large 250-kW stationary fuel cells, alone or in tandem, are being used for backup power and as a source of distributed generation supplying electricity to the utility grid. The expanded use of hydrogen as an energy source should help to address concerns over energy security, climate change and air quality.

A Department of Energy study compared alternative paths for future U.S. energy use: business-as-usual and energy-efficient. Both projections suggested a substantial rise in U.S. production CO_2 and the consumption of fossil fuels over the next few decades. The study predicted an increase in energy between 1985 and 2010 of about 30%. The projected oil and gas increase remained relatively constant over this period, but coal consumption increased greatly by more than 100%. CO_2 emissions rose from 1.25 billion metric tons per year to about 1.73 billion metric tons in 2010. This is a 38% increase in CO_2.

The major cause for the 38% increase in CO_2 was a more than doubling of the coal use in electric utilities and a near doubling of coal use in industrial use. The energy efficiency path still increased CO_2 production to 1.5 billion metric tons per year. The high-efficiency case does use less coal. Other energy studies predict a decline in energy-growth rates and a decline instead of an increase in CO_2 emissions.

One DOE forecast sees U.S. energy production with a free economic viability and strong technological growth. Other forecasts predict an energy future tied to broad societal goals of economic efficiency and equity with policy changes used to reach objectives. Market interventions that could reduce the energy supply include petroleum product taxes, oil import fees and carbon taxes for greenhouse problems.

CARBON MARKETS

Europe's carbon market is growing quickly after the introduction of tradable annual allowances for greenhouse gas emissions under the Kyoto treaty that went into effect in 2005. In this new market-based emission-trading system, light polluters can sell some of their surplus allowances to heavier polluters. This can result in a reduction of emissions at a lower cost than if each installation had been obliged to meet an individual target but the allowances to produce one kilowatt-hour of coal-fired power can cost more than the coal itself.

The shift in the U.S. economy from energy-intensive activities such as steel manufacturing to information-intensive activities such as computer and software design will continue to improve our gross national product while reducing our dependence on oil and coal.

Many studies assume improvements in the gas mileage of cars and efficiency in the production of energy in power plants, in industrial applications and in home heating, lighting and other sectors. U.S. manufacturers could improve the average energy efficiency of cars and trucks. But, as America's fleet of older vehicles is replaced with newer cars with less pollution, CO_2 emissions may change very little or even increase since additional miles may be driven.

One high-efficiency case assumes that by the year 2010 new cars would average 52 miles per gallon and would penetrate 50% of the U.S. market. This would be possible if small hybrids take over a major part of the market.

Other studies predict that new car efficiencies could be even greater than that, with a fuel economy for the average vehicle of 75 miles per gallon.

One NEPP report assumes that the U.S. economy would reduce its dependence on energy at the rate of about 1.7% per year, while others believe that more active efforts to make our economy less dependent on energy could result in a rate of about 4% per year. They also assume very high-efficiency lighting and the rapid deployment of electric-power-generating stations that are 50% or more efficient than present facilities.

Improvements in efficiency along with major efforts to redirect energy use towards improved environmental quality would not only reduce emissions but there would be many other benefits.

In 1950 the U.S. CO_2 emissions were almost 40% of the global total. By 1975 this had dropped to about 25%, and by the late 1980s it was about 22%. If the U.S. held emissions constant at 1985 levels, a reduction of 15% from the emissions in 1995 and a 28% reduction from the forecast emissions in 2010, then global emissions would be reduced by only 3% in 1995 and 6% in 2010. Even if U.S. emissions were cut by 50% below the 1985 levels, global emissions would continue to grow and would drop by less than 15% in the year 2010. This supports the assumption that world emissions will continue to grow.

Indirect effects are also very likely, because if the U.S. employed technology to reduce CO_2 emissions, then the resulting cost reductions would provide a competitive advantage for a while and would then be imitated by foreign competitors. This could energize global emission reductions. One path would be to develop crop strains that could take advantage of CO_2.

LIMITING DAMAGES

Climate changes may not be prevented, but it may be possible to minimize any damages from an altered climate. Certain preventive strategies could actively limit emissions of substances thought to be harmful. One strategy designed to avoid damage to the ozone layer was the reduction or banning of all uses of CFCs.

The Montreal Protocol of 1987 proposed a 50% cut in CFCs by the year 2000, but not all nations signed the treaty. Most scientific studies push for at least a 90% ban if the ozone hole is to be reversed. This would not only help protect the ozone layer but would cut emissions of a trace greenhouse gas that could be responsible for up to 25% of global warming. The use of artificial fertilizers in agriculture also generates atmospheric nitrogen compounds that can reach the stratosphere and possible destroy ozone.

Present theories of the origin of acid rain indicate that we can limit acid rain by reducing sulfur dioxide emissions and moving to low-sulfur fuels; but, only about 20% of the world's petroleum reserves are low in sulfur. Switching U.S. midwestern power plants to low-sulfur coal could cause economic problems since much of the coal from the Midwest and Appalachia has a high sulfur content. Most of the electric power generated in the Midwest uses high-sulfur coal and it would cost tens of billions of dollars to scrub the sulfur out of coal.

An energy cost would also be paid for the processes that remove the sulfur along with environmental problems from disposing of it. About 5% more coal would be needed to keep electricity production from these power plants at current levels if most of the sulfur is scrubbed out.

It is also possible to keep sulfur dioxide from reaching the atmosphere by washing the coal or by removing the SO from the flue gas. Simple washing removes about 50% of the sulfur. Additional removal of up to 90% requires high temperatures and high pressures and may cost ten times as much as washing. Flue gas desulfurization (scrubbing) by reacting the effluent gas with lime or limestone in water can remove 80-90% of the sulfur but creates large amounts of solid waste.

Techniques for minimizing emission of SO_2 from burning power plants has no effect on nitrogen oxide (NO_x) emissions. Oxides of nitrogen result from the burning of nitrogen normally found in combustion air. The percentage of NO_x generated by the burning of air is about 80% in conventional coal-fired boilers and depends mostly on the temperature of combustion.

Improved furnace designs and combustion techniques could reduce NO_x emissions from stationary sources by 40-70%. These methods are not in widespread use now. The processes for removing NO_x from flue gases are in an early stage of development.

REDUCING CARBON DIOXIDE

Reducing the amount of CO_2 in the atmosphere could involve prescrubbing to take the carbon out of fuels before combustion, leaving only hydrogen to be burned. Another approach is postcombustion scrubbing which removes CO_2 from the emissions stream after burning.

Among the prescrubbing techniques is the hydrocarb process, where hydrogen is extracted from coal and the carbon is then stored for possible future use or buried. Using this process, only about 15% of the energy in coal is converted to hydrogen for use as fuel in existing coal power plants. There is also much residual solid coal material to store.

It is estimated that this would cost about $8,000 per capita in the United States for 300,000 megawatts of generating capacity to replace the coal consumed in the U.S. for electrical power generation. Post combustion scrubbing is a well known but largely unapplied technology.

Removing 90% of the CO_2 from the stack gases would cost about 0.5 to 1 trillion dollars or $2,000 to $4,000 per capita. Removing the CO_2 at a power plant could use up about half the energy output of the power plant.

Pumping the carbon dioxide produced at industrial plants into the deep ocean is another technique that could reduce and delay the rise of carbon dioxide in the atmosphere. But, it would not prevent an eventual warming as some made its way back into the atmosphere. Reforestation could be used as a carbon bank to capture carbon from the atmosphere, but the decay or burning of harvested trees decades later would add some carbon.

In 2000, global warming talks in the Netherlands broke down over carbon accounting. The United States wanted to use its forest areas to offset some carbon emissions. This type of trading of carbon rights was the kind of approach that most mainstream environmental groups in the United States had promoted in an attempt to give business an inducement to conserve. In Europe, environmentalists have taken a more adamant stand against industry and looked at it as a plan for evading responsibility for cleaning up the global atmosphere.

The growing fossil fuel use in the 20th century changed the carbon record of the earth, but deforestation also had a major impact on carbon in the atmosphere. Forests serve as carbon sinks, producing oxygen while using carbon dioxide.

The clearing of forests in the United States early in the century, combined with a large increase in postwar tropical deforestation, where much of the wood was burned, released carbon dioxide to the air and changed the atmospheric components.

Carbon could be filtered from power plant emissions, compressed into a liquid, and pumped into ocean depths of ten thousand feet. Here, the water pressure would compress liquid carbon dioxide to a high enough density to pool on the seafloor before dissolving. At shallower depths it would just disperse. However, injecting vast quantities of carbon dioxide could acidify the deep ocean and harm marine life. Protesters have forced scientists to cancel experiments to test the scheme in Hawaii and Norway.

Researchers at the Monterey Bay Aquarium Research Institute, believe that rising carbon dioxide in the atmosphere will acidify the ocean's surface waters in any case and pumping some of the carbon into the ocean depths could slow that process.

Another plan is to pump the carbon into coal seams, old oil and gas fields and deep, porous rock formations. This high-pressure injection would also release the remaining oil or gas out of depleted fields.

SEQUESTRATION

Sequestration involves storing CO_2 in large underground formations. CO_2 separation and capture are part of many industrial processes, but using existing technologies would not be cost-effective for large-scale operations. Sequestration costs using current technology are quite high.

The practicality and environmental consequences of many sequestration techniques have not yet proven from an engineering or scientific aspect. Sequestration still requires much research and development before generating large volumes of hydrogen from coal and sequestering the CO_2 produced. CO_2 sequestration on a massive scale would need to be permanent to be practical.

Geologic sequestration is already being done in the North Sea. The field produces gas that is heavily contaminated with natural carbon dioxide. Before shipping the gas, the Norwegian oil company Statoil filters out the carbon dioxide and injects it into a sandstone formation half a mile below the seafloor.

The U.S. Department of Energy has a test project to drill a 10,000-foot well in West Virginia and pump carbon dioxide into the deep rock.

Tapped-out oil and gas fields are full of drill holes that could leak the carbon dioxide. The stored gas might also seep into groundwater pools. But the North Sea project seems to be working well. Seismic images under the ocean floor show that a thick layer of clay capping the sandstone is sealing in the millions of tons of carbon dioxide injected.

Other researchers are working on projects that would allow the burning of fossil fuels. Researchers at Princeton are exploring a technology that would take the carbon out of coal. In this multistep process the coal reacts with oxygen and steam to make pure hydrogen that could be burned to produce electricity or used in hydrogen-powered cars. The byproducts are mostly carbon dioxide but there are also the contaminants that coal-burning plant now emit, such as sulfur and mercury. These would be buried.

Vegetational carbon banks would compete with agriculture for land and nutrient resources. It is estimated that a land area about the size of Alaska would need to be planted with fast-growing trees over the next 50 years to use up about half the projected fossil-fuel-induced CO_2 at a cost of about $250 billion or $50 per person for the global population. One problem is that once the trees are fully grown they no longer take up CO_2 very rapidly and would need to be cleared so new trees could be planted to continue a quicker uptake. Old trees could be used for lumber, but not fuel, since this would release the CO_2. If used as fuel, a delay of 50 years, (the typical growth time) would occur and move up the buildup rate of atmospheric CO_2.

Other proposals for counteracting global warming from the greenhouse effect include releasing dust or other particles to reflect away part of the solar energy normally absorbed by earth. This could work on a global average basis, but the mechanisms of warming and cooling would vary and large regional climatic changes could still occur.

CONSERVING ENERGY

Energy conservation can help reduce the impact of several current problems. Increasing energy efficiency could reduce or delay atmosphere pollution from many fronts while improving national security through increased energy independence. The environmental effects of carbon dioxide and acid rain would be reduced along with the risk of possible climatic changes.

Through 1975 to 1985 startling gains in energy efficiency in the U.S. lowered fossil fuel emissions while the gross national product increased. These gains in energy efficiency were driven by the OPEC oil price jumps. The 1975-1985 time period was one in which economic growth and energy growth remained relatively unlinked. Most historic periods show the reverse trend. The DOE viewed this period as a deviation.

The United States uses twice as much energy in manufacturing than Japan, West Germany, or Italy and the cost of this energy keeps the cost of products in the U.S. higher.

The U.S. Environmental Protection Agency (EPA) launched the Green Lights program in 1991. Green Lights is a voluntary, nonregulatory program aimed at reducing the air pollution that results from electric power generation. Participants committed to upgrade a total of 4 billion square feet of facility space, this is more than 3 times the total office space of New York, Los Angeles, and Chicago combined.

Green Lights Partners are public and private organizations that agree to upgrade their lighting systems wherever profitable. The test of profitability for upgrades is a return on investment of the prime rate plus 6%. Most Green Lights Partners cut their lighting bills in half, while improving their work environment. Green Light Partners agree to survey the lighting system in all of their facilities and upgrade the lighting system in 90% of qualifying building space. The upgrades must be completed in 5 years.

Firms that have signed onto the EPA program, include the Fortune 500 as well as federal, state and local governments. Schools and universities are also included.

Also, in the 1990s, the Environmental Protection Agency began to focus on pollution prevention. The idea was to cut pollution using natural ecosystems as a model. Industrial systems should not be open-ended, dumping endless byproducts, but closed, as nature is, continuously cycling and recyling. This concept includes life cycle assessment (LCA) which considers:

- the source of raw materials,
- the dependency on nonrenewable resources,
- energy and water use.
- transportation costs,
- the release and use of carbon dioxide,
- recovery of materials for recycling or reuse.

LCA requires three stages: taking inventory, assessing impact, and assessing improvements. Taking inventory involves using a database to quantify energy and raw-material requirements (inputs) and environmental outputs, such as air emissions, water effluents and solid and hazardous waste for the life cycle of the product. Energy inputs should take into account transformation costs (raw materials into products), transportation costs and any reduction cost when using recycled materials. Recycling has made some strides since 1980 but much more could be done. (Table 2-6)

Table 2-6. Generation and Recovery of Municipal Solid Waste (millions of tons)

	1980	*1990*	*1995*	*1999*
Total generated	151.5	206.2	211.4	229.9
Paper and paperboard	54.7	72.7	81.7	87.5
Ferrous metals	11.6	12.6	11.6	13.3
Aluminum	1.8	2.8	3.0	3.1
Other nonferrous metals	1.1	1.1	1.3	1.4
Glass	15.0	13.1	13.6	12.6
Plastics	7.9	17.1	18.9	24.2
Yard waste	27.5	35.0	29.7	27.7
Other wastes	31.9	50.7	52.4	60.1
Total recovered	14.5	23.6	54.9	63.9
Paper and paperboard	11.9	20.2	32.7	36.7
Ferrous metals	0.4	2.6	4.1	4.5
Aluminum	0.3	1.0	0.9	0.9
Other nonferrous metals	0.5	0.7	0.8	0.9
Glass	0.8	2.6	3.1	2.9
Plastics	-	0.4	1.0	1.4
Yard waste	-	4.2	9.0	12.6
Other wastes	0.6	1.8	3.2	4.0
% recovered total	9.6	16.4	26.0	27.8
Paper and peperboard	21.8	27.8	40.0	41.9
Ferrous metals	3.4	20.4	35.5	33.6
Aluminum	16.7	35.9	31.4	27.8
Other nonferrous metals	45.5	66.4	64.3	66.9
Glass	5.3	20.0	24.5	23.4
Plastics	0	2.2	5.2	5.6
Yard waste	0	12.0	30.3	45.3
Other wastes	1.9	3.6	6.1	6.7

Impact assessment requires knowing which materials, processes, or components may be toxic and their impact on the environment and health which varies according to the amounts involved. Disposable or rechargeable batteries require weighing performance (battery-charge life) against toxicity.

More companies are incorporating life-cycle costs and life-cycle assessment into their operations. The U.S. Air Force has developed a computer-aided software-engineering tool, for defining the complex sets of interacting activities in the life cycle of an aircraft.

LCA emerged to analyze the manufacturing of toxic chemicals, but now it even affects electronic and other manufacturing sectors. The energy-efficient Green PC is an example. Computers account for about 5% of all commercial energy in use today, and this could soon double. Standby or idle power for some products like telephone-answering machines are greater than the power consumed during operation.

LCA encloses the entire life cycle of a product from raw-material extraction to end-of-life management alternatives including landfilling, incineration, and recycling. Customer use of a product is a major contributor to smog, nitrogen oxides, acid rain, and carbon-dioxide release all stemming from a product's energy consumption.

In one study of the energy consumption of a portable telephone, the energy spent in production was found to be greater than lifetime use. The energy expended in production included that required for not only material transformation but also the energy needed to keep workers comfortable such as heating and air conditioning.

Hewlett-Packard and Xerox are recycling their hardware in Europe. Xerox reprocessed copiers yield 755,000 components (51% by weight), and recycled 46% by weight into reusable materials. This left only 3% of the parts for disposal. All plastic parts should carry recycling symbols and making parts from fewer material types and reducing paint, platings, and screws can also aid in recycling.

Replacing older inefficient electricity-generating plants with much more efficient new plants could save large amounts of energy. Some of the older plants lose two-thirds of the heat energy as waste heat at the site. Replacing these plants with those with more efficient boilers, controls and turbines would reduce the lost of heat energy to about half. The plants could also switch from coal to natural gas which could greatly reduce acid rain problem while cutting CO_2 emissions in half.

Automobile emissions are being decreased with improvements in the design of combustion chambers and the computer control of combustion mixtures. Exhaust-gas catalytic converters also limit emissions. But, electric and fuel cell-powered cars could greatly reduce air pollution in cities, but only if the electric power sources used to charge the batteries or create the hydrogen fuel were themselves less polluting. More energy-efficient mass transit can also reduce emissions.

Seattle, Portland, San Diego, Salt Lake City, Austin and Minneapolis are among the cities that have implemented programs to cut carbon dioxide emissions along with Boulder and Fort Collins, Colorado, Burlington, Vermont, Cambridge, Massachusetts, and New Haven, Connecticut. Chicago and Los Angeles have adopted climate protection programs. San Francisco plans to reduce its greenhouse gas emissions by more than 2.5 million tons with mass transit and hybrid vehicles, energy conservation, green building codes and solar power for buildings and homes. Seattle's municipally owned electric utility has adopted a climate-neutral program where it invests in emissions reductions programs around the world to offset its own carbon dioxide output. In 2008 California changed its decision to force automakers to cut carbon dioxide emissions from cars and trucks by relaxing its zero emissions program.

In the 1980s, U.S. carmakers fought against tighter fuel economy standards. When the energy crisis began in 1973, American automobiles averaged about 13 miles per gallon of gasoline (mpg). By 2003, that number had increased to 22 mpg.

The number of vehicle miles traveled has more than doubled between 1970 and 2003 to almost 2.9 trillion miles, so these gains in fuel efficiency were mostly offset. The improvement in efficiency was spurred by legislation passed in 1975 that established Corporate Average Fuel Economy or CAFE rules. This allowed automakers to produce any kind of car as long as all the vehicles when averaged meet the mpg standards set by the government. In 1992, when Bill Clinton campaigned for president he promised that he would increase the CAFE standard to 45 MPG. About this same time period, President Bush signed a global warming treaty at the 1992 Earth Summit in Rio de Janeiro, Brazil. In this treaty, industrialized nations agreed by the year 2000 to voluntarily cut back their carbon dioxide emissions to the level they were at in 1990. To meet this goal, U.S. vehicles would need to be three to four times more efficient than they were, averaging about 80 to 90 MPG.

The auto industry balked at Clinton's 45 MPG goal and when elected, Clinton broke his promise. In 1993, the administration announced that the federal government would join American automakers to produce a new, super-efficient car.

One of the most significant developments in automobiles was the emergence of the sport utility vehicle or SUV as a dominant vehicle in the U.S.

SUVs and light trucks are thought to use too much gas and cause excess pollution compared to the smaller sedans. Light trucks were exempt from the 1975 fuel economy legislation since it was argued that farmers and other workers needed them for business. Actually, many more trucks are used for the same purposes as cars.

By the 1990s, U.S. carbon emissions were rising while Americans were spending more time on the road and traveling in more of the least fuel-efficient vehicles. Minivans, SUVs, and pickup trucks made up about 40% of all vehicles sold in the United States.

By 1999 SUVs were getting larger and larger with some more than 18-feet-long and weighing as much as 12,500 pounds which is about as much as four mid-sized sedans. Fuel economy was about 10 mpg. The average fuel economy of all cars and trucks in the United States in 2003 model year remains at about the same level since the decade of the 1990s.

EMISSION TARGETS

Today's automobiles may be up to 96% less polluting than cars 35 years ago but automobiles still produce a quarter of the carbon dioxide generated annually in the United States.

A global accord on reducing hydrocarbon emissions was reached at the 1992 Early Summit in Brazil but only Great Britain and Germany came close to meeting their 2000 targets. The United States was short of its goal by 15 to 20%. This was a commendable effort at international cooperation but almost every country is filling its roads with more and more autos.

The international agreement on global warming signed by 150 countries in Kyoto, Japan, in 1997 required a drastic reduction in automobile exhaust emissions. Greenhouse gases were to be reduced to 5.2% below 1990 levels by 2012.

Objectors to Kyoto say it is based on questional science and would damage the U.S. economy. It exempts two of the world's biggest polluters, China and India, which together produce about as much CO_2 as the United States.

The question is not if the greenhouse effect exists, it pivots on the theory that emissions have an effect on global warming. Many reports concern the effects of global warming, many of these go unchallenged but some are questioned and reported on. Tanzania's minister of tourism has disputed claims by a group of American scientists that a third of Kilimanjaro's ice fields has disappeared during the last 12 years and that the rest will be gone by 2015. Climatologists blame the melting on global warming and deforestation at the base of the mountain. The melting of the ice field could affect the water supply and also reduce the amount of tourist dollars that benefit the country.

There has been concern that another major hurricane hitting New Orleans could prompt legislation on global warming that may do nothing about tropical storms but would damage the American economy. This became clearer when Robert F. Kennedy, Jr. connected Hurricane Katrina's severity to President Bush's opinion on carbon-dioxide emissions. Katrina's strength was not affected by global warming as many contend and there is no proof that any such warming will lead to more frequent, or more intense storms.

Hurricane damage may seem to be increasing, but this may not be a sign of global warming. The 2004 hurricane season may only partially be due to climates change.

Several factors contribute to hurricane formation, including El Niño cycles, upper stratospheric circulation patterns and the rain in the Sahara area of Africa. The 2004 hurricane season was mostly due to the alignment of these critical elements. The general agreement on climate change and hurricanes is that hurricanes may not become more common but that they may increase in intensity.

In 2005 the floating ice cap on the Arctic Ocean was at its smallest size in a century of recording keeping. This development was explained by global warming and a likely rise in ocean temperatures.

The theory and hypothetical effects of global warming have become a reality to many. In 1979 the National Academy of Sciences undertook its first rigorous study of global warming, through the nine-member Ad Hoc Study Group on Carbon Dioxide and Climate. The panel concluded that if carbon dioxide continues to increase there was no reason to doubt that climate changes would result and that these changes would not be negligible. Since then, global carbon-dioxide emissions have continued to rise, along with the planet's temperature. But in 2007 temperatures appeared to decrease, still most major glaciers in the world are shrinking.

No matter what is done at this point, global temperatures may continue to increase in the coming decades although there has been no major temperature changes measured in the upper atmosphere. There may be changes in monsoon patterns, ocean currents, or major droughts which will all be blamed on global warming.

Many activists and environmentalists believe that climate change is the major threat facing human civilization in the 21st century and that institutions are doing little to battle the problem.

Climate change has become a burning issue, but given the way some environmentalists and others exploit it, and the inaccurate record of past predictions of ecological disaster, skepticism is still a reasonable position. The hyping of the issue may even have begun to backfire on environmentalists.

A 2004 Gallup Poll indicated that there was declining public interest in global warming. Part of this may be the inability of the scientific community to provide a probability estimate of either a rise in temperature or the effects of such a rise, either regionally and globally. This tends to show how limited the present knowledge of the world's climate actually is. If the basic theory of global warming is correct, then much more work is needed to provide a true understanding of regional and global climate change.

During the past millennium the average global temperature was essentially flat until about 1900, then spiked upward, like the upturned blade of a hockey stick. Some view this as a clear indication that humans are warming the globe, but others hold that the climate is undergoing a natural fluctuation not unlike those in past eras.

One theory is that farming practices started global warming. Many point to human actions that first began to have a warming effect on Earth's climate in the past century. But other evidence indicates that concentrations of carbon dioxide began increasing about 8,000 years ago, in spite of natural trends indicating they should have been decreasing, and that methane began to increase in concentration about 3,000 years later. In the past few decades methane increases seen to be leveling at about 1.7 parts per million in the atmosphere.

In the northern hemisphere, meteorologists measured record-setting spring and summer temperatures in 2004 and the level of atmospheric carbon dioxide also reached a record high, averaging 379 parts per million, a jump from 2003 levels that was much greater than the average annual increase of 1.8 parts per million recorded over the past decade.

But, two global climate models show that even if the concentrations of greenhouse gases in the atmosphere had been stabilized by the year 2000, we were already committed to further global warming.

There is an effort to tighten estimates of how the Earth will respond to climate warming. The sensitivity of new climate models has improved, but to fully understand the Earth's response to climate warming, a better knowledge of clouds and aerosols is needed, as well as improved and more and better records of past climate changes and their drivers.

In 2004, some studies indicated that between 1900 and 2100, temperatures will increase between 1.4 and 5.8°C. Many scientific questions remain regarding climate change for both policy makers and the public.

ICE CORES

The climate has the ability to shift into radically different states according to ice cores extracted from Greenland's massive ice sheet in the early 1990s. These rods of ice are up to three kilometers long and provide a set of climate records for the past 110,000 years. They allow the investigation of annual layers in the ice cores which are dated using a variety of methods. The composition of the ice provides the temperature at which it formed.

This work reveals a history of wild fluctuations in climate, long deep freezes alternating with brief warm spells. Central Greenland has experienced cold drops as great as six degrees Celsius in just a few years. Central Greenland also experienced almost half of the heating sustained since the peak of the last ice age (more than 10 degrees C) in just one decade. This jump occurred about 11,500 years ago and is the equivalent of Moscow or Minneapolis having the same climate as Madrid or Atlanta.

The 10-degree warming in the northern waters is thought to be part of a warming trend across a broad part of the Northern Hemisphere. This caused increased precipitation that was far reaching. In Greenland, the thickness of the annual ice layers showed that snowfall doubled in a single year.

Air bubbles in the ice corroborated the increased wetness in other areas. The amount of methane in the bubbles indicates that this gas was entering the atmosphere 50 percent faster during the warming than it had earlier. The methane probably entered the atmosphere as wetlands flooded in the tropics and ice and snow thawed in the north.

Warming spikes appeared more than 20 times in the Greenland ice records. Within hundreds or thousands of years after the start of a warm period, the climate went into slow cooling followed by quick cooling over as short a time as a century. There would then begin another warming that could take only a few years.

During the colder periods, icebergs floated as far south as Portugal. One of these cold spells probably forced the Vikings out of Greenland. This period is known as the Little Ice Age, which lasted from about 1400 to 1900.

Cold, wet times in Greenland occurred with very cold, dry, windy conditions in Europe and North America along with very warm weather in the South Atlantic and Antarctica. This weather is indicated by studies of high mountain glaciers, the thickness of tree rings, and the types of pollen and shells found in mud at the bottoms of lakes and oceans.

Cold periods in the north meant drought to Saharan Africa and India. About 5,000 years ago a sudden drying spell changed the Sahara from a green region spotted with lakes to a hot sandy desert.

In modern times, changing patterns in the North Pacific have been strong enough to cause severe droughts, such as the one that triggered the U.S. dust bowl of the 1930s. These warm spells, cold snaps or extended droughts were caused by a gradual change in temperature or other physical condition that pushed a critical driver of climate toward some threshold.

UNDERGROUND CARBON

In Saskatchewan, deep underground, an experiment is underway to determine if carbon dioxide can be safely buried. Carbon sequestration could prove to be an effective way to reduce greenhouse gases.

The Weyburn oil field is 70 miles south of Regina and 50 miles north of the U.S. border. It could hold over 20 million tons of carbon dioxide over the project's expected 25-year lifespan. Saskatchewan's oil fields are expected to have enough capacity to store all the province's carbon dioxide emissions for more than three decades.

The Canadian government believes that carbon gas storage will help the country meet its emissions reduction targets under the 1997 Kyoto Protocol. It requires industrialized nations to cut emissions of greenhouse gases by an average of 5% between 2008 and 2012.

The Weyburn project began four years ago and has the backing of international energy companies, the United States, European Union and Canada, which have contributed $21 million.

In 1986, 1,700 people in West African Cameroon, suffocated when a giant bubble of naturally occurring carbon dioxide erupted from Lake Nyos and displaced the available oxygen in the immediate area.

Deep-well injection of the gas may force briny water to the surface, potentially polluting streams and aquifers. Earthquakes have also been reported in places where deep-well injection has occurred and carbon dioxide can convert to an acid in groundwater. Carbon storage provides a unique advantage, buried in an oil field, the gas boosts oil production by forcing residual deposits to the surface. At Weyburn, oil production is up 50% since carbon dioxide injection began four years ago.

The Weyburn site was selected because, during 44 years of oil exploration, Saskatchewan required oil companies to keep extensive geological records. Core samples from 1,200 bore holes allowed an extensive look at subsurface conditions and a way to track the movement of oil and gases.

Carbon dioxide is injected almost a mile underground under a thick rock layer. The buried carbon dioxide is tracked by checking vapors in wells and groundwater testing. Seismic tests provide a picture of subsurface conditions.

The site has hundreds of oil wells over a 70-square-mile area. Each well shaft can act as a conduit to bleed carbon dioxide to the surface. Some wells are being closed off while others are checked for traces of carbon dioxide.

Computer models are being used to forecast how the site will perform over several millenniums. One computer model showed that carbon dioxide could migrate upward about 150 feet in 5,000 years although it would still be far below the surface.

Every day, almost 5,000 tons of liquefied carbon dioxide arrives from a plant near Beulah, N.D. This plant is operated by the Dakota Gasification Co., which converts coal to natural gas. The liquid carbon dioxide passes through a 220-mile-long pipeline before it is pumped underground in Canada.

Separating the carbon dioxide is expensive since the scrubbing process uses almost one-third of the energy produced by the power plant. It costs about $30 a ton to separate carbon dioxide from industrial exhaust, although the technology exists to cut this almost in half. One

Energy Department's goal is to get this down to $8 a ton. At this price, the emissions could be captured and stored in the U.S. while increasing the cost to produce electric power by less than 10%.

President Bush has promoted carbon capture and burial as a way to reduce greenhouse gas emissions. The Energy Department's goal for power plants would have them capture 90% of their carbon emissions by 2012.

California may have enough depleted oil fields and subsurface saline deposits to store all the carbon dioxide that the state's power plants can produce for the next few centuries, according to the Lawrence Berkeley laboratory. Pilot projects using carbon dioxide injection to enhance oil recovery have been conducted in Kern County.

A consortium of eight partners, including Canada, the United States, the European Union and BP (formerly British Petroleum) have a $25-million project to explore new technology to capture and store carbon gas.

The project has found techniques that reduce costs for geological carbon storage by up to 60%. Although more savings are needed before economical large scale operations. Geological storage is one option that could play an important part in carbon dioxide control.

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Chapter 3

Alternative Fuel Sources

Some problems of the automobile began as the smell of unburned gasoline grew beginning in 1905. Gasoline caused noticeable pollution and its status as a nonrenewable resource was questioned. Engineers and industry analysts began to wonder if an ample supply would remain available with the growing popularity of the automobile. Alternative fuels such as grain alcohol were available, but alcohol was double the price per gallon at the turn of the century. This did not include the federal excise tax that was placed on alcohol in 1862 to help reduce the Union's costs in the Civil War. In 1907, the tax was repealed, but, the procedure of denaturing alcohol, to make it undrinkable and enforce the sobriety of Americans, added to its price and gave gasoline the advantage. It also took more alcohol to produce the same amount of power than gas.

The car industry started in the United States with only 8,000 registered cars and trucks in 1900, but there were over 215 million by 2000. This growth started with the efforts of hundreds of companies, but it became almost the exclusive domain of Ford, General Motors and Chrysler in the U.S. and a few other companies in Europe and the rest of the world. In Detroit, almost 140 auto companies were formed from 1900 to 1903, but about half of these would fail by 1904.

Leaded gasoline became a major factor in engine performance. Early cars had to be cranked by hand to start. But in 1911, the invention of the self-starter eliminated the need of hand cranking. Automakers could now provide larger cars with larger, easy-to-start engines. But as larger cars were produced, a knocking sound appeared when the engine was climbing hills or accelerating. If cars were going to be larger, then a way had to be found to eliminate the potential engine damage from engine knock. Soon after the invention of the self-starter, engineers at Dayton Engineering Laboratories Company (DELCO) found that ethanol or grain alcohol could be used to reduce knock.

In 1921, the DELCO lab, which was now part of GM, found that tetraethyl lead was an excellent antiknock compound. By 1923, leaded gas was being pumped at Dayton, Ohio. In the following year, GM, DuPont

Chemical and Standard Oil of New Jersey combined their patents and produced leaded gasoline under the Ethyl brand name.

A few months before Ethyl went on sale, the U.S. Public Health Service stated tetraethyl lead was poisonous and had the potential to produce lead oxide which could affect public health in heavily traveled areas. In 1923, General Motors, financed a study by the U.S. Bureau of Mines on the safety of tetraethyl lead. The bureau issued a report downplaying leaded gasoline's potential adverse impact on public health.

The burning of large quantities of gasoline starting in the 1950s caused lead deposits to occur in the soil. The widespread use of leaded gasoline was becoming a health hazard.

In the U.S., seven million tons of lead were released between the 1920s and 1986, when it was phased out as automakers switched to unleaded gasoline and catalytic converters.

The spreading of economic development to all reaches of the globe also fueled the growth of the automobile. The industrialized nations including Japan, Britain, Germany, France and others have seen great changes in overall energy needs as well.

METHANOL AS FUEL

Our present transportation system and its infrastructure favor liquid fuels. Methanol or wood alcohol is a potential source or carrier of hydrogen.

Fuel cell vehicles with onboard methanol reformers would have very low emissions of urban air pollutants. Daimler-Chrysler has built demonstration fuel cell vehicles that convert methanol to hydrogen.

Methanol, CH_3OH, is a clear liquid and also the simplest of the alcohols, with one carbon atom per molecule. Methanol is extensively used today, the U.S. demand in 2002 was over a billion gallons. Methanol is mainly synthesized from natural gas, it can also be produced from a number of CO_2-free sources including municipal solid waste and plant matter.

The largest U.S. methanol markets were for producing the gasoline additive MTBE (methyl tertiary butyl ether) as well as formaldehyde and acetic acid. MTBE is being phased out since it has been found to contaminate water supplies.

Methanol is already used as an auto fuel. It has been the fuel of choice at the Indianapolis 500 for more than three decades, partly because it improves the performance of the cars but it is also considered much safer. It is less flammable than gasoline and when it does ignite, it causes less severe fires. One study for the U.S. Environmental Protection Agency (EPA) concluded, that the use of methanol can result in a 90% reduction in the number of automotive fuel related fires compared to gasoline.

It is also toxic and a few teaspoons of methanol consumed orally can cause blindness. A few tablespoons can be fatal, if not treated. Methanol is also very corrosive, so it requires a special fuel-handling system.

Methanol also seems to biodegrade quickly when spilled and it dissolves and dilutes rapidly in water. It has been recommended as an alternative fuel by the EPA and the DOE, partly because of reduced urban air pollutant emissions compared to gasoline. Most methanol-fueled vehicles use a blend of 85% methanol and 15% gasoline called M85. Building a methanol infrastructure would not be as difficult as converting to hydrogen. While methanol can be produced from natural gas, it can also be distilled from coal or even biomass. In the 1980s, methanol was popular for a brief time as an internal-combustion fuel and President Bush even discussed this in a 1989 speech.

But, methanol is highly toxic and while it has some emissions benefits it adds tangible amounts of formaldehyde to the air. The world methanol infrastructure is the equivalent of about 5% of U.S. gasoline consumption, but new sources could be built up quickly. A major manufacturer of methanol, Methanex has stated that it could build a $350 million plant in 3 years that could fuel 500,000 cars.

Methanol can be pumped in existing gas stations, but since the fluid is corrosive; the pumps, lines, and tanks would have to be made of stainless steel. If there is a demand, the costs would likely be handled by private investors.

While hydrogen could be obtained with onboard reforming, one problem is the presence of sulfur in the catalysts used in PEM type auto fuel cells. One technique is to use a zinc-oxide bed to trap the sulfur, but this adds to the cost, weight, and size of the reformer. Refineries could also produce a new grade of gasoline with low-sulfur content. Along with being a smog enhancer, sulfur affects the performance of internal-combustion catalytic converters in the same way as it affects fuel cells.

Sulfur can increase emissions by 20%. California uses low-sulfur fuel and the concentration is about 40 parts per million. In the rest of the country it is about 350 parts per million. A national low- sulfur standard is estimated to add five cents per gallon to gasoline.

If fuel cell cars run on gasoline, there is minimum disruption, but many predict that methanol will serve as a bridge to direct hydrogen. Early fuel cell cars may run on methanol, but rapid advances in direct-hydrogen storage and production could bypass any liquid fuel phase.

When gasoline or methane is used as a source of hydrogen, the hydrogen is separated from the hydrocarbon molecules using partial oxidation and autothermal reformers. Cost is an issue for onboard gasoline reformers and another is that the high temperature at which they operate does not allow for rapid starting. The reforming process also involves a loss of about 20% of the energy in the gasoline. In 2003, Nuvera Fuel Cells developed a 75-kW gasoline reformer. It has an 80% efficiency but requires more than a minute to start. Nuvera has been working to get this down to 30 seconds and believes that the reformer could eventually sell for about $2,000.

Gasoline fuel cell vehicles (FCVs) could be an interim step. Their main advantage is the use of an available fuel. An affordable gasoline reformer could allow a market for fuel cell vehicles without a hydrogen infrastructure.

Methanol has several advantages for powering fuel cell vehicles. A study for the California Fuel Cell Project (CAFCP) pointed out methanol's availability without new infrastructure, high hydrogen-carrying capacity and the ability to be stored, delivered, and carried onboard without pressurization. Methanol reformers operate at lower temperatures (250°C-350°C), so they are more practical than onboard gasoline reformers. Methanol reformers could also be used at fueling stations to generate forecourt hydrogen.

Direct methanol fuel cells (DMFCs) can run on methanol without a reformer. But, practical, affordable DMFCs for cars and trucks may still be years away.

Methanol has been used to make MTBE, a gasoline additive now being phased out because of environmental concerns such as groundwater contamination. Although methanol exists in nature and degrades quickly, MTBE is a complex, compound that exhibits little degradation once released into the environment.

If there were to be a dramatic increase in U.S. methanol use, most of the supply would have to be imported. Biomass-generated methanol might be economical in the long term, but there is a significant amount of so-called stranded natural gas in areas around the globe that could be converted to methanol and shipped by tanker at relatively low cost. There would also need to be enough natural gas for a growing demand for gas-fired power plants and fuel cells. Methanol from natural gas would have little or no net greenhouse gas benefits in fuel cell vehicles. But, the price of methanol may not remain competitive with gasoline if methanol demand increases. Health and safety concerns would need to be solved and direct methanol fuel cells would need to be affordable.

ENERGY FROM BIOMASS

Biomass energy comes from organic plants or animal matter. Biomass energy or bioenergy is a general term for the energy stored in organic wastes. The energy conversion process can range from harvesting crops and burning them or distilling their sugars into liquid fuels. Biomass energy production can replace a variety of traditional energy sources such as fossil fuels in solid or liquid forms. One of the most common sources of biomass energy is wood and wood wastes. Other sources include agricultural residues, animal wastes, municipal solid waste (MSW), microalgae and other aquatic plants. Crops may also be grown for harvesting their energy content. These crops include grains, grasses, and oil-bearing plants. Medium-Btu gas is already being collected at more than 120 landfills in the U.S. These energy farms have the potential of providing a more important global energy resource.

RECYCLED CARBON

Biomass technology allows the carbon in the organic matter to be recycled. Unlike the burning of fossil fuels, the combustion of biomass recycles the carbon set by photosynthesis during the growth of the plant. In biomass energy production, the combustion of plant matter releases no more carbon dioxide than is absorbed by its growth and the net contribution to greenhouse gases is zero.

Wood and wood waste includes residues from the forest and the mill. Bark, sawdust and other mill wastes are all suitable fuels. Agricultural residues include corncobs, sugar cane bagasse (the stalks after processing), leaves, and rice hulls. MSW materials include paper products, cloth, yard wastes, construction debris, and packaging materials.

Biomass materials depend on local conditions. In tropical areas, sugar cane is widely grown and bagasse is available as an energy feedstock. Rice growing areas have rice husks available. The Midwestern area of the U.S. can use corn husks and forested areas have timber residues.

Biomass is not a renewable resource unless creation of the source equals or exceeds its use. This is true in energy farms and standard crops, particularly forests.

BIOMASS USE

Prior to the widespread use of coal and oil, biomass in the form of firewood was the principal energy source in the U.S. This was also true in most other countries. In the Canada of 1867, biomass was used for 90% of its energy. Only 10% of this nation's energy supply came from other sources such as coal and hydropower. As coal and then oil became more widespread, the use of biomass dropped, reaching a low point by 1960. But since then, the trend is upward with biomass gaining popularity as an energy source. In the forest products industry, wood waste supplies a large percentage of the energy needed. This ranges between 65 and 100%, depending on the country.

Biomass supplies almost 15% of the world's energy. In developing countries this amount can be as high as 50%. Nepal, Ethiopia, and Haiti derive most of their energy from biomass. Kenya, Maldives, India, Indonesia, Sri Lanka, and Mauritius derive over half.

In the U.S. about 8% of the energy is provided by biomass and almost 90% of this comes from the combustion of wood and wood residues. The use of biomass increased from an installed capacity of 200 megawatts in 1980 to over 7,700 megawatts in 1990. The search for cleaner fuels and landfill restraints are the main reasons for increased biomass utilization. The cost of waste disposal has soared and landfill sites are closing faster than new ones are opening up. The Environmental Protection Agency (EPA) estimated that between 1978 and 1988, 70% of the nation's landfills, about 14,000 sites closed.

By the 1990s several states had developed notable biomass energy. Florida's power plants generated more than 700 megawatts of energy from biomass and almost one fourth of Maine's baseload requirements were met with biomass generation. Hawaii generated about one half of its energy from renewable sources and one half of this came from biomass. States with large populations used biomass to help dispose of their waste.

Florida, California and New York were large users of MSW for energy.

In Canada, biomass energy equaled the energy produced by nuclear plants and represented about one half of that produced from coal. Biomass made up 12% of the energy in the Atlantic area and almost 25% in British Columbia. In Canada, biomass energy was used for greenhouse heating, health-care facilities, educational institutions, office and apartment buildings, and large industrial plants including automobile manufacturing and food processing. Developed nations that generated higher proportions of their energy from biomass include Ireland with 17% and Sweden with 13%.

BIOMASS FEEDSTOCKS

Biomass feedstocks can be used to create gaseous and liquid fuels. These can be used on-site, to improve the efficiency of the process or they can be used in other applications. Sugar, starch or lignocellulosic biomass such as wood, energy crops, or MSW can provide alcohols such as methanol, ethanol, and butanol. These fuels may be used as a substitute, or additive, to gasoline. In the biofuel process plant grains and fiber are converted into sugar and fermented into ethyl alcohol or ethanol. Typically used as a blending agent with gasoline, higher concentrations can reduce greenhouse gasses by 80% compared to straight gasoline.

ETHANOL FUEL

Most ethanol is made from corn. Ethanol produced from corn, provides about 25% more energy than that required to grow the corn and distill the ethanol. Ethanol from other sources includes dedicated energy crops such as switchgrass, which may be grown and harvested with less energy consumption. Methanol can also be produced from biomass by chemical processes. Fermentation is an anaerobic biological process where sugars are converted to alcohol by micro-organisms, usually yeast. The resulting alcohol is ethanol. It can be used in internal combustion engines, either directly in modified engines or as a gasoline extender in gasohol. This is gasoline containing up to 20% ethanol.

This type of fuel comes from distilleries using corn, sorghum, sugar beets and other organic products. The ethyl alcohol, or ethanol fuel produced is generally mixed in a ratio of 1-to-10 with gasoline to produce gasohol. The mash, or debris, that is left behind contains all the original protein and is used as a livestock feed supplement. A bushel of corn provides two and a half gallons of alcohol plus byproducts that can almost double the corn's value. Ethanol is a renewable source of energy, but critics question turning food-producing land into energy production. Cellulose ethanol eliminates the diversion of food crops to fuel. It can be produced from agricultural residues which are often destroyed by burning.

Ethanol is a healthy industry in some parts of the United States and the rest of the world. It is an alternative as an automobile fuel. Brazil has a large ethanol industry, producing about three billion gallons each year from sugar cane.

RENEWABLE FUEL STANDARD

The U.S. Environmental Protection Agency (EPA) has established the Renewable Fuel Standard (RFS). The RFS was mandated by the Energy Policy Act of 2005. It requires that by 2012, at least 7.5 billion gallons of renewable fuel be blended into motor vehicle fuel sold in the U.S.

The program is based on a credit trading system that provides a flexible way to comply with the annual standard by allowing renewable fuels to be used where they are most economical. By 2012, the program may cut petroleum use by almost 4 billion gallons and reduce annual greenhouse gas emissions by 13 million metric tons. This would be the equivalent of removing about 2.4 million cars from the road.

By 2007, about 4% of all the fuel sold or dispensed to U.S. motorists came from renewable sources, which is almost 5 billion gallons of renewable fuels. New and expanded plants now under construction are expected to push the annual production of ethanol well above this level.

The EPA will no longer require facilities that use carbohydrate feedstocks in producing ethanol to count fugitive emissions of regulated pollutants. These are emissions that do not come from process stacks or vents. This may allow some plants to expand production. It will also allow new ethanol facilities to emit up to 250 tons of regulated pollutants per year in areas that are not exceeding EPA's air quality standards and not in an Ozone Transport Region, where ground-level ozone is a problem.

One source of ethanol is sugar cane or the molasses remaining after the juice has been extracted. Other plants such as potatoes, corn and other grains require processing to convert the starch to sugar. This is done by enzymes. Biodiesel fuel is derived from vegetable oils or waste animal fats. It is a renewable, clean burning fuel that can be used for diesel engines or oil heating.

When biomass is transformed into energy by burning, it releases CO_2 that was previously sequestered or held in the atmosphere, for some time, so the net CO_2 emitted is zero. Biomass provides the potential of a sustainable way of providing energy.

BIOMASS PROCESSES

Plants create energy through photosynthesis using solar radiation and converting carbon dioxide and water into energy crops. Technology allows us to take that energy and transform it through a variety of processes for our uses. The three basic types of bioenergy conversion are direct combustion, thermochemical conversion, and biochemical conversion.

The direct combustion of wood and other plant matter has been a primary energy source in the past. Any type of biomass can be burned to produce heat or steam to turn a generator or perform mechanical work. Direct combustion is used in large power plants that produce up to 400 megawatts. Most direct combustion systems can use any type of biomass as long as the moisture content is less than 60%. Wood and wood residues are commonly used along with a number of other agricultural residues.

Bioenergy can be derived from biomass products such as energy crops, forestry and crop residues and even refuse. One characteristic of these biofuels is that three fourths or more of their energy is in the volatile matter or vapors, unlike coal, where the fraction is usually less than half. It is important that the furnace or boiler ensure that these vapors burn and are not lost. For complete combustion, air must reach all the char, which is achieved by burning the fuel in small particles. This finely-divided fuel means finely-divided ash particulates which must be removed from the flue gases. The air flow should be controlled. Too little oxygen means incomplete combustion and leads to the production of carbon monoxide. Too much air is wasteful since it carries away heat in the flue gases. Modern systems for burning biofuels include large boilers with megawatt outputs of heat.

Direct combustion is one way to extract the energy contained in household refuse, but its moisture content tends to be high at 20% or more and its energy density is low. A cubic meter contains less than 1/30th of the energy of the same volume of coal. Refuse-derived fuel (RDF) refers to a range of products resulting from the separation of unwanted components, shredding, drying and treating of raw material to improve its combustion properties. Relatively simple processing can involve separation of large items, magnetic extraction of ferrous metals and rough shredding. The most fully processed product is known as densified refuse-derived fuel (d-RDF). It is the result of separating out the combustible part which is then pulverized, compressed and dried to produce solid fuel pellets with about 60% of the energy density of coal.

THERMOCHEMICAL CONVERSION PROCESSES

Thermochemical conversion processes use heat in an oxygen controlled environment that produce chemical changes in the biomass. The process can produce electricity, gas, methanol and other products. Gasification, pyrolysis, and liquefaction are thermochemical methods for converting biomass into energy.

Gasification involves partial combustion to turn biomass into a mixture of gases. Gasification processes may be direct or indirect. The direct processes uses air or heat to produce partial combustion in a reactor. Indirect processes transfer the heat to a reactor its walls using heat exchangers or hot sand. This process produces low- or medium-Btu gases from wood and wood wastes, agricultural residues and MSW. Processing these synthetic gases with water can produce ammonia, methanol, or hydrogen. Commercial gasification systems exist, but their widespread use has been limited by hauling distances for the feedstock.

PYROLYSIS AND LIQUEFACTION

Pyrolysis is a type of gasification that breaks down the biomass in oxygen deficient environments, at temperatures of up to 400°F. This process is used to produce charcoal. Since the temperature is lower than other gasification methods, the end products are different. The slow heating produces almost equal proportions of gas, liquid and charcoal, but the output mix can be adjusted by changing the input, the temperature, and the time in the reactor. The main gases produced are hydrogen and carbon monoxide and dioxide. Smaller amounts of methane, ethane, and other hydrocarbons are also produced. The solids left are carbon and ash. The liquids are similar to crude oil and must be refined before they can be used as fuels.

In liquefaction systems wood and wood wastes are the most common fuelstocks. They are reacted with steam or hydrogen and carbon monoxide to produce liquids and chemicals. The chemical reactions that take place are similar to gasification but lower temperatures and higher pressure are used. Liquefaction processes can be direct or indirect. The product from liquefaction is pyrolytic oil which has a high oxygen content. It can be converted to diesel fuel, gasoline or methanol.

BIOCHEMICAL CONVERSION / FERMENTATION

Biochemical conversion, or bioconversion, is a chemical reaction caused by treating moist biomass with microorganisms such as enzymes or fungi. The end products may be liquid or gaseous fuels. Anaerobic digestion and fermentation are the two processes used for biochemically converting biomass to energy.

Anaerobic digestion involves limiting the air to moist biomass such as sewage sludge, MSW, animal waste, kelp, algae, or agricultural waste. The feed stock is placed in a reaction vessel with bacteria. As the bacteria break down the biomass, they create a gas that is 50 to 60% methane. Small scale digesters are used on Asian and European farms. Sewage treatment plants use this process to generate methane and digesters are used to compost municipal organic waste. Anaerobic systems range from large systems that can handle 400,000 cubic feet of material and produce 1.5 million cubic feet of biogas per day to small systems that handle 400 cubic feet of material and produce 6,000 cubic feet of biogas a day.

Fermenting grains with yeast produces a grain alcohol. The process also works with other biomass feedstocks. In fermentation, the yeast decomposes carbohydrates which are starches in grains, or sugar from sugar cane juice into ethyl alcohol (ethanol) and carbon dioxide. The process breaks down complex substances into simpler ones.

Microalgae and oilseed crops can provide diesel fuel. The use of these alcohol fuels can reduce air pollution. Methane made from anaerobically digested manure was used to light streets in England as early as 1895. Anaerobic digestion is also used to produce fertilizers.

SYNTHESIS GAS FUEL

Biomass can be converted to synthesis gas (syngas), which consists mainly of carbon monoxide (CO_2), carbon dioxide (CO_2), and hydrogen (H_2), using the gasification process. Gasification technology has been in a period of intensive development in the last few decades. Large-scale demonstration facilities have been tested and some commercial units are in operation. The problems with the application of gasification have been economic and not technical.

In the past, the product from gasification has been electricity or heat and the value of these products has not been adequate to justify the capital and operating costs. However, if gasification is combined with the production of higher value liquid fuels, it can become a more viable alternative energy technology. After gasification, anaerobic bacteria are used to convert the CO, CO_2, and H_2 into ethanol.

Bioengineering Resources, Inc. (BRI) has developed syngas fermentation technology that can be used to produce ethanol from cellulosic wastes with high yields and rates. The process of combined gasification/fermentation has been under development by BRI for several years. The feasibility of the technology has been demonstrated and the yields can be high because most of the raw material, except for the ash and metal, is converted to ethanol. BRI's bioreactor systems for fermentation have retention times of only a few minutes at atmospheric pressure and less than a minute at elevated pressures. These retention times mean very reasonable equipment costs. The biocatalyst is automatically regenerated by the slow growth of the bacteria in the reactor.

BIOFUELS

By 2006, the U.S. had 77 ethanol plants producing more than 3 billion gallons of ethanol per year. Canada produced an additional 60 million gallons. Corn was the feedstock in 62 of the 77 U.S. plants. Other feedstocks included seed corn, corn and barley, corn and beverage waste, brewery waste, cheese whey, corn and milo, corn and wheat starch, potato waste and various sugars. The U.S. had 11 additional plants under construction and 55 proposed. West Central Soy processes soybeans to a food grade oil. Alcohol and a catalyst are then used to produce biodiesel fuel and glycerin.

In the oil industry, biofuels interest has been growing. BP, Royal Dutch Shell and others are viewing these fuels as a possible future replacement for gasoline and are spending millions on research and product development. Along with Chevron and ConocoPhillips, they are developing alternatives such as solar, wind, geothermal and hydrogen as well as biofuels.

Oil and natural gas are their primary products, but many are investing in wind, geothermal and biofuel. Although these investments are a small percent of their total business, but, in terms of alternative energy spending, they are significant. Between 2002 and 2006, Chevron spent about $2 billion on alternative and renewable energy technologies, including geothermal, hydrogen, biofuel, advanced batteries and energy efficiency improvements. By the end of 2009, the company will have spent $4.5 billion on alternative energy. Chevron has invested in Galveston Bay Biodiesel LP, a Texas firm, building a large biodiesel plant that will use soybeans and other renewable feedstock. Chevron has also partnered with the Weyerhaeuser Company in the production of biofuel from wood waste and funded research at the Colorado Center for Biorefining and Biofuels, Georgia Institute of Technology, University of California and Texas A&M, directed at developing cellulosic and hydrogen transportation fuels.

BP has investments in an ethanol plant with DuPont and Associated British Foods. It is also investing in cellulosic ethanol research and developing jatropha as a biodiesel feedstock. BP and DuPont are planning a biobutanol demonstration plant and BP would like to eventually convert their ethanol plant to biobutanol production. BP has a $400 million investment with Associated British Foods and DuPont to build a bioethanol plant in the U.K. that may be converted to biobutanol. It has spent $500 million over 10 years at the Energy Biosciences Institute in California to research future biofuels and $9.4 million over 10 years to fund the Energy and Resources Institute (TERI) in India to study the production of biodiesel from Jatropha curcas. It also has a $160 million joint venture with D1 Oils to develop the planting of Jatropha curcas.

Royal Dutch Shell has invested in cellulosic ethanol company Iogan and Germany's Choren Industries, which is building a demonstration biomass-to-liquids plant using wood feedstock. Royal Dutch Shell has also partnered with Codexis in exploring biomass energy production.

Shell has spent about $1 billion on renewable fuels since 2000. Shell has invested largely in next generation cellulosic biofuel which is a long-term commitment.

ConocoPhillips will see a more immediate payoff in its agreement with Tyson Foods to process animal fats into renewable diesel. The company already has one renewable diesel plant in operation and another going online. ConocoPhillips also produces renewable diesel from soybean oil at an Irish refinery and plans similar operations at its Borger, Texas refinery. It is providing a $100 million upgrade at the refinery to process animal fats from Tyson Foods. ConocoPhillips also funds research at the Colorado Center for Biorefining and Biofuels and gave Iowa State University $22.5 million over eight years for research on producing renewable fuels from biomass.

ConocoPhillips is also studying the use of algae as a renewable diesel feedstock and is a founding member of the Colorado Center for Biorefining and Biofuels in Boulder. This research group is involved with algae, cellulosic and other biofuels. Other group members include Chevron, Dow Chemical, Shell Global Solutions, GreenFuel Technologies, Range Fuels, Solix Biofuels and Blue Sun Biodiesel.

ExxonMobil has given $100 million to the Stanford University Global Climate and Energy Project, where research projects are involved with hydrogen power, advanced combustion, solar energy, biomass, advanced materials, catalysts and CO_2 storage, CO_2 capture, and separation.

Although obtaining and transporting feedstocks can be an obstacle, the USDA and DOE believe that as plants are built around the country, this will create local demand and farmers will respond.

The Andersons is an agricultural firm in Maumee, OH, with corn storage, transport, ethanol production and delivery. They had about $2 billion in sales in 2007 which placed them as the third largest diversified U.S. ethanol producer. Others are the giant Archer Daniel Midland and eight smaller firms: Aventine Renewable Energy, Bunge Limited, Green Plains Renewable Energy, Pacific Ethanol, U.S. Bioenergy, VeraSun Energy and Verenium. The Andersons have developed a diversified ethanol business operating 14 grain elevators in the Midwest to supply its own ethanol plants along with others. It has built its ethanol plants near its corn supplies in Ohio, Illinois, Indiana and Michigan to minimize transport. Its newest plant is a joint venture with Marathon Oil of Houston and will be in Greenville, OH.

BIOFUEL LEGISLATION TRENDS

Farm lawmakers have been pushing for more biofuel production. This legislation would offer over $2 billion for loans, grants and other incentives over a five year period. Biomass R&D grants would total $420 million over five years with $800 million in loans for the building and start up of biorefineries. At least half of these funds will be for loans of less than $100 million each for small to midsize operations. There will also be $500 million over five years for loans, loan guarantees and grants to farmers, ranchers and small businesses for renewable energy systems, such as wind turbines and biodigesters to harvest methane from animal waste. Individual loan guarantees would be capped at $25 million. There will also be 1.2 billion in incentives for next generation biofuel production which does not include corn ethanol and $74 million by 2012 for the Biomass Energy Reserve. This would provide incentives to farmers who grow dedicated energy feedstock crops.

The Forest Biomass for Energy program will acquire $75 million for research for the harvesting, transporting and processing of woody biomass for bioenergy production. There are also programs for the feasibility studies for ethanol pipelines, funds for USDA to buy up excess sugar stock for ethanol and grants for improving energy efficiency on farms.

Green payments may also be included. These are USDA payments to farmers and ranchers who implement whole-farm comprehensive conservation plans. This funding goes along with encouraging production to meet the demand for biofuels by increasing soil and water conservation.

The bulkier biomass crops such as wood waste, switchgrass, miscanthus or other cellulosic feedstocks have less sugar than corn or sugar cane, so it requires more biomass volume to yield the same quantity of ethanol that corn or sugar can produce.

Research at the DOE, Oak Ridge National Laboratory and the Regional Biomass Processing Center at Michigan State University is involved in treating the plant material by making it denser and easier to ship. A comprehensive farm bill is expected to fund more research on harvesting, storing and transporting cellulosic feedstocks with incentives to farmers to grow these new crops.

BIOFUEL RESEARCH

USDA researchers in biodiesel are investigating peanuts in Georgia. Some varieties such as Georganic have been found to be high in oil content with low production costs, requiring only one herbicide application and no fungicides. The Georganic plants are not suitable for the growing of edible peanuts. Traditional peanuts can produce 120 to 130 gallons of biodiesel per acre, compared with about 50 gallons of biofuel per acre from soybeans.

A cost efficient way to utilize wheat in ethanol production has been developed by researchers from Greece and the U.K. This process splits the grain into separate components, separating out the nonfermentable solids, and then uses a group of enzymes to ferment the proteins and starches using a single liquefaction and saccharification step.

The University of Nebraska has developed the Biofuel Energy Systems Simulator (BESS) software program to analyze energy yield, efficiency, greenhouse gas emissions and resource requirements for corn ethanol plants. It quantifies the environmental impact of ethanol production from seed to fuel, including energy and greenhouse gas use from crop production, byproduct use, waste disposal and transportation. The program will be expanded to assess bioethanol production from other sources as well as biodiesel production.

In 2007 a bumper crop in corn took the edge off problems with supplies. The USDA confirmed that corn acreage was up almost 20% from 2006, with farmers planting almost 2.5 million more acres than they had planned. The crop was estimated at 13 billion bushels, up 23% from 2006. This caused corn prices to drop 40 cents to 50 cents a bushel, but increasing demand for corn to produce ethanol and to feed livestock in Asia, Latin American and elsewhere kept world stocks low.

China's rapid growth in ethanol output has dropped off due to a government rule in 2007 that restricts production to nonfood feedstocks. The country has four state-licensed and subsidized fuel-grade ethanol plants which will continue to operate. Another 6 to 10 new plants are due to open, but they will need to use cassava and sorghum, instead of corn. The Chinese government does not consider cassava and sorghum as food grains, but they are staples in some countries. China may have trouble finding adequate nonfood feedstocks since little additional arable land is available. Only a few acres are planted in sorghum and none to cassava. The government will divert some corn acreage to these crops, but China's need for food and livestock feed does not leave that much acreage for nonfood production. China is already a large importer of starch crops and increased demand for them will drive up world prices. To offset this, China plans to lease several million acres in Laos and Indonesia for the production of cassava and palm oil.

Demand has been heating up corn prices and they are likely to remain high for the next few years. But, the USDA maintains there is plenty of demand for distiller grains (DG) which are ethanol's main coproduct. The potential to use these coproducts is great according to USDA's National Agricultural Statistics Service (NASS). A recent NASS survey found that of more than 9,000 livestock operations contacted in 12 midwestern states, more than a fifth of dairy producers and roughly a third of both hog and beef producers were considering adding DG to their livestock feed.

Others predict that the ratio of corn to distillers grains being fed to livestock will go from 11/1 to 3/1 in 10 years. Animal nutrition studies indicate that the optimal inclusion rates of DG in feed rations are 30-40% for beef cattle, 20-25% for dairy cows, 20% for hogs and 15% for poultry. DG replaces corn pound for pound in feed rations, usually at a lower price, so it will be in demand. The main barrier to the use of DG has been availability. Distiller grains have a short shelf life and can be difficult to store and expensive to transport. Wet DG is heavy and can mold in less than two weeks in the summer months or freeze if stored outdoors in winter. Now, with over 100 new grain ethanol plants in 21 states it should be easier for farmers to locate nearby supplies. In 2007 about 3.4 billion bushels of the fall corn harvest went into fermentation vats, which supplied almost 30 million tons of DG in 2008, more than a 60% jump from the year before. The proceeds from DG also aid ethanol producers, adding up to 15% to their revenue. These distiller grain sales can drop the cost of corn by about a third. When corn is $3 a bushel, an ethanol producer gets $1 back from distiller grain sales.

CELLULOSIC ETHANOL FUEL

The commercial production of cellulosic ethanol is moving closer with advances in technology along with federal and private funding for new plants and research centers. These are accelerating the time to volume production which could push the cost of ethanol from cellulosic feedstocks to well under $1.00 a gallon below the cost of corn ethanol.

The process of using concentrated acid hydrolysis was developed in the 1940s but new biological and gasification technologies are expected to cut costs by $1 a gallon, making the fuel competitive with both corn ethanol and gasoline. When the capital costs of building a new gasoline refinery are included, gasoline would cost about the same as making cellulosic ethanol using traditional acid hydrolysis. The biggest hurdle is the high capital cost of cellulosic biorefineries, which are two to three times more than corn ethanol plants. But these costs are expected to come down significantly in several years. A cellusosic biorefinery requires a large amount of expensive equipment, but as process improvements occur less expensive equipment should be required.

The Department of Energy (DOE) is helping six firms build cellulosic biorefineries with grants totaling about $385 million. When fully operational, the six plants will produce more than 130 million gallons of cellulosic ethanol a year. DOE is also investing $375 million into three new Bioenergy Research Centers to speed up the development of cellulosic ethanol and other biofuels.

POET LLC of Sioux Falls, SD, is planning a 125-million-gallon-a-year biorefinery in Emmetsburg, Iowa. POET is one of several companies pursuing the production of cellulosic ethanol using enzymatic hydrolysis to break down the cellulose and produce sugars. This process will be aided greatly from the development of genetically modified enzymes and other microorganisms from Verenium Corporation and Mascoma Corporation in Cambridge, MA. They have developed microorganisms that generate enzymes that both break down the biomass cell walls, exposing the sugars, and ferment the sugar into ethanol. This would be a major cost savings since it typically costs 10-15 times as much for the enzymes used in the fermentation of cellulosic material that those used in corn-based ethanol production.

In 2007 Verenium began work on a demonstration-scale cellulosic ethanol plant in Jennings, LA. The plant is expected to have an output of 1.4 million gallons a year, using sugar cane bagasse and a special breed of energy cane as feedstocks.

A commercial-scale cellulosic ethanol plant is also planned by Mascoma. It will use wood chips and other nonfood agricultural crops and be located in Michigan. Dynamotive Energy Systems has an agreement with Mitsubishi on a series of projects, including licensing Dynamotive's technology for small plants. Based in Vancouver, Canada this cellulosic ethanol company has offices in the U.S., U.K. and Argentina.

Other companies, such as Genencor and Novozymes are providing producers with enzymes that are genetically modified to extract the sugars from a variety of biomass feedstocks. Verenium, Mascoma, Cargill, DuPont and Archer Daniels Midland have received DOE grants totaling $23 million for improved microorganisms. Codon Devices and Agrivida are working on the development of corn varieties using genetically engineered enzymes that degrade the cornstalk, husks and other plant material into sugars. Codon Devices' Biologic engineering technology is being used to develop the optimized enzymes in a shorter time than usually needed using traditional approaches in enzyme development. Other companies are working on thermochemical processes that do not use enzymes. Range Fuels of Broomfield, CO is working on such a plant in Soperton, GA. Range Fuels has a grant of up to $76 million from DOE and will use a two-step process to convert biomass wood chips and forest residue first to synthesis gas and then to ethanol. At first the plant will produce about 20 million gallons of ethanol a year and in a few years, the output will be increased to 100 million gallons per year. Eventually, the company plans to reach 1 billion gallons a year with all its plants. Alico will also use a thermochemical process to provide up to 14 million gallons of ethanol a year at a plant in LaBelle, Florida. Alico received a $33 million DOE grant for capital expenses and will gasify wood waste and agricultural residues into ethanol, ammonia and hydrogen.

NewGen Technologies in Charlotte, NC, and its subsidiary, NewGen BioFuels, is buying up biofuel producers to secure supplies of ethanol and biodiesel for its terminals owned by ReFuel America, NewGen's U.S. fuel distribution subsidiary. In Houston, GreenHunter BioFuels will open a biodiesel refinery by converting an existing waste oil/chemical refinery for the production of biodiesel and distillation of methanol. The plant will be able to use a variety of feedstocks, including soy, palm and jatropha oils and/or animal and poultry fats. BlueFire Ethanol Fuels will build California's first cellulose-to-ethanol plant near Lancaster, in northern Los Angeles County. The 3.1 million gallon a year plant will use agricultural and wood waste streams as feedstock. It is designed to use recycled water and will supply almost 70% of its energy with lignin, an ethanol coproduct. BlueFire plans to use this plant as the model for factory-made system modules that can be quickly erected at other sites.

Eventually different technologies will be used for different feedstocks. The three approaches are concentrated acid hydrolysis, thermochemical and biological. A hybrid may also emerge.

ALGAE

Algae requires only sunlight, water and carbon dioxide to grow and can quadruple in a day. It helps to remove pollutants from the air and water and has the potential to replace gasoline in the U.S. Algae as a feedstock for biofuels has many advantages over other biomass sources and it will eventually overshadow all others. But, large-scale production is still years away.

Algae are highly efficient as converters of solar energy into chemical fuel. Some strains are over 50% oil and their yield per acre is very high. The average per-year, per-acre oil yield for algae grown for use in the food and pharmaceutical industries today is enough to make about 5,000 gallons of biodiesel. In comparison, an acre of soybeans typically yields enough oil to make about 70 gallons of biodiesel and an acre of corn will provide about 420 gallons of ethanol. The potential yield of algae according to the Department of Energy's National Renewable Energy Laboratory, is up to 15,000 gallons of biodiesel a year from a saltwater pond.

Ocean Technology & Environmental Consulting (OTEC) is developing photobioreactors that produce algae in layers or shallow ponds. These organisms also thrive on harmful emissions such as nitrogen from wastewater and carbon dioxide from power plants. Growing them may help to solve some environmental problems while providing a source of fuel. OTEC is working on the Mohave Generating Station in Laughlin, Nevada. It will install photobioreactors to capture the carbon emissions from the plant. The CO_2 will then be used to increase production at a nearby site.

GreenFuel Technology Corporation of Cambridge, MA is working with power plants in Arizona, Louisiana and Germany to build algae producing photobioreactors. Recent tests by GreenFuel showed that its system captured about 80% of the CO_2 emitted during the daytime sun.

HYDROGEN FUEL

The costs associated with making a changeover to hydrogen fuel seems high, but the environmental costs of finding, transporting and burning fossil fuels are not included in the current energy pricing structure. The costs of atmospheric pollution may be billions of dollars in additional health care costs as well as forest and crop losses and the corrosion of buildings and other structures.

Many groups in the U.S., Germany, Japan, France and other countries are involved in hydrogen research and development. Hydrogen fueled engines tend to be more energy efficient because of their complete combustion. Gasoline and diesel engines form carbon deposits and acids that erode the interior surfaces of the engine and contaminate the engine oil. This increases wear and corrosion of the bearing surfaces. Since hydrogen engines produce no carbon deposits or acids, they should require far less maintenance. Hydrogen can also be used in more efficient Stirling cycle engines.

In the 1920s, a German engineer, Rudolf Erren, began modifying internal combustion engines to use hydrogen. Erren modified many trucks and buses and a captured German submarine in World War II had a hydrogen engine and hydrogen powered torpedoes that were designed and patented by Erren.

The first hydrogen automobile in the U.S. was a Model A Ford truck, modified in 1966 by Roger Billings while he was a high school student. A few years later at Brigham Young University, he won a 1972 Urban Vehicle Design Contest with a hydrogen Volkswagen. Billings started Billings Energy Corporation in Provo, Utah where he modified a wide range of vehicles, including a Winnebago motor home with the engine fueled by hydrogen as well as the generator and appliances. Billings has also built a hydrogen home where the modified appliances operate on hydrogen.

Most of these vehicles are dual fueled and run on hydrogen or gasoline. The driver is able to switch from hydrogen to gasoline. Billings also adapted a Coleman Stove for hydrogen. A small hydrogen storage tank with iron-titanium metal hydrides was used. Special burners have also been used by the Tappan Company for hydrogen stoves. Hydrogen burns with an invisible flame, so Tappan used a steel wool catalyst that sits on the burner head. The stainless steel mesh glows when heated and resembles an electric range surface when the burner is on.

Hydrogen research programs were started up in the U.S. Air Force, Navy and the Army in the 1940s when fuel supplies were a concern. After World War II and prior to the Arab oil embargo in 1973, oil was selling for less than $3 per barrel. Fuel supply was not a concern. During the Arab oil embargo in 1973, there were long gas lines in the U.S. and the price of oil quadrupled. This started renewed research into alternative energy supplies including solar power.

STORING HYDROGEN

Studies have indicated that large-scale storage could take place with gaseous hydrogen underground in aquifers, depleted petroleum or natural gas reservoirs or man made caverns from mining operations. One of the obstacles in using hydrogen as an automotive fuel is storing it safely and efficiently on board vehicles. Although it is possible to store hydrogen as a high pressure gas in steel containers, disadvantages exist because of the weight of the storage containers and the safety hazard in the event of an accident. Other methods of storage for hydrogen include solid or liquid hybrids, low temperature cryogenic liquids, or a combination of the two.

Liquid hydrogen as a method for storing and transporting hydrogen can have several advantages over gases. The liquid form has a higher energy density and is easier to transport and handle. At atmospheric pressures, hydrogen is a liquid at -253°C (-423°F), which is only a few degrees above absolute zero. It must be stored in highly insulated tanks. Liquid hydrogen is a cryogenic fuel. Cryogenics is the study of low temperature physics. A beaker of liquid hydrogen at room temperature will boil as if it was on a hot stove. If the beaker of liquid hydrogen is spilled on the floor, it is vaporized and dissipates in a few seconds. If liquid hydrogen is poured on the hand, it would feel cool to the touch as it slides through the fingers. This is due to the thermal barrier that is provided by the skin. But, place a finger in a vessel containing liquid hydrogen and severe injury will occur in seconds because of the extremely cold temperature. In most accidents, the most serious concern would be a fuel fed fire or explosion. In this case, liquid hydrogen is generally considered to be a preferred fuel.

Liquid hydrogen as a fuel option could be utilized on a large scale since it most resembles gasoline in terms of space and weight. Although a liquid hydrogen storage tank for a vehicle could weigh about five times heavier in dry weight than a 30 pound gasoline tank, in vehicles that carry greater volumes of fuel, such as trucks or trains or aircraft, the difference in tank weight could be more than offset by the difference in fuel weight. Studies by Lockheed Aircraft have shown that a large commercial aircraft could have its overall takeoff weight reduced by as much as 40% if liquid hydrogen were used instead of aviation fuel. Liquid hydrogen has the lowest weight per unit of energy, with relatively simple supply logistics with normal refuel times and is generally safer than gasoline in accidents. However, cryogenic fuels like liquid hydrogen are more difficult to handle and substantially more difficult to store compared to hydrocarbon fuels like gasoline or aviation kerosene.

Even with highly-insulated double-walled, vacuum-jacketed storage tanks liquid hydrogen can evaporate. This evaporation increases the pressure on the tank wall and the gaseous hydrogen must be vented to the atmosphere to keep the tank from rupturing. Stationary liquid hydrogen storage tanks that are used in laboratories are able to keep the hydrogen in a liquid state for several months. It should be possible to build vehicular storage tanks that would maintain hydrogen in a liquid state for several weeks. The small quantity of hydrogen evaporating from such tanks could also be sent to a fuel cell that would use the hydrogen to generate electricity. It is also possible to vent the vaporized hydrogen gas to an auxiliary hydride system for storage.

This venting of the fuel must be done to keep a fuel tank full when refueling. In an enclosed space, the vented hydrogen also presents a risk because of hydrogen's wide flammability limits.

Hydrogen explosions are rare, but any combustible gas in an enclosed space can be a safety problem. One solution is to burn off the escaping hydrogen and use this energy for heating or cooling.

The double-walled vacuum jacketed storage tanks and piping that are required for liquid hydrogen are expensive compared to conventional fuel storage tanks. A gasoline tank might cost about $150, while a liquid hydrogen storage tank could cost up to a few thousand dollars. Because of the energy density of liquid hydrogen, it requires a fuel tank that is three to four times as large in volume as required for gasoline or aviation fuel.

Liquid hydrogen fuel systems would require changes in the energy infrastructure and end use systems, such as stoves, engines and fueling systems. While disadvantages of liquid hydrogen are substantial, they can be minimized. A few thousand dollars for a liquid hydrogen storage tank seems high, but consider that the emissions control equipment required on gasoline fueled engines adds much to the cost of current vehicles. As production volumes of cryogenic storage tanks increase, the cost of cryogenic tanks are expected to drop below $1,000.

Although cryogenic fuels are difficult to handle, a self-service liquid hydrogen pumping station was built decades ago at Los Alamos National Laboratory. It was shown to be feasible for refueling vehicles over an extended period of time without any major problems. Cryogenic storage is used by the National Aeronautics and Space Administration (NASA). Liquid hydrogen, along with liquid oxygen has been used as a rocket fuel since World War II. As a fuel for the space shuttle, almost 100 tons (400,000 gallons) are stored in the shuttle's external tank. To prepare for a shuttle launch requires fifty tanker trucks to travel from New Orleans to the Kennedy Space Center in Florida. This represents a great deal of experience in shipping liquid hydrogen. Since 1965, NASA has moved over 100,000 tons of liquid hydrogen to Kennedy and Cape Canaveral by tanker truck.

Liquid hydrogen can be stored in newer vessels that are relatively compact and lightweight. General Motors has designed a 90-kg cryogenic tank that holds 4.6-kg (34 gallons) of liquid hydrogen.

Liquefying hydrogen requires special equipment and is very energy-intensive. The refrigeration requires multiple stages of compression and cooling and about 40% of the energy of the hydrogen is required to liquefy it for storage. Smaller liquefaction plants tend to be more energy-intensive which presents a problem for local fueling stations.

Another problem with liquefied hydrogen is evaporation since hydrogen in its liquid form can easily boil off and escape from the tank. NASA loses almost 100,000 pounds of hydrogen when fueling the shuttle requiring 44% more to fill the main tank. In an automobile, this can be important particularly when it remains idle for a few days. The GM tank has a boil-off rate of up to 4% per day. There are techniques for bleeding and using the evaporating hydrogen, but this adds system complexity. Liquid hydrogen fuel on board a vehicle would also allow the use of a small, efficient fuel cell Stirling engine cryocooler system to provide air conditioning.

Liquid hydrogen requires extreme precautions in handling because of the low temperature. Fueling is usually done mechanically with a robot arm. Even in large, centralized liquefaction units, the electric power requirement is high with 12 to 15 kilowatt-hours (kWh) needed per kilogram of hydrogen liquefied.

COMPRESSED HYDROGEN

Compressed hydrogen has been used in demonstration vehicles for many years and most prototype hydrogen vehicles use this type of storage. Hydrogen compression is a mature technology and low in cost compared with liquefaction. The hydrogen is compressed to 3,600 to 10,000 pounds per square inch (psi), but even at these high pressures, hydrogen has a much lower energy per unit volume than gasoline. The higher compression allows more fuel to be contained in a given volume and increases the energy density but it also requires a greater energy input.

Compression to 5,000 or 10,000 psi takes several stages and requires an energy input equal to 10 to 15% of the fuel's energy. Compressing 1-kg of hydrogen into 10,000 psi tanks can take 5-kWh or more of energy.

Compressed hydrogen can be fueled relatively fast, and the tanks can be reused many times. The main technical issues are the weight of the storage tank and the volume needed. Tank weight can be improved with the use of stronger and lightweight materials. Tank volume is improved by increasing the pressure. Until recently, a 5,000 psi tank was considered to be the maximum allowable, but now 20,000 psi tanks are being built. GM has made a successful vehicle test of a 20,000 PSI (700 bar) hydrogen storage system. The newer 20,000 PSI tank technology extends the range of the HydroGen3 fuel cell vehicle by 60-70 percent compared to an equivalent-sized 5,000 PSI system.

The higher pressures also increases costs and complexity requiring special materials, seals and valves. Pressure tanks are usually cylindrical in order to provide integrity under the pressure. This reduces some flexibility in vehicle design. Liquid fuel tanks can be shaped according to the needs of the vehicle. The cost of storage increases with the pressure. An 8,000 psi storage vessel may cost several thousand dollars per kilogram of capacity. This can be almost 100 times the cost of a gasoline tank, but advances in material science and economies of scale could greatly reduce this cost.

STORAGE IN METALS

Metal hydrides may also be used for hydrogen storage where the hydrogen is chemically bonded to one or more metals and released with a catalyzed reaction or heating. The hydrides can be used for storage in a solid form or in a water-based solution. When a hydride has released its hydrogen, a byproduct remains in the fuel tank to be either replenished or disposed of.

Hydrides may be reversible or irreversible. Reversible hydrides act like sponges, soaking up the hydrogen. They are usually solids. These alloys or intermetallic compounds release hydrogen at specific pressures and temperatures. They may be replenished by adding pure hydrogen. Irreversible hydrides are compounds that go through reactions with other reagents, including water, and produce a byproduct. This byproduct may have to be processed at a chemical plant.

Some hydrides are heavy and their storage capacity may be less than 2% by weight. So each 1-kg of hydrogen can require 50-kg or more of tank. A tank with 5-kg of hydrogen could weigh more than 250-kg. This weight reduces fuel efficiency.

Metal hydrides can hold a large amount of hydrogen in a small volume. A metal hydride tank may be one third the volume of a 5,000 psi liquid hydrogen tank. Hydride tanks can take on different shapes depending on the vehicle design.

Many hydrides have a theoretical capacity to store a higher percentage of hydrogen by weight and are a major subject of ongoing research. Research also continues in the area of suboptimal hydrogen release. This is the release of only a part of the stored hydrogen.

Refueling can take more than five minutes since some hydrides are slow to absorb hydrogen. Others are slow to release it during use. The chemical process in irreversible hydrides can also be very energy-intensive.

Hydride materials absorb hydrogen like a sponge and then release it when heated. There are hundreds of hydride materials. The first hydride systems used in automotive vehicles consisted of metal particles of iron and titanium that were developed at Brookhaven National Laboratory. These were tested by Daimler-Benz in Stuttgart, Germany. These early hydride systems were shown to be safe for storing hydrogen in automobiles, but they are almost 5 times heavier than liquid hydrogen storage systems.

Other hydride systems do not have such weight penalties and include magnesium nickel alloys, non-metallic polymers, or liquid hydride systems that use engine heat to disassociate fuels like methanol into a mixture of hydrogen and carbon monoxide.

An iron titanium hydride tank system, for a range of 300 miles (480 kilometers), could weigh about 5,600 pounds (2,520 kilograms). A liquid hydrogen tank for this range would weigh about 300 pounds (136 kilograms), a comparable gasoline tank would weigh about 140 pounds (63 kilograms).

An electric vehicle with a similar range and lead acid batteries would have a battery weight of about 6,500 pounds (2,925 kilograms). More efficient battery systems are becoming available but the most efficient electric vehicles of the future may be energized by fuel cell systems that convert hydrogen and oxygen directly into electricity. These systems would depend on having hydrogen fuel more readily available.

There has also been work with hydrogen storage in buckyballs or carbon nanotubes. These are microscopic structures fashioned out of carbon. This research indicates a potential storage technique using a combination of chemical and physical containment at very high temperature and pressure.

No storage tank technology has all of the ideal characteristics for commercial applications. It would have to be compact, lightweight, safe, inexpensive, and easily filled. Compressed gas is well developed in spite of its drawbacks, liquid hydrogen is usable but not widely considered practical and hydrides may be a future technique. A 2003 report by the National Research Council found that compressed hydrogen storage at 5,000 to 10,000 psi would be costly, not only for the storage canisters but also for the compressors and energy needed for compression at refueling stations.

Various technologies may be used, according to the application. Cars, sport utility vehicles, vans, buses, and heavy trucks have different needs and these needs also vary by application, such as urban fleet trucks and long-haul fleets. In some vehicles, volume is more important while in others it may be weight or cost.

Compressed gas is being used in most current demonstration vehicles. But, the path to commercialization of any major new technology is a long one. In 2003 Toyota recalled some of its hydrogen-powered fuel cell vehicles when a leak was found in the fuel tank of one of the cars leased to Japan's Ministry of the Environment. The leak was found when a driver at the ministry heard a strange noise in the car when he was filling up the hydrogen tank. The problem was quickly identified and fixed a few weeks later.

HYDROGEN AND SAFETY ISSUES

It is widely believed that hydrogen is particularly dangerous and some relate hydrogen energy to the hydrogen bomb. When hydrogen is used in fuel cells, a simple chemical reaction takes place involving the transfer of electrons to produce an electric current. A hydrogen bomb requires a high temperature nuclear fusion reaction similar to that which occurs in our sun and other stars.

In 1937 the German airship the Hindenburg contained hydrogen when it burst into fire in a publicized incident. While 35 people lost their lives and another 62 survived, the Hindenburg did not explode, it caught fire. The flames spread quickly and the airship sank to the ground. The fire started as the airship was venting some of its hydrogen, to get closer to the ground, during an electrical thunderstorm. The airship was also moored to the ground by a steel cable, which acts as an antenna for electrical discharges.

Prior to the fire, the Hindenburg had completed 10 round trips between the U.S. and Europe. A sister ship, the Graf Zeppelin, made regular scheduled transatlantic crossings from 1928 to 1939 with no incidents. There were 161 rigid airships that flew between 1897 and 1940, almost all of these used hydrogen and 20 were destroyed by fires. Of these 20, seventeen were lost in military action where in many cases the fires resulted from enemy fire during World War I.

Hydrogen explosions can be powerful when they occur, but they are rare. Hydrogen must be in a confined space for an explosion to occur. In the open it is difficult to cause a hydrogen explosion without using heavy blasting caps.

In 1974, NASA examined 96 accidents or incidents involving hydrogen. At this time, NASA tanker trailers had moved more than 16 million gallons of liquid hydrogen for the Apollo-Saturn program. There were five highway accidents that involved extensive damage to the liquid hydrogen transport vehicles. If gasoline or aviation fuel had been used, a spectacular fire would have resulted, but none of these accidents caused a hydrogen explosion or fire.

A well publicized event where explosive mixtures of hydrogen and oxygen were present in a confined space occurred during the events in 1979 at the Three Mile Island (TMI) nuclear facility in Pennsylvania. Nuclear reactors operate at very high temperatures. To prevent their six to eight inch thick steel reactor vessels from melting, large amounts of cooling water are continuously circulated in and around the reactor vessel. An average commercial-sized reactor requires about 350,000 gallons of water per minute. During the process of nuclear fission, the center of the uranium fuel pellets in the fuel rods can reach 5,000°F. The cooling water keeps the surface temperature of the pellets down to about 600°. If the circulating water is not present, in 30 seconds the temperatures in the reactor vessel can be over 5,000°. This temperature is high enough to melt steel and thermochemically split any water present into an explosive mixture of hydrogen and oxygen. This is what happened at TMI. If a spark had ignited the hydrogen gas bubble that drifted to the top of the containment building, the resulting explosion could have fractured the walls. This would have resulted in the release of large amounts of radiation at ground level. The hydrogen gas bubble was vented, since as long as it remained in the confined space of the containment building, the potential for detonation existed. A hydrogen gas bubble developing from a nuclear reactor accident is a highly unusual event and is an example of the particular environment that is required for hydrogen to explode.

At Wright-Patterson Air Force Base, armor-piercing incendiary and fragment simulator bullets have been fired into aluminum storage tanks containing both kerosene and liquid hydrogen. The test results indicated that the liquid hydrogen was safer than conventional aviation kerosene. Other tests have involved simulated lightning strikes, with a 6-million volt generator that fired electrical arcs into the liquid hydrogen containers. None of these tests caused the liquid hydrogen to explode. Fires did occur from the simulated lightning strikes, but the fires were less severe even though the total heat content of the hydrogen was twice that of kerosene. These tests indicated that liquid hydrogen would be safer than fossil fuels in combat where a fuel tank could be penetrated.

Hydrogen does have a wider range of flammability when compared to gasoline. A mixture as low as 4% hydrogen in air, or as high as 74% will burn, while the fuel to air ratios for gasoline range from 1 to 7.6%. It also takes very little energy to ignite a hydrogen flame, about 20 micro-joules, compared to gasoline which requires 240 micro-joules. However, these characteristics are reduced by the fact that as the lightest of all elements, hydrogen has a very small specific gravity. The diffusion rate of a gas is inversely proportional to the square root of its specific gravity so the period of time in which hydrogen and oxygen are in a combustible mixture is much shorter than other hydrocarbon fuels. The lighter the element is, the more rapidly it disperses when it is released in the atmosphere.

In a crash or accident where hydrogen is released, it rapidly disperses up and away from the ground and any combustible material within the area. Gasoline and other hydrocarbon fuels are heavier since the hydrogen is bonded to carbon which is a much heavier element. When hydrocarbon fuels vaporize, their gases tend to sink rather than rise into the atmosphere. This allows burning gasoline to cover objects and burn them. In most accidents, hydrogen would be a more desirable fuel.

In 1977, two fully loaded Boeing 747 commercial aircraft crashed into each other on a foggy runway in the Canary Islands. This accident was then the worst in aviation history and took 583 lives. An inquiry concluded most of the deaths in the Canary Islands accident resulted from the aviation fuel fire that lasted for more than 10 hours. G. Daniel Brewer, who was the hydrogen program manager for Lockheed, stated that if both aircraft had been using liquid hydrogen as fuel instead of kerosene, hundreds of lives would have been saved. He listed several reasons. The liquid hydrogen would not react with oxygen and burn until it first vaporized into a gas. As it evaporated, it would dissipate quickly. This would limit the fuel fed portion of the fire to only several minutes instead of hours. The hydrogen fire would have been confined to a relatively small area as the liquid hydrogen vaporized and dispersed into the air, burning upward, instead of spreading like the aviation fuel. The heat radiated from the hydrogen fire would be far less than a hydrocarbon fire and only objects close to the flames would be affected. Hydrogen fires produce no smoke or toxic fumes, which is often the cause of death in fires.

In a liquid hydrogen fuel storage tank the gaseous hydrogen vaporizes and fills the empty volume inside the tanks. This hydrogen is not combustible since there is no oxygen present. In gasoline or other hydrocarbon fuel tanks, air fills the empty volume of the tanks and combines with vapors from the fuel to produce a combustible mixture.

On September 11, 2001, two fully loaded Boeing 767 commercial aircraft were hijacked and flown into the World Trade Center towers. Over 3,000 were killed as fires from the jet fuel caused the buildings to collapse. If hydrogen were used as the fuel, the damage would have been limited to the immediate crash sites, the buildings would probably be still standing and many lives would have been spared.

The hydrogen studies by Lockheed found that along with the fuel's safety characteristics, liquid hydrogen fueled aircraft would be lighter, quieter, with smaller wing areas and could use shorter runways. Pollution would be much less and the range of an aircraft could be almost doubled, even though the takeoff weight remain about the same.

A hydrogen fueled vehicle could be fueled by vacuum jacketed liquid hydrogen storage tanks. Vacuum jacketed cryogenic fuel lines carry the liquid hydrogen from the storage tanks. One of the two lines, takes up the gaseous hydrogen displaced from the fuel tank by the incoming liquid hydrogen for returning to the liquefaction plant.

Dr. Warner Von Braun was a German rocket engineer who helped to develop the V-2 rockets in World War II. He was involved in the first efforts to use liquid hydrogen as a rocket fuel. After the war, Von Braun had a major part in the development of the rocket engines for the U.S. space program.

Since liquid hydrogen has the greatest energy content per unit weight of any fuel, NASA used liquid hydrogen as the primary fuel for the Saturn 5 moon rockets and the Space Shuttle.

The Shuttle's main liquid hydrogen-oxygen tank is the largest of the three external tanks. The two smaller boosters use a solid aluminum based fuel.

NASA has also funded research by several aerospace firms, including Lockheed and Boeing, to determine if liquid hydrogen could be practical for commercial aircraft and what modifications would be needed for airports and fueling systems.

NASA has used large quantities of gaseous and liquid hydrogen for many years, which required developing the necessary pipelines, storage tanks, barges and transport vehicles. As a result of this experience, NASA has concluded that hydrogen can be as safe or in some ways safer, than gasoline or conventional aviation fuels.

NASA originally wanted to develop a reusable manned liquid hydrogen-fueled launch vehicle for the space shuttle program, but Congress would not vote for the additional funds that would be needed. Less expensive solid rocket boosters were used, which turned into a tragedy when one of the seals of the solid rocket boosters failed during a cold weather launch. This caused the explosion of the Challenger shuttle in 1986 and the loss of its entire crew, including the first teacher on a spaceflight.

BIOMASS HYDROGEN

Biomass could be a source of hydrogen. The biomass includes any material that is part of the agricultural growing cycle. Agricultural food, wood and waste products can be used as well as trees and grasses grown as energy crops.

Biomass may be a low cost renewable source of hydrogen in the near future. It could be a major renewable source of hydrogen. Biomass can be gasified and converted into hydrogen and electric power. The process is similar to coal gasification.

Biomass gasification processes are in the demonstration phase. Biomass can also be gasified together with coal. Royal Dutch/Shell has commercially demonstrated a 25/75 biomass/coal gasifier.

The CO_2 could be extracted from biomass gasification since it is similar to coal gasification. It would mean extracting CO_2 from the air while growing and then injecting that CO_2 into underground reservoirs through the gasification and sequestration process.

Biomass may not be feasible for small scale on site hydrogen production. The cost of delivered hydrogen from biomass gasification is estimated to range from $5 to $6/kg, depending on the type of delivery used. Studies by NREL suggest a lower cost, especially for pyrolysis, if the technology is improved. Waste biomass, such as peanut shells or bagasse which is the residue from sugar cane is the most cost-effective source, but the supply is limited.

Pyrolysis involves the use of heat to decompose biomass into its components. This could result in bio-refineries where biomass is converted into many different useful products. The biomass is dried and heated, the coproducts are removed and hydrogen is produced using steam reforming.

Hydrogen from biomass would have to be cost-competitive with gasoline and with other sources of hydrogen. If hydrogen is generated from large biomass plants away from cities, there would be significant infrastructure costs for delivering the hydrogen to consumers.

Even in a country with much arable land such as the U.S., a large part of the agricultural land would be needed for biomass production for it to serve as a major source of fuel. A good fraction of arable land in the United States (and the world) would be needed for biomass-to-hydrogen production sufficient to displace a significant fraction of gasoline which may not be a practical or politically feasible approach. The United States uses about 350 million acres for crops and about 10% of this is cropland idled by federal programs.

Anaerobic digestion, like pyrolysis, occurs in the absence of air. But, the decomposition is caused by bacterial action rather than high temperatures. This process takes place in most biological materials, but it is accelerated by warm, wet and airless conditions. It occurs naturally in decaying vegetation in ponds, producing the type of marsh gas that can catch fire.

Anaerobic digestion also occurs in the biogas that is generated in sewage or manure as well as the landfill gas produced by refuse. The resulting gas is a mixture consisting mainly of methane and carbon dioxide. Bacteria breaks down the organic material into sugars and then into acids which are decomposed to produce the gas, leaving an inert residue whose composition depends on the feedstock. The manure or sewage feedstock for biogas is fed into a digester in the form of a slurry with up to 95% water. Digesters range in size from a small unit of about 200 gallons to ten times this for a typical farm plant and as much as 2000 cubic meters for a large commercial installation. The input may be continuous or batch.

Digestion may continue for about 10 days to a few weeks. The bacterial action generates heat but in cold climates additional heat is normally required to maintain a process temperature of about 35°C. A digester can produce 400 cubic meters of biogas with a methane content of 50% to 75% for each dry ton of input. This is about two thirds of the fuel energy of the original fuelstock. The effluent which remains when digestion is complete also has value as a fertilizer.

FUEL FROM WASTES

A large part of municipal solid wastes (MSW), is biological material. Its disposal in deep landfills furnishes suitable conditions for anaerobic digestion. The methane that is produced was first viewed as a possible hazard and this led to systems for burning it off. In the 1970s some use was made of this product. The waste matter is miscellaneous in a landfill compared to a digester and the conditions not as warm or wet, so the process is much slower, taking place over years instead of weeks. The product is called landfill gas (LFG) and is a mixture consisting mainly of CH_4 and CO_2.

A typical site may produce up to 300 cubic meters of gas per ton of wastes with about 55% by volume of methane. In a developed site, the area is covered with a layer of clay or similar material after it is filled, producing an environment to encourage anaerobic digestion. The gas is collected by pipes buried at depths up to 20 meters in the refuse. In a large landfill there can be several miles of pipes with as much as 1000 cubic meters an hour of gas being pumped out. The gas from landfill sites can be used for power generation. Some plants use large internal combustion engines, standard marine engines, driving 500-kW generators but gas turbines could provide improved efficiencies.

The fuel gas from biomass gasifiers can be used to operate gas turbines for local power generation. A gas-turbine power station is similar to a steam plant except that instead of using heat from the burning fuel to produce steam to drive the turbine, it is driven directly by the hot combustion gases. Increasing the temperature in this way improves the thermodynamic efficiency, but in order not to corrode or foul the turbine blades the gases must be very clean which is why many gas-turbine plants use natural gas.

One biomass conversion plant converts wood chips into a methane rich gas that can be used in place of natural gas. Another biomass plant in Maine burns peat to produce power. In addition to trees, some smaller plants, like the creosote bush, which grow in poor soil under dry conditions, can be used as biomass. The biological materials that can be used as fuel can be grown on otherwise unproductive land.

BIOMASS POTENTIAL

Developing biomass energy can provide economic, political, social and environmental advantages. The energy potential of biomass has been estimated at almost 42 quadrillion Btus which is about 1/2 of the total energy consumption in the United States. Biomass provides the U.S. with about the same amount of energy as the nuclear industry.

Biomass can provide substitutes for fossil fuels as well as electricity and heat. Its resource base is varied. Arid land, wetlands, forest, and agricultural lands can provide a variety of plants and organic matter for biomass feedstock.

Converting waste products to energy also lowers disposal costs and provides cost savings in purchasing energy supplies. Profitability can be improved by using waste to create energy. The sugar industry converts bagasse to energy and sells excess power. Biomass facilities often require less construction time, capital, and financing than many conventional plants.

Greenhouses, lumber mills, canneries, farmers, and manufacturers can reduce energy and disposal costs by using their waste as feedstock for energy systems. In Ireland, greenhouses for early tomatoes are heated with biomass from willow wood. The willow wood fuel costs one third as much as the oil it replaced.

In the Northeast alone, biomass accounts for over $1 billion in the economy and almost 100,000 jobs. Biomass production offers crop alternatives and the potential for increased income to farmers. Fields that are not used in winter can produce biomass, and varying crops in the same fields can help protect soil quality.

Biomass energy offers an increased supply with a positive environmental impact. If grown on a sustainable basis, it causes no net increase in carbon dioxide and the use of alcohol fuels reduces carbon monoxide emissions. Biomass is renewable as long as it is grown on a sustainable basis.

Although the feedstocks are widespread, they must be used locally since their bulk makes it costly to transport the feedstocks. In California, it has been uneconomical to transport wood residues more than 100 miles. The bulkiness of biomass resources can also cause storage problems.

Many available biomass feedstocks have a high moisture content, which lowers their heat value. Preprocessing can help, but adds to the cost. There are also some biomass conversion technologies that are only marginally beneficial and this keeps them from being cost-competitive.

A large increase in biomass energy production has the potential to cause serious environmental problems. Land use issues and concerns about pollution are major concerns. Areas with fragile ecosystems and rare species would need to be preserved. Agricultural lands would also compete with food production. The loss of soil fertility from overuse is a concern. Biomass production would need to be varied and sustainable while preserving local ecosystems.

Pollution problems could result from the expanded use of fertilizers and bioengineered organisms on energy farms. The introduction of hazardous chemicals from MSW into the agricultural system could result in increased air and water pollution.

The usual goal for installing other energy systems in industries or institutions is to achieve a net savings in energy costs. These savings are achieved when the energy costs of the sources being replaced are more than the total operating and installation costs of the energy system.

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Chapter 4

Hydrogen Sources

Most of the hydrogen that is manufactured now is made by reacting natural gas with high temperature steam, to separate the hydrogen from the carbon. But, manufacturing hydrogen from fossil fuel resources does not help the fossil fuel depletion problem. Hydrogen could become the prime provider of energy, that would solve the problems of atmospheric pollution and oil depletion. Hydrogen powered fuel cells have wide applications and could replace batteries in many portable application, power vehicles and provide home and commercial electrical needs.

Making hydrogen from water through electrolysis was initially promoted by nuclear engineers who thought that nuclear generated power would be inexpensive enough to make hydrogen.

In Britain, one hydrogen experiment was financed by the Swedish steel industry and SAAB among other firms. Power at a small home was provided by a computer-controlled windmill in the garden. The power was used to electrolyse filtered water into hydrogen and oxygen. The hydrogen gas was used for cooking and heating the house and as fuel for a SAAB car.

Hydrogen has an energy content three to four times higher than oil, and it can be produced from all known energy sources, besides being a byproduct of many industrial processes.

The National Academy of Sciences committee believes that the transition to a hydrogen economy could take decades. Challenges exist in producing, storing and distributing hydrogen in ample quantities at reasonable costs without producing greenhouse gases that may affect the atmosphere. The extraction of hydrogen from methane generates carbon dioxide. If electrolysis is used for splitting water into hydrogen and oxygen, the electricity may be produced by burning fossil fuels which generates carbon dioxide. Hydrogen is also a leak-prone gas that could escape into the atmosphere and set off chemical reactions.

Also, using fossil fuels to make hydrogen can take more energy than that contained in the hydrogen. Researchers at the Idaho National Engineering and Environmental Laboratory and Cerametec in Salt Lake City have found a way to electrolyze water and produce hydrogen with less energy. The higher production rate of hydrogen is obtained with high-temperature electrolysis. An electric current is sent through water that is heated to about 1,000°C. As the water molecules break up, ceramics are used to separate the oxygen from the hydrogen. The hydrogen that is produced has about half the energy compared to the energy required for the process.

Most of the hydrogen used in the chemical and petroleum industry is manufactured from natural gas, which has a hydrocarbon molecule of four hydrogen atoms bonded to one carbon atom. Gasoline is a hydrocarbon molecule that is made up of eighteen hydrogen atoms that are attached to a chain of eight carbon atoms. High temperature steam is used to separate the hydrogen from the carbon. If the cost of the natural gas is $4 per million British thermal units (MMBtu), the cost of the gaseous hydrogen will be about $10.00 per MMBtu. If the hydrogen is liquefied, an additional $8.00 to $10.00 per MMBtu must be added to the cost of the gaseous hydrogen, making the cost of liquid hydrogen produced by this method about $20.00/mmBtu. If hydrogen is manufactured from water with electrolysis equipment, its cost is roughly equivalent to $5/mmBtu per 10 mills ($5/mmBtu/cent/kWh) and will follow the increasing cost of energy.

Hydrogen can also be manufactured from coal-gasification facilities at a cost that now ranges from $8 to $12 per MMBtu, depending on the cost of coal and the method used to gasify it. But, making hydrogen from nonrenewable fossil fuels does not solve the problem of diminishing resources or the environmental problems.

Most of the easy-to-get oil has already been found, and increasingly, exploration efforts have to drill in areas that are more difficult. Many areas have been closed to drilling in the United States. At some point, in the future, it may take more energy to extract the remaining fossil fuels than the energy they contain.

HYDROGEN GENERATION

Hydrogen production has commercial roots that go back more than a hundred years. Hydrogen is produced to synthesize ammonia (NH_3), for fertilizer production, by combining hydrogen with nitrogen. Another major use is hydro-formulation, or high-pressure hydro-treating, of petroleum in refineries. This process converts heavy crude oils into engine fuel or reformulated gasoline. The annual world production is about 45 billion kgs or 500 billion Normal cubic meters (Nm^3). A Normal cubic meter is a cubic meter at one atmosphere of pressure and 0°C. About one half of this is produced from natural gas and almost 30% comes from oil. Coal accounts for about 15% and the rest 4-5% is produced by electrolysis.

Hydrogen production in the United States is currently about 8 billion kg (roughly 90 billion Nm^3). This is the energy equivalent of 8 billion gallons of gasoline. Hydrogen demand increased by more than 20% per year during the 1990s and has been growing at more than 10% per year since then. Most of this is due to seasonal gasoline formulation requirements.

HYDROGEN RESEARCH

The U.S. has invested millions of dollars and decades of innovation in hydrogen energy technology. More than fifty years of direct investment by NASA and the Department of Defense has created a national ability in using hydrogen energy. The Department of Energy's National Laboratory system has contributed greatly in the support technology for the implementation of hydrogen energy. These National Laboratories are significant resources for our energy future. These centers can help in addressing complex and risky technical questions. Few industries can afford to conduct the R&D that is conducted at these labs. Solar hydrogen production from photocatalytic water splitting is one of these areas.

Hydrogen as an energy carrier has great potential as the foundation for a globally sustainable energy system using renewable energy. Hydrogen can be made safely and environmentally friendly from water. The many potential energy uses include powering non-polluting vehicles, heating homes and fueling aircraft.

One hydrogen research project, part of the Strategic National R&D Program, includes thermochemical, photocatalytic and photobiological water splitting for generating hydrogen using sunlight as the primary energy source.

Solar hydrogen production from photocatalytic water splitting involves the cleavage of water to form hydrogen and oxygen and would be an ideal source of hydrogen for energy needs. The feedstock is water and the resulting fuel, hydrogen, burns with little or none polluting products.

The main reaction product is water vapor. The water splitting reaction is endothermic and the energy required for a significant hydrogen production rate is high.

Solar energy is available in abundant supply and nonpolluting. It is an extremely attractive means to convert solar energy to chemical energy.

The photocatalytic process uses semiconducting catalysts or electrodes in a photoreactor to convert optical energy into chemical energy. A semiconductor surface is used to absorb solar energy and to act as an electrode for splitting water. The technology is still at an early stage of development. The most stable photoelectrode is TiO_2 but this material has a conversion efficiency of less than 1%. New materials, which require no external electricity still need to be found. In order to reduce corrosion, ultra thin layers of protective material on the semiconducting surface may be used. Research is also directed in the areas of low cost systems, multiple layers of organic dyes, and thin film semiconductors.

Hydrogen production can also be based on a water-splitting thermochemical cycle using metal oxides. The simplest thermochemical process to split water involves heating it to a high temperature and separating the hydrogen from the equilibrium mixture. The decomposition of water does not progress well until the temperature is about 4700 degrees K. The problems with materials and separations at such high temperatures makes direct decomposition not practicable at this time. A two-step water-splitting cycle, based on metal oxides redox pairs bypasses the separation obstacle. Multi-step thermochemical cycles allow the use of more moderate operating temperatures, but their overall efficiency is limited by an irreversibility associated with heat transfer and product separation.

Hydrogen production by a 2-step water splitting thermochemical cycle based on metal oxides redox pairs is being investigated in the areas of the thermodynamics, technical feasibility, and cost. A lower-valence metal oxide is able to split water with a partial reduction of the metal oxide without the use of a reducing agent. Hydrogen and oxygen are derived in different steps, without the need for high temperature gas separation. Possible redox pairs include the following: Fe_3O_4/FeO, ZnO/Zn, TiO_2/TiO_x (with $X < 2$), Mn_3O_4/MnO and Co_3O_4/CoO.

Hydrogen has a unique role in a secure energy future for the United States. The U.S. could be energy self-sufficient with hydrogen, ensuring our national stability from an energy security, supply, and economic perspective.

Hydrogen can also be produced from resources that are renewable, such as the direct and indirect sources of solar energy, this includes the large quantities of agricultural wastes, sewage, paper and other biomass materials that have been accumulating in landfills.

Generating hydrogen from such waste materials may turn out to be one of the least expensive methods of producing hydrogen since this resource is quite extensive. It has been estimated that in the U.S., roughly 14 quads of the annual 64 quad total energy requirement could be met from renewable biomass sources, which is about 20% of our total energy needs.

Sewage in vast quantities of billions of gallons per day could be recycled to produce a renewable source of hydrogen. This can be accomplished either by utilizing the non-photosynthetic bacteria that live in the digestive tracts and wastes of humans and other animals, or by pyrolysis-gasification methods.

Advanced sewage treatment systems could turn the billions of gallons of raw sewage that is being dumped into rivers and oceans into relatively low-cost hydrogen.

High-temperature nuclear-fusion reactors may some day be practical as renewable sources of energy for hydrogen production, but they are most likely many years away. Typically, over 100 million degrees F temperatures are required for nuclear fusion to occur and this technology, while under development, is not expected to be commercially viable in the near future.

NATURAL GAS HYDROGEN

Natural gas is the least expensive source of hydrogen today. But, there may not be enough natural gas to meet the demand for natural gas power plants and to supply a hydrogen fueled economy. The prices of natural gas, hydrogen and electricity could see dramatic increases as the demand for natural gas to make hydrogen increases.

The delivered cost of hydrogen from natural gas would need to become competitive with the delivered cost of gasoline. The infrastructure costs must be managed over time with total estimates reaching a trillion dollars or more.

It is not known which would be cheaper and more practical, electrolysis or reforming methane at small local filling stations or at large centralized plants. Technological advances are sure to change many aspects and questions.

Water is the source of hydrogen for the electrolysis process. Decomposing water into hydrogen and oxygen using electricity is a mature technology widely used around the world to generate very pure hydrogen. But, it is energy intensive and the faster you generate the hydrogen, the more power that is needed per kilogram produced. Commercial electrolysis units need almost 50-kWh per kilogram, which represents an energy efficiency of 70%. This means that more than 1.4 units of energy must be provided to generate 1 energy unit in the hydrogen.

Most electricity comes from fossil fuels, and the average fossil fuel plant is about 30% efficient, then the overall system efficiency is close to 20% (70% times 30%). Almost five units of energy are needed for every unit of hydrogen energy produced.

Larger electrolysis plants are cheaper to build per unit output and they would provide a lower price for electricity generation than smaller ones at local filling stations. These smaller plants are sometimes called forecourt plants since they are based where the hydrogen is needed.

Hydrogen can be generated at off-peak rates, but that is easier to do at a centralized product facility than at a local filling station, which must be responsive to customers who typically do most of their fueling during the day and early evening, the peak power demand times. To circumvent peak power rates, the National Renewable Energy Laboratory (NREL) suggests that forecourt plants would need large oversized units operated at low utilization rates with large amounts of storage. This would require additional capital investment. It is estimated that the cost of producing and delivering hydrogen from a central electrolysis plant is $7-$9/kg. The cost of production at a forecourt plant could be $12/kg.

High cost is probably the major reason why only a small percentage of the world's current hydrogen production comes from electrolysis. To replace all the gasoline sold in the United States today with hydrogen from electrolysis would require a doubling of the electrical power that is sold in the United States at the present time which is about 4 trillion kW.

HYDROGEN USE

Hydrogen use is continuing to grow in the United States, building a national core competence in hydrogen applications. It is used as an industrial chemical, an energizing additive to fossil fuel, a coolant and an aerospace fuel. Hydrogen is the lightest and most abundant element in the universe. It can exist as a gas or a liquid and can also be stored at room temperature in a solid form (hydride) as a compound.

For the past several years both industry and government have explored ways to use hydrogen as a commercial fuel. Hydrogen may be used to generate power by combustion or by using direct conversion with fuel cells. Both generation methods are highly efficient and environmentally clean. Hydrogen produced from electrolyzing water or from reforming fossil fuels is currently used in over one hundred different industries from petrochemical and glass manufacturing to food processing and electronics. The use of hydrogen is growing rapidly worldwide but the Hydrogen Economy will be realized when hydrogen becomes competitively priced as an energy commodity rather than as a chemical.

Hydrogen energy for commercial power is primarily the result of the initial investments the U.S. made in defense and aerospace technology. NASA is one of the largest users of hydrogen as a fuel. The Department of Defense and the Department of Transportation are expanding their interests in hydrogen both as a fuel and in the uses of fuel cells. The potentially large economic and security advantages of using locally produced hydrogen as a widespread energy carrier for both stationary and transportation applications is now recognized by both the Administration and the Congress. Enabling legislation, including reauthorization of the Hydrogen Future Act, enjoys widespread bipartisan support. The Vice Presidential task force on energy also gave formal recognition to hydrogen as a key element in the National Energy Policy Report.

Government participation in these activities is the absorption of the high risks in the development and deployment of these enabling technologies. The Government recognizes the promise of hydrogen energy and can assist industry to promote commercialization of the technologies, the growth of industry and the development of a compatible infrastructure.

A growing number of states are taking initiatives in implementing hydrogen energy projects. California is doing this in transportation applications. The California Fuel Cell Partnership has been placing fuel cell passenger cars and fuel cell buses on the road. In addition to testing fuel cell vehicles, the Partnership will also identify fuel infrastructure issues and prepare the California market for this new technology. Texas is taking action with stationary and portable applications through the Texas Fuel Cell Alliance. Florida has a hydrogen business council to increase awareness and initiate hydrogen projects, building on NASA's longstanding commitment to hydrogen.

Hydrogen is a proven, effective carrier of energy that has been used regularly by NASA and the petrochemical community. Today our cars are fueled with hydrogen enriched gasoline and the automobile industry is developing fuel cell powered cars operating on hydrogen while the capacity to produce and distribute hydrogen in the United States is growing.

Hydrogen can be a complement to other renewable energy technologies such as wind or solar because of its unique ability to store energy and release it efficiently, and should be embraced by all clean energy advocates.

Foreign governments are also investing heavily in hydrogen energy. Japan's WE-NET program and the Canadian/German direct sponsorship of Ballard, the pioneer in fuel cell development, are major examples. Iceland has made an announcement that it will be implementing hydrogen energy with government money in concert with Norsk Hydro Electrolysers, DaimlerChrysler, and British Dutch Shell.

There are champions for hydrogen on Capitol Hill and in the current administration. These champions see the promise of hydrogen as it evolves into an American energy commodity changing the economics of energy around the world.

The support for hydrogen is bipartisan. Hydrogen's inclusion in the National Energy Policy was important. There are increasing calls for national hydrogen imperatives of meaningful scale based upon emerging technologies. The rising tide of a hydrogen vision can result in a firm foundation for implementation. The U.S. Congress has a responsibility to assure there will not be improper regulatory barriers or trade restrictions that prevent this new American industry from competing internationally. The Hydrogen Technical Advisory Panel, appointed by the Secretary of Energy, has recognized this as well as hydrogen's unique ability to address national security imperatives.

Many U.S. companies are supporting the implementation of hydrogen. They can compete effectively on an international basis and build a real economic force. A key part of our security is to build equipment that can be exported to our allies. Our industrial base can then enjoy access to world markets.

Hydrogen could compete economically. Utilization concepts range from fuel cells to internal combustion with hydrogenated fuels. These offer flexibility without source dependency. As an energy carrier, hydrogen has some key characteristics: manufactured and stored locally, economic control over energy and environmental quality.

The increased use of renewable hydrogen energy can reduce the vulnerability to physical attack, economic attack by OPEC sanctions or embargo, terrorist attacks (since hydrogen dissipates faster than gas or jet fuel), and many cumulative environmental problems.

Hydrogen energy is an important long-range solution to our dependence on oil. A sudden rise in gasoline prices occurs when even one refinery shuts down since we have not built a new refinery in over 30 years and we are becoming more dependent than ever on foreign oil.

The price of oil itself is not clearly accounted for until the subsidies for exploration and the actual cost of Middle East defense is added. Only recently have the true costs of fossil fuel energy been studied, from defense commitments to long term health care for nationwide respiratory illnesses. Hydrogen must face economic comparisons to gasoline, but we notice that the oil and gas industries are already investing in the hydrogen economy.

GASOLINE REFORMING

The use of available fuels will allow fuel cells on the market more quickly. Hydrogen could be processed from gasoline onboard vehicles until hydrogen becomes a more practical fuel choice. DaimlerChrysler has been working with an onboard sensor that would tell what kind of fuel is being pumped in and then adjust the reformer on the fly. This system would allow different fuels to be reformed at different temperatures using varying proportions of steam and air.

An onboard hydrogen tank has several problems since hydrogen leaks easily, is hard to store and hard to compress and burns quickly. Overcoming all these concerns has been expensive but most of the major auto companies has solved these problems for the most part in their prototype fuel cell vehicles. Refueling tends to be difficult although there are now a number of hydrogen refueling stations in use around the world.

STEAM REFORMING

Steam reforming is expected to remain the most cost-effective means for producing hydrogen in volume. A steam reformer's main function is to produce hydrogen. Hydrocarbon feed gas is mixed with steam and passed through catalyst-filled tubes. Hydrogen and carbon oxides are produced. Steam reformers are also used in syngas, ammonia and methanol plants.

The hydrogen producing reactions are limited by thermodynamic equilibrium. The reactions must take place under carefully controlled external firing, with heat transfer taking place from the combustion gas in the firebox to the process gas in the catalyst-filled tubes. Carbon monoxide in the product gas is converted almost completely to hydrogen in the downstream catalytic reactor.

Hydrocarbon feedstocks for steam reformers include natural gas, refinery gas, propane, LPG and butane. Naphtha feedstocks with boiling points up to about 430°F can also be used. The ideal fuels for steam reformers are light hydrocarbons such as natural gas and refinery gas, although distillate fuels are also used. Residual fuels are not used since they contain metals that can damage reformer tubes.

Reformers are fired to maintain a required process gas outlet temperature. Most modern reformers are top fired. In a top-fired reformer, the burners are located at the top of the furnace and fire downward. Process gas flows downward through catalyst-filled tubes. This flow of process gas and flue gas allows the highest flue gas temperature when the in-tube process gas temperature is lowest and the lowest flue gas temperature when the in-tube process gas temperature is highest. This results in tubewall temperatures that are uniform over the tube's length and since the average tubewall temperature is lower this reduces tube cost and increases tube life.

Also, as the flue gas cools, it sinks in the same direction as its normal flow which results in stable furnace operation. Flue gas back-mixing is avoided and the flue-gas outlet temperature is closer to the process-gas outlet for maximum furnace efficiency.

The burners at the reformer's top are in an enclosure called a penthouse. The flue gas is collected at the bottom in horizontal fire-brick ducts called tunnels. Flue gas exits horizontally into a waste heat recovery (WHR) unit. Combustion gas is drawn through the WHR unit by an induced-draft fan and then discharged to the atmosphere through a stack.

The shift reaction is independent of pressure, but the reforming reaction equilibrium is favored by low pressure. At lower pressures, the conversion of hydrocarbon to hydrogen is higher.

In most hydrogen plants, a pressure-swing adsorption (PSA) system is used for hydrogen purification. In these plants, a major portion of reformer fuel is PSA offgas with a hydrocarbon stream for makeup fuel.

Modern hydrogen plants typically use a PSA unit for hydrogen purification since PSA units are more efficient at higher pressures. The minimum pressure for PSA operation is 150 to 200 psig. The optimum pressure may be as high as 300 to 400 psig. In hydrogen plants the reformer outlet pressure usually runs between 150 and 400 psig.

In most applications, the hydrogen product requires a much higher pressure for refinery hydrotreating applications. Hydrogen plant reformers typically operate at process gas outlet temperatures of up to 1,600°F. At these temperatures, the outlet piping limits the reformer outlet pressure to about 400 psig. This corresponds to a hydrogen product pressure of about 350 psig.

The reforming reaction equilibrium is favored by high temperature. Reformer process-gas exit temperatures are typically 1,500°F to 1,600°F. Lower temperatures give inadequate conversion and higher temperatures increase metallurgical requirements, tubewall thickness and fuel consumption. The reforming reaction rate becomes significant at about 1,000°F. An inlet temperature near this value is typically achieved by preheating the reformer feed.

The hydrocarbon feed must contain sufficient steam to avoid carbon formation on the catalyst. The steam-to-carbon ratio is defined as moles of steam per mole of carbon in the hydrocarbon. The steam-to-carbon ratios are about 3.0 for hydrocarbon feedstocks but lower values can be used for some feedstocks. Carbon formation is more likely with heavier feedstocks. An alkali-based catalyst can be used to repress carbon formation.

Heat flux is defined as heat input per unit of time per square unit of inside tube surface. A low heat flux provides extra catalyst volume and lower tubewall temperatures. This increases the reforming reaction conversion and increases tube life. A high heat flux reverses these effect, but reduces the number of tubes. The flux is highest at the zone of maximum heat release and then drops to a relatively low value at the tube outlet.

The reformer pressure drop depends on the number of tubes, tube diameter and catalyst selection. The typical pressure drop ranges from 40 to 60 psi. The reforming catalysts are made in a ring or modified ring form. Nickel is the chief catalytic agent. Heavier feedstocks use an alkali promoter is to suppress carbon formation.

Higher heat fluxes require a modified ring shape to sustain the reforming reaction conversion. A dual charge of catalyst may also be used. The tube's top half has a high-activity catalyst to prevent carbon formation in the maximum flux zone. The bottom half may be a more conventional and less expensive catalyst. The modified ring catalysts can furnish higher activity for about the same pressure drop.

The reformer tubes typically operate at maximum temperatures of 1,600°F to 1,700°F and are designed for a minimum stress-to-rupture life of 100,000 operating hours. A 35/25 Ni/Cr alloy is used that is modified with niobium and microalloyed with trace elements such as titanium and zirconium. Smaller tube diameters provide better heat transfer and cooler walls. This reduces tube and fuel costs and increases tube life. But more tubes increases the pressure drop. The optimum inside tube diameter is 4 to 5 in. The wall thickness may be as low as 0.25 inch with a length of 40 to 45 ft. The lane spacing between tube rows must be enough to avoid flame impingement from the burners. Typical spacing is 6 to 8 feet.

The burners are located between tube rows. A larger number of burners reduces the heat release per burner and allows a smaller flame diameter and a reduced lane spacing. A ratio of one burner for every 2 to 2.5 tubes provides a uniform heat release. Most burners are a dual-fired design, firing both PSA offgas and supplemental makeup gas. Low NO_x burners are used to meet environmental requirements. Makeup gas can be used to induce flue gas into the flame, reducing the flame temperature and NO_x level. In a well functioning unit NO_x levels as low as 0.03 lb/MMBtu are possible.

The piping design limits variations in gas flow to the tubes and burners to ±2.5% to keep tubewall temperatures uniform. The PSA offgas flow is available to the burners at only about 3 psig. If preheated combustion air is used, the differential air pressure across each burner is typically less than 2 inches of water. The distribution is aided with symmetrical piping.

The flue gas tunnels are rectangular fire-brick structures at the reformer's bottom. They act as horizontal ducts for flue gas removal. The flue gas exits at 1,800°F to 1,900°F. A heat recovery unit is provided to recover heat from this gas. This unit contains a reformer feed preheat coil, steam superheat coil, steam generation coil and boiler feed water preheat coil.

When combustion air preheat is used, the air preheat unit may replace the boiler feed water coil. Flue gas exits this unit at about 300 degrees F. This provides a typical heat loss of 3% of the overall reformer efficiency. Steam is also made in a process steam generator which extracts heat from the reformer outlet process gas. The heat recovery unit and process steam generator normally have a common steam drum.

The steam generation pressure must be high enough to produce steam. The minimum pressure is 100 to 150 psig above the hydrogen product pressure, depending on the plant pressure drop. Considerably higher steam pressures are not uncommon. Reformers generating 1,500 psig steam can be found in some industries.

HYDROGEN AUTO POWER

Hydrogen powered cars need to hold enough fuel to get the 300 mile driving range of today's IC cars. Hydrogen service stations are few, so refueling becomes a problem. About 12,000 fuel stations in the hundred largest cities in the U.S. would put 70% of the population within 2 miles of fuel. At a cost of one million dollars per station, $12 billion would be needed to provide a fuel infrastructure. This is less than half of what it would cost to build the Alaska pipeline in today's dollars.

Shell Hydrogen is planning for the first use of fuel cell cars in 2010 with a surge between 2015 and 2025 but technical and market challenges could delay any commercial success of the fuel cell car. Car manufacturers must raise onboard hydrogen storage capacity, cut the price of fuel cell drive trains and increase the power plants' operating lifetimes. Hydrogen fueling must be in enough stations to allow drivers to enjoy a range comparable to diesel fuel. If fuel cell and internal combustion cars have the same refueling, power, and convenience features, and one costs much more than the other, it will suffer.

The 50 million tons of hydrogen that is produced worldwide per year is enough to fuel 200 million vehicles. The hydrogen produced from natural gas in a two step reforming process costs about $4 to $5 per kilogram which is the chemical equivalent of a gallon of gasoline.

When hydrogen is produced from water, it takes 50-kW of power costing about $2.50 per kg of hydrogen at present utility rates. This does not include other costs such as physical plants, storage facilities and transportation.

Plug Power, a Latham, NY, based manufacturer of stationary hydrogen fuel cell generator units for backup power has developed a hydrogen fueling station with the help of Honda. This station uses a small steam reformer that extracts hydrogen fuel from natural gas using steam. The steam reformer has been reduced to half the size of the previous version.

Along with refueling vehicles, the system provides hydrogen into a fuel cell stack to produce electricity for buildings on the site, which are also warmed by the waste heat generated by the power unit.

The fuel dispensing pump is about the size of a washing machine. First, the car is grounded by attaching a wire to the vehicle. The fuel hose nozzle is inserted into the refueling port and locked in place. Filling the car's tank takes about five or six minutes. The unit produces enough hydrogen to refill a single fuel cell vehicle a day. In Torrance, California, Honda has built a service station that splits water into hydrogen and oxygen using solar power.

The problems facing the development of a hydrogen infrastructure include the lack of demand for cars and trucks with limited fueling options and any incentive to invest in a fueling infrastructure unless there are enough vehicles on the road.

The global cost of a complete hydrogen transition over the next 30 years is estimated to cost from $1 to $5 trillion. A study by GM estimated that $10 billion to $15 billion would be needed to build 11,700 new fueling stations. This would allow a driver to be within two miles of a hydrogen station in most urban areas and there would be a station every 25 miles along major highways. The urban hydrogen stations could support about one million fuel cell vehicles. Twelve billion may seem like a lot of dollars, but in today's world, cable companies are paying $85 billion for cable system installations.

Hydrogen filling stations are now scattered in Europe, the U.S. and Japan. These are the first prototypes of an infrastructure with about 70 hydrogen refueling stations operating worldwide. The California Hydrogen Highway program has a goal of 200 stations along major highways in the state. The building of a hydrogen infrastructure in the 21st century can be compared to the investment in railroads in the 19th century or to the creation of the interstate highway system in the 20th century.

The 50 to 60 million tons of hydrogen produced in the U.S. a year may not be pure enough for fuel cells. Many of the problems in fuel cell development have occurred from impurities in the industrial hydrogen purchased for fuel.

ENVIRONMENTAL ISSUES

From the perspective of greenhouse gases, electrolysis is unsettled for the foreseeable future since both electrolysis and central-station power generation are relatively inefficient processes and most U.S. electricity is generated by the burning of fossil fuels. Nuclear and renewables make up only about 1/3 of total generation.

Burning a gallon of gasoline releases about 20 pounds of CO_2. Producing 1-kg of hydrogen by electrolysis could generate about 70 pounds of CO_2. A gallon of gasoline and a kilogram of hydrogen have almost the same energy, and even allowing for the improved efficiency of fuel cell vehicles, (more mpg or mpkg) producing hydrogen from electrolysis could produce more greenhouse gases if fossil fuels are used. These economic and environmental issues can make it difficult to pursue the generation of significant quantities of hydrogen from the present U.S. electric grid in the near future.

Hydrogen could be generated from renewable electricity, but the renewable system most suitable for local generation, solar photovoltaics, is expensive because of the cost of photovoltaic panels. The least expensive form of renewable energy, wind power, is only about one tenth of 1% of all U.S. generation, although that figure is rising.

Generating hydrogen from electrolysis powered by renewables is viewed by some as a good use of that power for economic and environmental reasons. But, the United States would need abundant low-cost renewable generation before it could divert a substantial fraction to the production of hydrogen. If forecourt hydrogen generation from solar photovoltaics becomes practical in the first half of the century, it could supply enough hydrogen to the growing amount of fuel cell cars and generating systems while hydrogen generated from the vast wind resources of the Midwest would need large infrastructure costs for delivering it to other parts of the country. A large steam reformer plant could supply 1 million cars with hydrogen.

While we may be close to cost-effective fuel cell prototypes, there must be the infrastructure to support them. Another problem that we are getting closer to is fuel storage and the high-density storage of hydrogen gas.

Methanol would allow a transitional phase where some fuel cell vehicles use methanol, which is relatively simple to reform and would not present too big a change from our current system. However, methanol is toxic and very corrosive. Gas stations would need to be retrofitted to operate with it (new fuel tanks and fuel lines.) But, many gas station tanks are already methanol- compliant.

Politics plays a role in which fuel is used. Ethanol, for example, can be made from corn and is popular in the Midwest.

Fuel cells are overdue in becoming a major part of our energy future. Then, one in three or even one in two of the cars on the road may be fuel cell vehicles. There are obstacles and challenges to that happening, but there does not seem anything insurmountable. The cost of materials is being reduced and high-volume manufacturing will bring production costs down. A decreased reliance on fossil fuels is needed with a mix of electrics, fuel cell cars and hybrids.

While the mass production of fuel cell cars is some time away, if cost-competitive fuel cell stacks are available soon, it can change the competitive mix of transportation options.

The present period is similar to 1900, when gasoline, electric, and steam cars all competed for market share, with the public and the industry unsure of the future. Fifty years from now the fossil fuel era may be seen as a distant memory just like we look at the steam age now.

FUEL CELLS ON THE MARCH

Fuel cells have been making advances in limited applications. Delta Airlines is using a hydrogen fueled tow tractor at the Orlando Airport. General Motors has delivered its first fuel cell truck to the U.S. Army while the U.S. Navy plans to use fuel cells for ship-board power with hydrogen sourced from diesel fuel. John Deere is testing fuel cell modules for off-road applications. Hydrogen is considered a good replacement for diesel in locomotives. Recent testing indicates that it could be economical for railroads.

Dow Chemical and General Motors are installing up to 400 fuel cells at Dow plants. Hydrogen is a natural byproduct at Dow and will provide 35 megawatts at its facilities.

The HyNor project in Norway includes plans to build a hydrogen highway between Oslo and Stavanger on the southern coast of the country with refueling stations spaced along the route. Iceland plans to build up a small fleet of fuel cell buses in the capital, Reykjavikk, and then slowly convert every vehicle on the island including fishing boats to create the world's first hydrogen economy.

In 1998 the auto industry moved from weak commitments to a solid move toward fuel cells and fuel cell vehicles. All the auto companies began pursuing hydrogen fuel cells in some way.

London's first fleet of fuel cell taxis went into operation in 1998. The ZEVCO Millennium vehicle appears to be a standard London taxi, but it has an alkaline fuel cell (most carmakers use PEM technology). The fuel cell charges a battery array used to power the electric motor. The fuel cell runs on hydrogen gas stored under the cab's floor and acts more like a range extender than a primary power source.

At the 2005 International Conference and Trade Fair on Hydrogen and Fuel Cell Technologies there were more than 600 fuel cell vehicles. In Europe the potential market for hydrogen and fuel cell systems is projected to reach several trillion Euros by 2020.

The new cars on the road in the future are likely to be a mix of vehicles including those with electric/hybrid drive. This would include battery EVs, hybrids with direct-injection diesels, turbo generators and fuel cells.

DaimlerChrysler is delivering fuel cell vehicles to customers in California. Shell Oil has established a Hydrogen Economy team dedicated to investigate opportunities in hydrogen manufacturing and fuel cell technology in collaboration with others, including DaimlerChrysler.

One of Ford's partners, Virginia-based Directed Technologies directed Ford to build that cars that carry hydrogen gas, eliminating the need for costly and bulky reformers. Along with onboard hydrogen storage, they also hold that the problems of building the hydrogen infrastructure can be overcome.

Others affirm the superiority of direct hydrogen, but feel that liquid fuels such as methanol are the answer for the near future. If methanol is used directly, there has to be an onboard reformer and a revised infrastructure to deliver it. But methanol does have some advantages. There is excess generating capacity, and it's the least expensive fuel to transport. Some 70% of the world's oil is in OPEC countries, and 65% of it is in the Persian Gulf. If we switch to methanol, which is produced from natural gas, we can diminish that dependency.

A truly zero-emissions hydrogen generating system using solar or natural sources is popular where the fuel is produced from an aggregate of photovoltaic collectors, wind generators, and biomass. This would allow a motor vehicle fuel so clean-burning that you could drink the effluent from the tailpipe with no urban smog from vehicles or generating stations.

For transportation, fuel cells have important advantages. Three main automotive goals are efficiency, range, and emissions. Gasoline and diesel fuels have the efficiency and range, but there are emissions problems. Batteries meet the emissions and the efficiency goals, but not the range. The fuel cell promises to have extremely low emissions, with excellent range and efficiency, providing the storage problems are solved. Hydrogen is an amazing substance. It is lighter than air. In its liquid form, you could throw it at people and it would evaporate before it hit them. However, fuel cells may be slow in coming. Fuel cell stacks are feasible in commercial form and the projected date of 2010 is a time some companies like DaimlerChrysler are comfortable with, after years of research and development. Complex fuel processors that can handle gasoline, like the system developed by Arthur D. Little, have been proved to work, but actual production models are still in development.

DaimlerChrysler's efforts to make a gasoline reformer work was slightly disappointing so the carmaker announced it would concentrate its efforts on methanol, signing on to a program advanced by its partners in the Alliance. Since then, DaimlerChrysler demonstrated a gasoline-powered fuel cell Jeep.

DaimlerChrysler was slow on producing hybrids, since it felt that Americans would not get too excited about fuel savings. The Toyota Prius and other hybrids have proved this wrong and manufacturers have not been able to keep up with the demand. Until the merger with Daimler-Benz, Chrysler was working on both fuel cell and hybrid technology.

During the 1980s, before its work on fuel cells, Daimler-Benz was experimenting with hydrogen in internal-combustion engines. It conducted road tests in Berlin from 1984 to 1988, with ten vehicles and over 350,000 miles of driving tests. In this same time period, BMW began testing cars that use liquid hydrogen and this work continues. The German government committed more than $100 million to these projects.

However, burning hydrogen is less desirable than using it in a fuel cell. The direct combustion of hydrogen releases carbon monoxide, hydrocarbons and some particulates, although these are only about 0.1 of that from the burning of fossil fuels.

If there is any technology on the horizon with the potential to replace the IC engine, it's fuel cells. Almost every automaker has a fuel cell program underway, and over the years, fuel cells have shrunk to one-tenth their original size. Energy output has risen by a factor of five in this time period.

Initially, pure hydrogen gas could be used for fleet vehicles, which includes delivery trucks, taxis and buses and onboard reformed methanol could be the fuel for passenger cars. Fleet vehicles are usually served by large garages with trained staff and could have the facilities for in-house hydrogen production. Without the reformers, fleet vehicles could be less complex and would be able to work within the range limitation of onboard hydrogen tanks.

Fuel cell research has become a major international trend with many engineers working on this technology worldwide. Germany already has enough methanol production to fuel 100,000 cars and worldwide, there is enough methanol for 2 million cars.

DaimlerChrysler renewed its interest in liquid hydrogen, and that was the fuel in NECAR IV that appeared in 1999. NECAR IV was among the first drivable, zero-emission, fuel cell cars in the United States along with the Ford and GM fuel cell prototypes. It was a major advance over NECAR III, whose cell and reformer took up all the passenger space. NECAR IV was still heavy and slower to accelerate than Ford's P2000 fuel cell car, but it had room for five, with a 40% power increase over the earlier version, a higher top speed of 90 miles per hour and a range of 280 miles.

BMW will offer a 7 series version which will operate on hydrogen and gasoline. BMW and DaimlerChrysler are in partnerships with the German company Linde, a builder of liquid hydrogen refueling stations. But handling liquid hydrogen is difficult, since hydrogen reaches a liquid state at minus 400°F, the cold fuel can cause serious damage to skin. Liquid hydrogen stations could be run by robots. There already is such a station in Munich. Making liquid hydrogen work as an auto fuel requires some new techniques, like attaching the tank to the car with a magnetic holder to isolate it from thermal convection. A liquid hydrogen tank could be a little larger than a gasoline tank and it would offer a comparable range. A superinsulated tank can keep liquid hydrogen cold for weeks, but after a time it would warm up and return to a gaseous state, requiring that it be vented from the tank. This hydrogen gas can be recaptured and reused but this is one the practical challenges being worked on.

HYDRIDE STORAGE

The developmental efforts and formidable challenges of hydrogen delivery and storage are being addressed. All fuel cells need hydrogen to operate, but a low cost, safe and efficient storage system has been elusive. Until recently, there were only two ways of storing pure hydrogen on vehicles as a cryogenic liquid or pressurized gas. Practical cryogenics is a wily task and pressurization can be bulky and potentially dangerous. Gasoline or methanol teamed with an onboard reformer to extract the hydrogen adds substantial costs and complexity to a vehicle, while voiding any zero-emissions classification. Reformers also create trace emissions from burning some of the liquid fuel in order to create the heat necessary to initiate the chemical reaction. Even direct methanol fuel cells (DMFCs) which require no reformer or stored hydrogen do not have zero emissions.

Energy Conversion Devices (ECD) of Troy, Michigan has announced a potential breakthrough in solid hydrogen storage. ECD is one of the parent companies of GM Ovonics, patent holder for the nickel metal hydride battery. A hydride, by definition, is a solid material that stores hydrogen.

ECD uses a modified hydride powder to store the hydrogen electron. Typically you can only store 1-2% by weight of the hydrogen in a hydride material. This is 1-2 grams of hydrogen for every 100 grams of hydride. ECD is storing 7% by weight, which is more efficient than liquid or compressed hydrogen. This is done by adding a high percentage of magnesium. Typically it takes hours to get the hydrogen back out but ECD has solved that.

Hydrogen fueling might also take place at a gas station that has an underground reformer being fed by natural gas. The hydrogen could be pumped into the car much the same as gasoline, filling the storage material in less than three minutes. A tank for a high efficiency vehicle like the PNGV cars would be about the size of a gas tank on today's mid-size car and only slightly heavier than a current tank when filled with gasoline. GM has a fuel cell-powered version of its Precept PNGV vehicle with a 500-mile range using solid hydrogen storage. Shell Oil formed a joint venture with ECD to further develop the storage method and supporting infrastructure.

A hydrogen infrastructure for fueling could cost hundreds of billions, since there is such a limited hydrogen-generating and distribution system now. Decentralizing production, by having reformers in commercial buildings and even in home garages in combination with local power generation would reduce some of the cost. Larger reformers in neighborhood facilities could be the service stations of tomorrow.

One factor in the shift to fuel cells is concern over climate changes. Global warming is a factor of concern with the world population continuing to grow rapidly and developing economies starting to demand private cars. This creates more fuel demands and more urgency on environmental fronts and alternative fuels.

The DOE provides support to American companies, but the level of support has been less than the federal support in Germany and Japan. In

1993, Japan started a major 28 year, $11 billion hydrogen research program called New Sunshine. It surpassed Germany's hydrogen program to become the biggest program at that time. The basic hydrogen research included work on the metal-hydride storage systems that are used in Toyota's fuel cells. German government support has declined since reunification. About $12 million was budgeted in 1995.

DIRECT HYDROGEN STORAGE

Direct hydrogen research has involved tests with fuel tanks pressurized at 5,000 pounds per square inch, which could provide a reasonable range without a reformer. Carbon-fiber composites which have been used in lightweight car bodies could also be used but they are very expensive. The hydrogen fuel tank needs to provide a range of about 350 miles without using excessive space. A light fuel cell car with a 5,000-psi carbon-fiber tank might be able to travel almost 225 miles before needing to be refueled. Direct hydrogen storage is getting close to an acceptable range, but there could be a liquid fuel stage. This would allow the use of the existing gasoline refueling infrastructure that cost hundreds of billions to build.

INFRASTRUCTURE CHOICES

Hydrogen infrastructure will depend on where the hydrogen is produced and what form it is stored. The major choices are onboard hydrogen production, centralized production, and production at fueling stations. Reforming either methanol or gasoline into hydrogen onboard a vehicle is likely to be less efficient than stationary reforming. Onboard reformers produce less pure hydrogen, which reduces the fuel cell's efficiency. The overall efficiency for gasoline and methanol fuel cell vehicles is likely to be much lower than for hydrogen fuel cell vehicles. The onboard reforming of gasoline to hydrogen produces modest emission benefits.

Onboard gasoline reforming could serve as an interim step and accelerate the commercialization of PEM fuel cells. It does not require a hydrogen infrastructure. Onboard methanol reformers are likely to be even less efficient than gasoline reformers. For the immediate future, increases in methanol production are likely to come from overseas natural gas.

Any significant use of methanol as a transportation fuel would require additional investments in fuel production and delivery. As hydrogen fuel cell vehicles become more efficient and popular, any investments in methanol infrastructure would become lost. The fuel infrastructure might have to be changed from gasoline to methanol and then from methanol to hydrogen. An affordable direct methanol fuel cell is needed as well as an affordable way to generate large quantities of methanol from renewable sources.

Fuel companies like Royal Dutch/Shell have invested heavily in hydrogen. Transition fuels such as onboard methanol-to-hydrogen conversion would require infrastructure investments, which would be difficult to justify.

A study by Argonne National Laboratory estimates infrastructure costs for fueling about 40% of the vehicles on the road with hydrogen could be close to $600 billion. Building an initial production capacity in the United States could cost $10 billion by 2015 and $230 to $400 billion by 2030. Building the distribution system could add $175 billion by 2030.

The centralized production of hydrogen should provide less expensive hydrogen than production at local fueling stations. Resource centered hydrogen production near large energy resources, such as sources of natural gas are not carbon free like wind power and biomass. Centralized units can time their electricity consumption for compression during off-peak rates compared to local fueling stations and save on electricity costs.

Hydrogen delivery with tanker trucks carrying liquefied hydrogen, is energy-intensive. Pipelines are a less energy intensive option, but they are expensive investments. Until there are high rates of utilization the high capital costs hold back investment in these delivery systems. Trucks carrying compressed hydrogen canisters may be used for the initial introduction of hydrogen.

The production of hydrogen at local fueling stations is favored by those who want to deploy hydrogen vehicles quickly. The hydrogen could be generated from small stream methane reformers. Electrolysis is considered to be more expensive. Fueling stations would have a reformer, hydrogen purification unit and multi-stage hydrogen compressor for high-pressure tanks. There would also be a mechanical fueling system and on-site high-pressure storage. Advances will be required in reformers and electrolyzers, compressors, and systems integration.

The National Renewable Energy Laboratory, found that forecourt hydrogen production at fueling stations by electrolysis from grid power was most expensive, at $12/kg with forecourt natural gas production at $4.40/kg.

But, natural gas may be the wrong fuel on which to base a hydrogen-based transportation system. A large fraction of new U.S. natural gas consumption will probably need to be supplied from overseas. While these sources are more secure than the sources for oil, replacing one import with another does not move us towards energy independence.

Natural gas can be used far more efficiently to generate electricity or to cogenerate electricity and steam than it can be to generate hydrogen for use in cars. Using natural gas to generate significant quantities of hydrogen for transportation would, for the foreseeable future, damage efforts to battle CO_2 emissions.

In 1998 a report prepared for the California Air Resources Board (CARB) called Status and Prospects of Fuel Cells as Automotive Engines favored methanol fuel cell stacks in cars over a direct-hydrogen infrastructure. Hydrogen is not as ready for private automobiles because of the difficulties and costs of storing hydrogen on board and the large investments that would be required to make hydrogen more available.

The report noted that the automotive fuel cell is being pushed along due to the almost $2 billion international investment and that fuel cells would provide an environmentally superior and more efficient automobile engine.

The CARB report indicated that hydrogen would be produced at large, central facilities similar to a gasoline refinery. But hydrogen could also be made at neighborhood refueling stations or at renewable energy farms. The report also stated that hydrogen compressed at 5,000 pounds per square inch may not be able to supply the required range.

In a study by Ford with a fuel efficiency of 70 miles per gallon the size of the tank needed for a 350-mile range would impact both the passenger and cargo space. Some fuel cell prototype cars place the tank on the roof, like the NECAR II van, but this is not acceptable for a passenger car. Storing the fuel in special structures has been demonstrated by Toyota and Honda, but the metals are costly. Ford's latest fuel cell cars use a long fuel tank area under the passenger space.

Northeastern University has worked on a high-density storage system based on the absorption powers of carbon nanofilters. This form of storage could make direct-hydrogen cars practical. The National University in Singapore has had some encouraging results in this area.

Directed Technologies, a consultant to Ford, believes that hydrogen could be delivered at around the same cost as its equivalent in gasoline, but this compares a 24.5-miles-per-gallon gasoline car using taxed gas with an 80-miles-per-gallon fuel cell car using untaxed hydrogen. When both vehicles get 80 miles to the gallon and neither fuel is taxed, then hydrogen can cost 2 to 3 times more per mile. But, generating hydrogen through renewable sources could reduce these costs in the future.

A Princeton study of the Los Angeles area focused on the potential for solar photovoltaic plants in the desert areas east of the city. The study concluded that enough hydrogen could be produced with solar power in an area of 21 square miles to fuel one million fuel cell cars.

The wind site areas at Tehachapi Pass and San Gorgonio are believed to have a similar potential. Geothermal power would be another renewable source. A problem in generating hydrogen this way is the long-distance pipelines required since the gas is leaky compared to other products.

NATURAL GAS AND ELECTROLYSIS

Natural gas is a major feedstock for near-term hydrogen production in the U.S. Natural gas is a non-renewable resource, and hydrogen production from reforming natural gas would result in substantial carbon dioxide emissions. Great supplies of natural gas are found in sensitive locations and unstable parts of the world, along with petroleum. To power 40% of the U.S. auto fleet with hydrogen from natural gas in 2025, using high efficiency fuel cells, would require a 1/3 more natural gas using projected 2025 levels. Natural gas is already in heavy demand as a clean fossil fuel for power plants, so alternative sources of hydrogen production are needed. Unless global warming emissions are stored underground, natural gas use will continue to contribute to global warming. But, natural gas could act as a transition fuel.

Electrolysis using renewable electricity, wind, water or photovoltaics, could produce a domestic, non-polluting hydrogen transportation fuel. But, hydrogen produced today by this method can be more than 3 times the cost of an equivalent gallon of gasoline. If the electricity is supplied from the present electrical grid, which is more than 50% coal-fueled, it would generate even larger amounts of carbon emissions than the natural gas process.

In order for hydrogen fuel cell vehicles to reduce global warming gases, the electrolysis process will need to become more efficient, and the electric power will need to be produced from a higher percentage of low-to zero-carbon sources (renewables or coal with carbon capture and storage).

Current projections indicate that electrolytic hydrogen from grid electricity in the U.S. would create a net increase in global warming gases. Dedicated sustainable energy crops could also serve as a part of a hydrogen economy since they can be a carbon-free source of hydrogen through biomass gasification, or be converted to cellulosic-based ethanol and then to hydrogen. This option is attractive since ethanol is a room temperature liquid fuel and substantially easier to transport. Energy crops could also diversify agricultural markets, help stabilize the agricultural economy, aid rural economic development and reduce the adverse impacts of agricultural subsidies on developing countries. More research and development of the production processes of biomass to hydrogen and ethanol-to-hydrogen is needed to make this source of energy a cost-effective and viable option.

Eventually, hydrogen could also be produced directly from renewable sources through photoelectrochemical or photobiological processes, but these are still at an early stage of research and development.

The Bush administration's hydrogen fuel initiative emphasized producing hydrogen from coal. Coal has the advantage of being a domestic resource, but it has major emissions of carbon dioxide and pollutants. These problems can be addressed using coal gasification with carbon capture and storage. Then hydrogen from coal could become viable.

There is a need of large-scale carbon storage projects. The Department of Energy has been working on projects to gasify coal producing both hydrogen and electricity while storing the waste carbon dioxide in geologic formations.

Clean options include nuclear power to produce hydrogen with no emissions. But expanding nuclear power means overcoming safety, waste disposal and security concerns.

Hydrogen has the potential to play a major role in energy independence but policies are needed that mobilize our present technologies. This means raising fuel economy standards, increasing hybrid vehicle use and developing options such as cellulose ethanol.

NUCLEAR POWER AND HYDROGEN

A Massachusetts Institute of Technology (MIT) study on the future of nuclear power argues that nuclear power could be an important carbon-free source of power that can make a significant contribution to electric power supplies. The study also found that a survey of adults in the United

States indicated that those who are very concerned about global warming are no more likely to support nuclear power than those who are not. Other evidence suggests that the responses in Europe would not be very different. The MIT report concluded that more of the public needs to understand the links among global warming, fossil fuel usage and the need for low-carbon energy sources.

The World Energy Council has said that meeting new demands for electricity while reducing the current level of emissions will require tripling the world's nuclear plant capacity by 2050.

Three Mile Island and Chernobyl occurred more than 20 years ago and the nuclear power freeze is beginning to thaw. High priced oil and natural gas make atomic energy appear cheap by comparison. Global-warming concerns are pushing a new interest in nuclear power. After a decade where no nuclear power plants came online in the United States, 31 new reactors are planned.

The DOE is predicting the need for 50% more electric power by 2030. This new demand could be met by nuclear power instead of pollutants spewing fossil-fuel plants. Worldwide power is anticipated to double by 2030 as more developing nations buy electrical products.

Currently, 28 reactors are under construction in China, India, Russia and other nations. While numerous important issues endure such as the toxic byproducts, nuclear power is in a resurgence with investor interest rising as well.

General Electric (GE) is a major provider of boiling water reactors, which are 81 of the world's 442 nuclear plants. GE recently agreed to pool its nuclear business in a joint venture with Japan's Hitachi.

Nuclear generating plants have a big advantage over fossil-fuel plants when comparing the costs of operation and upkeep. Nuclear plants cost about $1.72 kilowatt-hour to operate according to the Nuclear Energy Institute while that figure is $2.21 for coal plants, $7.51 for gas and $8.09 for oil. The difference is due to fuel costs, which make up 78% to 94% of the cost for producing electricity at fossil-fuel plants but only 26% at nuclear plants. Although the price of uranium for nuclear plants has risen sharply, it has much less impact on overall costs.

It is more expensive to build nuclear plants which cost $2,000 per kilowatt-hour of output, compared with $1,500 for coal plants and $800 for gas plants, according to the International Energy Agency. It takes years to go through the regulatory hurdles for a new nuclear plant, build it and obtain a license to operate. Any new plants conceived today may be 10 years away.

A variety of energy options should be pursued: increased use of renewable energy sources, carbon sequestration at fossil-fuel plants, improved efficiency of energy generation and use, and the increased use of nuclear power. Public misunderstanding is likely to begin in the political arena and a greater appreciation of the relation between nuclear power and emissions reduction is critical if the use of nuclear power is to be expanded. Environmental groups include a large and dedicated antinuclear majority and some environmentalists who might favor nuclear will vacillate over that view publicly. The nuclear industry may be impeded because power companies have been forced to rely on fossil-fuel plants for so long. The Bush administration has aggressively supported nuclear power but has avoided emphasizing the link between nuclear power and the reduction of greenhouse gases.

Nuclear power presents many challenges and is not acceptable unless plants remain committed to safety and the Nuclear Regulatory Commission continues its detailed oversight. Progress toward the safe final disposition of nuclear waste must be attained. Tightening safeguards against the diversion of commercial technology to weapons use also must be given a high priority among all nations.

All of these challenges can be met. Nuclear power plants have better safety records today and new generations of reactors have designs that improve safety even further. Debate continues about Yucca Mountain as a disposal site for nuclear waste, but the scientific community agrees that deep geological disposal sites are suitable for the disposition of spent fuel. Stronger international commitments hold the promise of preventing nuclear power from contributing to the proliferation of nuclear weapons. Nuclear power should be seen as part of the solution, bridging more advanced technology until other carbon-free energy options become more readily available.

The calls for a reduction of U.S. hydrocarbon use by 90% would eliminate 75% of America's energy supply are unrealistic. This 75% of U.S. energy cannot be replaced by alternative green sources in the near future. In spite of wide support and subsidies for decades alternative sources still provide a small percent of U.S. energy. The U.S. cannot continue to be a net importer of energy without losing its economic and industrial strength and its political independence.

Nuclear energy can be less expensive and more environmentally sensitive than hydrocarbon energy, but it has been the victim of the politics of fear. The problem of high-level nuclear waste has been mostly created by government barriers to American fuel breeding and reprocessing. Spent nuclear fuel can be recycled into new nuclear fuel.

Reactor accidents have been greatly publicized, but there has not been one death associated with an American nuclear reactor accident. However the dependence on automobiles results in more than 40,000 deaths each year. All forms of energy generation, including alternatives like solar and wind involve industrial deaths in the mining, manufacture, and transport of materials they require. Nuclear energy requires the smallest amount of resources and thus has the lowest risk of deaths.

Future developments in energy technology can alter the relative economics of nuclear, hydrocarbon, solar, wind, and other methods of energy generation. Conservation if practiced extensively as a replacement to hydrocarbon and nuclear power means a major step backward for our modern world.

The United States is paying more than $300 billion per year to pay for foreign oil and gas. Energy production has surged abroad while domestic production has stagnated. This is largely due to complex government regulations and energy policies which have made the U.S. an unfavorable place to produce energy. The repeal of this conglomerate of regulations, tax incentives and subsidies to energy generation industries would do much to foster energy development and allow a free competition to determine the best energy paths. Technological advances reduce cost, but usually not quickly. International rationing and taxation of energy has also been proposed as energy policy.

Nuclear power can be safer, less expensive, and more environmental agreeable than hydrocarbon power. But solid, liquid and gaseous hydrocarbon fuels provide many conveniences and the infrastructure to use them is already in place.

Oil from shale or coal liquefaction can be less expensive than crude oil at current prices, but production costs are higher than developed oil fields. There is an investment risk that crude oil prices could and then liquefaction plants could not compete. Nuclear energy does not have this disadvantage.

In the U.S. about 20% of the electric power is produced by 104 nuclear power reactors with an average output of almost 900 megawatts per reactor or 93-GWe (gigawatts) total. If this were increased by 250-GWe, nuclear power could fill all current U.S. electricity requirements.

If the heat from these additional nuclear reactors were used for coal liquefaction and gasification, the U.S. would not need to use its oil resources. According to some estimates the U.S. has about 25% of the world's coal reserves. This heat could also be used to liquefy biomass, trash, or other source of hydrocarbons.

The Palo Verde nuclear power station near Phoenix, Arizona, was originally intended to have 10 nuclear reactors with a generating capacity of 1,243 megawatts each. As a result of public pressure, construction at Palo Verde was stopped after three operating reactors were completed. This installation is on 4,000 acres and is cooled by waste water from the city of Phoenix, which is nearby. An area of 4,000 acres is 6.25 square miles or 2.5 miles square. The power generating facilities occupy a small part of this area.

If a facility like Palo Verde were built in 1/2 of the 50 states and each installation included 10 reactors as initially planned for Palo Verde, these plants, operating at the current 90% of design capacity, would produce 280-GWe of electricity.

Allowing a construction cost of $2.3 billion per 1,200 MWe reactor with 15% for economies of scale, the total cost of this entire project would be $1/2 trillion, or about 2 months of the current U.S. federal budget. This is 4% of the annual U.S. gross domestic product.

Along with these power plants, the U.S. could build up a fuel reprocessing capability to allow spent nuclear fuel to be reused which would lower fuel cost and eliminate the storage of high-level nuclear waste. Fuel for the reactors has been estimated to be available for 1,000 years using standard reactors with high breeding ratios and breeder reactors where more fuel is produced than consumed.

Only about 33% of the thermal energy in today's nuclear reactors is converted to electricity. Some newer designs can convert almost 50%. The heat from a 1,243-MWe reactor could produce 38,000 barrels of coal-derived oil per day.

The additional Palo Verde facilities could provide a yearly output of about 3.5 billion barrels per year with a value, at $90 per barrel, of more of $300 billion per year. This is about the oil production of Saudi Arabia.

The current proven coal reserves of the United States are predicted to support this production level for 200 years. This liquefied coal reserve exceeds the proven oil reserves of the entire world. The reactors could also produce hydrogen or gaseous hydrocarbons from the coal as well. The excess heat from nuclear power plants could be used for central heating.

The United States needs more low-cost energy and across the globe, billions of people in all nations seek to improve their lives with abundant low-cost energy, which has become the driving force of technological progress. In newly developing countries, that energy is coming largely from hydrocarbon sources.

Energy has become the foundation of wealth and can provide better food production. Energy-intensive hydroponic greenhouses are 2,000 times more productive per unit land area than modern American farming methods. If energy is abundant and inexpensive, there are almost no limits to world food production.

Fresh water is also in short supply in many areas. Plentiful inexpensive energy allows sea water desalination to provide almost unlimited supplies of fresh water.

Over the past few centuries, technological progress has depended on the use of abundant energy. These advances have improved many aspects of human life. In the 21st century low cost energy will be needed to continue this advance. If the future is harmed by world energy rationing, the result could be human suffering and the Earth's environment would be a victim as well.

Low cost energy is important to the environment. We are beyond the age of subsistence living and prosperous living is needed to provide for environmental preservation and enhancement which an impoverished population cannot afford.

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Chapter 5

Trends in Transportation

The first automobiles in the 1890s were a luxury item for the rich, but the car became a mass-produced commodity within a few decades. Orders for these gasoline buggies increased to meet the demand and this new industry would go on to affect many areas of modern life from housing to recreation. Steam cars competed with internal combustion vehicles in the first decade of the 20th century. The Stanley, Locomobile, and White steam cars were admired for their quiet operation and range. There was also no need of a crank handle for starting. Starter motors in gasoline cars would appear much later. This edge was shared by electric cars and was a real consideration since careless cranking could injure your arm.

However, steam cars needed up to half an hour to build up a head of steam and required large amounts of water and wood. Then, there was also the fear of boiler explosions.

The gasoline engine was greatly improved after 1905 and the use of steam cars disappeared. By 1911, White and Locomobile discarded steam and switched to gasoline engines.

EARLY ELECTRIC CARS

Early electric cars were popular for a while but they would lose their popularity to the wider driving range of the gasoline car. The lack of good roads outside the cities forced most of the early traffic on local streets. While cars kept within the city limits, the shorter range of the electric car was not a problem.

The early electric cars were favored by many city dwellers and were popular as taxis. In the New York of 1898, the Electric Carriage and Wagon Company had a fleet of 12 electric cabs with well-appointed interiors available on the city streets.

In 1900, at the first National Automobile Show a poll showed that electric power was the first choice, followed closely by steam. Gasoline was a distant third, with only 5% of the vote. During that year almost

1,700 steam, 1,600 electric and 100 gasoline cars were made.

Many steam car developers did not get beyond building a few hundred or thousands units, but many of the early gasoline car pioneers became major manufacturers. Gottlieb Daimler, Henry Ford, Ransom Olds, Carl Benz, William Durant (General Motors founder), James Packard and John Studebaker are a few who played important roles in the early years of autos.

Some of these began their work with electric cars. In Germany Ferdinand Porsche, built his first car, the Lohner Electric Chaise, in 1898 at the age of 23. The Lohner-Porsche was a first front-wheel drive car with four-wheel brakes and an automatic transmission. It used one electric motor in each of the four wheel hubs similar to today's hybrid cars, which have both gas and electric power. Porsche's second car was a hybrid, with an internal-combustion engine driving a generator to power the electric motors in the wheel hubs. On battery power alone, the car could travel 38 miles.

One invention that hurt the electric car was the self-starter for gasoline engines. Engine cranking from the seat instead of the street would eliminate a major advantage of the early electric cars. Charles Kettering's starter caught on quickly and the sales of electrics dropped to 6,000 vehicles, only 1% of the total, by 1913. In that year, sales of the Ford Model T alone were over 180,000. Electric carmakers closed down or united. There were almost 30 companies selling electrics in 1910 and less than 10 at the end of World War I. A few, such as the industry leader Detroit Electric, lasted into the 1920s.

An early hybrid was the Woods Dual Power coupe, which was produced from 1917 to 1918. It had a four-cylinder gasoline engine next to an electric motor. Woods had been manufacturing electric cars since 1899 and the company attempted the hybrid to stay in business. But the car was expensive and its fuel economy was not an advantage since gasoline was not expensive. Few were sold.

Before the electric car died the speed and range had been improved. The last Detroit Electrics had a competitive top speed of 35 miles per hour by the early 1920s. The light Dey runabout of 1917 was available for $985.

By 1926, there were more than 8 million automobiles in America along with a new coast-to-coast federal highway (U.S. Route 40). By then the electric car had lost most of its support.

Henry Ford was the father of mass production, but it was Alfred P Sloan, Jr. the President of General Motors, who introduced the annual model change as a way to keep the consumer in new cars with features the older vehicles did not have. The company succeeded not by offering consumers a basic means of transportation (Ford's plan) but by offering faster cars that grew with more style and power with every year. It provided GM's dominance in the industry for decades.

By 1929, nearly half of all U.S. families owned an automobile, this percentage was not reached in England until the late 1960s. But, there was some opposition to the automobile, the first vehicles were noisy and scared horses. Some Minnesota farmers even plowed up roads but most Americans greeted the car with enthusiasm as the automobile replaced the horse and wagon as a more efficient means of transportation. As the auto industry grew, it changed America's relationship with farming and the land and transformed the car from a riding luxury to a goods gathering essential. Most of America's food and clothing was once produced in the home, but by the 1920s it was purchased in the towns and villages.

By the 1930s, 66% of rural families and 90% of urban families bought store-bought bread instead of baking their own. This increased shopping resulted in more auto use as priorities changed. The auto provided a convenient way of going to the market and stimulated the growth of suburbs which had began as early as the 1840s with the start of railroad travel. This growth continued with a surge after the Civil War with the construction of streetcar lines.

As the nineteenth century ended, the larger cities such as New York, Chicago, and Philadelphia were transformed into assembly plant and manufacturing centers. Then after World War I the growth of office buildings in the cities occurred and this forced workers into the suburbs. They used cars to commute to work and by 1940 about 15 million Americans lived in communities without public transportation.

Franklin Roosevelt's New Deal would spend huge amounts of money building roads but little on mass transit. Starting as early as 1916, the Federal Road Act made funds available to states to establish highway departments. Legislation passed in 1921 established the Bureau of Public Roads and planned a network of highways linking cities of more than 50,000 people. But, it was during the New Deal that major road-building began. Almost half of the two million people employed in New Deal programs worked in constructing roads and highways. During the 1930s, the total amount of surfaced roads doubled, to more than 1.3 million miles, while mass transportation languished. Public transit received only a tenth of the money that the Works Progress Administration spent on roads. America was becoming an asphalt nation due to weaknesses in the streetcar industry, the push to sell buses, and the state-sponsored building of roads during the Depression.

ELECTRIC REVIVALS

Electrics have made some reappearances over the years. A major effort occurred after the fuel problems from the Arab oil embargo in 1973. But in the late 1950s the utility-endorsed Henney Kilowatt of 1959 to 1961 appeared as a converted French Renault Dauphine. About 120 Henneys were built and other efforts were even not that successful.

A number of 1970 era electrics came out of the 1973 oil embargo. Among these strange looking electric cars was the Free-Way Electric, which resembled a bug, the 3-wheeled Kesling Yare, with Starwars styling and the B&Z Electric, which appeared to have been made of wood scrapes. Florida-based Sebring-Vanguard sold 2,200 of their 2-seat, plastic body CitiCar following the 73 oil embargo. They looked like a phone booth on wheels and were powered by golf-cart batteries with a top speed of 30 miles per hour and a range of 40 miles in warm weather. Viable commuter EVs would have to wait until the conversions of the late 1980s.

STEAM REVIVALS

There have also been revivals of the steam car. Robert McCulloch, the chain-saw millionaire, spent part of his fortune on a steam prototype, called the Paxton Phoenix, between 1951 and 1954. William Lear of Learjet fame, spent $15 million in 1969 on a turbine bus and a 250-horsepower turbine steam car. Both used quiet, efficient steam engines although the bus had reliability problems and poor gas mileage. Lear also tried to enter a steam car into the 1969 Indianapolis 500. The British firm of Austin-Healey was also working on a steam car in 1969. It had four-wheel drive. However, even prosperous entrepreneurs like McCulloch and Lear found that they lacked the means and support structure to successfully mass market a competitive car. Alternative power systems would have to wait until air-quality regulations resulted in some breakthroughs with hybrid and even fuel-cell cars.

In the 1950s, the Volkswagen Beetle became a popular small car and by 1960 had sales of hundreds of thousands. Other economy cars included several compacts such as the Ford Falcon and Dodge Dart. In Europe, 50-

miles-per-gallon microcars like the BMW Isetta and Morris Minor were enjoying some success.

Most modern electric cars in the 1960 to 1980 era were subject to fail, with their pop-riveted bodies and non-existent marketing. The Urba Sports Trimuter of 1981 was 3-wheeler with a pop-up canopy, needle nose and a top speed of 60 miles per hour that the owner would build from a set of $15 plans.

ENERGY TRENDS

The modern suburban home with its car, lawn and undetached house uses mostly nonrenewable fossil fuels. In the decades after World War II, American homes consumed increasing amounts of energy. During the 1960s, energy use per house rose by 30%. However, the high-energy home was not unavoidable. Even in the 1940s many popular magazines featured articles on solar building design. Resourceful homes were oriented toward the south to use the sun's heat in the winter and had large overhangs to reduce the effects of the summer sun. They conserved natural resources and appealed to America's wartime conservancy. In the late 1940s and early 1950s, solar homes received earnest attention from architects, builders, and the media. The World War II era represented a time of resource conservation. But, as the 1950s bloomed, the availability of cheap heating fuels like oil and natural gas reduced the need to conserve. The federal government reduced investments in solar design and research efforts and the use of coal, oil, and gas for heating increased. Suburban home energy use also increased as many discovered air conditioning. In 1945, few American homes had air conditioning, even though the technology was available since the 1930s.

As air conditioning units became cheaper and more compact in the late 1940s, sales boomed. Once the wartime housing shortage ended in the mid-1950s, builders used air conditioning to increase the demand for new homes. The addition of air conditioning in new homes allowed buyers to trade up. Air-conditioned offices helped fuel the demand for central air conditioning in homes. The National Weather Bureau, in 1959 started issuing a Discomfort Index, providing a measure of heat and humidity. The air conditioning industry grew as the index became more popular. Between 1960 and 1970, the number of air-conditioned houses grew from one million to nearly eight million. These energy using units added certain comforts to the home and made life more tolerable in many areas of the country. It also helped to reduce the effects of suffering from heart or respiratory diseases.

The boom in suburban home building also had other effects on energy resources. As large-scale builders cleared the land of trees, the new homes were subject to more heat and more cold, increasing the energy that was required to keep the temperature comfortable inside.

AUTO EFFICIENCY

While smaller cars may use less petroleum, they are not inherently more efficient. Of the energy released in combustion only 12-15% is finally applied to move the car. Most of the rest is lost due to the thermodynamic inefficiency of the engine and escapes as heat. The remainder is drained off by such factors as aerodynamic drag, rolling resistance of tires, transmission slippage, internal friction, idling, and air conditioning. Just to push the air out of its way, a car may use 50% of the available energy at 55 mph and 70% at 70 mph.

Large frontal areas create air turbulence and drag. Bodies derived from wind tunnel testing can provide a more smooth air flow around the vehicle. Details such as mirrors, rain gutters, trim, wheel wells and covers can also be more appropriate for air flow. Radial tires can reduce fuel consumption as much as 3%. Puncture-proof tires of plastic could save even more and eliminate the cost and weight of a spare tire and wheel.

Automatic transmissions impose a mileage penalty of about 10% compared to manual gearboxes. Continuously variable transmissions can provide better mileage. A stop-start engine that shuts down if a car is idling or coasting can cut gas consumption by about 15%. A touch on the accelerator restarts the engine. This is done in many modern hybrids. Better lubricants and bearings can reduce friction, and microprocessors can monitor systems and make adjustments to keep operation at peak efficiency without or despite actions by the driver. Computer engine controls are used in most modern engines but they are optimized for pollution control and not mileage. The proper maintenance of roads can improve mileage by 5% but much maintenance is delayed due to funds and the overuse of our roads from high traffic. Combustion engines operate best at about 45-MPH and ideally traffic should be speeded up in cities and slowed down in the country. This is difficult to achieve although possible, low highway speeds are unpopular and higher city speeds are impractical for safety reasons. Congestion also causes mileage to below optimum levels.

As the price of petroleum for gasoline and diesel engines converges with that of alternate energy sources, new power systems will become more widely available. Battery-powered electric motors have their advantages; quietness, low pollution and simplicity. But, their disadvantages of limited range between recharges (which are also limited), weight, and bulk reduce their market potential. New battery systems could give better performance but they have not been available. Lithium ion battery systems have become more popular for many applications but there have been several reports of fires in automotive systems. Efficiency can also be increased by using flywheels to equalize power demands on batteries during acceleration and hill climbing.

Electric motors are paired with small combustion engines in hybrid systems with electric power for low speeds and combustion for highway passing. Hybrid systems offer much better mileage and have proved to be popular beyond the estimates of most auto manufacturers.

Power systems that run on compressed gases such as propane, methane, or hydrogen are problematical. Range may be limited since distribution systems are not in place and each station pump could cost $30,000. So-called synthetic fuels could be used directly in engines or to generate electricity from fuel cells for electric motors. Other combustion engines such as the sterling motor may also become options.

As the auto met America's need for transportation, cars released people from train and streetcar schedules, allowing them the freedom to travel at their own pace. Automobiles were marketed using this concept of freedom. Advertising also stressed the comfort of automobiles free from the problems of snow or rain. Independence was the message being conveyed.

In the late 1920s and early 1930s many popular cars combined smooth curved surfaces from aerodynamic studies with the integration of components into the main body of the car. The visual influences ranged from aircraft and boats to racing cars.

POST-WAR AUTOS

The post-World War II years brought cheaper, mass-produced cars which seemed to have the same features as earlier luxury cars. Europe also moved its car manufacturing into a mass-production industry and introduced more efficient production methods in their factories.

The move to a standardized automobile that everyone could afford was more than an economic goal. In Europe it was also political. The creation of a car for the people was a symbol of the masses promoted by fascist and liberal governments. These people's cars included the British Morris Eight and the Italian Fiat Topolino.

In the United States Ford and Chrysler tried to emulate the luxury cars of Cadillac and Packard. The difference between the automobiles aimed at the rich and the poor in Europe remained more distinct. Luxurious, chauffeur-driven cars were produced by Rolls-Royce and Hispano Suiza and contrasted with tiny cars produced for the low end of the market.

Cars for the masses tended to be as small as possible. Low fuel consumption was also a key requirement of these vehicles. During the postwar years many workers in Europe exchanged their bicycles and motorcycles for cars. The postwar European people's car also became a mark of national identity. The small cars of the 1950s had some features in common but they were all distinctive and created for the roads that had to carry them, such as the efficient autobahns of Germany or the less developed rural roads of France. Few cars moved across national borders in these years. A number of low-priced bubble cars appeared but many of these were less than stable. There was some risk in driving these unstable three-wheelers, but a number of Japanese microcars reappeared in the 1990s as the need to lower fuel consumption made them appealing once again.

The Japanese people's car was a product of the late 1950s and 1960s. By the 1980s Japan had expanded its auto manufacturing and was the world's second largest manufacturer of automobiles, after the U.S.

The auto was a major factor in the expansion of the suburbs in the 1950s. America had a corresponding need for increased mobility. A car was needed to do the shopping and increased affluence made the purchase of a car possible for many who had never owned one before.

In the late 1950s and early 1960s new kinds of automobiles appeared; compacts, personal luxury cars and pony cars. These competed with the sedans that had dominated in an earlier time. Cars in America from the late 1940s to the early 1960s were reproduced on an annual basis, like fashion goods, in their attempts to outdo each other. They featured incremental improvements which led to bigger and better cars for the consumer and the age of fins. New colors such as pink, pale green and lemon yellow tried to seduce consumers. Labor-saving devices, such as power steering and electric windows also became popular. Lush interiors were directed at female consumers while the jet fighter imagery of the exterior was designed to have a masculine appeal.

The postwar economic boom brought the automobile within the reach of more people than ever before but the American automobile culture was attacked in the late 1950s by Vance Packard and in 1965 by Ralph Nader in a book called Unsafe at any Speed. Growing safety concerns led to the passing of the National Traffic and Motor Vehicle Safety Act in 1968.

The mid-1950s saw the appearance of American sports cars, such as the Corvette and the Thunderbird. In the 1930s young men started to build and race their own hot rods or custom cars. This eventually led to the advent of muscle cars and pony cars. They lasted for less than a decade, but the muscle cars were powerful and fast. The first muscle car was the Pontiac GTO followed by the Firebird, Trans Am and Camaro. The Ford Mustang of 1964 was the first pony car. Other muscle and pony cars followed, such as the Dodge Charger and the Chrysler Barracuda. By the early 1970s muscle and pony cars had become bigger and heavier.

The oil crisis and the rising environmental movement of the early 1970s stopped the growth of these gas-guzzlers. To some the car ceased to express the good life and began to become a threat to the future of society.

The Jeep and its variations were a part of the American scene from the mid-1940s. It retained its identity as a utility vehicle for the consumer market and in 1974 the Cherokee appeared as the first of the sports utility vehicles (SUVs). Another utility vehicle that reached international status was the British Land Rover. The original Land Rover was a basic vehicle with no thought to physical comforts. In 1970, Rover combined the utility of the Land Rover in rough terrain with the comfort and luxury of its sedans. The result was the Range Rover, which was produced until 1995.

Both the American Jeep and the British Land Rover were highly successful with consumers. They symbolized a working society that used material goods as tools. In rural and urban areas, these utility vehicles could serve several purposes. But, by the end of the century this concept seemed to be largely symbolic. This type of vehicle was widely emulated in the 1980s and 1990s as the concept of the sports utility vehicle grew quickly and was produced by manufacturers around the world. In the late 1980s Chrysler converted the Jeep into an urban car. Japanese manufacturers followed the SUV concept with the Toyota Landcruiser, Isuzu Trooper and other high-off-the-ground, four-wheel-drive, large-wheeled vehicles.

RECENT TRENDS

The fears of car safety and pollution in the 1960s were followed by the sudden oil crisis of the early 1970s. The anti-car lobby viewed the car as a bad symbol of modern life to be attacked rather than adored but in the 1950s there was an optimism and exuberance that pushed the design of automobiles beyond aesthetic limits. The oil crisis produced a movement towards economy and utility, as manufacturers moved to make cars more functional. Style was succeeded by aero aesthetics mainly for fuel efficiency. Manufacturers found themselves working with more regulations and safety related data.

Japan played a major role in the new range of automobiles which included the sports utility vehicles (SUVs) and their variations. Different market sectors required different types of cars. These ideas in Japan spread to the United States and Europe and the car became a lifestyle accessory.

Technology provided new materials, safety systems and new forms of in-car communications as car manufacturing became increasingly global. In the U.S., masculine cars saw a revival while Japan, with its congested cities, developed new minicars. Microcars from Japan and Korea in the 1990s, included the Suzuki Wagon, Daihatsu Move and Daewoo Matiz. Mitsubishi was producing cars in the 1920s while Nissan and Toyota built cars in the 1930s. The Toyota model AA of 1936 was modeled after the Chrysler De Soto Airflow.

The fuel crisis of the 1970s started a movement in car design towards more utilitarian vehicles. Technological aspects were widespread and consumers would no longer make purchasing decisions on this basis alone. It became difficult to distinguish between the different models. A new emotionalism had entered the world of car purchasing and symbolic meanings acquired a new level of importance for consumers.

In 1900, there were only a few thousand motor vehicles in the United States and the public had a choice between steam, electric, or gasoline automobiles. A gasoline-based transportation system was not a foregone conclusion. The public had become used to horses and the image of sitting near a boiler, battery or gas tank and moving by a series of explosions, was not attractive.

More than a century later, auto transportation may be at a similar crossroads, with competing technologies in various stages of development. Just as in 1900, there can be many turns in the road as technical breakthroughs and problems occur. Newer more advanced propulsion systems will be developed to replace the internal-combustion engine. More efficient, cleaner cars will emerge from the many research projects under way. New technologies such as the familiar hybrids with both gas and electric power will grow even more popular along with fuel cell vehicles which are, basically, electric cars.

Further improvements to gasoline cars may make them modern high-tech wonders, but their roots are still in the 19th century. Modern materials, electronics, and manufacturing processes will continue to improve and they make modern vehicles closer to the theoretical ideals of gasoline engine technology. But increasing regulations on exhaust emissions, forecasts of oil shortages and the potential of global warming by greenhouse gases have led the motor vehicle industry and national governments to spend tens of billions of dollars over the last decade on cleaner, more efficient technologies to succeed the century old internal combustion (IC) engine.

Fuel cell vehicles are viewed as one of the best long term options. A hydrogen fuel cell vehicle has advantages over alternatives, such as hybrid vehicles which combine IC engines with electrochemical batteries and still require petrochemical fuels that exhaust carbon dioxide and pollutants.

FUEL CELL TRENDS

Fuel cells could become a major player in our energy future. In order to see more cars on the road that are fuel cell vehicles, many obstacles and challenges will have to be overcome, but there does not seem to be anything that is insurmountable. The cost of specialized materials is dropping and higher-volume manufacturing will bring production costs down.

Fuel cells promise an efficient, combustion-less virtually pollution-free source of electric power. As stationary power sources, they are capable of being sited in downtown urban areas or in remote regions. They are very quiet and have few moving parts, using an electrochemical process discovered more than 150 years ago. Fuel cells were used to supply electric power for spacecraft in the 1960s. Today, they are being used worldwide to provide on-site power and waste heat for military bases, banks, police stations, and office buildings using natural gas as a fuel.

SPACE SHUTTLE FUEL CELLS

The Space Shuttle Orbiter has three fuel cell power plants onboard which are all reusable and restartable. The fuel cells are located under the payload bay area in the forward portion of the orbiter's midfuselage. The three fuel cells operate as independent electrical power sources, each supplying its own isolated 28 volt dc bus. The fuel cell consists of a power section, where the chemical reaction occurs, and an accessory section that controls and monitors the power section's performance. In the power section, where hydrogen and oxygen are converted into electrical power, water and heat, there are 96 cells contained in three substacks. Manifolds run the length of these substacks and distribute hydrogen, oxygen and coolant to the cells. The cells contain an electrolyte consisting of potassium hydroxide and water, an oxygen electrode (the cathode) and a hydrogen electrode (the anode).

The accessory section monitors the reactant flow, removes waste heat and water from the chemical reaction and controls the temperature of the stack. The accessory section consists of the hydrogen and oxygen flow system, the coolant loop and the electrical control unit.

Oxygen is routed to the cell's oxygen electrode, where it reacts with the water and returning electrons to produce hydroxyl ions. The hydroxyl ions migrate to the hydrogen electrode, where they enter into the hydrogen reaction. Hydrogen is routed to the fuel cell's hydrogen electrode, where it reacts with the hydroxyl ions from the electrolyte.

The resulting electrochemical reaction produces a flow of electrons to provide the electrical power along with water and heat. The power is used by the orbiter's electrical system. The oxygen and hydrogen are consumed in the reaction in proportion to the orbiter's electrical power demand.

The excess water vapor is removed by an internal circulating hydrogen system. Hydrogen and water vapor from the reaction exits the cell stack and is mixed with hydrogen from the storage and distribution system. It then enters a condenser, where waste heat from the hydrogen and water vapor is transferred to the fuel cell coolant system. The resulting temperature drop condenses some of the water vapor to water droplets. A centrifugal water separator then extracts the liquid water and pressure-feeds it to potable tanks in the lower deck of the pressurized crew cabin. Water from the potable water storage tanks is used for crew consumption and cooling the Freon-21 coolant loops. The remaining circulating hydrogen is directed back to the fuel cell stack.

The fuel cell coolant system uses a liquid fluorinated hydrocarbon and transfers the waste heat from the cell stack through the fuel cell heat exchanger of the fuel cell power plant to the Freon-21 coolant loop system in the midfuselage. Internal control of the circulating fluid keeps the cell stack at an operating temperature of approximately 200°F.

As the reactants enter the fuel cells, they flow through a preheater to warm them from a cryogenic temperature to 40 degrees F or more. They are also sent through a 6-micron filter and a two-stage, integrated dual gas regulator module. The first stage of the regulator reduces the pressure of the hydrogen and oxygen to 135-150 psia. The second stage reduces the oxygen pressure to a range of 62-65 psia and keeps the hydrogen pressure at 4.5-6 psia differential below the oxygen pressure. The regulated oxygen lines are connected to an accumulator, which maintains an equalized pressure between the oxygen and the fuel cell coolant. If the oxygen's and hydrogen's pressure decreases, the coolant's pressure is also decreased to prevent a large differential pressure inside the stack from deforming the cell stack structural elements.

On leaving the dual gas regulator module, the incoming hydrogen mixes with the hydrogen-water vapor exhaust from the fuel cell stack. This saturated gas mixture is sent through a condenser, where the temperature of the mixture is reduced, which condenses part of the water vapor to form liquid water droplets. The liquid water is then separated from the hydrogen-water mixture by the hydrogen pump/water separator.

A hydrogen pump circulates the hydrogen gas back to the fuel cell stack, where some of the hydrogen is consumed in the reaction. The rest flows through the fuel cell stack, removing the water vapor formed at the hydrogen electrode. The hydrogen-water vapor mixture then combines with the regulated hydrogen from the dual gas generator module, and the loop starts again.

The oxygen from the dual gas regulator module flows directly through two ports into a closed-end manifold in the fuel cell stack to provide optimum oxygen distribution in the cells. All the oxygen that flows into the stack is consumed, except during purge operations.

Fuel cells can also convert the energy in waste gases from water treatment plants to electricity. In the future, fuel cells could be in automobiles while allowing homeowners to generate electricity in garages.

Electric cars have proved less attractive to the mass market. The worry of having to plug them in to recharge them is combined with the dread of coming to a sudden halt in an inconvenient place when the batteries run out of power. DaimlerChrysler's electric NeCar 4 was widely promoted but was not able to counteract the disadvantages of electric power.

In the 21st century, new initiatives are visible in car design. Many possibilities present themselves, some rooted in past developments, others exploiting new possibilities that are linked to technological, social and cultural issues. Many depend on new technologies such as the use of fuels other than gasoline, computer-based power control and braking systems as well as navigation systems for enhanced safety.

Mazda and others have been working on advanced safety vehicles with monitor screens to show rear and side views, voice-interactive navigation systems and collision avoidance technology. The Ford 24.7 concept car had a computer console in the dashboard with Internet access that is voice-activated.

New materials can provide fuel-efficiency through lightness. Aluminium and plastics will be used more extensively. Nissan's Hypermini is made almost entirely of these materials. These materials are also combined in new ways. The Dutch company Hoogovens has worked with I.D.E.A. SpA to build a car from a laminated sandwich of aluminum and plastic.

Among the new car designs in Japan was the Toyota Will-vi concept, a minivan reminiscent of Citroen's 2CV. A similar lifestyle concept car is the Honda Fuya-jo which also appeared in 1999. This is a tall vehicle with semi-standing seats.

In the United States cars have been getting bigger and more aggressive. In Japan they are getting smaller, boxier and taller. One development is an emphasis on interior space with more room and more flexibility combined with a basic exterior. Here the exterior becomes more of a container than a symbol of power and speed.

In the search for new markets manufacturers have been creating new kinds of cars by merging existing model types. The SUV has merged with the MPV and the MPV with the microcar. As society becomes more complex, and niche markets more specialized, manufacturers seek new formats to meet the needs of lifestyle shifts. There is an awareness that cars play an important role in the formation of personal or group identity. Several recent concept cars are structured in new ways with doors opening in a novel manner and interiors with a high level of flexibility.

Any new technology must also appeal to consumers. The challenge is to create an aesthetic that is of the moment and in keeping with the spirit of an age in which people value the planet and its resources.

DaimlerChrysler has been working on hybrid cars while Opel General Motors has built a hydrogen-powered car, HydroGen 1. Ford plans to make its SUVs lighter and more aerodynamic and had plans to introduce an electric version of its Escape SUV. Pininfarina's Metrocubo of 1999 is a hybrid car.

The hybrid car combines a gasoline engine with an electric motor. Honda launched its hybrid Insight model in 2000. A gasoline engine in the front is combined with an electric engine in the rear. The batteries add to the weight of the vehicle so weight reduction was accomplished with a body made of aluminium and nylon. The Insight was the first car to offer a hybrid solution to the general public. It advantages were the 30 km/liter (83 mpg) fuel economy and the generation of about half of the carbon dioxide of comparable small cars. Toyota also produced a hybrid car, the Prius.

The GM Saturn Vue Green Line Aura sedans are available as a mild hybrid. The Vue uses GM's 170 hp 2.4 liter Ecotec four cylinder engine with a large belt driven alternator. It serves as a motor-generator that recharges a 36 volt nickel metal hydride pack and a lead acid 12 volt battery for the accessories. The belt has 7 ribs and 2 tensioners. It is used for starting as well as helping acceleration.

THE PNGV PROGRAM

During the Clinton administration, the PNGV (Partnership for a New Generation of Vehicles) program was started at the end of 1993. The long term goal was an environmentally friendly car with up to triple the fuel efficiency of current mid-size cars without sacrificing affordability, performance or safety.

This was a national research program with research support for over 350 automotive suppliers, universities and small businesses. There were seven government agencies along with the United States Council for Automotive Research (USCAR) that joined with representatives from GM, Ford, and DaimlerChrysler.

The ten-year plan was to produce low-emission, 80-per-gallon family cars. The first designs appeared as working models in 2000. There was a timetable calling for production-ready prototypes, but the program was not binding.

PNGV was promoted as a program to get government and industry together for cleaner air program and for cutting dependence on foreign oil with a budget of about $200 million a year. The program did little for fuel economy since the average mileage has actually gone up slightly.

A 2002 report by the National Academy of Sciences stated that automobile fuel economy could be increased by 12% for small cars and up to 42% for large SUVs. The study did not include the greater use of diesels and hybrids. Other studies have indicated that even greater savings are possible while maintaining or increasing passenger safety.

Europe has an agreement with automakers that would reduce the CO_2 emitted per mile by 25% from 1996 to 2008 for light duty vehicles, which would result in an average fuel efficiency of about 40 mpg. Japan has a similar goal.

California has the strictest air quality standards in the U.S. and has been promoting zero emission vehicles (ZEVs). Electric cars have not been as successful as expected and fuel cell vehicles are viewed the logical path to ZEVs.

In California most of the electricity comes from natural gas, nuclear, renewables and other low carbon generating sources, resulting in about half the CO^2 emissions per kilowatt-hour compared to total U.S. emissions. One of the CAFCP's goals is to demonstrate advanced vehicle technology by operating and testing vehicles under real-world conditions in California. Other goals are to demonstrate the viability of alternative fuel infrastructures including hydrogen and methanol stations. This will allow the state to explore a path to commercialization and identify potential problems while increasing public awareness on fuel cell vehicles.

The first few dozen fuel cell vehicles on the road in California include buses and light-duty vehicles with dozens more to be added later. Eight hydrogen fueling stations are planned to dot the state from Los Angeles to Sacramento. California plans to establish a hydrogen freeway that would provide fueling stations for hydrogen-powered vehicles at convenient locations through the state. But, a state cannot build a nationwide fueling infrastructure. California can play a leadership role in fuel cell vehicles in the United States, much as Iceland is doing for the rest of the world.

CAFE

A 27.5 miles per gallon CAFE standard was set for the different product ranges in 1985 and never achieved. In 1997 it reached 17.0 and then started dropping. There have been only light penalties for producing the present mix with more large sport utility vehicles, which are about 30% of new car purchases.

Import cars have also not increased fuel economy. In 1992, the American car buyer could purchase some 26 compact cars that got at least 30 miles per gallon, but this number has dropped to less than ten. As automakers compete for market share, their interests may diverge on design and economy issues.

PNGV had the involvement of nineteen federal government labs. The Department of Energy (DOE) provided about two-thirds of the federal support for PNGV research and development efforts. In 2003, PNGV was transformed into the FreedomCAR program with the focus on research and development in fuel cells and hydrogen infrastructures and technologies.

The DOE now has a fuel cell automotive program and the government has a somewhat abstruse alternative fuels approach. DOE's role is to support the research that validates the technology. It is up to the automakers to use it in vehicles and put it in the dealer's showrooms.

THE FREEDOM CAR PROGRAM

The Freedom CAR program is a partnership between DOE and the U.S. automobile manufacturers to promote the development of fuel cells and hydrogen as a primary fuel for cars and trucks, as part of an effort to reduce American dependence on foreign oil. The program involves eleven sectors of the fuel cell and auto industries. Under Freedom CAR, the government and the private sector will fund research into advanced, efficient fuel cell technology that uses hydrogen to power automobiles without creating any pollution. The plan is rooted in President Bush's call issued in the National Energy Plan, to reduce American reliance on foreign oil through a balance of domestic energy production and technology to promote greater energy efficiency.

Freedom CAR isn't an automobile it's a new approach to powering the cars of the future. The C-A-R in Freedom CAR stands for Cooperative Automotive Research.

Freedom CAR is a long-term research program aimed at developing a fuel cell operating system for tomorrow's cars and trucks. It looks to fundamental research and development. Freedom CAR replaces and greatly improves upon the Partnership for a New Generation of Vehicle program.

Like the old PNGV program, Freedom CAR will be a public-private partnership, combining DOE's National Labs with industry and innovations at the nation's universities.

The transition to hydrogen-powered vehicles is an important step the nation can take towards preserving American transportation freedoms and strengthening U.S. energy security.

The U.S. Council for Automotive Research recognizes that altering the overall U.S. petroleum consumption pattern will require a multi-tiered approach, including policy and research programs. The transportation sector has a significant role to play in addressing the challenge and success from FreedomCAR research initiatives will contribute to broader national goals and objectives.

DaimlerChrysler, Ford, and General Motors are the primary members along with the DOE. FreedomCAR focuses on jointly developing technologies important to the automotive industry such as fuel cells and hydrogen from domestic renewable sources. The transition of vehicles from gasoline to hydrogen is viewed as critical both to reducing carbon dioxide emissions and to reducing the U.S. reliance on foreign oil. It will strive to develop technologies that allow the mass production of affordable hydrogen-powered fuel cell vehicles and the hydrogen-supply infrastructure to support them. Freedom CAR also supports petroleum-dependent technologies that have the potential to reduce oil consumption and environmental impacts.

In a hydrogen internal combustion engine, you can decrease the timing to near top dead center since hydrogen burns quicker. Adjusting the intake pressure and the fuel/air ratio can provide an engine with 15% more HP and 30% more fuel efficiency since hydrogen has triple the energy by weight of that of gasoline and twice that of propane. Engine life may be extended 3-4 times that of a gasoline engine since there are no carbon deposits.

AUTO INDUSTRY PROGRESS

GM has been using its electric vehicle (EV1) as the base for its next generation of hybrid and fuel cell cars, while Ford has been working on the P2000 lightweight sedan as a development vehicle. It uses Ford's aluminum 1.2 liter direct-injection DIATA engine and achieves 63 miles per gallon. The hybrid model has an even higher mileage.

DaimlerChrysler's ESK2 was introduced at the Detroit Auto Show in 1998. It was a lightweight, aerodynamic 70-miles-per-gallon hybrid car and provided a platform for alternative fueled vehicles including fuel cells.

Ford has been at work on a car powered by direct hydrogen. It was equipped with a 5,000-psi compressed hydrogen tank, but this would only provide a range of 50 miles, although the acceleration was excellent. Ford will be reducing even more weight off the car along with other improvements. The P2000 was one of the world's few operational fuel cell cars when it was completed.

GM'S ADVANCED TECHNOLOGY

GM conducted its first fuel cell testing in 1964 and in 1968 GM produced the auto industry's first operational fuel cell powered vehicle. The first drivable fuel cell concept car was based on the GM Opel Zafira minivan in 1998. The HydroGen1 fuel cell vehicle based on the Opel Zafira compact van served as the pace car for the men's and women's marathons at the Summer Olympics in Sydney, Australia.

GM created Giner Electrochemical Systems (GES) with Giner, Inc., to perform fuel cell research and development. Giner is the leader in the PEM-based technology used in most automotive applications. GM's FCEV is a fuel cell electric vehicle and PNGV demonstrator that was designed to achieve 108 m.p.g. gasoline equivalent.

In 2000 GM announced a breakthrough catalyst system with the current generation gasoline fuel processor that achieved more than 80 percent efficiency.

By 2001 GM had set 15 international endurance records for fuel cell powered vehicles by HydroGen1 at GM's Mesa, Arizona Proving Grounds. HydroGen1 completed 862 miles in a 24-hour endurance run.

In 2004 a retail hydrogen fueling station opened in Washington D.C. in a partnership between Shell and GM to develop hydrogen-fueled vehicles on a commercial scale. The station will service GM fuel cell vehicles. Both compressed and liquid hydrogen refueling are available.

Also, in 2004 GM and Shanghai Automotive started the development of a demonstration vehicle using fuel cell technology, building on GM's HydroGen3 fuel cell vehicle. It was designed to show the benefits of fuel cell vehicles in real life applications. GM won top honors in several categories with it's HydroGen3 fuel cell vehicle at the 2004 Michelin

Bibendum competition in Shanghai. The competition pitted 74 hybrid, diesel and fuel cell vehicles, measuring acceleration, fuel efficiency and CO_2 emissions.

In 2004 the state of Maryland announced plans to lease a GM HydroGen3 vehicle. The vehicle is used as part of the state's fleet and represented a step in laying a foundation for a future economy driven by hydrogen. Maryland is also pursuing the development of a hydrogen fueling station and industrial park where all of the buildings would be powered by hydrogen. In 2004 the U.S. Postal Service announced it would lease a GM HydroGen3 fuel cell vehicle to add to its fleet of mail delivery vehicles in Washington, DC. The vehicle is assigned to a postal delivery route in the Ft. Belvoir, Virginia, area.

GM and Federal Express announced a partnership where the HydroGen3 fuel cell vehicle will be used by Federal Express in the first commercial use of a fuel cell vehicle in Japan. FedEx will use the HydroGen3 vehicle during one year for regular delivery services in two downtown districts of Tokyo. GM also launched a Washington-based fleet of hydrogen-powered vehicles.

GM set a new world distance record in 2004 for fuel cell technology with a run of HydroGen3 over 6,000 miles through 14 European countries. This nearly doubled the previous distance record set by Daimler Chrysler in 2002. HydroGen1 was the only fuel cell-powered vehicle to finish Bibendum's 350-kilometer course from Los Angeles to Las Vegas. These design innovations should be useful in future production versions but getting them to work efficiently in a production car will not be an easy task, although that would provide a path for practical fuel cell cars. DaimlerChrysler has built several car and bus fuel cell prototypes, starting with a hydrogen-powered internal-combustion minibus in 1975.

THE DAIMLER-BENZ NECAR

Daimler-Benz built the NECAR (New Car) I, a commercial van that was its first fuel cell vehicle, in 1994. NECAR I was a prototype and most of the cargo area was used for the fuel cell equipment. The roof held a large hydrogen tank.

NECAR II was a smaller van built in 1996. It has seating for six and was capable of 60 miles per hour and could travel 150 miles before the onboard hydrogen tanks needed to be refilled. The range of 150 miles pushed Daimler-Benz into fuel reforming as seen on NECAR III. This has an onboard reformer and the range increased to over 300 miles.

NEBUS appeared in 1997 and showed the fuel cell downsizing done by Ballard. It has ten of the company's 25-kilowatt fuel cell stacks in its rear compartment. It is a functional city bus, with a comparable range. It is similar but not identical to the buses Ballard has put on the streets of Vancouver and Chicago.

BMW has made progress with liquid hydrogen and has manufactured several models in its 7 series that can run on this fuel. It is stored in a tank behind the rear seats. Ford has teamed up with DaimlerChrysler, and General Motors with Toyota, to develop cars with hydrogen fuel cells.

GM AND DOW

GM and Dow launched a joint project in 2004 for proving the viability of hydrogen fuel cells. In the first phase, a single GM test cell was connected to Dow's power distribution grid and also to Dow's hydrogen clean-up and pipeline system to generate electricity for the Dow chemical plant. Phase II expands the project from a single GM test cell to a multi-cell pilot plant at Dow's Texas Operations in Freeport, Texas.

In the world's largest fuel cell application at a chemical manufacturing site, Dow's by-product hydrogen created as a part of Dow's manufacturing processes, will be converted to electricity by a GM fuel cell. The electricity that is generated will power up the plant. Dow could eventually use up to 35 megawatts of power generated by 500 fuel cell units.

GM also announced an agreement with the BMW Group to jointly develop refueling devices for liquid hydrogen vehicles and invited other carmakers and suppliers to join this initiative.

Japan's Ministry of Land, Infrastructure and Transport (MLIT) granted GM the first-ever approval to drive a liquid hydrogen-fueled vehicle on public roads in Japan. With a driving range of 400 kilometer (250 miles), HydroGen3 has the highest driving range of any fuel cell vehicle approved for public roads in Japan.

HY-WIRE

GM's Hy-wire was named Car of the Future by the Belgian Association of Professional Auto Journalists. The honor is awarded to the vehicle considered the most innovative, the most spectacular, the most original or the most practicable.

Hy-wire was recognized as the Environmental Strategy Concept Car of the Year by Automotive News. It also has the North American International Auto Show Eyes on Design award for Most Significant Design Enabler and Golden Marker Award for Excellence in Design by Car Styling Magazine.

Hy-wire was awarded Time Magazine Coolest Invention 2002 Award and AUTOnomy was ranked by Popular Science as the breakthrough automotive technology of the year in the Best Of What's New issue. Hy-wire was the world's first drivable vehicle that combined a hydrogen fuel cell with by-wire technology.

In GM's Hy-wire hydrogen powered concept vehicle, there is a fuel cell for the power source and electronics replace mechanical parts in the steering and braking systems. The driver looks through a large, sloped windshield that covers space usually taken up by an engine. There is no dashboard, instrument panel, steering wheel or pedals, only a set of adjustable footrests.

All controls are electronic, the driver twists a pair of handles to go, moves them to turn and squeezes to stop. The car's fuel cell produces 94 kilowatts of power which is equivalent to 126 horsepower, about the same as a Ford Focus. The Hy-Wire generates a loud whine while moving and can travel 140 miles before refueling.

Individual drive motors on each of the vehicle's four wheels allows a fuel cell powered all wheel drive system. Three tanks hold Hy-wire's hydrogen fuel, compressed at 5,000 pounds per square inch. These were developed by Quantum Fuel Systems, the company that developed the industry's first 10,000-psi tanks, which could allow a fuel cell car to have a driving range of 230 miles.

Beneath the passenger cabin is an 11-inch-thick aluminum frame that holds all of the electric motors, microprocessors, mechanical parts, fuel-cell components, hydrogen tanks and other systems needed to operate the vehicle. The control wiring is carried in a single harness and permits designers to locate the operating controls virtually anywhere in the wide-open interior.

The compact, flat profile of GM's fuel cell which is about the size of a personal computer frees designers from the structure imposed by making room for a large internal combustion engine.

GM has provided the U.S. Army with a diesel hybrid military pickup truck equipped with a fuel cell auxiliary power unit that could become the model for the Army's new fleet of 30,000 light tactical vehicles by the end of the decade. GM has its Fuel Cell Development Center in Honeoye Falls, N.Y. to develop fuel cell technology for commercial use.

In 2005 GM delivered the first GM fuel cell powered pickup truck built for the U.S. military. Partnerships with customers like the U.S. military help to advance a hydrogen economy and gain real-world experience with hydrogen and fuel cells.

GM's AUTOnomy was awarded the Engine of the Year Award in Best Concept category by Engine Technology International. The Chevrolet S-10 Gasoline-Fed Fuel Cell Vehicle was the world's first drivable fuel cell vehicle that extracts hydrogen from gasoline to produce electricity. GM's Phoenix is a fuel cell wagon developed jointly by the Pan Asia Automotive Technology Center (PATAC), a joint venture of GM and the Shanghai Automotive Industry Corporation (SAIC).

GM and Hydrogenics have developed a fuel cell unit that provides back-up power to cell phone towers during power outages. Hydrogenics will market the fuel cell unit with Nextel.

GM has a multi-year collaborative research agreement with ChevronTexaco to advance fuel cell technology and gasoline processing for fuel cell vehicles. This will accelerate GM's gasoline-fed fuel cell vehicle to retail customers. GM also has an agreement with Suzuki Motor Corporation to collaborate on fuel cell vehicle development, focusing on small cars.

GM also announced the expansion of fuel cell development activity with Giner, Inc., to include applications beyond the transportation field, including hydrogen generation for refueling systems and regenerative fuel cells for stationary power. GM's fuel cell stack set a new world standard for power density that packed 60% more power. The new stack generated 1.75 kilowatts (kW) per liter.

GM's Gen III was the world's first gasoline fuel processor for fuel cell propulsion. Gen III had the capacity to start in less than three minutes.

GM has a 25-year collaboration with General Hydrogen to accelerate the spread of a hydrogen infrastructure and to speed the introduction of fuel cell vehicles into North America, Europe, Asia and emerging markets. The European Well-to-Wheel study shows that fuel cell cars offer solutions to curtail greenhouse gas emissions. The Well-to-Wheel study by GM, Argonne National Laboratory, BP, ExxonMobil, and Shell indicated that hydrogen-powered fuel cell vehicles offer the cleanest and most efficient combination of fuel and propulsion system in the long-term.

GM has a minority ownership position in QUANTUM Technologies to develop hydrogen handling and electronic control technologies for fuel cell applications. QUANTUM is an industry leader in hydrogen storage and handling in automotive applications. GM and Toyota have a multi-year technology agreement on combining research on fuels for fuel cells and fuel infrastructure with ExxonMobil.

GM will also provide 13 fuel cell powered vehicles while Shell Hydrogen LLC established New York State's first hydrogen service station in the New York City metropolitan area in 2006. This is part of the U.S. Department of Energy's Infrastructure Demonstration and Validation project.

In 2005 GM's Sequel was unveiled in Detroit. The Sequel is GM's vision of reinventing the automobile with a fusion of technologies including advanced materials, electronic controls, computer software and advanced propulsion.

The General Motors Sequel fuel cell concept car holds enough fuel for 300 miles. It fits the seven kilograms of hydrogen into an 11-inch thick skateboard chassis. The Sequel has been called a crossover SUV. Since mechanical components are replaced by electrical parts, interior layouts can be more open with more space in smaller vehicles.

The technology concepts first introduced in Autonomy and then Hy-wire have become more authentic in the Sequel which demonstrates the vision that fuel cells are the ultimate answer. GM, along with others, has been working at reinventing the auto. GM developed its AUTOnomy and Hy-wire concept cars. Now, with the fuel cell Sequel, GM has been able to double the range and half the 0-60 mph acceleration of these cars in less than three years.

The Sequel is almost the size of a Cadillac SRX. It has a 300-mile range on a refueling of hydrogen and accelerates to 60 mph in less then 10 seconds. Other fuel cell cars have a driving range of 170-250 miles and cover 0-60 mph in 12-16 seconds depending on whether they use a battery.

All of the drive power of the Sequel is in an 11-inch-high chassis. The individual powered wheels provide excellent control on snow, mud, ice and uneven terrain. GM's start-up time in freezing conditions is less than 15 seconds at -20°C. GM knew that if they are going to put these cars into the marketplace, they would have to start in the middle of a northern winter.

GM also believes that it could eventually close down engine and transmission factories around the world and have a single plant making fuel cells for all of its vehicles. There are 29 types of engines made in 28 GM plants worldwide and 20 transmissions made in 20 worldwide plants.

A fuel cell vehicle requires only 1/10 the parts needed for internal combustion models. A change to fuel cell power could end overcapacity problems for GM. It would no longer have to consider different state or country environmental regulations. Fuel cells also free designers and allow them to be more creative with styles and body designs.

GM has pledged to develop a hydrogen fuel cell vehicle that would compete with conventional cars in volume by 2010. The company has 1,000 people working on the project in government, university and private labs in 14 countries. It has spent over $1 billion on the project since 1996. DaimlerChrysler has also spent a billion on hydrogen fueled technology.

GM's international Global Alternative Propulsion Center is responsible for developing fuel cells for world markets. The center has several operations in Germany, where in concert with German subsidiary Opel, it has built the Zafira fuel cell minivan.

FORD'S FUEL CELL VEHICLES

The Ford Ecostar van program was launched in 1993 in response to the announcement of GM's EV1. Ford also started building fuel cell prototypes, but they were not really road-ready vehicles.

In 1997, Ford announced that it would invest $420 million in a global alliance with what was then Daimler-Benz and Ballard Power Systems. This provided Ballard with an important infusion of capital. As a result of these investments, Ford owned 15% of Ballard and DaimlerChrysler 20%. It was a critical moment for fuel cells since the total investment was reaching almost $1 billion, including the $450 million by DaimlerChrysler. The alliance of Ford, Volvo, and DaimlerChrysler was pushing the leading edge of fuel cell innovation. Ballard has focused on PEM cells with a goal to have commercial fuel cells available by 2010.

Ford planned to produce a fuel cell family car based on the aluminum and composite P2000 which is like the Ford Contour but weighs a thousand pounds less. In 1997, Ford announced that its fuel cell car would carry compressed hydrogen, but the fuel storage question may be still open.

In Germany, Daimler-Benz's fuel cell prototypes included the NECAR III. This was a Mercedes-Benz A-Class car with Ballard's methanol-reformed fuel cell system.

DaimlerChrysler's fuel cell was in the Mercedes-Benz B-class car. The fuel cell is a sandwich design with the polymer PEM cell between two gas permeable electrodes of graphite paper. Hydrogen is introduced to one side of the fuel cell while the other side is exposed to the air. Like the GM Hy-Wire platform, the fuel cells, fuel tank and fuel systems are under the floor. The compressor is in the front of the car to reduce the noise. There are four hydrogen sensors on the fuel cell stack, on each of the hydrogen tanks, another at the electric motor and another inside the cabin. The high torque electric motor developed 100-kW of motive power which was 35-kW more than the previous design for the A-class. The fuel cell is also more efficient. An enhanced hydrogen storage system gives the vehicle a range of 250 miles (400-kM). The Ballard fuel cells are expected to last at least 5,000 hours in a car and 10,000 hours in a bus.

In 2005 GM joined with Sandia National Lab in a partnership to design and test an advanced method for storing hydrogen. The 4-year, $10 million program is intended to develop and test tanks that store hydrogen in sodium aluminum hydride. The goal was to be able to store more hydrogen onboard that other hydrogen storage methods currently in use.

Toyota and Honda have been experimenting with both methanol and metal-hydride storage of hydrogen. Honda has built several test cars, in 1999 a Honda FCX-V1 (metal-hydride hydrogen) and FCX-V2 (methanol) were tested at a track in Japan. The Ballard powered version-1 was ready, but proved to be a little sluggish and noisy. The other car suffered from a noisy fuel cell. Both Honda fuel cell test cars were built on the chassis of the discontinued EV Plus battery electric. Honda used a different and more aerodynamic body.

The 2005 Honda FCX is a four-seat compact hatchback with an ultracapacitor to provide short bursts of power for passing and hills. Many of the other fuel cell vehicles use batteries for this power. The use of the ultracapacitor can eliminate the expensive replacement of the batteries when battery life is over. The energy from a regenerative braking system is stored in the ultracapacitor, which is a low voltage, high efficiency capacitor. The 2005 FCX had a top speed of 92 miles per hour with a range of 200 miles. The equivalent fuel economy is 62 miles per gallon for city driving and 51 on the highway.

The FCX-V2 used a Honda designed fuel cell and reformer. Downsizing the methanol reformer remained to be done and both test cars had room only for a driver and passenger. Fuel cell components took up the rear seats. The need to test fuel cell cars under real-life conditions is one reason Honda joined DaimlerChrysler in the California Fuel Cell Partnership. More recently Honda announced the first lease of its advanced

FCX fuel cell vehicle.

Toyota began to work with PEM cells in 1989 and produced a methanol reformed car, the FCEV, in 1997. This car was based on Toyota's electric RAV4.

Toyota has also worked on storing hydrogen in metal hydrides. This technology has been tried by other companies and rejected because the metals are too heavy. Toyota obtained a 155-mile range with metal hydride storage. Toyota has also developed 35-MPa and 70-MPa high pressure hydrogen tanks that have been certified by the High Pressure Safety Institute of Japan.

Toyota is sharing some of its fuel cell research including vehicle recycling and reduction of greenhouse gases with GM, its partner on a number of projects. GM is also spending $44 million in a joint project with the Department of Energy to put fuel cell demonstration fleets on the road in Washington, D.C., New York, California and Michigan.

Toyota has been sharing technology with partner GM on electric, hybrid, and fuel cell cars. In 1998, the research division was testing methanol reformers and metal hydride hydrogen storage and had prototypes of each.

In July 1998, Toyota said it would try to have a fuel cell automobile ready by 2003, but later this target date was dropped. Toyota believed that there are major cost problems for onboard reformers and saw direct hydrogen as a big technical challenge. Still, it kept working in these areas and its FCHV (fuel cell hybrid vehicle) became the first vehicle in Japan to be certified under the Road Vehicle Act.

A later version of Toyota's FCHV fuel cell hybrid vehicle successfully completed a long-distance road test by traveling from Osaka to Tokyo, approximately 560 kilometers, on a single tank of hydrogen. This FCHV is 25% more fuel efficient than earlier versions, thanks to improvements in the fuel cell stack and to improvements in the control system for managing fuel cell output and battery charging/discharging. It also uses 70Mpa high-pressure hydrogen tanks capable of storing approximately twice the amount of hydrogen as previous tanks.

Fiat has been working on its Fuel Cell Pandas. Centro Ricerche Fiat (CRF) delivered several Nuvera fuel cell powered Panda vehicles to the municipality of Mantova, Italy, as part of the Zero Regio demonstration project. The Pandas were presented alongside an ENI multi-fuel refilling station, offering pressurized hydrogen at 350 bar.

General Motors introduced the HydroGen4, the European version of the Chevrolet Equinox fuel cell vehicle in 2007. The HydroGen4 is designed for a life cycle of two years/80,000 kilometers and can start and run at sub-zero temperatures. It represents a considerable advancement over the HydroGen3.

Hyundai introduced its new i-Blue Fuel Cell Electric Vehicle. The i-Blue platform incorporates Hyundai's third-generation fuel cell technology and is powered by a 100-kW electrical engine and fuel cell stack. It is fueled with compressed hydrogen at 700 bar stored in a 115 liter tank. The i-Blue is capable of running more than 600-km per refueling stop and has a maximum speed of 165-km/h.

In 2010, Mercedes-Benz plans to launch the first series-production car of the B-Class F-Cell vehicle. This F-Cell will contain the next generation fuel cell engine with a redesigned stack that is 40 percent smaller and produces 30 percent more power.

HYDROGEN BUS TECHNOLOGY

The Hydrogen Bus Technology Validation Program in Davis/Sacramento, California is a multi-district partnership of the City of Davis, Yolo County Transportation District (YCTD), University of California, Davis (UC Davis), UniTrans (Transit authority for the City of Davis and UC Davis), and NRG Tech.

The City of Davis receives the project funds for disbursement to the other project partners. The program seeks to validate advanced clean fuel technologies in a practical application.

Hydrogen fuel-based technologies hold great promise in reducing carbon dioxide and toxic air emissions from mobile sources in meeting current clean air standards and proposed greenhouse gas reductions.

The Hydrogen Bus Technology Validation Program will use the hydrogen powered buses to provide service in the Davis/Sacramento region. Some buses will operate on a blend of natural gas and hydrogen using advanced internal combustion engines with technology developed for NASA. Others will be Proton Exchange Membrane (PEM) fuel cell buses and operate on compressed hydrogen. All the buses will be 40-foot transit buses. After a testing period, UniTrans and YCTD will run the buses along standard transit routes. The buses will refuel at the modified UniTrans depot, which will support compressed hydrogen and hydrogen/natural gas fueling.

Hydrogen-enriched natural gas buses are expected to meet the California Air Resources Board's transit emissions requirements. They also pave the way for a hydrogen infrastructure that can support fuel cells for transportation. The use of hydrogen powered buses and infrastructure facilities conforms with the goals of the California Fuel Cell Partnership, the U.S. Department of Energy, the U.S. Department of Transportation, and the U.S. Environmental Protection Agency.

UniTrans is the host and operator of the clean fleet and the refueling facility. The Yolo County Transportation District will operate the project buses serving Sacramento, including the Sacramento International Airport. UC Davis is the technical lead for design and evaluation. NRG Technologies, Inc., is modifying the natural gas buses to operate on a mixture of compressed natural gas (CNG) and hydrogen.

A commercial CNG bus with a John Deere 8.1 liter engine will undergo modifications to the engine for operation on a mixture of 30% hydrogen and 70% natural gas by volume. This is expected to reduce emissions of NO_x substantially without a significant reduction in engine power.

Freightliner and the U.S. Department of Energy Advanced Vehicles Program are exploring using fuel cell auxiliary power units (APUs) in lieu of main engine idling in their vehicles. The truck auxiliary power application may offer a viable near-term market for small (1- 5-kW) fuel cells.

It is estimated that idling uses 9,090 gallons of fuel over five years for an average late model truck that idles 6 hours per day, 303 days per year. The fuel cost over this five-year period could be $35-40,000 in addition to preventative maintenance and engine overhauls. Idling is also estimated to contribute 1 to 3 tons of nitrogen oxide emissions and 40 to 120 tons of carbon dioxide over a five-year period. Fuel cell APUs in lieu of idling could greatly reduce truck fuel consumption, pollution emissions, greenhouse gas emissions, and trucking costs.

At Forschungszeutrum Julich GmbH in Julich, Germany, scientists developed an in-line reformer to oxidize carbon-containing fuel impurities in a liquid state instead of a gaseous state. By reforming in a liquid, a fuel cell avoids the energy losses associated with reforming fuels in gas. Compared to pure gaseous oxygen, liquids are easier to store and handle.

Oxidized impurities in the fuel are also adsorbed and oxidized by the reactor which has U.S. Patent 6,068,943. Suitable oxygen-containing compounds include peroxo monosulfuric acid, a peroxide of the alkali or alkaline earth metals in an acid solution. These oxygen-containing compounds can be catalytically decomposed to release oxygen. Liquid oxygen-containing compounds can be easily mixed with the liquid fuel.

Gaseous oxygen can hardly be mixed with liquid fuel. The addition of pure oxygen to the fuel can be used only in combination with gaseous fuel. This limitation is eliminated with the addition of a liquid oxygen-containing compound. The dosed admission of an oxygen-containing compound is controlled dependent on the contact voltage of the fuel cell. If the voltage is below a characteristic value, the oxygen-containing compound is fed into the fuel supply line to prevent energy output losses. The dosage is also controlled so no explosive mixture is formed.

VOLVO AND FUEL CELLS

Volvo has modified a Renault Laguna station wagon with a 30-kilowatt fuel cell, running on liquid hydrogen. The Fuel Cell Electric Vehicle for Efficiency and Range (FEVER) car was partly financed by the European Union. It was completed in 1997 and has a 250-mile range. Even though it was a station wagon, the fuel cell car has room only for its driver.

Volvo is also a partner in another European project, the Capril project, which is managed by Volkswagon. A fuel cell VW Golf was built to run on methanol. Volvo developed the compressor, power converter and energy control system.

In 1992, Volvo built an aluminum-bodied hybrid Environmental Concept Car (ECC) to California emission mandates. It had the recyclable plastic panels and water-based paints that are used by Volvo. A series hybrid drive train was used where a diesel gas turbine drives a generator to charge a battery pack to power an electric motor. The system is complex, but the car achieves good performance with low emissions and a 400-mile range.

Volvo was testing 50-kilowatt stacks from Ballard before the Ford purchase and has been building bifuel natural gas and gasoline cars and hybrids. By 1998 it was selling 500 bifuel sedans a year with many going to natural gas utilities in Europe. By 1999, it was working on a powersplit hybrid car, which automatically shifts from the electric motor to an internal combustion engine like many of today's hybrids.

In fuel cell development, the high cost of precious metals has led to ways to lower the platinum content. Methods include raising the activity of the catalyst, so less is needed and finding more stable catalyst structures that do not degrade over time while avoiding reactions that can contaminate the membrane.

Researchers at 3M have been able to increase catalytic activity with nanotextured membrane surfaces that employ tiny columns to increase the catalyst area. Other materials include nonprecious metal catalysts such as cobalt and chromium along with particles embedded in porous composite structures.

A fuel cell vehicle must have enough hydrogen to provide a reasonable driving range. For a range of 400 miles, 5-7 kilograms of hydrogen may be required, most fuel cell prototypes hold a little more than about half this amount.

Hydrogen can be stored in high pressure tanks as a compressed gas at ambient temperature and there has been much work on increasing the pressure capacity of composite pressure tanks. Liquid hydrogen systems that store the fuel at temperatures below –253°C have been successful. But, almost one third of the energy available from the fuel is needed to maintain the temperature and keep the hydrogen in a liquid state. Even with thick insulation, evaporation and losses through seals results in a loss every day of about 5% of the total stored hydrogen.

Alternative storage technologies include metal hydride systems where metals and alloys are used to hold hydrogen on their surfaces until heat releases it for use. They act like a sponge for hydrogen. ECD Ovonic, a part of Texaco Ovonic Hydrogen Systems, has been active in this area. The hydrogen gas in the high pressure storage tank chemically bonds to the crystal lattice of the metal or alloy in a reaction that absorbs heat. The resulting compound is a metal hydride.

Waste heat from the fuel cell is used to reverse the reaction and release the fuel. In 2005 GM and Sandia National Laboratories launched a $10-million program to develop metal hydride storage systems based on sodium aluminum hydride.

Metal hydride storage systems can be heavy and weigh about 300 kilograms. Researchers at the Delft University of Technology in the Netherlands have found a way to store hydrogen in water ice, a hydrogen hydrate, where the hydrogen is trapped in molecule sized cavities in ice. This approach is much lighter than metal alloys.

In the past, hydrogen hydrates have been difficult to produce, since they require low temperatures and pressures in the range of 36,000 psi. Working with the Colorado School of Mines, the Delft group used a promoter chemical (tetrahydrofuran) to stabilize the hydrates at 1,450 psi. This approach would allow about 120 liters (120 kilograms) of water to store about six kilograms of hydrogen. Storing in hydrides creates heat and in order to get the hydrogen out the hydride must be heated.

GM has been working on a system that would cool hydrogen to -196°C at 1,000 psi. This would be less costly and reduce the boil off.

FUEL CELL FREEZE UPS

In Albany, NY, the state government started leasing Honda FCX hydrogen fuel cell cars on a cold November morning. Previous fuel cell vehicle demonstration programs have occurred in warmer areas to ensure that the fuel cell stacks would not freeze up. Subzero temperatures can change any liquid water present into expanding ice crystals that can puncture thin membranes or crack water lines. Honda has demonstrated that their fuel cell units can operate under winter conditions, this was an important achievement for practical fuel cell cars.

The freeze-resistant 2005 FCX models can operate at -20°C. Other companies, including DaimlerChrysler and GM have also had success with cold-starting cells. The technique used is to keep all water present as a vapor and not allow water droplets to occur.

DaimlerChrysler had a fleet of more than 100 F-cell fuel cell cars called the F-Cell which were used for worldwide testing. They have also built 33 fuel cell buses for 10 European cities as well as Beijing and Perth. DaimlerChrysler has invested over $1 billion in hydrogen fuel cell technology. The fuel cell vehicle fleet is powered by Ballard stacks.

Pacific Gas and Electric (PG&E) added F-Cell vehicles to its clean fuels fleet for testing. PG&E has the fourth largest alternative-fuel truck fleet in the nation.

The operational experience and technical data will help improve the next generation of fuel cell vehicles. The data collected will also contribute to the U.S. Department of Energy's Hydrogen Learning Demonstration Project and support the federal Freedom Car Program.

PG&E is involved in other demonstration projects to enhance gas-to-hydrogen reforming technology and to incorporate hydrogen-fueling capability into existing natural gas stations to accommodate fuel cell vehicles. PG&E's natural gas distribution infrastructure could become part of the hydrogen highway network. The project will help to determine if the technology will meet fleet operations needs in the future and provide an evaluation of fueling technology.

PG&E is a member of the California Fuel Cell Partnership along with the former DaimlerChrysler, Air Products and Chemicals, and British Petroleum. A variety of PG&E employees will be using the F-Cell vehicles including, fleet mechanics, inspectors, service planning representatives, project managers and officers. PG&E expects to average at least 35 miles per day on each of the vehicles.

The Peugeot Quark ATV uses an air-cooled fuel cell with a 40 cell nickel metal hydride battery. The 9 liter hydrogen tank can be pressurized to 10,150 psi for a range of up to 80 miles. The tank is designed to be exchanged for a full one when empty. Each 17 inch wheel has its own electric motor that can produce 74 pound-feet of torque. The motors also supply regenerative braking.

In addition to GM, DaimlerChrysler, Ford, Honda, Toyota and others have spent billions developing alternative fuel vehicles. GM wants to become the first carmaker to sell a million fuel cell vehicles and hopes to have them on the market by 2010.

A hydrogen infrastructure could cost hundreds of billions, since there is a limited hydrogen-generating capacity now. But, decentralizing production, by having reformers in buildings and even in home garages in combination with local power generation, reduces some of that excessive cost. Larger reformers in neighborhood facilities could be the gas stations of tomorrow. One study of the near-term hydrogen capacity of the Los Angeles region concluded that hydrogen infrastructure development may not be as severe a technical and economic problem as often stated. The hydrogen fuel option is viable for fuel cell vehicles and the development of hydrogen refueling systems is taking place in parallel with various fuel cell vehicle demonstrations.

Hydrogen fuel cells are being prompted by the desire to reduce global warming and control the spread of pollution in the developing world. Fuel cells offer a major step in improved efficiency and reduced emissions. Hydroelectric dams could also be impacted by fuel cells. With more fuel cells around, electricity prices may fall and dam owners could make more profit selling hydrogen than selling electricity.

COMPUTER MODELING

Some computer models of fuel cell cars show the power needed at the wheel which is computed from the weight of the car, energy of the fuel, accessories and other variables including mileage. An onboard reformer has been shown to provide 70 miles per gallon, but compressed hydrogen increases this to the equivalent of 100 miles per gallon. The models show that 60-70 miles per gallon is possible in hybrid cars using small gasoline or direct-injection diesel engines, which have much higher emissions.

In 1998 the auto industry turned from weak commitments to a solid move toward fuel cells and EVs. All the auto companies are pursuing hydrogen fuel cells in some way. But, the new cars on the road in the near future are likely to be a mix of vehicles including those with electric drive, including battery EVs, hybrids with gasoline and direct-injection diesels, turbo generators and fuel cells.

The move to fuel cells may not be pushed by declining oil supplies. The cost of developing new oil discoveries continues to fall and we may not see a forced drop in productivity. It was thought that there was 1.5 billion barrels of oil in the North Sea, but now there appears to be 6 billion barrels. We may not begin to reach the physical limits of oil production until mid-century. Supplies could tighten quickly from natural or man-made disasters and recent price rises are driven by increasing worldwide demands. Older oil fields are being pursued to meet this demand, but full development is expected to take years.

One factor in the shift to fuel cells is concern over climate changes. We may be nearing the end of the carbon economy and the replacement of internal combustion power with fuel cells. Technology is driving our lives with tiny chips that have many times the computing power of larger older computers, yet they cost less to manufacture. Lighter, stronger materials and structures make electrical drives more feasible. Technology, legislative mandates and increased competition for markets will drive the fuel cell for automobiles and electrical power.

DOE RESEARCH

The DOE is funding research in areas such as compressed natural gas storage, direct-injection diesels with emissions-reducing catalytic converters, direct-hydrogen fuel cells including a 50-kilowatt automotive unit than runs without an air compressor and the Epyx gasoline reformer. DOE also supports national laboratories, such as Los Alamos which has been working on PEM fuel cells. This is the type used on the Gemini space program.

The liquid fuel reformer that has been worked on at Los Alamos and the Argonne National Labs is a fuel-flexible processor which can reform gasoline, natural gas, methanol, or ethanol at the control of a switch. This would also allow the use of the existing fuel infrastructure, but this approach forces the use of a more complicated, heavier system for vehicles. Los Alamos has also worked with General Motors and Ballard on PEM research which resulted in a 10-kilowatt demonstration unit.

DOE provides support to American companies, but the level of support is less than the federal support in Germany and Japan. In 1993, Japan started a major 28 year, $11 billion hydrogen research program called New Sunshine. It surpassed Germany's to become the biggest program at that time. Basic hydrogen research included work on the metal-hydride storage systems that are used in Toyota's fuel cells. German government support has declined since reunification.

Hydrogen fuel cells have become an international effort. Shell Oil established a Hydrogen Economy team dedicated to investigate opportunities in hydrogen manufacturing and fuel cell technology in collaboration with others, including DaimlerChrysler.

Fuel cells would provide an environmentally superior and more efficient automobile engine. This is being pursued with a combination of resources by strong organizations acting in their own interests and with support from public policy groups.

In one study by Ford, even with a fuel efficiency of 70 miles per gallon, the size of the tank needed for a 350-mile range would greatly impact both the passenger and cargo space. But, computer models show that 100 miles per gallon are possible.

Several prototypes have placed the tank on the roof, like the NECAR II van, this might be acceptable in a high roofed van but not in most passenger cars. High weight in the roof also makes the vehicle unstable at higher speeds. Storing the fuel in special structures has been done by Toyota, Honda and others, but the metals and structures are expensive.

Some timetables for fuel cell prototypes announced by government and industry have proven too conservative. Many auto companies already have running drivable fuel cell prototypes. There was also some modest commercialization being achieved by 2004. Some of the predictions for commercialization have fallen behind or been discarded, but this is normal where complex products are involved and where vast market forces are at work. In the early days of automobiles little infrastructure was available, it grew along with the demand. The product was simple and could be repaired on the road with a few simple tools much as wagons were at the time. Transportation options were few and autos proved to be much superior over earlier methods of transportation. Today, hybrid cars are proving to be in demand and most manufacturers have models available in their lines or are planning to introduce them. If fuel cell cars run on gasoline, there is minimum disruption but many fossil fuel problems remain.

METHANOL FUEL CELLS

Daimler-Benz has accumulated data on NECAR III emissions with a dynamometer programmed for a mix of urban and suburban driving. The results were promising since there were zero emissions for nitrogen oxide and carbon monoxide, and extremely low hydrocarbon emissions of only .0005 per gram per mile. NECAR III did produce significant quantities of carbon dioxide similar to the emissions of a direct-injection diesel engine where the fuel is injected directly into the combustion chamber. Direct-injection produces less combustion residue and unburned fuel.

Methanol may serve as a bridge to direct hydrogen, but more hydrogen fuel cell vehicles are appearing. Rapid advances in direct-hydrogen storage and production could push any liquid fuel out.

Each year the U.S. consumes almost 200 billion gallons of gasoline, diesel fuel and other transportation fuels for road travel. This is about 20% of total U.S. energy consumption. When travel by air, water, and rail is added, including pipelines energy, total transportation energy rises to almost 30% of U.S. energy consumption.

The timetables announced by government and industry have generally been proven too conservative. Many auto companies already have running drivable fuel cell prototypes and it appears likely that some moderate commercialization will be achieved in the next decade. Hybrids are already here and proving to be popular because of their efficiency. They are providing valuable data on the type of electric drives that would be used in hydrogen fuel cell vehicles.

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Chapter 6

Power Generation

Power generation is being advanced by fuel cell technology as many fuel cell generators are being marketed now. Fuel cells can be used to generate electricity, heat, and hydrogen. One fuel cell provider FuelCell Energy uses this technique in its molten carbonate fuel cell. Some solid oxide fuel cell (SOFC) companies have been developing similar products.

Fuel cells operate much like a battery, using electrodes in an electrolyte to generate electricity. But, unlike a battery, fuel cells never lose their charge as long as there is a constant source of fuel.

Fuel cells can be used to power a variety of portable devices, from handheld electronics such as cell phones and radios to larger equipment such as portable generators. Other potential applications include laptop computers, personal digital assistants (PDAs), and handheld video cameras—almost any application that has traditionally used batteries. These fuel cells have the potential to last more than three times as long as batteries between refueling.

In addition to these smaller applications, fuel cells can be used in portable generators, such as those used to provide electricity for portable equipment. Thousands of portable fuel cell systems have been developed and operated worldwide, ranging from 1 watt to 1.5 kilowatts in power. The two primary technologies for portable applications are polymer electrolyte membrane (PEM) and direct methanol fuel cell (DMFC) designs.

STATIONARY POWER FUEL CELLS

The U.S. Department of Energy's Office of Fossil Energy has a joint program with fuel cell developers to develop the technology for stationary power applications includes central power and distributed generation.

The joint government-industry fuel cell program is aimed at giving the world's power industry a revolutionary new option for generating electricity with efficiencies, reliabilities, and environmental performance beyond conventional electricity generation.

During the 1970s and early 1980s, the Federal program included the development of the phosphoric acid fuel cell system. This was considered the first generation of modern-day fuel cells. Largely because of the support provided by the Federal program, United Technologies Corporation and its subsidiaries manufactured and sold phosphoric acid fuel cells throughout the world.

In the late 1980s, the DOE shifted to the development of advanced higher temperature fuel cell technologies, especially molten carbonate and solid oxide fuel cell systems. Federal funding for these technologies resulted in private commercial manufacturing facilities and commercial sales.

While first generation fuel cells continued to be of interest, the present goal of the DOE's Fossil Energy fuel cell program is to develop low cost fuel cells. The target cost is $400 per kilowatt or less, which is significantly lower than today's fuel cell products. It is expected that lower cost fuel cells will result in more widespread utilization.

Fuel cells are not being installed in more applications because of their cost. The fuel cells used in the space program were extremely expensive at $600,000/kW and impractical for most power applications. But, over the decades, significant efforts have made them more practical and affordable.

Fuel cells can cost about $4,000 per kilowatt, but a gas or diesel generator is $800 to $1,500 per kilowatt, and a natural gas turbine may be even less. A modern gas turbine such as General Electric's 7H turbine is a 40-foot-long, 400,000-pound unit that runs on natural gas. It produces 50% more power than the earlier 7FA with lower NO_x and CO_2 emissions. Conventional gas turbines use air for cooling, but the 7H uses steam at 700°F. The steam absorbs heat better than air which allows a higher peak operating temperature without increasing the temperature in the combustor, where most the unit's greenhouse gases are produced. Two 7H turbines are to be used in a plant at Riverside, California, where they will provide 775-MW to power about 600,000 homes.

The U.S. Department of Energy has a major program in the Solid State Energy Conversion Alliance to bring about dramatic reductions in fuel cell costs. The goal to cut costs to $400 per kilowatt by the year 2010 would make fuel cells competitive for most power applications. The objective is to develop a modular, all-solid-state fuel cell that can be mass-produced for different products in the same way as electronic components are made.

TECHNOLOGY ADVANCES

Fuel cell technology continues to advance with materials research. The catalyst material has been one of the major expenses in fuel cell design. An anode with about 40% less catalyst has been developed at Forschungszentrum Julich GmbH in Julich, Germany. It has a bipolar plate with areas of different catalytic activity levels. The anode substrate has one phase that does not act as catalyst to methane-vapor reforming reactions, and another phase where it acts as a catalyst.

The concentration of the non or slightly catalytic effective metallic phase can be adjusted. A reduced catalyst concentration for a delayed methane-vapor reforming reaction are then present if they are placed in the fuel cell adjacent to the gas passages.

The catalyst amount is reduced, but the relative speeds of the electrochemical and the reformation reactions remain essentially the same.

Global Thermoelectric of Calgary, Alberta, Canada, has successfully completed the testing of several latest generation prototype residential 2-kW fuel cell systems. The project is part of an alliance with Enbridge, Inc., and will help to commercialize residential fuel cell systems.

Global has also completed the development of a 5-kW propane partial oxidation (POX) reformer and has demonstrated Global's SOFC technology to use propane as a feedstock. The reformer was based on an existing natural gas fuel processor modified to reform propane. Single cell and stack testing showed that Global's SOFCs can use propane reformate using partial oxidation reforming with only a minor impact on performance when compared to operating on hydrogen.

Global has also designed and built a dual-stage, low-temperature adsorbent desulfurizer. Sulfur in propane can exceed as much as 300-ppm compared to natural gas, which ranges from 2 to 15-ppm sulfur and it must be removed to block any poisoning of the fuel cell. The test results indicated that no sulfur compounds were present in the outlet gas of the desulfurizer. The system design uses a modular assembly and layout, including a circular hot box where the fuel cell stacks and the fuel processor are located and easily accessed.

ON-SITE POWER

A hydrogen economy may be jump started with distributed power. These are stationary fuel cells that generate on-site power in critical areas, schools, apartment buildings or hospitals. The cost of fuel cells would have to come down to less than $1,000 per kilowatt. At $800 to $1000 per kilowatt fuel cells would be economical for buildings. The excessive space and weight would not matter so much for an installation in a basement or in an outside area.

The waste heat the fuel cell generates can be used in a cogeneration process to provide services like heating, cooling, and dehumidification. Instead of the 50% efficiency of a fuel cell with a reformer, or 60-70% without one, 90% or better is possible for the total system efficiency.

In most situations, the waste heat is enough of a commodity to pay for a natural gas line and a mass-produced reformer to turn it into hydrogen. Then, the effective net cost of providing electricity to the building is about 1-2 cents per kilowatt hour.

CARS AS POWER PLANTS

As the building market for fuel cells grows, costs will come down and allow more economical fuel cells in cars. Buildings use 2/3 of all electricity in the United States, so there is the possibility of large fuel cell volumes. Both the building and vehicular fuel cell markets are potentially so large that when either of them starts moving it will push the other.

Stationary and mobile fuel cells could have a potential relationship that goes beyond cost and volume. A fuel cell in a vehicle is a multi-kilowatt power generator on wheels, which is driven about 5% of the time and parked the other 95% of the time.

These fuel cell cars could be used to provide power and even water to buildings where people live or even work. Commuters could drive their cars to work and connect them to a hydrogen line. While they worked, their cars would be producing electricity, which they could then sell back to the grid. The car, instead of just occupying a parking space, would become a profit generator.

Thinking about cars as power plants is not something that we are conditioned to do, but it is an indication of how fuel cells could impact our lives as mobile utilities.

Fuel cell vehicles could provide extra value when they are in use, by acting as these mobile power sources. Most cars are used for 1 or 2 hours of the day. When they are not used, they are often parked where electricity is needed—offices, stores, homes or factories. If all cars were fuel cell powered, the total power generation capacity would be several times greater than the current U.S. power generation.

Parked fuel cell cars could be plugged into the grid to generate power. If only a small percentage of drivers used their vehicles as power plants to sell energy back to the grid, many of the power plants in the country could be closed.

However, if the major source of hydrogen is reformed natural gas, the cost of generating electricity with a low-temperature fuel cell would be about $0.20 per kilowatt-hour. This is more than double the average price for electricity. It would also produce 50% more carbon dioxide emissions than the most efficient natural gas plants which are combined cycle natural gas turbines. Low-temperature fuel cells operating on natural gas are not as efficient at generating electricity. A stationary fuel cell system achieves high efficiency by cogeneration.

But, cogeneration would add to the complexity of the vehicle. Connecting a vehicle to the electric grid will also require some additional electronics. Extracting useful heat would involve new ductwork and possibly heat exchangers. This could be a problem for existing buildings, where parking may not be adjacent to heating units. Most homes could probably use the heat from a 1 kilowatt (kW) fuel cell, but a car will probably have a 60/80-kW fuel cell.

Home electricity generation with either a stationary or a mobile fuel cell may not provide any cost savings that would jump-start commercialization. Also, a method is needed to get hydrogen to your home or office to power the fuel cell after your car's onboard hydrogen is consumed. For relatively small amounts of hydrogen, bottled hydrogen is likely to be expensive per kilogram. It could also be expensive to generate hydrogen onsite. Hydrogen generation and purification units may be too expensive for home use and local electricity and natural gas prices are much higher than for larger users.

FUEL CELL BENEFITS

Fuel cells are the cleanest and most efficient technologies for generating electricity from fossil fuels. Since there is no combustion, fuel cells do not produce any of the pollutants commonly emitted by boilers and furnaces. For systems designed to consume hydrogen directly, the only products are electricity, water and heat.

When a fuel cell consumes natural gas or other hydrocarbons, it produces some carbon dioxide, though much less than burned fuel. Advanced fuel cells using natural gas, for example, could potentially reduce carbon dioxide emissions by 60% compared to a conventional coal plant and by 25% compared to modern natural gas plants.

Also, the carbon dioxide is emitted in concentrated form which makes its capture and storage, or sequestration, much easier. Fuel cells are so clean that, in the United States, over half of the states have financial incentives to support their installation. In fact, the South Coast Air Quality Management District in southern California and regulatory authorities in both Massachusetts and Connecticut have exempted fuel cells from air quality permitting requirements. Some states have portfolio standards or set asides for fuel cells. There are major fuel cell programs in New York (NYSERDA), Connecticut (Connecticut Clean Energy Fund), Ohio (Ohio Development Department), and California (California Energy Commission). Certain states have favorable policies that improve the economics of fuel cell projects. For example, some states have net metering for fuel cells which obligates utilities to deduct any excess power produced by fuel cells from the customer's bill.

Fuel cells are also inherently flexible. Like batteries in a flashlight, the cells can be stacked to produce voltage levels that match specific power needs; from a few watts for certain appliances to multiple megawatt power stations that can light a community.

SOLID STATE ENERGY CONVERSION ALLIANCE

The Department of Energy formed the Solid State Energy Conversion Alliance (SECA) with a goal of producing a solid-state fuel cell module that would cost no more than $400/kW. This would allow fuel cells to compete with gas turbine and diesel generators. The plan is to develop a compact, lightweight, 3-kW to 10-kW building block module that can be mass-produced using many of the same manufacturing advances that have greatly lowered costs for electronics equipment. These building blocks would be clustered into a number of custom-built stacks for a variety of applications ranging from small portable power sources to megawatt generating systems.

SECA is made of fuel cell developers, small businesses, universities and national laboratories. It is administered by the Energy Department through the National Energy Technology Laboratory (NETL) and its Pacific Northwest National Laboratory (PNNL).

The High Temperature Electrochemistry Center (HiTEC) Advanced Research Program provides crosscutting, multidisciplinary research supporting SECA, Fuel Cell Coal Based Systems, and FutureGen. HiTEC is centered at Pacific Northwest National Laboratory (PNNL) with satellite centers at Montana State University and the University of Florida. Research includes the development of low-loss electrodes for reversible solid oxide fuel cells, the development of high temperature membranes for hydrogen separation, and the study of fundamental electrochemical processes at interfaces. HiTEC is also pursuing the development of high temperature electrochemical power generation and storage technologies and advanced fuel feedstock.

Several projects focus primarily on solid oxide fuel cells (SOFCs). Coal-based power production systems that incorporate SOFC have the potential for significantly higher efficiencies and lower emissions than conventional technologies. In addition, high-temperature electro-chemical systems can enhance energy storage in central coal power plants, reducing the impact felt during hours of peak demand and making the plants more cost effective.

The SECA program currently has six competing Industry Teams supported by a Core Technology Program. The teams are led by: FuelCell Energy, Delphi, General Electric, Siemens Power Generation, Acumentrics, and Cummins Power Generation.

The benefits and feasibility of hybrid systems have been established with conceptual studies and small-scale demonstrations fueled with natural gas. If large-scale, greater than 100-MW, fuel cell/turbine hybrid systems are to become a reality a reduction in fuel cell costs and scalability to larger units is required. The SECA program demonstrated 3 to 10 kW SOFC systems with costs of less than $800/kW in 2005.

Fuel cell/gas turbine hybrids will form the essential power block component of the FutureGen plant, allowing high overall efficiency and exceptional environmental performance to be achieved at low cost.

FUEL CELL/COAL-BASED GENERATION

The SECA Fuel Cell Coal-based Systems program was started in 2005. The goal is to develop and demonstrate fuel cell technology for central power station and produce affordable, efficient, environmentally-friendly electricity from coal. The program leverages advances in solid oxide fuel cell (SOFC) technology under the SECA program.

The research is focused on future energy needs with near-zero emissions in coal-fueled power station applications. Key system goals include:

- A 50 percent or greater overall efficiency in converting the energy in coal to electrical power.
- The capture of 90 percent or more of the carbon in the coal fuel as CO_2.
- A cost of $400 per kilowatt, excluding the coal gasification and CO_2 separation systems.

The projects are being conducted by three research teams led by General Electric Hybrid Power Generations Systems (GE HPGS), Siemens Power Generation and FuelCell Energy. The projects concentrate on fuel cell technologies that can support power generation systems larger than 100 megawatts. GE HPGS is a partner with GE Energy, GE Global Research, PNNL and the University of South Carolina in developing an integrated gasification fuel cell (IGFC) system. It would merge GE's SECA-based planar SOFCs and gas turbines with coal gasification technologies. The system design will use a SOFC/gas turbine hybrid as the main power generation unit.

Siemens Power Generation is a partner with ConocoPhillips and Air Products and Chemicals, Inc., (APCI) to develop large-scale fuel cell systems based upon their gas turbine and SECA SOFC technologies. The design will use an ion transport membrane (ITM) oxygen air separation unit (ASU) from APCI with improved system efficiency.

FuelCell Energy is a partner with Versa Power Systems, Nexant, and Gas Technology Institute to develop more affordable fuel-cell-based technology that uses synthesis gas from a coal gasifier. The key objectives include the development of fuel cell technologies, fabrication processes, and manufacturing capabilities for solid oxide fuel cell stacks for multi-megawatt power plants.

The High Temperature Electrochemistry Center (HiTEC) Advanced Research Program provides research for supporting SECA, fuel cell coal based systems, and FutureGen. HiTEC is located at the Pacific Northwest National Laboratory (PNNL) with support groups at Montana State University and the University of Florida. Research includes:

- The development of low-loss electrodes for reversible solid oxide fuel cells.
- The development of high temperature membranes for hydrogen separation.
- The investigation of fundamental electrochemical processes at interfaces.

HiTEC is also investigating the development of high temperature electrochemical power generation and storage technologies and advanced fuel feedstocks.

SOFC research is conducted at the University of Utah, Massachusetts Institute of Technology, Northwestern University, United Technologies Research Center, and SRI International.

Coal-based power production systems that use SOFC systems could have higher efficiencies and lower emissions than conventional technologies. High-temperature electrochemical systems could improve energy storage in central coal power plants, reducing the peak capacity during high demand periods and greatly reducing costs.

FUEL CELL INCENTIVES

The Energy Policy Act of 2005 included the first tax incentive for fuel cell power plants at the Federal level. To qualify, a facility must have an integrated system with a fuel cell stack assembly with a balance of plant components that convert a fuel into electricity using electrochemical means. The facility must have an electricity-only generation efficiency of greater than 30 percent and generate at least 0.5 megawatts of electricity, which was placed in service after December 31, 2005, and before January 1, 2009. The owners can claim the 1.5 cents-per-kilowatt-hour (indexed for inflation) credit for a five-year period starting on the date the facility was placed in service.

States that have major fuel cell programs include New York (NYSERDA), Connecticut (Connecticut Clean Energy Fund), Ohio (Ohio Development Department), and California (California Energy Commission).

General Motors is also applying cell technology to stationary power. Dow and GM are working on a significant fuel cell application at the

Dow Chemical Company plant in Freeport, TX. The Freeport plant is the home of Dow's largest chemical manufacturing installation in the world and one of the world's largest chemical plants. In 2004 Dow Chemical and GM began the installation of fuel cells to convert excess hydrogen into electricity.

HYDROGEN AT DOW

Hydrogen is a natural by-product of chemical manufacturing at Dow. Dow has used its excess hydrogen as fuel for boilers and also sells hydrogen to industrial gas companies for resale to their customers. Using this hydrogen through a fuel cell to generate electricity is more efficient and economically desirable than either of these applications. By efficiently consuming by-product hydrogen in a fuel cell, Dow will reduce emissions of greenhouse gases and create competitively priced electricity. Dow and GM aim to prove the viability of hydrogen fuel cells for a large industrial power system.

The initial GM fuel cell will generate 75 kilowatts of power which is enough electricity for fifty average homes. Dow and GM plan to ultimately install up to 400 fuel cells to generate 35 megawatts of electricity. That would be enough power for 25,000 average sized American homes. While this may seem like a lot of capacity, it represents only two percent of the total Dow needs at this site. Dow believes that this will make them less dependent on fossil fuels and help usher in a more sustainable future.

DIVERSIFYING THE ENERGY SUPPLY

As part of an ongoing effort to diversify its energy supply and advance the implementation of clean, distributed generation on Long Island, the Long Island Power Authority (LIPA) announced that it will purchase 45 fuel cell systems for installation across Long Island, for the first time installing them in Long Island homes.

Twenty-five of the 5-kW fuel cell systems called GenSys5CS will be installed at LIPA's West Babylon Fuel Cell Demonstration Site, which currently contains fuel cell systems feeding directly into the Long Island electrical grid. The remaining 20 systems will generate on-site heat and power for single or multi-family residential sites, for the first time in LIPA's service territory. The GenSys5CS unit transforms natural gas to hydrogen.

LIPA will evaluate and measure the potential of fuel cells for heat and power generation and backup supply, which will help achieve a goal of 25 percent of New York's electricity needs supplied by alternative energy technologies within 10 years. LIPA has also been placing Plug Power fuel cells at various commercial locations around Long Island, including Hofstra University, and the Babylon and East Hampton Town Halls. Thousands of Long Island homes and businesses may eventually have fuel cells to relieve LIPA of some of the resources needed to build additional on-island power plants.

Plug Power has delivered enough systems to generate over 1.6 million kilowatt-hours of electricity, a large portion of it on Long Island. Plug Power's fuel cell systems are to be sold globally through a joint venture with General Electric.

NATURAL GAS FUEL CELLS

Fuel cells running on natural gas typically use about three of the four hydrogen atoms in methane (CH_4) for power generation. The remaining hydrogen goes into the flue gas or stack effluent with differing amounts of CO_2, CO, and water vapor, depending on the type of fuel cell. The flue gas is sometimes vented to the atmosphere but it can be combusted for heat and used for reforming.

Hydrogen can be separated from the flue gas at low cost in high-temperature fuel cells. A SOFC system may be able to cogenerate hydrogen for about $3.00 per kg which can match gasoline. Since these fuel cells could be part of the fueling station, there would be no need for a hydrogen delivery infrastructure.

GRAVITY FUEL CELLS

A fuel cell with heat- and gravity-driven circulation of fuel and oxidizing gases would need no pumping equipment which consumes power and requires servicing. Heat and gravity can take over the functions of a pump or compressor for either a SOFC or PEMFC (Proton Exchange Membrane Fuel Cell) system. With heated gaseous fuels and oxidizing agents, the gas flow through the fuel cell is opposite to the gravity forces. In the lower part of the fuel cell, the gas is heated and by the well-known chimney effect, the gas flows upward through the fuel cell without the use of a pump or a compressor and then falls with gravity as it cools and becomes denser.

Since no power is consumed for moving the fuel or the oxidizing agent through the cells, the efficiency of the fuel cell is increased. Operation without pressurization eliminates the moving parts making the fuel cell less expensive and more reliable. Pressurization can also be added for increased performance where the whole assembly is placed under pressure.

The fuel and oxidizing-agent circuits include upper- and lower-reversal points. At the upper-reversal points, fuel and oxidizing agents flowing counter to gravity forces begin to flow in the direction of gravity. The opposite takes place at the lower-reversal point.

The heat- and gravity-driven circulation is due to the arrangement of the fuel cells between the upper- and the lower-reversal points. This arrangement allows the fuel and oxidizing agent to pass through the fuel cell after passing through the lower-reversal point and before passing through the upper-reversal point. The fuel or oxidizing agent are heated while passing through the fuel cell so the gravity-driven flow of the fuel or the oxidizing agent through the fuel cell is sustained.

The gravity-driven flow through the fuel cell is further supported by the arrangement of cooling fins or a cooling coil for removing the heat between the lower- and upper-reversal points. In the arrangement, the fuel or oxidizing agent passes the fins or coil, removing heat after passing the upper-reversal point and before passing the lower-reversal point.

The coil or zigzag fin shape provides a relatively large heat exchange surface area. This permits a larger amount of heat to be transferred to the cooler environment as compared to a return duct running in a straight line between the upper- and the lower-reversal points.

The fuel cells and heat sinks occupy more than 80% of the straight line distance between the lower- and the upper-reversal points. Then the gravity forces are particularly effective for the transport of the fuel or the oxidizing agent.

In the area of the upper-reversal point, the heated fuel and oxidizing agent are cooled. As a result, the fuel's and oxidizing agent's density and weight are increased after passing the upper-reversal point so that they flow downward. In this way, a gravity-driven flow of fuel and oxidizing agent through the fuel cell is generated. The gravity-driven flow through the fuel cells with circulating system is particularly suitable for fuels such as liquid methanol.

CODE RESTRICTIONS

Hydrogen-powered fuel cells have great potential as a clean and cost-competitive source of electricity. As this technology gets closer to widespread commercialization, there is concern that the use of fuel cells is being slowed by conflicting local and regional safety and building codes.

Unresolved issues such as conformance with electrical, plumbing, fuel-management, and emissions rules and other safety considerations could hinder the efforts of companies that manufacture, sell, and install natural-gas-powered fuel cells for residential, industrial, and commercial applications.

Companies such as United Technologies Corp. (UTC), Ballard Energy Systems, Plug Power, M-C Power, AlliedSignal, and Siemens-Westinghouse have been developing fuel cell products for the commercial market and may be impacted by this trend.

There are existing standards covering electrical, fuel handling, and pressure issues applicable to fuel cells. But, there are almost no standards in place that address fuel cells specifically.

The standards that do exist, such as those provided under American National Standards Institute (ANSI) Z21.83, only cover part of the product market. In the installation of fuel cells for residential use, the ANSI standard does not apply. If it were, some of the requirements could be excessive and push up costs. The standard may also miss problems unique to residential users.

Besides the interest in safety, installation, and operational standards for fuel cells, there's also a demand for performance standards measuring energy output, fuel consumption, efficiency, and emissions.

The establishment of standards is important to product acceptance and broader public understanding of the overall safety of fuel cells.

RESIDENTIAL FUEL CELLS

Residential fuel cells have potentially huge markets in North America and other parts of the world. Plug Power, LLC, a joint venture of DTE Energy Co., Mechanical Technology Co., of Latham, N.Y., and General Electric began mass production of 7-kW residential fuel cell units in 2001. The fuel cells are based on proton exchange membrane technology. Competitors include Ballard, UTC, and others.

Coal is the most abundant fossil fuel in the U.S. and many other countries. In the U.S. coal makes up about 95% of all fossil energy reserves. These reserves could last several hundred years at the current level of coal consumption. Major developing countries such as China and India, which are now using more and more of the world's oil, also have large coal reserves.

Coal is also a source of hydrogen. The coal is gasified and the impurities are removed so the hydrogen can be recovered. This results in significant emissions of CO_2.

GASIFICATION TECHNOLOGIES

The Tampa Electric Company plant in Polk County, Florida uses coal gasification to generate some of the nation's cleanest electricity. Coal gasification represents the next generation of coal-based energy production. The first pioneering coal gasification power plants are now operating in the United States and other nations. Coal gasification is gaining increasing acceptance as a way to generate extremely clean electricity and other high-value energy products.

Instead of burning coal directly, coal gasification reacts coal with steam and carefully controlled amounts of air or oxygen under high temperatures and pressures.

The heat and pressure breaks the chemical bonds in coal's complex molecular structure with the steam and oxygen forming a gaseous mixture of hydrogen and carbon monoxide. Gasification may be one of the better ways to produce hydrogen.

Pollutants and greenhouse gases can be separated from the gaseous stream. As much as 99% of sulfur and other pollutants can be removed and processed into commercial products such as chemicals and fertilizers. Unreacted solids can be collected and marketed as co-products such as slag for road building.

The primary product is fuel-grade, coal-derived gas which is similar to natural gas. The basic gasification process can also be applied to other carbon-based feedstocks such as biomass or municipal waste.

Coal gasification offers a more efficient way to generate electric power than conventional coal-burning power plants. In a conventional plant, heat from the coal furnaces is used to boil water, creating steam for a steam-turbine generator.

In a gasification-based power plant, the hot, high pressure coal gases from the gasifier turn a gas turbine. Hot exhaust from the gas turbine is then fed into a conventional steam turbine, producing a second source of power. This dual, or combined cycle arrangement of turbines is not possible with conventional coal combustion. It offers major improvements in power plant efficiencies.

Conventional combustion plants are about 35% efficient (fuel-to-electricity). Coal gasification could boost efficiencies to 50% in the near term and to 60% with technology improvements. Higher efficiencies mean better economics and reduced greenhouse gases.

Compared to conventional combustion, carbon dioxide exits a coal gasifier in a concentrated stream instead of a diluted flue gas. This allows the carbon dioxide to be captured more easily and used for commercial purposes or sequestered.

Historically, the use of gasification has been to produce fuels, chemicals and fertilizers in refineries and chemical plants. DOE's Clean Coal Technology Program allowed utilities to build and operate two coal gasification power plants; Tampa, Florida, and West Terre Haute, Indiana. A Clean Coal Technology gasification project is also operating at Kingsport, Tennessee, producing coal gas that is chemically recombined into industrial grade methanol and other chemicals. Gasification power plants are estimated to cost about $1200 per kilowatt, compared to conventional coal plants at around $900 per kilowatt.

The Vision 21 program is focused on new concepts for coal-based energy production where modular plants could be configured to produce a variety of fuels and chemicals depending on market needs with virtually no environmental impact outside the plant's footprint. Membranes would be used to separate oxygen from air for the gasification process and to separate hydrogen and carbon dioxide from coal gas.

Improved gasifier designs would be more durable and capable of handling a variety of carbon-based feedstocks. Advanced gas cleaning technologies would capture virtually all of the ash particles, sulfur, nitrogen, alkali, chlorine and hazardous air pollutants.

The Clean Coal Power Initiative would spend $2 billion over the next 10 years for these high-potential, but still high-risk, technologies. Targets are an efficiency greater than 52% with emissions of NO_x = 0.06, lb/million Btu and SO_2 = 0.06 lb/million Btu and a cost of less than $1,000/kW.

Estimates for producing and delivering coal-generated hydrogen range from $4.50 to $5.60/kg, which is getting close to the cost of U.S. gasoline on an equivalent energy basis.

Many countries and companies have channeled R&D efforts into generating hydrogen and electricity from coal without releasing CO_2. Gasification and cleaning can be used that combines coal, oxygen or air, and steam under high temperature and pressure. The process generates a synthesis gas (syngas) of hydrogen and CO_2. The syngas does not contain impurities such as sulfur or mercury. A water-gas shift reaction is then used to increase hydrogen production and create a stream of CO_2 that can be removed and piped to a sequestration site. The hydrogen-rich gas is sent to a Polybed Pressure Swing system for purification and transport. The remaining gas that comes out of the system can be compressed and sent to a combined cycle power plant. These are similar to the natural gas combined cycle plants used today.

Hydrogen as well as syngas may also be used to power a combined cycle plant. The plant output can be adjusted to generate more power or more hydrogen as needed.

Cogeneration of hydrogen and electricity from coal, coupled with CO_2 extraction needs to be an affordable and practical system for generating both energy carriers. Hydrogen could be generated from large coal plants outside cities, close to existing coal mines, then the infrastructure costs for delivering the hydrogen could be high.

FUTUREGEN

In 2003 the Department of Energy announced FutureGen, also known as the Integrated Sequestration and Hydrogen Research Initiative. This is a 10-year, billion dollar project to produce a 275-MW prototype plant that will cogenerate electricity and hydrogen and sequester 90% of the CO_2.

This advanced coal-based, near-zero emission plant is planned to produce electricity that is only 10% more costly than current coal-generated electricity while providing hydrogen that can compete with gasoline. The cost of hydrogen delivery is not included in this goal.

A 2002 study for the National Energy Technology Laboratory found that coal gasification systems with CO_2 capture could reach efficiencies of 60% or more in cogenerating hydrogen and electricity using different configurations of turbines and solid oxide fuel cells (SOFCs).

Building large commercial coal gasification combined cycle units could be difficult based on the history traditional power generators have had with simpler chemical processes. Sequesting the CO_2 can be another technological challenge.

BIOMASS POWER

Biomass can generate energy in many different forms. Refuse derived fuels (MSW) can produce steam or electric power. They can also be converted to other fuels using chemical or biological processes producing ethanol or methanol. The wood and pulp industries use their wastes to provide a significant part of their heat, steam, and electricity needs.

The first commercial power plant to burn cattle manure to generate electricity was established in the Imperial Valley of southern California in 1987. The plant had a capacity of about 17 megawatts and supplied electricity to 20,000 homes. The manure is burned to produce steam for the generator.

Panda Ethanol of Dallas, Texas, is using cow manure to power four ethanol plants. It gets the manure from near-by feedlots and uses a technology developed by Energy Products of Idaho heating the manure with sand to produce methane more quickly. Panda is building a 100 million gallon/year ethanol plant that will use syngas from cow manure.

E3 BioFuels and Prime Biosolutions of Omaha, Nebraska, combine a 30,000-head feedlot with a 25-million gallon ethanol refinery using anaerobic digestors to capture methane from the manure. There are plans to build 15 similar plants in the next 5 years. In Hawaii, sugar producers derive 150 megawatts of energy from burning bagasse.

Mills that process rice may also generate process heat, that can be used for direct heating, steam generation, mechanical power or electrical power. For every five tons of rice milled, one ton of husks with an energy content equivalent to one ton of wood is left as residue. A rice mill in Louisiana has satisfied all its power needs since 1984 from an on-site rice-husk power plant. The plant sells surplus energy to the local utility.

In Honduras an energy-efficient power plant used all the wastes of a large lumber mill. It sold power to the grid, produced an internal rate of return on equity investment of 75%, and paid back the initial investment in about three years.

A study by the United States Agency for International Development on the use of sugar cane residues for power in Thailand, Jamaica, the Philippines and Costa Rica found that cane power can have lower unit costs than most of the other power generation options available in these countries. In Thailand the study found that a new cane power plant could supply power at about $0.030 per kilowatt hour. This was well below the cost of power generated in that country with imported coal at $0.044 per kilowatt hour or domestic natural gas at $0.040 per kilowatt hour.

Another study by the California Energy Commission found that wood-fired boilers can be installed for about 20% less than a coal unit. Biomass conversion plants are often smaller than fossil fuel units and can be built more quickly and with less capital investment.

Biomass wastes offer a cost-effective energy alternative, but energy plants grown specifically for energy production may not be competitive with fossil fuels. New biotechnologies are needed to improve the energy production in crops, along with new combustion technologies and more efficient gas turbines.

THE FUTURE FOR BIOMASS

Farming acreage for biofuels dropped in the early 1990s, but has increased 10-15% since then. The U.S. Department of Energy projected in 1989 that biomass could potentially become the world's largest single energy source if intervention to protect the climate takes place.

France has been experimenting with short-rotation forestry on more than 400 hectares of land. Northern Ireland is conducting similar experiments. India has expanded its network of biogas digesters, which supplies compost to farmers and power to local communities. Finland provides almost 20% of its energy needs from biomass and is working to increase this to 35% through using forest and peat feedstocks.

The increased use of MSW as a fuel is expected in the future. The United States produces over 200 million tons of garbage each year. MSW is a large, growing resource, even after recyclables are removed.

Unfamiliar fuels such as those derived from algae could also be used but these still need more development. Other areas that need development include micro organisms for anaerobic digesters, genetic engineering for superior microbes, yeasts, and fungi, catalytic processing of lignins to liquid fuels and advanced fermentation techniques.

Worldwide the acreage used for biomass crops is expected to double or even quadruple in the next few decades. About 1% of arable land is used for biomass, by 2030 this number may be 2-4%.

SOLAR POWER

Solar power has the potential of becoming more consequential as an energy alternative. Photovoltaic (PV) cells are becoming less expensive and finding more applications. Many small and large nations are increasing their use of solar energy.

A typical 100-cm silicon cell produces a maximum current of just under 3 amps at a voltage of around 0.5 volts. Since many PV applications involve charging lead-acid batteries, which have a typical nominal voltage of 12 volts, the solar modules often consist of around 36 individual cells wired in series to ensure that the voltage is usually above 13 volts which is enough to charge a 12 volt battery even on overcast days.

In a typical monocrystalline module, the open circuit voltage is 21 volts and the short circuit current is about 5 amps. The peak power output of the module is 73 watts, achieved when the module is delivering a current of some 4.3 amps at a voltage of 17 volts.

When cells are delivering power to electrical loads under real-world conditions, the intensity of solar radiation often varies over time. Many systems use a maximum power point circuit that automatically varies the load seen by the cell in such a way that it is always operating around the maximum power point and so delivering maximum power to the load.

PV MATERIALS

Silicon is the most popular material for photovoltaic (PV) power. Another material is gallium arsenide (GaAs), which is a compound semiconductor. GaAs has a crystal structure similar to that of silicon, but it consists of alternating gallium and arsenic atoms. It is well suited for PV applications since it has a high light absorption coefficient and only a thin layer of material is required, which reduces the cost.

GaAs cells can also operate at relatively high temperatures without the performance degradation that silicon and many other semiconductors experience. This allows GaAs cells to be suitable for concentrating PV systems.

Cells made from GaAs are more costly than silicon cells, because the production process is not as well developed, and gallium and arsenic are not abundant materials. GaAs cells have been used when very high efficiency is needed regardless of cost such as required in space applications. They were also used in the Sunraycer, a photovoltaic-powered electric car, which won the Pentax World Solar Challenge race for solar-powered vehicles in 1987. It ran the 3000-km from Darwin to Adelaide, Australia at an average day time speed of 66-km per hour. The 1990 race was won by a car that used monocrystalline silicon cells of the advanced, laser-grooved buried-grid type. The 1993 winner was powered by 20% efficient monocrystalline silicon PV cells, which provided an average speed of 85-km per hour over the 300-km course.

Solar cells do not use most of the energy of sunlight. Light from the sun has an average temperature of about 6300°K. The Helmholtz ratio of sunlight is about 95%. This means that theoretically it should be possible to convert 95% of the radiant-energy to electricity.

In practice, solar cells may only convert about 10% of the radiant energy into electricity. The other 90% of the sunlight is converted into thermal energy.

When the sunlight strikes the semiconductor material, an electrical potential is created by dislodging electrons due to the impact of the photons. Sunlight is made of photons that contain different amounts of photon-energy at different frequencies. The semiconductor material cannot readily be matched to convert all types efficiently. This means that some photons will not be converted at all because they have too little photon energy and some photons will only have a part of their energy converted to electricity because they have too much photon energy.

Solar cells that have several layers of different semiconductors can be much more efficient. Each layer can be matched to a specific photon energy range.

Another type of solar cell separates the light into different colors. Then each color is converted using a different type of semiconductor for higher efficiency.

Solar cells may also use lenses or parabolic concentrators to convert more of the radiant energy into thermal-energy. The lens increases the brightness of the light and converts some of the photon energy into thermal energy. A vapor cycle engine could be used to convert this thermal energy into electricity. This could provide an efficiency of nearly 30% in large installations. An advantage with this system is that during the night or on cloudy days fuel can be burned in a separate boiler to operate the system. With the right solar concentrator and engine, efficiencies of over 50% are possible. A modern gas turbine combined cycle can have up to 60% efficiency and uses a much lower temperature of combustion than the sun. The difficulty with solar energy involves the path that is used to get the sunlight into the process. Most collection schemes allow radiant-energy to escape. One way coatings generally only work to keep some of the lower energy rays from escaping but not the higher energy rays.

Solar concentrators contract the solar radiation from a relatively large area onto a small area. A parabolic mirror of four feet in diameter covers an area of 4 pi, or 12.57 square feet (1.17 square meters). This surface area is measured on a plane and is slightly less than the surface area of the curved mirror. If the sun is about 20% down from peak strength, its strength should be about 800 watts per square meter. Then the total amount of energy striking the mirror is almost 1,000 watts.

SOLAR GROWTH

The sun's output is abundant and free, but it is also diffuse. Its potential as a resource has not always been welcomed. In 1985, the old Central Electricity Generating Board in England stated that large-scale electricity generation from solar power had the disadvantages of high cost, large demands on land area and in the United Kingdom (U.K.) low levels of solar radiation. British Nuclear Fuels, stated that 150 square km of solar panels would be needed to produce as much energy as a typical nuclear power station.

But, the sun's energy can be harnessed in various ways. Buildings can capture and retain the sun's warmth using passive solar heating. Solar collectors or panels can be added to buildings to generate power.

Freiburg, Germany, probably has more solar energy projects than anywhere in Europe. The city has a 65 page guide book of examples ranging from solar powered parking meters to the solar heated headquarters building of the International Solar Energy Society.

Solar thermal power plants concentrate the sun's heat to raise steam and drive generators. During the 1970s oil crises, several were built in the southwestern United States. Five are operated by the Kramer Junction Company (KJC) in California's Mojave Desert. These plants have rows of parabolic trough reflectors covering an area of more than 405 hectares. The troughs reflect the sun's rays onto a network of steel tubes containing a fluid which is heated up to 390°C. This fluid is pumped through heat exchangers to produce steam for generator turbines with an total output of 150-MW.

Photovoltaics are adaptable and do not need deserts or cloudless skies. The application of PV systems to buildings shows that solar electricity can now be produced without needing any extra land. Arrays of PV modules can be designed into new buildings or added to old ones. Building integrated PV systems have been installed on the roofs and facades of houses, factories, offices, schools, public buildings and stadiums. The power produced can be on site, stored or fed to the grid. Most systems, except for the very smallest, are connected to local supply networks, and with suitable connections and metering, many owners can sell their surplus current to the utility.

SOLAR FUEL CELL GENERATORS

DBK has their own brand of 1.2-60-kW solar fuel cell generators. The fuel for a solar based fuel cell generator is sunlight and water. The core technology for their product line of Regenerative Fuel Cell (RFC) systems is the Proton Exchange Membrane, or PEM, fuel cell. This technology uses a solid polymer membrane as the system electrolyte. This material works like battery acid but is inert and safe to touch. It functions to transport hydrogen ions or protons to set up either electrolysis or fuel cell reactions.

In the charge, or electrolysis mode, the process splits water into hydrogen and oxygen and can produce hydrogen directly without mechanical compression. Water enters the cell and is split at the surface of the membrane to form protons, electrons and gaseous oxygen.

The gaseous oxygen leaves the cell while the protons move through the membrane under the influence of the applied electric field and electrons move through the external circuit. The protons and electrons combine at the opposite surface to form pure gaseous hydrogen.

A fuel cell uses the reverse process. Hydrogen along with oxygen from the air are applied to the cell. The hydrogen splits to release its electrons to the external circuit and provide power to the load. The protons move across the membrane, attracted by the oxygen potential, and combine with the oxygen to form water at the opposite electrode surface.

A regenerative fuel cell system combines both of these processes using a hydrogen storage vessel to store energy. PEM regenerative fuel cells were developed in the early 1980s by NASA for applications in space based energy storage. Since that time, others have advanced the concept using both PEM and alkaline fuel cell technology.

An RFC can provide seasonal energy storage and there is near-zero self discharge. It provides high levels of storage at a reasonable cost and has the ability to store energy from multiple energy sources.

SOLAR ROOFS

Solar tiles look similar to regular roof tiles but provide power for their owner. Each solar roof on an average house over its lifetime prevents about 34 tons of greenhouse gas emissions.

The energy potential of light falling on building roofs is immense. A 1999 report for the U.K. Department of Trade and Industry stated that PV systems installed on all available domestic and non-domestic buildings in the U.K. by 2025 could generate close to their average yearly power needs. BP Amoco is one of the world's largest manufacturers of photovoltaic cells. They claim that if every south-facing roof and office wall in the U.K. had solar panels, this could generate more than the U.K.'s total power requirements.

In a country like Britain with its cool and wet weather, solar might not be expected to produce enough energy. But most studies indicate that solar energy, particularly if complemented by other renewables, could play a more important role than previously thought.

Many countries have programs for solar power. Germany started its 1,000 Roofs Programme in 1990. This was a joint effort by federal and state governments for roof-mounted grid connected PV systems in the 1 to 5-kW range. Installation costs were offset by 70% subsidies and over 2,000 systems were approved. The project has since been increased to 100,000 roofs, which is the equivalent of 300-MW. Italy has a 10,000 PV roof program and the Dutch government is aiming for 100,000 PV roofs by 2010 and 560,000 by 2020.

In 1997 the European Commission made a proposal to generate 12% of the European Union's (EU) power from renewable sources by 2010. This would include 40,000-MW from wind farms, 10,000-MW from biomass and 50,0000 PV systems on roofs.

BP Solar and several financial institutions recommended a U.K. program of at least 70,000 PV rooftops, a national share of the EU target. The U.K. renewables goal would be 5% of power from renewable sources by 2003, and 10% by 2010.

Another EU plan would export 500,000 PV systems to villages outside Europe. These systems would be used for decentralized electrification in developing countries, while increasing the solar manufacturing industry in Europe.

Solar PV is believed to be on the edge of a trillion dollar market. Many oil companies are diversifying into renewables with optimistic expectations. Shell now manufactures PV cells in Germany and the Netherlands and predicts by 2050, that half the world could be powered by renewable energy. BP Amoco and Shell have been installing PV cells in some of its filling stations. BP Amoco believes that by 2050 all Europe's power could be met by solar energy.

The key is a reduction of costs. Solar panels are expensive since photovoltaic technology is still in its infancy. Although the price of PV cells has fallen significantly, PV electricity is still not without a subsidy. As more PV systems are built and installed, the market should result in solar electricity becoming more and more competitive.

Japan is subsidizing 10,000 PV installations on domestic buildings, while the United States has the goal of a million solar roofs by 2010, which include solar heating systems as well as photovoltaics.

Photovoltaics may provide a revolution in the supply of electric power. Still, to ensure that new buildings contribute to sustainable development a less cautious bureaucracy is needed, which is less resistant to new ideas and not associated with vested interests, especially in the non-renewable electricity industry. Logistical problems have also damped solar energy growth. This includes the difficulty of finding reputable contractors to install solar panels.

There are more than two billion people without access to electricity, according to the United Nation's Development Program. When night falls in the developing world, 70% of the population are without electrical lighting. Most of these rural areas are too isolated to be connected to a utility grid.

Solar Electric Light Fund (SELF) is a non-profit charitable organization started in 1990. SELF promotes and develops energy self-sufficiency in developing countries. Using the latest photovoltaic (PV) technology, it brings power to the developing world. Some of SELF's projects include a rural solar project in Karnataka, India, PV systems for up to 10,000 houses in Zimbabwe and equipping rural schools in Southern Africa with solar-powered computers and wireless Internet access. In 2001, almost 75% of the voters in San Francisco supported a $100 million bond for solar on buildings in that city. The Sacramento Municipal Utility District (SMUD) has a waiting list of building owners who want solar on their rooftops. It has installed over 10-MW of systems. In some areas of California, Home Depot is selling complete solar power systems.

Since 1998, the California Energy Commission has been pushing a program to encourage homeowners to erect photovoltaic panels on their roofs, offering to subsidize about one-third of the cost.

In 2000, Los Angeles, California announced a goal of 100,000 roofs covered with solar electric panels by the end of the decade. The Los Angeles Department of Water and Power began offering subsidies that would reimburse buyers for half the price of each new solar energy system. For an average home, a photovoltaic package may cost between $10,000 and $20,000, including installation before the rebate.

The price of photovoltaics continues to drop and interest is continues to grow. States such as New York, Arizona, Florida and Washington have joined California in a major effort to allow homes and businesses to use solar power.

The systems are almost maintenance free, but panels must be cleaned of dirt, dust and leaves. They need to be installed on roofs without shade on south-facing roofs.

The reliability and cost of solar electric technologies should continue to improve, although solar power only accounts for less than 1% of all power consumed. The U.S. produces about 300 megawatts of electricity with solar which is about the same amount produced by a mid-size traditional power plant. If solar energy is to provide a significant part of the world's energy needs, the cost of solar must be competitive with other energy sources such as natural gas, nuclear or coal.

California has nine solar stations with 11 square miles of mirrors focused on steam drums that drive steam turbines. They can generate 413 megawatts (MW) of electricity which is less than 1% of the state's capacity. Because the sun sets at night and is sometimes attenuated by clouds, the plant production only averaged 0.3% of California's electricity.

They are supported by federal solar power tax credits along with California's Public Utilities Regulatory Policy Act (PURPA) contracts and renewable power subsidies. When these tax credits were interrupted for eleven months in 1991, the plants' operator, LUZ, immediately went bankrupt then SEGS, an Israeli government corporation, took over operation.

One problem has been the cost of the solar panels. Los Angeles began its solar program after state legislators mandated that utilities spend about 3% of their revenue on efficiency, conservation and renewable energy. For solar, the power department had $75 million to spend over a five year period. The power department would pay $5 for each watt of solar installed on a residence or business. Homeowners typically purchase a 1- or 2-kW system meaning that the municipal utility paid between $5,000 and $10,000 of the cost. The systems that are eligible for rebates must be tied into a utility's electric power grid. If there is a surplus of solar power, it goes back into the power grid. A 2-kilowatt solar system can supply an average-sized home with 20 to 90% of its electrical needs, depending on how many lights, appliances and air conditioners are running, and how efficient they are. After the subsidy, and depending on how the system is paid for (cash or borrowed money), a solar system may pay for itself in as little as 6 years and as much as 36 years. The L.A. Department of Water and Power was not deregulated along with the three major utilities in California. It has some of the lowest power rates in the state making the economical argument harder to make. To receive the full $5 per watt subsidy, the L.A. Department of Water and Power requires a homeowner to purchase solar panels from a manufacturer based in the city. This was done to encourage the local growth of an emerging industry.

Siemens Solar reports the interest in solar from consumers has been sometimes overwhelming and that supply has been a problem. Most U.S. manufactured units are shipped to countries such as Germany, Japan and Scandinavia, which have had generous subsidies for years.

WIND POWER

Wind power is used in over 65 countries and the basic principles of wind energy have been used for centuries. Windmills existed in the 7th century in Persia. An older image of wind power is Don Quixote and the wooden towers with cloth-covered sails turning in the wind. But today's wind turbines use a giant propeller on a tall metal pole. As it rotates, the propeller drives a generator to supply nearby users or send power to the grid. One commercial user, Corn Plus is adding two wind turbines for power at its ethanol plant in Winnebago, Minnesota. They will produce 4.2-MW which is about 45% of the plant's needs.

During the development of electrical generating equipment in the late 1800s, both Europe and America began to experiment with wind power for electrical generation. Among the first to develop wind-powered electrical generators was the Danish professor, Poul La Cour, who worked on wind systems from 1891 to 1908. He also saw the use of hydrogen as a fuel and the use of wind-powered electrical generators to electrolyze hydrogen and oxygen from water. Another early investigator who promoted wind-powered hydrogen production systems was J.B.S. Haldane a British biochemist at Cambridge, England. In 1923, he predicted that England's energy problems could be solved with a large number of wind generators supplying high voltage power for hydrogen production.

During World War II, Vannovar Bush was the Director of the U.S. Wartime Office of Scientific Research and Development. He was concerned about American fuel reserves and thought that wind generators could be a solution. Percy Thomas was a wind power advocate on the Federal Power Commission, who convinced the Department of the Interior to construct a large prototype wind generator. In 1951, the House Committee on Interior and Insular Affairs killed this plan. Wind-generated electricity could not compete with coal that was selling for $2.50 per ton or diesel fuel at $0.10 per gallon. The promise of even less expensive electricity that was too cheap to meter from nuclear power plants resulted in the loss of almost all Federal programs to develop wind-powered energy systems.

Today's wind machines are known as wind turbines and can have rotors that cut through the air at heights of up to 100 meters. More and more of these giant machines are being installed around the world. Wind power only provides 0.15% of the world's total electricity, but it has become the fastest growing form of energy production.

For the past few decades, manufacturers have been streamlining components and installing onboard computers to tilt the propeller blades for maximum efficiency for the wind conditions. In the 1980s, the average turbine was 20 meters high with a 26-kilowatt (kW) generator and a rotor diameter of 10.5 meters. A typical turbine today can be 55 meters high, with a rotor diameter of 50 meters and a capacity of 1.6-MW. The power it produces may supply 500 homes.

Since 1992, more commercial wind farms have been installed than ever before with 40,000 turbines in 40 countries. Wind energy capacity is growing at almost 30% annually. By 1998, it reached 10,000 megawatts (MW), which can supply a country the size of Denmark and the wind power industry had sales of $2 billion with 35,000 jobs worldwide. The prime movers were an increasing environmental awareness and commitments to reduce greenhouse gas emissions made under the Kyoto Protocol of 1997.

But wind and solar are expected to provide only 1% of the world's energy by 2030 while the International Energy Agency estimates that the world will need to invest $16 trillion over the next 30 years to maintain and expand the energy supply.

The European Union supplies tax breaks and investment plans for renewable sources such as wind power. There are plans to install 40,000 megawatts by 2010. Denmark receives 10% of its power from wind energy with an installed capacity of 1,700-MW. Germany is not far behind and is the wind sector's fastest growing market.

Wind power in the U.S. has not received this level of support. Every two years, a fight in congress erupts on the renewal of an important wind power tax credit. Similar battles occur in state legislatures that have wind power tax credits. According to U.S. energy officials, wind power could provide 5% of the nation's electric power by 2020, compared to the current 0.1%.

Wind power has been slowed by public opposition. In 2002, a citizen's group in Prince Edward County, Ontario, vetoed a small windfarm project on the coast of Lake Ontario near Hillier. They proposed that the 22 proposed wind turbines would be noisy, kill birds and harm the neighborhood by being too visible. These are common complaints about windfarms, but at a distance of about 200 meters, the sound of a windfarm is faint. At closer distances the noise is similar to the sound of an airplane's engine from inside the cabin. Even under the spinning blades it is possible to converse in a normal voice. One Dutch study showed that a small windfarm is less harmful to birds than 1-kilometer of road or powerlines.

The U.K. has the best wind resources in Europe, but attempts to set up wind farms were stopped when local authorities failed to issue permits for turbine construction. The national government had no guidelines and policies allowing local authorities to cooperate.

In India and China, wind power can provide broad areas of the rural population that are without electricity. Wind investment plans are being offered to these countries by Denmark, Germany and the Netherlands. India has almost 850-MW of installed capacity and is first among the developing countries and fourth in the world after Germany in wind power. About 600 wind turbines are producing 260-MW in China. New Zealand has its Tararua Wind Farm which is the largest in the southern hemisphere with a capacity of 12-MW. In North Africa, Morocco recently installed 50-MW and Egypt 30-MW. Wind power could provide at least 20% of every continent's energy needs. There is enough wind to provide twice the expected global power demand for 2020.

If 10% of energy needs were met by wind power, there would be about 10 billion tons less of worldwide carbon emissions out of a world total of 60 to 70 billion tons. To achieve this, 120 times more wind capacity is needed.

Initial investments are high, but operation and maintenance costs for wind power are low. Bigger and better turbines have resulted in wind power prices dropping by about 20% over the past several years. In Denmark, wind power costs were almost 17 cents per kilowatt hour (kWh) in the early 1980s. This includes equipment, labor, interest on loans, operation and maintenance. It dropped to about 6.1 cents by 1995 and was 4.5 cents by 2001. Power from a new coal-fired power plant can cost 5 to 6.4 cents per kWh and 4 to 5.7 cents per kWh for a gas-fired plant, and 4.6 to 6.5 cents per kWh for a nuclear plant, according to UNIPEDE, the European Utility Association.

The cost of wind-powered electricity should continue to fall in the future but the steep start-up costs of installing wind turbines are the downside of wind power.

NUCLEAR POWER

Nuclear is an energy option that provides about 20% of our power. France uses nuclear energy to generate almost 80% of its electric power and a number of other countries are more dependent on this energy option than the United States even though the technology was invented and developed here. Nuclear power could make the U.S. less dependent on foreign oil and provide a clean option for producing hydrogen.

The nuclear power industry has been at a standstill in the United States based on fears that nuclear is too dangerous. Besides France at 80%, Belgium generates 60% of its power from nuclear, Switzerland 42%, Sweden 39%, Spain 37%, Japan 34% and U.K. 22%. These countries that generate a higher percentage of their power with nuclear energy than the U.S. have done so without any loss of life or harm to the environment. No form of power generation is 100% safe but nuclear power may be safer than many alternatives for generating large amounts of electrical energy, such as oil and coal plants. This is because the fuel in a nuclear power plant is highly concentrated. One uranium fuel pellet measures about 0.3-inch diameter by 0.5-inch long and can provide the equivalent energy of 17,000 cubic feet of natural gas, 1,780 pounds of coal, or 149 gallons of oil. Since relatively little fuel is used, relatively little waste is produced and this waste is contained within the plant walls. This is not the case with fossil fuel plants, which emit tons of pollutants into the atmosphere. Some nuclear power plants have cooling towers that emit water vapor.

Nuclear power plants could also be a major source of hydrogen. If electrolysis of water with electricity from a nuclear power plant is not economical, the waste heat from these plants may be high enough to generate hydrogen by the thermochemical decomposition of water into hydrogen and oxygen. Thermochemical water splitting at temperatures above 750°C could provide a 40 to 50% efficiency in hydrogen production and the cogeneration of electricity might raise the overall efficiency to 60%. The DOE has been investigating thermochemical hydrogen production with nuclear power. Their goal is a demonstration of commercial production by 2015. Nuclear generated hydrogen could be a practical solution, with about 100 nuclear water splitting plants supplying hydrogen for fuel cell generators.

Nuclear power is now cheaper than fossil fuels, but there are concerns about safety, environmental health and terrorism. The problems in the long-term of radioactive wastes can be resolved and nuclear power shown as a safe and economical source of hydrogen to attract the investment capital to build 100 new plants. Modular plants similar to those used in France would greatly improve safety and licensing issues. Hydrogen would probably be generated from nuclear power plants away from urban areas so there would be infrastructure costs for delivering the hydrogen.

Nuclear fission power plants were at one time thought to be the answer to diminishing fossil fuels. Although the enriched uranium fuel was also limited, an advanced nuclear reactor called breeders would be able to produce more radioactive fuel, in the form of plutonium, than consumed. This would make plutonium fuel renewable. Although plutonium has been called one of the most toxic elements known, it is similar to other radioactive materials and requires careful handling since it can remain radioactive for thousands of years.

Conventional nuclear reactors and advanced breeder reactors were America's primary energy strategy since the 1950s to resolve the fossil fuel problem but when a reactor accident occurred in 1979 at Three Mile Island in Pennsylvania, public and investor confidence in nuclear fission dropped. The accident was triggered by the failure of a feedwater pump that supplied water to the steam generators. The backup feedwater pumps were not connected to the system as required, which caused the reactor to heat up. The safety valve then failed to act which allowed a radioactive water and gas leak. This was the worst nuclear power accident in the U.S., but in this accident no one was killed and no one was directly injured. At Three Mile Island faulty instrumentation gave incorrect readings for the reactor vessel environment. A series of equipment failures and human errors along with the defective instrumentation allowed the reactor core to be compromised and go into a partial melt. The radioactive water that was released from the core was confined within the containment building and very little radiation was released.

At Three Mile Island, the safety devices operated as planned and prevented any serious injury. This accident resulted in improved procedures, instrumentation, and safety systems being implemented. The Three Mile Island Unit 2 core has been cleaned up and the radioactive deposit stored. The Three Mile Island Unit 1 is still operating with a clean record.

Worldwide reactors continued to be built until the accident at Chernobyl occurred. Several features made the Chernobyl accident unique to a Soviet style reactor. One was the use of graphite as a moderator, which caught fire. Another was the absence of water to contain radioactivity. But, the most important may have been an inadequate containment structure. There were also problems in controlling the stability of the reactor and the control rods had to be changed frequently in order to keep the reactor stable.

Before the accident at least 6 safety mechanisms were disconnected to conduct experiments to increase the output of the reactor. This was the direct cause of the accident and as the power output surged from 7 to 50% in a few seconds there was a lost of coolant. The heat then melted the graphite rods used as a moderator.

An experiment to find out how long power was generated as the reactor unit was shut down was authorized. But, automatic shut-down mechanisms were blocked that may have come into operation at low capacity levels. These included the reactor's emergency cooling system and its low water level safeguard. Extra pumps were also turned on to raise the amount of steam going to the generator. These pumps were operated over the allowable level. This became the worse nuclear power plant disaster on record when the Chernobyl reactor had a hot gas explosion. In a Western nuclear power plant, the explosion would have been contained because Western plants are required to have a containment building with a solid dome of steel reinforced concrete that contains the reactor. The Chernobyl plant did not have this containment feature, so the explosion blew through the roof of the reactor building allowing radiation and reactor core parts to escape into the air.

The design of the Chernobyl plant was deficient in other ways. Western reactors are designed when operating to maintain negative power coefficients of reactivity that prevent such runaway accidents. The Chernobyl plant would not have been issued a license to operate in the U.S. or other Western countries.

The Chernobyl accident was in many ways the worse possible scenario having an exposed reactor core and roofless building. Two plant workers died from the blast and fire, 22 other plant workers and 6 firefighters received huge radiation doses and died within months.

A toxic gas disaster occurred when 2,300 were killed and 200,000 others injured in a few hours when the gas escaped from the Union Carbide pesticide plant in Bhopal, India.

RADIOACTIVITY

When uranium undergoes fission, the uranium atoms split and release neutrons. Some of these neutrons split other uranium atoms, which produce radioactive waste products. The net result of the fission process is the generation of intense heat which is used to generate steam for the generators. A nuclear reactor and a nuclear weapon both release a number of neutrons during the fission process over a given period of time. If the number of neutrons are limited for triggering the fission chain-reaction, the reaction can be controlled for producing energy. If too many neutrons are released, the chain-reaction will accelerate, resulting in an explosion. To prevent this from happening, nuclear reactors use control rods and water circulation to regulate the fission process by absorbing the extra neutrons. However, some of these neutrons will move into the steel structures which hold the fuel assemblies and the cooling water which flows between them. Other neutrons may penetrate the concrete shielding outside the steel reactor vessel. These neutrons are absorbed by the atoms of iron, nickel and other elements that they pass through.

When atoms absorb neutrons, they become unstable and release particles making them radioactive for differing lengths of time. A material like nickel-59 has a half-life of 80,000 years, it needs to be shielded for about a million years.

Reactor fuel consists of uranium that has been formed into a usable metal alloy and provided as small pellets, rods, or plates. The fuel is encapsulated with a metal cladding, such as zircaloy, which adds mechanical strength and also prevents radioactive contamination. Nuclear reactor waste or spent nuclear fuel consists of the fuel pellets that have been used in a reactor over a period of time, usually about 3 years, and have lost their ability to provide enough energy. This spent fuel is still radioactive and must be shielded to prevent any release.

Spent fuel is stored in shielded basins of water or dry vaults. As the radioactive decay drops to safe levels, it may take hundreds to thousands of years. Nuclear waste containers are designed for an underground storage period of at least 10,000 years. Spent fuel will be stored on a permanent basis once a national repository is approved. The planned nuclear waste facility at Yucca Mountain is still involved in ongoing debates and studies. The opening of a national long-term storage site is becoming decades behind schedule because of opposition.

Other countries, such as France, have progressive nuclear fuel recycling programs where a large percentage of the unused uranium and the small amount of plutonium produced in the spent fuel is salvaged and then processed into new reactor fuel. According to the Nuclear Energy Institute (NEI), only 3% of spent fuel is waste. Another 96% is unused uranium and 1% is unused plutonium created during the fuel cycle.

Nuclear fuel recycling allows more efficient nuclear fuel usage and less buildup of nuclear waste. Nuclear power reactors are designed to minimize plutonium build up and much of the plutonium that is produced inside the reactor is used during an ordinary fuel cycle.

It is highly improbable that a nuclear fission power plant would ever explode like a nuclear bomb, but a loss of coolant accident could result in a melt down condition. In a melt down, a large amount of radiation can be released at ground-level. A nuclear or conventional chemical or steam explosion could disperse much of the radioactive particles into the atmosphere. This is essentially what happened when the Chernobyl gas explosion occurred in the Soviet Union in 1986.

Highly publicized nuclear accidents such as those that occurred at Chernobyl and Three Mile Island must be considered anomalies. Nuclear power plants have multiple safety measures in place to prevent radiation leaks. The small amount of radioactive waste produced by nuclear reactors is controlled and usually contained in the plant facility.

Fossil fuel electrical power plants can be more hazardous to humans than nuclear power plants because of the pollutants. A 1,000 megawatt (MW) coal-fired power plant releases about 100 times as much radioactivity into the environment as a comparable nuclear plant. A 1,000-MW power plant will use 2,000 railroad cars of coal or 10 supertankers of oil but only 12 cubic meters of natural uranium every year. Fossil fuel plants can produce thousands of tons of noxious gases, particulates, and heavy metal bearing radioactive ash along with solid hazardous waste. There are up to 500,000 tons of sulfur from coal, more than 300,000 tons from oil, and 200,000 tons from natural gas. A 1,000-MW nuclear plant releases no noxious gases or other pollutants and much less radioactivity per capita than is encountered from airline travel, a home smoke detector, or a television set.

While nuclear power plants use multiple layers of protection from the radioactive particles inside the reactor core, a serious accident can cause the release of radioactive material into the environment. It is not a nuclear explosion, because the uranium fuel used in a nuclear power plant does not contain a high enough concentration of U-235. For an explosion to occur, the uranium fuel inside the reactor would have to be enriched to about 90% U-235, but it is only enriched to about 3.5%.

The amount of radiation that is emitted by nuclear power plants, with their thick shielding is quite low. Environmental Protection Agency (EPA) guidelines limit the annual whole body dose to 25 millirems for uranium fuel operations. The National Council on Radiation Protection and Measurements (NCRP) and the EPA estimate that the natural background radiation from the Earth's crust is about 23 millirems per year at the Atlantic Coast and 90 millirems per year on the Colorado Plateau. Radiation inside the human body is about 40 millirems per year from the food and water we take in and can be up to 200 millirems per year from radon in the air. The annual radiation dose from outer space can be 26 millirems at sea level or 53 millirems at elevations of 7,000 to 8,000 feet. The dose from a medical X-ray is about 20 millirems, and the dose from a 1,000-mile airline flight is about 1 millirem. A cross country air trip and return can be more than 5 millirems. We can also receive 1-2 millirems annually from watching television or using computers and can get another 7 millirems each year from living in a brick building. We could receive .03 millirem annually by living 50 miles away from a coal-fired power plant, but only .009 millirem by living 50 miles away from a nuclear power plant.

Radioactivity, radioactive elements and nuclear reactors are found in nature. There are at least 14 natural fission reactors in the Oklo-Okelobondo natural uranium formation in Gabon on the west coast of Africa. These fossil reactors had sufficient amounts of U-235 to allow chain reactions to occur.

ADVANCED REACTORS

In the 1980s the U.S. Department of Energy began developing a liquid sodium cooled reactor which was expected to be safer with minimal corrosion. It was also to be more efficient and able to use 15 to 20% of the uranium fuel instead of 1 to 2%. The breeder reactor creates more fuel than it consumes by converting U-238 into plutonium 239. It uses a 10-20% enriched core of uranium and plutonium surrounded by a shell of U-238. The neutrons emitted by the core are absorbed by the U-238 in the shell which is transmuted into plutonium-239. Less radioactive waste was also a feature compared to the light water reactors in use in the U.S. The Integral Fast Reactor would also be capable of breeding plutonium which could be used as nuclear fuel. This type of reactor was seen as the key to a nuclear future.

Liquid sodium is a volatile substance that can burst into flames if it comes into contact with either air or water. An early liquid sodium-cooled breeder reactor, the Fermi I, had a melting accident when 2% of the core melted after a few days of operation. Four years later when the reactor was about to be put into operation again a small liquid sodium explosion occurred in the piping.

France has the largest implementation of breeder reactors with its 250-MW Phenix reactor and 1200-MW Super-Phenix. The Phenix went into operation in 1973 and the Super-Phenix in 1984. Japan has its 300-MW Monju reactor which was put into service in 1994. While India has the 500-MW PFBR and 13.2-MW FBTR. These reactors produce about 20% more fuel than they consume. Optimum breeding allows about 75% of the energy in natural uranium to be used compared to 1% in a conventional light water reactor.

Nuclear fusion reactors do not split uranium atoms. They fuse hydrogen atoms in a process similar to that which occurs in the Sun and other stars. Although fusion physics is a common occurrence in stars, controlled fusion experiments continue. In 1994, the Tokamak facility at Princeton reached a fusion plasma temperature of 510 million degrees and had a power output of 10.7 megawatts.

The basic fuel in a fusion reactor is deuterium, a heavy form of hydrogen found in water. One out of every 6,500 molecules of ordinary water contains deuterium. It costs about 10 cents to separate the deuterium from a gallon of ordinary water. One teaspoon of deuterium has the energy equivalent of 300 gallons of gasoline and 1,000 pounds of deuterium could operate a 1,000 megawatt power station for a year.

The waste from fusion is much less toxic that of fission reactors. Most of the waste will occur in the surrounding materials of the process, the steel vessels and piping. The materials have half-lives in tens rather than thousands of years and are expected to be reusable in 20 years.

Much research has been done on this technology but instability and efficiency problems remain. The U.S., Japan, France, Germany, Russia and other European countries have all been involved in fusion research. Some fusion energy systems may use energy pellets which would make them similar to coal-fueled power plants. Energy production in the future could be greatly altered with small, clustered, safe high-temperature fusion reactors burning cheap, abundant fuel.

In 1989, two scientists, at the University of Southampton in England, announced that they had generated a fusion reaction that produced more energy than the reaction consumed at room temperature. They believed that commercial reactors based on this new low-temperature fusion process could be in operation in about 20 years. However, many experts were skeptical of their claims and they pointed out that the announcement occurred at a press conference rather than from a paper at a technical conference. It is impossible to know if the cold fusion process is valid. The possibility of such a breakthrough in nuclear energy could have a profound impact on global energy. Although, there is still the issue of radioactive wastes that will be generated from such nuclear reactions.

THE NUCLEAR FUTURE

The U.S. Navy has had an admirable performance record with its fleet of nuclear surface ships and submarines. There are major differences in the size of the nuclear systems used by the U.S. Navy. The Nautilus submarine used a 60 megawatt reactor which was scaled up to 600, 900 and then over 1000 megawatts for commercial power plants.

The reactors used by the Navy were initially about six times more costly per kW than commercial units. In 1973, it cost about $2,400 per kW to build a U.S. Navy nuclear reactor, compared to $400 per kW for commercial plants at that time. By the 1990s capital costs for commercial reactors would be reaching $3,000 per kW. The decisions made by utility regulators in the 1970s and the 1980s left utilities barely able to pay for billion dollar construction costs. Now, the U.S. produces more than half of its power with less expensive coal plants.

The Nuclear Energy Institute (NEI) is an industry lobbying group for nuclear power. Its studies show that nuclear production costs are lower than other central power sources, including coal. The NEI costs are 1.83 cents per kilowatt hours for nuclear, 2.07 cents for coal and 3.52 cents for natural gas. These are the plant operating costs.

The cost of nuclear power has been aided by government support. The government has covered those costs not met by the utility for waste disposal and decommissioning. Nuclear operating costs do not include the construction and operation of the U.S. government uranium fuel enrichment facilities. Other excluded operating costs include Federal regulation and long term waste disposal. Utilities and nuclear waste processing companies have no long-term legal or financial responsibility to manage the radioactive wastes.

One view is that nuclear energy is expensive, damages the environment and is harmful to human health and when the cost of construction and dealing with regulations and nuclear waste is included nuclear power becomes more costly.

The capital costs of building nuclear plants has increased greatly over the decades. Much of this has been due to increased regulations pushing some plants to $10 billion or more with the many modifications required.

The costs of dealing with a reactors' radioactive waste are estimated at $58 billion according to the Department of Energy. The costs of decommissioning, the tear down and clean up of old nuclear plants is also high. Decommissioning the Yankee Rowe plant in Massachusetts, which is about one-seventh the size of the largest nuclear reactor now operating, is expected to cost almost $500 million according to the Nuclear Information & Resource Service.

In New York state a reprocessing plant near Buffalo began to reprocess nuclear wastes in 1966. After 6 years Nuclear Fuel Services (NFS), a subsidiary of W.R. Grace's Davison Chemical Company, abandoned the facility. There were 2 million cubic feet of radioactive material left behind along with 600,000 gallons of radioactive liquid waste that was seeping into a creek that flows into Lake Erie the source of drinking water for Buffalo. The cost of cleanup was estimated to be $1 billion.

Nuclear plant utilities are protected from nuclear accidents under the federal Price-Anderson Act, which was passed in 1957. A utility's liability for an accident is limited to $7 billion. The estimate of Chernobyl's costs exceeds $350 billion.

More than $6 billion has been spent on high-level waste disposal. Spent fuel can be deadly for tens of thousands of years. In order to isolate it from the environment, nuclear waste is to be buried deep underground. Nevada's Yucca Mountain has been under consideration for decades and many in the nuclear industry believe that the Clinton administration blocked action on this site to gain support in this area.

Yucca Mountain may be the most studied area in history. The federal government claims that the environmental effects of the repository will be small and have essentially no adverse impact on public health and safety. These claims have been challenged and there has not been the political will to go ahead with the site.

The 104 nuclear plants in the U.S. provide about 20% of our total power. In the 1970s and 1980s U.S. nuclear plants operated at about 65% of their potential, but today with improved practices this output exceeds 90%. China has 6,600-MW of nuclear power now and has plans for 40,000-MW. India has 15 nuclear reactors with 8 more under construction including a 5000-MW breeder reactor scheduled to operate in 2010. Four more breeders are to follow by 2020. Breeders manufacture plutonium fuel from uranium fuel, which increases the amount of energy produced. Because of safety and proliferation concerns the U.S. is not building any breeders. After Three Mile Island and Chernobyl worldwide reactor building leveled off a little above 400. In the U.S. cancellations outnumbered the country's 103 operating reactors. One or two plants came online in the mid-1990s and no others were scheduled.

After the energy crisis occurred California, the call for increases in energy production included nuclear power. Nuclear power has been promoted as a clean source of energy that, unlike fossil fuels, produces no greenhouse gases or air pollution. Nuclear power is more environmentally friendly because it does not contribute to global warming the way fossil fuels do. Unlike coal, natural gas and oil-fired power plants, nuclear plants are free not only of carbon emissions but also of other noxious gases like sulfur dioxide, mercury and nitrogen oxide that have made fossil-fuel burning plants the biggest source of air pollution in the United States.

Nuclear energy does not produce as much CO_2 or other greenhouse gases as fossil power, but it's inaccurate to call nuclear technology CO_2 free. A large amount of electric power is used to enrich the uranium fuel, and the plants that manufacture the fuel in the U.S. are powered with coal. When fuel mining, preparation, transportation and plant construction are included with power production, nuclear power can produce about

5 grams/kWh. Wind or biomass power can produce 15-20 grams/kWh with hydro as much as 60 grams/kWh and solar 50-70 grams/kWh. Fossil fuels start at 120-180 grams/kWh for natural gas, 220 grams/kWh for oil and 270-360 grams/kWh for coal.

Uranium production does have a notable impact on ozone depletion. The Environmental Protection Agency's (EPA) Toxic Release Inventory showed that in 1999, the nation's two commercial nuclear fuel-manufacturing plants released 88% of the ozone-depleting chemical CFC-11 by industrial sources in the U.S. and 14% of the discharges in the whole world.

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Chapter 7

Heating and Cooling Energy

Most electric power plants produce electricity from steam that is used to rotate a power-generating turbine. The heat contained in the steam after it condenses is lost to the environment. In many industrial processes steam or heat is produced during production, but the mechanical energy in the steam or heat is not utilized.

Cogeneration combines the production of heat and the generation of electricity to provide a higher total efficiency than that of either process occurring separately. As the costs of fossil fuels and electricity continues to increase, cogeneration becomes more attractive.

A gas turbine power plant requires hot, high-pressure gases produced by burning oil or natural gas. The hot exhaust gases can be used to create steam in a boiler system. The efficiency can approach 90% if the system is properly designed.

A steam turbine power plant uses high-pressure steam produced in a boiler from burning fossil fuels or product waste to generate electricity. The low-pressure steam output can be for heating. The efficiency for this process can approach 85%.

In a diesel engine generator, waste heat can be recovered from the water-filled cooling jacket around the engine or from the exhaust gases. This heat can be used to heat water or to produce steam. Diesels often have lower efficiencies than either gas or steam turbines, but with cogeneration the total conversion efficiencies reach 90%. They are also capable of generating more electricity than comparable gas or steam turbines and are more appropriate for small-scale applications. One potential problem with diesel cogeneration is air pollution, but the newer diesel engines are cleaner than those produced in the past.

Fluidized bed combustion is a newer technology that burns coal in an efficient manner and can produce both electricity and heat. A mixture of finely crushed coal and limestone rides on a stream of air, which allows the coal to be burned at temperatures lower than conventional coal burners. This reduces the nitrogen oxide produced. The limestone absorbs sulfur from the coal, which reduces the sulfur dioxide.

COGENERATION SYSTEMS

Cogeneration systems can also use renewable fuel sources such as wood, waste products, wood gas or methane from sewage and garbage. The Sun-Diamond plant in Stockton, California used waste walnut shells into electricity for the plant and nearby homes. The walnut shells were used as fuel to produce steam to drive a turbine generator. The low-pressure steam output was then used for heat as well as to refrigerate the plant. The Sun-Diamond cogeneration system produced about 32 million KWH of electricity per year. It only used 12 million and sold the surplus power to Pacific Gas and Electric Company.

Small-scale cogeneration units are those in the 5- to 20-kilowatt range. In smaller cogeneration units, more heat is supplied than can be used, so these systems may also include heat storage components. Large-scale systems may be more cost-effective and preferable to smaller ones, but if a system is properly sized and installed, it will cost less per unit of energy produced. If multiple, smaller units are used, at least one of the units can be operating continuously, providing electricity at all times.

The Fiat Motor Company developed its TOTEM (Total Energy Module) using a four-cylinder automobile engine that burns natural gas and can be adapted to other fuels, including liquid petroleum gas (LPG) and alcohol. It has a heat recovery efficiency of about 70% and an electrical generating efficiency of about 25%. The heating efficiency is similar to a conventional heating system, but since the unit also generates electricity its total efficiency is over 90%. The 380 volt, 200 amp asynchronous generator unit can produce 15 kilowatts of electrical power and heat a 4- to 10-unit apartment building. Major maintenance is needed after every 3,000 hours of operation, or about every few years. This is the overhauling of the automobile engine. The system is cost-effective even with this overhaul requirement.

Large cogeneration units have had a long and successful operating history and are more durable than small-scale units. The larger systems operate at about 35% electrical conversion efficiency and 45% heat conversion efficiency. This means that 80% of the energy in the fuel is converted to heat or electricity.

Units that produce 50 to 100 kilowatts can heat multi-dwelling apartment buildings. They are fueled by natural gas or diesel fuel. Units of 200 to 2,000 kilowatts that operate on fuel oil or diesel fuel are suitable for large apartment buildings or small district heating systems. The heat from a cogeneration unit can be used as a heat pump source, with electricity from the unit powering the heat pumps. If some of the electricity generated is used for space heating, the system can be downsized by about 1/3. If the electricity is used to power water source heat pumps, an even smaller system is required.

Cogeneration equipment must be safely connected to the utility grid. Utilities have objected to independent power generation by arguing that safety hazards can exist for their workers if independent systems continue to operate during system-wide blackouts. Such problems can be avoided by the installation of appropriate, standard safety equipment at the cogeneration site.

A cogeneration system may use different fuels including natural gas, residual fuel oil, heating oil, diesel fuel and gasoline. Alternate fuel sources also include coal liquids or wood gas.

COGENERATION WITH FUEL CELLS

As stationary fuel cells reduce their costs with continuing R&D, they will be able to compete with other small- to medium-sized power generation sources for on-site generation, particularly cogeneration for factories and commercial buildings. The installed cost for fuel cell generation systems is expected to reach $800/kW.

Many studies indicate a large potential. A 2000 study for the DOE's Energy Information Administration found that the total power needs for combined heat and power (CHP) at commercial and institutional facilities was 75,000-MW. Almost two thirds of these required systems of less than 1-MW.

These systems are a good match for fuel cell generation. The remaining power needs in the industrial sector are almost 90,000-MW. This does not include heat-driven chillers or systems below 100-kW.

Ceres Power has designed and built an integrated, wall-mountable combined heat and power unit (CHP). The integrated CHP Unit is capable of generating electricity and all of the central heating and hot water requirements of a typical home, avoiding the need for a separate boiler. The CHP Unit uses the same natural gas, water and electricity connections as a boiler, and is thus easy to install.

Ceramic Fuel Cells Limited (CFCL) and E.ON U.K. have agreed to develop a fuel cell combined heat and power (CHP) unit that can be fitted into homes in the U.K. CFCL also formed a collaboration with Nuon NV and De Dietrich-Remeha Group to jointly develop a fully integrated micro-combined heat and power (m-CHP) unit for the residential market in The Netherlands and Belgium.

A typical fuel cell system that is commercially available in the United States is the 200 kilowatt (kW) PAFC unit produced by UTC Fuel Cells. This is the type of unit used to provide electricity and heat to the U.S. Postal Service's Anchorage Mail Handling Facility. In 2000, the Chugach Electric Association installed a 1 Megawatt (MW) fuel cell system at the Anchorage Mail Handling Facility. The system consists of five natural gas powered 200-kW PC25 fuel cells developed by UTC Fuel Cells. The fuel cell station provides primary power for the facility as well as half of the hot water needed for heating. Excess electricity from the system flows back to the grid for use by other customers.

The Town of South Windsor, Connecticut, used funding from the Connecticut Clean Energy Fund to install a natural gas powered 200-kW PC25 fuel cell system, from UTC Fuel Cells, at the South Windsor High School. The system provides heat and electricity to the high school along with learning opportunities for the students.

The Department of Defense (DOD) Fuel Cell Demonstration Program is managed by the U.S. Army Corps of Engineers. It was begun in the mid-1990s to advance the use of PAFCs at DOD installations. Under this program, stationary fuel cells were installed at 30 facilities and locations in the Armed Services. The fuel cells are used for primary and back-up power as well as heat.

The competition is entrenched in very mature, reliable, low-cost technologies compared to fuel cells and many barriers exist to impede the use of widespread use of small-scale CHP systems. These existing technologies and existing companies can be formidable for the spread of new technologies and new companies.

CHP TECHNOLOGY

On-site combined heat and power (CHP) which has existed for years, includes turbines, reciprocating engines and steam turbines. Gas turbines in the 500-kW to 250-MW produce electricity and heat using a thermodynamic cycle known as the Brayton cycle. They produce about 40,000-MW of the total CHP in the United States. The electric efficiency for units of less than 10-MW, is above 30%, with overall efficiencies reaching 80% when the cogenerated heat is used.

They generate relatively small amounts of nitrogen oxides other pollutants. Several companies have developed very low NO_x units. Their high temperature exhaust may be used to make process steam and operate steam-driven chillers. A 1-MW unit can cost $1,800/kW installed while a 5-MW unit may cost $1,000/kW installed.

In these systems, the turbine generator is about 1/3 of the total cost with the other costs including the heat recovery steam generator, electrical equipment, interconnection to the grid, labor, project management and financing.

Reciprocating engines are another mature product used for CHP. These stationary engines may be spark ignition gasoline engines or compression ignition diesel engines. Capacities range from a few kilowatts to over 5-MW.

Natural gas or alcohol fuels may also be used in the spark ignition engines. Electrical efficiency ranges from 30% for the smaller units to more than 40% for the larger ones. Reuse of the waste heat can provide overall efficiencies to 80%. The high-temperature exhaust of 700°F-1,000°F can be used for industrial processes or an absorption chiller. About 800-MW of stationary reciprocating engine generation is installed in the United States.

Development has been closely tied to automobiles and in the last few decades increases in electric efficiency and power density have been dramatic as well as emission reduction. Some units can even meet California air quality standards when running on natural gas. A 100-kW reciprocating engine generating system may cost $1,500-kW installed, while an 800-kW unit can cost $1,000-kW. The engine is about one fourth of the total price with the rest going to the heat recovery system, interconnect/electrical system, labor, materials, project management, construction and engineering.

Steam turbines are an even older technology, providing power for over 100 years. Most utility power is produced by steam turbines. The steam turbine generator depends on a separate heat source for steam, often some type of boiler, which may run on a variety of fuels, such as coal, natural gas, petroleum, uranium, wood and waste products including wood chips or agricultural by-products.

Steam turbine generators range from 50-kW to hundreds of megawatts. By 2000, almost 20,000-MW of boiler and steam turbines were used to provide CHP in the United States. For distributed generation, a boiler and steam turbine system can be expensive. But, a process that already uses a boiler to provide high pressure steam can install a back pressure steam turbine generator for low cost, high efficiency power generation. The pressure drops in the steam distribution systems are used to generate power. This takes advantage of the energy that is already in the steam.

A back-pressure turbine is able to convert natural gas or fuels into electric power with an efficiency of more than 80%, which makes it one of the most efficient distributed generation systems. The CO_2 emissions are low as well as pollution emissions.

The installed capital cost for these systems is about $500/kW. High efficiency, low cost and low maintenance allow these back-pressure installations to have payback times of two or three years.

Since electric utilities are in the business of generating and selling electricity they tend to view small power producers as competitors and have established rate structures that tend to discourage independent power generation. The Public Utilities Regulatory Policy Act (PURPA), which does not cover certain diesel engines, requires utilities to buy surplus power from and to supply back-up power to small power producers and cogenerators at nondiscriminatory fair rates.

The competition to a CHP project may also receive price breaks from the local utility. When the local utility learns that a company is considering cogeneration, it sometimes offers a lower electricity rate in return for an agreement not to cogenerate for a certain period of time. This is especially true for bigger projects or those that might replace a large portion of its total load with on-site generation. A lower utility bill reduces the future energy cost savings from the CHP project and thus reduces the return on investment and increases the payback time. Other barriers to distributed energy projects besides costs include project complexity and regulations.

A report by the National Renewable Energy Laboratory, studied 65 distributed energy projects and found that various technical, business practice, and regulatory barriers can block distributed generation projects from being developed. These barriers include lengthy approval processes, project-specific equipment requirements and high standard fees.

There is no national agreement on technical standards for grid interconnection, insurance requirements or reasonable charges for the interconnection of distributed generation. Vendors of distributed generation equipment need to work to remove or reduce these barriers. The Starwood hotel chain faced utility efforts in 2003 to block the installation of a

250-kW molten carbonate fuel cell in a New York hotel. It overcame these efforts mainly because the system represented only 10% of the hotel's total power. These barriers have been described as a battle between distributed generation and the local utility.

Distributed projects are not always given the proper credit for their contributions in meeting power demand, reducing transmission losses and improving environmental quality. The New York Power Authority (NYPA) and MTA New York City Transit (NYC Transit) are powering an expanded subway and bus maintenance facility with a clean energy 200-kilowatt (kW) fuel cell. The stationary fuel cell produces electricity through a virtually emission-free chemical reaction. The electrical power is produced when oxygen and hydrogen are combined and the by-products are essentially heat and hot water. The unit will displace some 2,800 barrels of oil per year.

The fuel cell project with New York City Transit is the latest in energy-efficiency and technology programs undertaken in support of the nation's largest public transit system. The New York Power Authority is the nation's largest state-owned electric utility, with 18 generating plants in various parts of the state and more than 1,400 circuit-miles of transmission lines. NYPA uses no tax money or state credit. It finances its operations through the sale of bonds and earns revenue from proceeds of its operations, which stems largely from the sale of electricity.

In 2005, the New York State Public Service Commission approved a Renewable Portfolio Standard providing for increased use of renewable energy sources, including fuel cells. This project in Queens will help to implement the vision that 25 percent of the state's energy will come from renewable sources by 2013. The maintenance facility includes lay-up tracks, circuit breaker houses, a signal relay room and a car washer to service the 7 Flushing line. The facility is the first major maintenance facility with sustainable Green design. Integrated into the design are photovoltaic roof cells, natural light and ventilation, motion detector light switches and a storm water retention system to wash the subway car fleet.

Fueled by natural gas, the 200-kW fuel cell will be a continuous source of power. The residual heat of almost 700,000 Btu per hour will be used for the shop's domestic hot water system. In case of a power disruption, the fuel cell will automatically supply electricity to the building's non-emergency lights. Combined with other sustainable green design elements, NYC Transit expects to use 36% less energy over the life of the new facility.

This project adds to NYC Transit's use of clean energy power sources. In 1996 NYPA installed a 300-kW roof-mounted solar power array at the Gun Hill bus depot in the Bronx. During warm weather months, the solar array supplies 15 percent of this bus depots' electrical needs. NYC Transit has been using solar energy to provide power to the Maspeth Warehouse Facility in Queens and the Jackie Gleason Bus Depot in Brooklyn since the late 1990s.

NYC Transit also has a 100-kW solar canopy at the reconstructed Stillwell Avenue Terminal in Coney Island. NYC Transit became a full signatory of the International Association of Public Transportation's (UITP) charter on Sustainable Development in Mobility in 2004 and was the first public transit agency in the world to attain international certification for environmental management (ISO 14001). The New York Power Authority is a major national proponent of clean distributed energy technologies with 2.4 megawatts of installed capacity. It has installed 11 fuel cells in the New York City metropolitan region including eight at wastewater treatment plants, operated by NYC, where the units generate power using as fuel the gases produced through the wastewater cleansing process.

COGENERATION REGULATIONS

A cogeneration unit may fall under the provisions of one or more environmental and regulatory acts that cover power generation and industrial installations. Most systems of 5 to 100 kilowatts are likely to be exempt from environmental regulations except local building and zoning codes. Larger systems with a capacity in the area of some 500 to 2,500 kilowatts must comply with emission limits for five pollutants: nitrogen oxides, sulfur dioxide, small suspended particulates in the air, carbon monoxide and the photochemical oxidants found in smog. State regulations may also apply to small cogeneration systems. Regulations that affect small cogeneration systems include those governing noise pollution, water discharge and solid waste disposal.

Systems with a generating capacity of 75,000 kilowatts or less are exempt from most federal regulations governing power generation. Systems larger than about 75,000 kilowatts, or that sell 25,000 kilowatts or 1/3 of their generating capacity must comply with the Environmental Protection Agency's Stationary Sources Performance Standards for Electric Utility Steam Generating Units.

In densely populated areas, a large cogeneration system may be required to comply with emission standards and install pollution control technology. There may also be noise pollution standards and water, air discharge and solid waste disposal permits.

INTEGRATING COOLING, HEATING AND POWER SYSTEMS

During the late 1980s and early 1990s, slow growth and recession forced industry to cut costs and reorganize. There were many mergers with plant closings or cutbacks, layoffs and delayed purchases for capital equipment. This reduction of personnel pressured the surviving departments to increase automation and become more efficient. The financial staff analyzed operations more closely and offered areas that might be improved. These economic factors along with technological advances in electronics and control hardware allowed plant automation changes that were not possible before.

When power deregulation became a reality, in several states such as California the way energy was bought changed rapidly. Energy deregulation offered great potential for cost savings. Utility deregulation was a direct result of the Federal Policy Act of 1992. More competitive market-based pricing began replacing state and federal rate structures. In states that were still regulated, utilities modified their rate structures to preserve their customer base in any future deregulated environment. Open, competitive energy markets appeared that were unrestricted by geographical boundaries and regulated rates. These different purchasing options and rate structures were similar to what occurred following the deregulation of the telephone industry.

Modern advances in metering hardware, communications, and software considerably reduced the cost of how to monitor and control energy use, especially in regulated environments with rate structures. These new tools and technologies even allowed companies to negotiate better rates with their utility suppliers.

As companies scrambled to find new ways to lower the once fixed cost of their energy use, these newer options also allowed companies to protect themselves against unexpected power outages.

ENERGY MANAGEMENT

The growth of energy control systems spiked during the energy crisis of the 1970s, when the rising prices of imported oil triggered restricted energy use and led to more efficient energy management and control techniques. This resulted in the development of modern energy management systems (EMS) for monitoring energy usage. These systems grew over the years in both sophistication and scope.

Another product area appeared in the 1980s called building automation systems (BAS). These systems included historical data, trend logging and fire and security functions in addition to conventional energy management functions.

Direct digital control systems appeared in the mid-1980s and displaced older analog closed-loop schemes for temperature control. These digital systems improved both accuracy and reliability. The earlier systems were modeled after existing system architectures and did not contain intelligent, standalone field devices. There were numerous interfaces to the various building systems and the major decisions were made at a central computer.

BUILDING AUTOMATION

Modern Building Automation Systems (BAS) attempt to limit the interfaces used in order to provide a more seamless, integrated network. Ideally, all of the various components communicate with each other in a common language.

Several levels of control are generally used with several levels of hierarchy in a distributed architecture. Each level serves its own purpose, but all levels are interconnected, similar to the operating structure of a corporation.

In building control the controlled parameters include basic functions such as discharge air temperature, space temperature, humidity and fan control. The benefits of such a control system in an intelligent, integrated heating and cooling network include repeatable and individual parameter or area (zone) control. Individual comfort control has been shown to increase employee output and provide an annual productivity gain of over $1000 per employee.

Networking takes building automation beyond traditional heating and cooling functions. Intelligent devices can be tied into the network, allowing data to be collected and energy usage to be measured. A networked system may also manage lighting, fire and access control. If these systems are fully integrated, then the expanded integrated control functions can also address environmental issues such as indoor air quality.

Increasingly, legislation is targeted at the monitoring of volatile organic compounds (VOCs) in the atmosphere, many of which are suspected carcinogens or are acutely toxic. Continuous multipoint plant monitoring gives continuous information on the status of ambient air pollution at numerous locations in the plant. It provides information on levels of pollutants that workers normally are exposed to and has the ability to detect a chemical leak.

Mass spectrometers measure the masses of positively charged ions striking a detector. This allows quantification of the sample by comparison with standard calibration gases for multicomponent mixtures. Mass spectrometers can analyze a sample point in less than 10 seconds.

Even small leaks from valves on pipes and storage tanks can be detected. This type of analysis can indicate the degradation of valves and flanges and allows preventive maintenance before a critical leak occurs. Information management is the highest level of control in the networked system. Data from hundreds or thousands of I/O points in a building or building complex can be accessed quickly and used to assist in decision-making.

Information management can provide both environmental compliance and energy management. Financial decision-making is also allowed along with environmental quality assurance. Networked control provides quality assurance which can be used to identify, analyze and improve building operations related to both comfort and security.

Direct Digital Control (DDC) evolved from the growth stage of the late 1970s which were triggered as a result of the energy price hikes of 1973 and 1977. Control system technology had been evolving but a number of factors combined to make computer-based control technology more viable. One of these was the decreasing cost of electronics which made control systems more affordable. At about the same time the interest in energy savings jumped and a number of incentives and tax credits became available which stimulated the market. These factors resulted in a demand for technology that would allow building owners to save energy.

These newly developed systems came to be known as Energy Management and Control Systems (EMCS). The computer in use at this time was the minicomputer. These systems utilized energy saving features for optimizing equipment operation, offsetting electrical demand and initiated the shut-down of equipment when not in use.

Next in the control evolution was the utilization of Direct Digital Control. This technology was used in industrial process control and even for some building applications as early as the 1950s, but it was not until much later that it became an acceptable technique for heating and cooling systems.

DDC is a closed loop control process that is implemented by a digital computer. In closed loop control, a condition is controlled by sensing the status of the condition, taking control action to ensure that the condition remains in the desired range and then monitoring that condition to evaluate if the control action was successful.

Proportional zone control is a type of temperature control. First, the zone temperature is sensed and compared to a setpoint. When the temperature is not at the setpoint, a control action is taken to add heat or cooling to the zone. Then, the temperature is sensed again for a new control cycle.

The control may go beyond basic proportional temperature control and to integral or derivative control. In this case, the integral or derivative is used to calculate the amount that the temperature is from the setpoint. The control action is now limited to avoid overshooting the setpoint and the oscillations that cause delays in control response. These delays can often occur with proportional control. Derivative control is often used in dynamic applications such as pressure control. Derivative control will measure the change of speed in the controlled condition and adjust the action of the control algorithm to respond to this change. The use of a combined Proportional, Integral and Derivative (PID) control loop allows the control variable to be accurately maintained at the desired levels with very little deviation. A combined sequence like PID can be used to integrate the control of several pieces of heating and cooling equipment to provide a more efficient and seamless operation. Combining this type of more accurate control with networking has been an important advance in building control.

In the mid-1980s when there was no shortage of oil, the absence of a national energy policy resulted in a drop in the demand for energy management systems. The slower but continuous growth of these systems led to an awareness of the benefits of computerized control. Real energy cost reductions were noted as well as the other benefits of improved control. These benefits include longer equipment life, more effective comfort levels and expanded building information. The use of heating and cooling controls are driven by higher energy costs and potential energy crises. These also force a return to growth in the use of Demand Side Management. The growing requirements of indoor air quality and related environmental requirements force more applications for intelligent buildings and the control integration that they utilize.

A distributed control system might control heating and cooling equipment and other loads such as lighting. Distributed control is applied at each piece of equipment to provide application specific control.

A number of products have been introduced that use a type of communication network known as sensor or field buses. This technology has been growing quickly. Remote support can take place through a modem interface over telephone lines or through the Internet. Building systems may also do alarm dial outs to pagers and telephones with voice synthesis. Using building wide controllers that support plug-and-play and objects, the system stores all critical system information at the controller level. Intelligent controllers of this type make it possible to dial into a system from a remote location, upload from the controllers and have full access to the system. Another related building wide control trend is integration at the functional level. This trend also includes a movement toward integrated control between systems with different functions such as security and building control systems.

The speed of information transfer can be increased by switching from twisted pair cables to coaxial or fiber optics, however, these types of cables add to the installation costs. In the future, communications between sensors and multiplex boxes and the rest of the system may use a combination of technologies including traditional means such as twisted wire and coaxial and non-traditional methods such as infrared or radio wave.

Peer controllers can be used for continuously interrogating the network for sequences such as morning warm-up. This feature would have been centralized in older systems. A single condition such as outside air temperature might have been monitored, and the building wide device would make a decision on start time based on this data and a stored sequence. When start up was required, that controller would signal the start of the sequence. With integrated control of this type, each controller can make independent decisions based on building wide data as well as local controller data. This results in a more reliable and effective building control system. Equipment level applications that are energy intensive include air handlers, chillers and boilers. Control sequences include such expanded applications as start/stop of non-HVAC loads and the on/off control of lighting and other electrical equipment.

In the future, virtual reality may allow the operator to experience the environment. Special headsets and gloves may be used. After a complaint of a hot or cold temperature or a draft, an operator may zoom in to the space to feel and measure the temperature. Zooming inside the VAV box, the operator could check the damper position and view readouts of air volume and temperature. The thermostat or damper control could be adjusted while observing the system's operation. The operator could also check the operation of fans, boilers and chillers using this zoom control. Adding a sensor to a room could be a simple operation. The sensor may have a self-adhesive backing and stick to the wall. Power could be supplied to the unit by a built-in solar cell with battery backup. The sensor would broadcast using infrared, radio wave, or microwave. The computer will recognize the sensor and assign a point number. The system would map the location of the sensor using triangulation of the signal and its internal map of the building. A self-optimization routine would be used to search for the optimum control strategy to utilize the new sensor.

Power management may involve devices that regulate the on and off times of selected loads, such as fans, heaters, and motors. These devices reduce the electrical demand (kilowatts) and regulate energy consumption (kilowatt hours). In the past most of the energy savings has mainly been in heating.

Power management devices can be electromechanical, electronic, or computer based. The operation of one or more loads is interrupted by the power management system based on control algorithms and building-operating parameters, such as temperatures, air flow, or occupancy. The savings in electrical energy use and cost range from 0 to 50% or more.

LIMITING DEMAND

Demand limit control is a technique that raises the cooling setpoint in order to reduce some stages of cooling. This is a building wide sequence that requires equipment turn-off and avoids demand peaks. Load-shaping involves the prediction of demand excursions for shedding loads or starting power generators to avoid setting new peaks.

Power-monitoring software can be used to analyze energy use and power quality. It can identify load profiles to help with rate negotiation. If companies know their energy profiles, how and when they consume power, they can negotiate better rates for the type and amount of power they need.

Electrical demand is defined as the average load connected by a user to an electrical generating system. It is measured over a short, fixed period of time, usually 15 to 30 minutes. The electrical demand is measured in kilowatts and recorded by the generating company meter for each measurement period during the billing month. The highest recorded electrical demand during the month is used to determine the cost of each kilowatt hour (kWh) of power consumed.

Linking power management systems to control systems allows the power information to flow from both systems. Load profiles can be developed to find any energy inefficiencies. Energy scheduling can be used to find the optimum energy schedule for new product lines or processes.

Real-time utility pricing means that production schedule energy requirements need to be compared with energy rate schedules for optimum energy benefits. The new energy supply market requires more companies to give back energy capacity during peak energy use times by scheduling lower-energy production. This can result in significant savings.

Intelligent metering and monitoring systems offer a low-cost method for quickly implementing energy saving practices. A Cutler-Hammer plant in Asheville, NC, installed a power management system in early 1997 when energy bills were running close to $45,000 a month. After 6 months of installation, the plant energy saving was $40,000. The power management system allowed plant engineers to identify wasteful procedures, shift loads to level the demand and perform preventive maintenance. Better control of area lights during off hours was possible. Large electric oven loads were timed during the late shifts when the total energy demand was lighter. Maintenance technicians were able to locate abnormal conditions with monitoring screens and then service the equipment before it broke down. The total return on investment was predicted to be less than two years.

LOAD SHEDDING

Some power management devices are known as load shredders. They reduce the demand or average load in critical demand periods by interrupting the electrical service to motors, heaters, and other loads for short periods. Since the load which has been turned off would normally have been operating continuously, the overall effect is to reduce the average load or demand for that period of time. The instantaneous load when the load is operating remains the same. When the period involved has the highest monthly demand, significant savings are possible in rate reductions. In periods other than the highest demand period, energy is still saved. Prior to the era of high energy costs, load shedding was used mainly to avoid demand cost penalties. Now, it is used to limit energy consumption, by cycling loads on and off for brief periods, as well as to reduce demand. Other techniques used to limit energy use include the computer optimization of start times, setpoints, and other operating parameters based on the weather, temperatures, or occupancy.

Electronic demand limiting includes devices that monitor and measure the actual demand and provide control actions to limit the operation of attached devices when the measured demand reaches a specified value. These devices require two signals, the kilowatt hour (kWh) or demand pulse, which indicates the units of electrical energy consumed and a timing pulse, which indicates the end of one demand pulse and the start of the next one.

Some load shedders use a demand target that is not fixed but increases at a steady rate. Other devices allow the off-on setpoints to be adjusted independently for individual loads. Loads can be cycled based on the maximum demand target, time of day and day or week, rate of demand increase, heating and cooling temperatures, pressures, fuel flow and rates, occupancy schedules, inside and outside temperatures, humidity, wind direction and velocity and combinations of the above factors. Durations can be variable and changed automatically according to these parameters.

In air conditioning systems, intake and exhaust dampers can be controlled on the basis of air temperatures, so that the mix of air requiring the least energy is obtained at all times. The start-up and shut-down of air conditioning, heating, and lighting systems can be regulated according to inside and outside temperatures as well as occupancy to produce the conditions which consume the least energy.

DEMAND MANAGEMENT

Utility programs for energy conservation have involved demand-side management (DSM). These programs try to impact how customers will use electricity. One technique is to even out the demand for electricity so that existing power generating stations are operating at efficient capacities throughout any 24 hour day rather than peaking up during business hours and late afternoon and then dropping down later in the evening. The other part of DSM is to constrain the need for new electricity capacities. DSM involves peak clipping, strategic conservation, valley filling, load shifting, strategic load growth and flexible load shaping. It may include interruptible services or curtailment of services for specified time periods for commercial customers. Peak clipping refers to reducing the customer demand during peak electricity use periods. This is done by using some form of energy management system. Valley filling increases the electricity demand during off-peak periods, which allows the utility to use its power generating equipment more effectively. Load shifting is like valley filling, since it uses power during off-peak periods. Both valley filling and load shifting programs can involve power or thermal storage systems.

Load growth planning is a related DSM program that encourages demand during certain seasons or times of the day. Flexible load shaping modifies the load according to operating needs and can result in interruptible or curtailment rates for customers. These DSM energy and load-shaping activities are implemented in response to utility-administered programs. There may be energy and load-shape changes arising from normal actions of the marketplace or from government-mandated energy-efficiency standards. In the late 1980s, utilities began offering commercial rebate programs for DSM. Some utilities pay 30 to 50% of the installed cost, while others base their rebate programs on the peak-kilowatt-demand savings achieved by new equipment.

DSM programs consist of planning and monitoring activities which are designed to encourage consumers to modify their level and pattern of electricity usage. Energy conservation is often rewarded by utility rebate programs. It may include energy audits, weatherization, high-efficiency motors, Energy Management, DDC systems and HVAC systems and equipment.

Consolidated Edison has a program for organizations that can reduce their summer electricity bills without buying new equipment. During the summer months, these customers agree to reduce electric demand by at least 200 kilowatts on demand. More than 100 organizations have been involved in this program. Duquesne Light Company in Pittsburgh and Georgia Power have interruptible economic development rates that operate in a similar way.

Con Edison also offers programs with energy audits and rebates for steam air conditioning, gas air conditioning, high-efficiency electric air conditioning, cool storage and high-efficiency motors. Georgia Power has its Good Cents building program for commercial customers with HVAC rebates, along with energy audits. Houston Lighting & Power (HL&P) has a program to encourage the use of cool storage technology. It provides building owners with a $300 cash incentive for each kilowatt reduction in peak demand. There is also a cool storage billing rate, which defines the on-peak demand as noon to 7 p.m. Monday to Friday throughout the year. Many buildings have increased in value and marketability as a result of these cool storage programs. In the Dallas/Fort Worth area, Texas Utilities had more than 135 cool storage systems in operation.

Kraft General Foods and Boston Edison have an energy-efficiency partnership that reduced the cost of ice cream manufacturing dramatically. This project decreased the cost of producing ice cream by one third. The ice cream manufacturer was able to upgrade most of its electrical energy-consuming capital equipment and obtain substantial rebates for the energy saved. The rebates returned more than 85% of a $3 million investment. This included refrigeration and defrosting equipment, lighting installation and monitoring equipment.

Besides rebates there are low- or no-interest equipment loans, financing, leasing and installation assistance and assured payback programs. Wisconsin Electric Power Company offers rebates of up to 50% of the project cost and loans with multiple rates and terms for 3 to 7 years. These programs are available to building owners and managers who install energy-efficient HVAC systems, window glazing, high-efficiency motors or building automation systems.

Commonwealth Edison Company in Chicago offers its Least Cost Planning load reduction program. In this program, businesses agree to curtail or reduce their electricity consumption to prescribed limits when the utility requests it. They are compensated with a special electricity rate that is performance-based. The worst performance during any curtailment period becomes the base for electricity charges.

According to the Edison Electric Institute (EEI), DSM programs grew from 134 in 1977 to nearly 1,300 by 1992. These DSM programs deferred more than 21,000 megawatts (MWs) in 1992. In 1997, about 1,000 electric utilities had DSM programs. A little more than half of these are classified as large and the rest are classified as small utilities. Large utilities are those that produce more than 120,000 megawatt hours. This group of larger utilities account for about 90% of the total retail sales of electricity in the United States.

Utilities are also supporting the adoption and implementation of stricter building codes and equipment efficiency standards. The increasing acceptance of energy management systems for building management applications has been pushed by federal mandates.

Appliance and equipment efficiency standards are having a notable impact on electricity demand in the United States. Standards have lowered national electricity use by 3%. A few energy efficiency measures, such as power-managed personal computers, have been widely adopted without financial incentives or much utility involvement.

Energy saving systems integrate the operation and management of heating, ventilation, air conditioning, security, light and fire safety systems to reduce energy costs and minimize carbon dioxide emission of commercial buildings. The weak link in most older systems is the dependence on a human operator. The future vision is a building that almost runs itself, from adjusting HVAC loads to dimming the lights.

Energy efficiency is part of an overall goal to reduce energy use and carbon dioxide emissions. The result is practical, computerized energy management systems that unify the operation and monitoring of heating, ventilation, air conditioning, security, lighting and fire safety systems.

HIGH-EFFICIENCY HEATING

Some newer heating system technologies involve modifications to conventional heat exchangers or the burn design. These changes provide steady-state efficiencies approaching 90%, with seasonal efficiencies to 85%. This is about 10% better than the steady-state efficiencies of 78 to 80% for the most efficient conventional designs.

One newer technique uses spark ignition in the combustion chamber to keep exhaust gases at 120°F instead of 400°F or more. In this process almost all the useful heat is removed and the gases are cool enough to be exhausted through a plastic pipe. This type of system allows seasonal and steady-state efficiencies to reach 90%. Air and natural gas are mixed in a small combustion chamber and ignited by a spark plug. The resulting pressure forces the hot exhaust gas through a heat exchanger, where water vapor condenses, releasing the latent heat of vaporization. In subsequent cycles, the fuel mixture is ignited by the residual heat.

One system manufactured by Hydrotherm, of Northvale, New Jersey, has efficiencies of 90 to 94%. The cost of the system is between 50 and 100% higher than a conventional one, but the improved efficiency can pay back the difference in 5 years.

Conventional flame retention burners create a yellow flame, while modified flame retention burners create a blue flame in the combustion chamber. This is done by recirculating unburned gases back through the flame zone. This produces more complete burning of the fuel and results in lower soot formation. These flame systems are available as a burner for retrofit to furnaces, or as a complete burner and boiler system for hot water distribution systems.

Variable fuel flow is used in burners to throttle or cut back the fuel flow rate, reducing flame size, as the system heating load varies. These burners have conventional steady-state efficiencies and higher seasonal efficiencies. They are available for large apartment boilers and furnaces.

There are also burners that can burn either oil or gas. They offer no efficiency advantages, but the ability to switch fuels in the event of a shortage or price differences is an advantage. They are available as combination burner and boiler units.

Tankless boilers offer some advantages in seasonal efficiencies, compared to conventional units, since there is less water to heat up and cool off. The savings are similar to that of using an automatic flue damper.

FLUE ECONOMIZERS

Flue economizers include small auxiliary air-to-water heat exchangers that are installed in the flue pipe. The unit captures and recycles the usable heat that is usually lost up the flue. The recaptured heat is used to prewarm water as it returns from the distribution system. If the flue temperature is lowered too much, moisture, corrosion and freezing may occur in the flue pipe. Depending upon the age and design of the boiler and burner, a flue economizer can provide annual fuel savings of 10 to 20% and a payback of 2 to 5 years.

Air-to-air flue economizers are also available for about 1/5 the cost but these save much less energy and are usually not tied into the central heating system. They are best for heating spaces near the flue.

GROUP HEATING

The technologies that are well suited to groups of buildings include cogeneration, district heating and seasonal energy storage systems. Cogeneration involves the simultaneous production of both space heat and electricity from an electrical generating system. A district heating system supplies heat and hot water from a central production facility to a number of residential, commercial and office buildings. A seasonal energy storage system is designed to store heat or cold energy during one season, when it is not needed, for use during another season.

To be cost-effective, these types of technologies are usually applied to groups of buildings, but cogeneration and seasonal energy storage systems may be sized for small-scale applications. District heating may include cogeneration or summer storage of solar energy for winter space heating.

District heating usually involves supplying hot water for space heating and hot water use from a central production facility to a group of residential or commercial buildings. District heating networks in Europe serve large portions of the populations of some countries. In Sweden, 25% of the population is served by district heating, in Denmark the number is over 30%, in Russia and Iceland it is over 50%. In the United States, district heating serves only about 1% of the population through older steam supply systems. In Europe, many of the district heating systems were installed during the rebuilding that followed World War II.

District heat replaces relatively inefficient home heating systems with a more efficient, centralized boiler or cogeneration system. This offers the potential of major energy savings, although some heat is lost during the distribution of hot water. A centralized boiler or cogeneration system can be used to produce heat. Large, centralized oil-fired boilers can remove as much as 90% of the energy contained in the fuel. Cogeneration systems can also have a total heat and electricity efficiency approaching this.

District heating systems can use the waste heat from electric generation and industrial plants that would be released to the air or to nearby water supplies. Some estimates suggest that district heating could save as much as one billion barrels of oil per year in the United States.

In some European cities, waste heat from fossil fuel electric power plants is used for district heating with an overall energy efficiency of 85%. These plants were not originally constructed as cogenerating units. Waste heat from industrial process plants can also be used. Geothermal sources are used to provide heat for district heating systems in Iceland and Boise, Idaho.

Hot water can be transported over longer distances with little heat loss while steam heat distribution systems can only serve high-density regions. The largest steam system in the United States is a part of New York's Consolidated Edison Company and serves a small part of Manhattan Island. The larger pipes or mains carry 200 to 250°F water under pressure. Return mains carry the cooler, used water at 120°F back to the central facility.

Costs can be lowered with the use of newer types of pipes, insulating materials and excavation techniques. Plastic piping in long rolls is laid in plastic insulation and placed in narrow trenches. Using these techniques, hundreds of feet of pipe can be laid quickly. Metal radiators can also be replaced by plastic units.

District heating systems are often financed by municipal bonds at low interest rates, to be repaid over a 30- to 40-year period. This makes the annual cost per home competitive with or less than that of conventional heating systems.

A seasonal energy storage system is designed to store heat or cold during one season, when it is not needed, for use during another season. These systems have a large energy storage component. They collect essentially free heat or cold when they are plentiful and save them until required. The only energy consumed is that needed to run the various parts of the system. Three types of systems exist: annual cycle energy systems, integrated community energy systems and annual storage solar district heating. The first two can provide both heating and cooling while the third is used for heating only.

The annual cycle energy system (ACES) has two basic components: a very large insulated storage tank of water and a heating-only heat pump. The tank contains coils of pipe filled with brine (salt water) warmed by the water in the tank. The brine circulates through a heat exchanger and transfers its heat to the heat pump refrigerant.

During the heating season, heat is removed from the water tank by the brine and transferred to the building at a temperature of 100 to 130°F. The system may also be used to provide domestic hot water. As heat is removed from the tank, the temperature of the water drops below the freezing point and ice begins to form on the brine circulation coils. By the end of the heating season, ice fills the entire tank. This ice is then used during the summer to provide chilled water for air conditioning. While the ice remains in the tank, the only power required for cooling is for the operation of a circulator pump and a fan.

In actual installations these systems have been shown to use about 45 to 50% of the electricity consumed in a similar house with conventional electric resistance heating. It is more efficient than a conventional air-to-air heat pump system, since the heat source is maintained at a constant, known temperature. In moderate cold climates with 6,000 degree-days, an ACEs uses about 25% less electricity than a conventional heat pump with a coefficient of performance of 1.5.

The initial cost of an ACES is much higher than that for conventional home heating and cooling systems, mainly because of the cost of the storage tank. Energy savings in a house with electric resistance backup can be over $1,000 per year, which gives about a 10- to 15-year payback.

The system is usually sized to meet the summer cooling requirements, rather than the winter heating load, of a building. In order to meet the total heating requirements of a building, an ACES is best suited for climates where the heat provided to the building from the tank during the winter is nearly equal to the heat removed from the building for cooling and transferred back into the tank during the summer. This is possible in areas where the winter and summer climates are not too extreme, such as Maryland and Virginia.

INTEGRATED COMMUNITY SYSTEMS

An Integrated Community Energy System (ICES) is a type of district heating and cooling system that uses heat pumps to collect and concentrate energy. The use of heat pumps allows free heat that would otherwise be lost to be removed from fuel cells, boiler waste heat, groundwater, lakes, solar and geothermal sources. An ICES has three major components: heat pumps, a heat source which may also act as heat storage and a distribution system. The heat pump section of an ICES may be centralized, distributed or cascaded. In a centralized system, one or more large heat pumps are used in a manner similar to the centralized boiler of a district heating system. The heat pumps are located in a central facility, and they remove heat directly from a heat source. This heat is then used to warm distribution water, which is then pumped to individual buildings.

In a distributed system, small heat pumps are located in each building. Water from the heat source is sent directly to an individual heat pump. Heat removed from the distribution water is then used to warm the building. Some heat pumps may be used to also provide cooling.

A cascaded system uses both centralized and individual heat pumps. A central heat pump removes low temperature heat from the primary source and adds it to the distribution water, which is sent to individual buildings. Heat pumps in the buildings then use this distribution water as a secondary heat source. This system is used when the primary source water is too corrosive, such as salt water, or contaminated, such as waste water.

The distribution system of an ICES is the same as that of a conventional district heating system. Each ICES has warm water supply and cool water return mains. Systems that supply both heating and cooling at the same time may have independent distribution systems for hot and cold water. Distributed systems using groundwater as a heat source may have only a distribution water supply line. Cascaded and distributed ICESs have separate heating distribution systems for each building.

Depending on the winter climate, the heat source can be a lake, reservoir, underground storage tank, aquifer (underground river or lake), solar-heated water, sewage or waste water, geothermal energy or waste heat from industrial or commercial facilities.

In an ICES that serves both small and large buildings, the surplus internal heat from the large buildings can be used to provide source heat to smaller ones. An ICES in areas with moderate winter temperatures may use air as a heat source. Systems that use lakes or reservoirs rely on the natural collection of heat by these water sources throughout the year.

The operation of an ICES depends upon the nature of the heat source and if the system is centralized, distributed or cascaded.

Solar energy can be used to warm heat pump source water. In this system solar collectors are mounted on a large, insulated water tank where the warmed water is stored. Most of the heat is collected in the summer for use during the winter. In the winter, the hot water can be used directly for space heating until it cools to about 85 to 90°F. The remaining heat can be removed and concentrated by a centralized heat pump.

An ICES using a large fabricated tank of water can operate as a community-scale ACES. The water in the tank is slightly higher than 32°F. During the winter a centralized heat pump removes heat from the tank, causing the formation of ice. This ice is then used for summertime air conditioning or for winter cooling of large buildings.

Sewage and wastewater heat sources are usually not much colder than the buildings from which they come. A cascaded ICES can remove heat from waste water and transfer it to the distribution system which then acts as a secondary heat source for heat pumps in individual buildings. Waste heat is often lost into the environment by industrial facilities in the form of hot water. This hot water can be used directly by the heat pumps in a centralized ICES.

ICES have several advantages over conventional district heating systems or individual building heating systems. An ICES will often serve business, commercial and residential districts. Since the peak heating and cooling demands of these different sectors may not occur at the same time of the day, a single moderately sized system can meet the varying peaks of the different sectors. If the ICES contains a short-term heat storage component, such as a water tank, the system can operate continuously and at a steady level around the clock with peak heat demand requirements drawn from storage.

Conventional heating systems burn fossil fuels at high temperatures to heat water to 120°F. Most district heating systems operate in the same way. In these cases, when the hot water cools to 90°F or less, it is no longer warm enough to supply heating. This remaining heat is eventually lost to the environment. An ICES can recover this low-temperature heat that would otherwise be wasted. This helps to increase system efficiency.

An ICES is often found to be economically competitive with conventional heating systems such as furnaces and/or boilers in individual buildings or district heating systems using fossil fuels. Capital costs are a good deal higher than those of conventional systems, but ICESs have lower energy requirements. Free environmental energy is substituted for the burning of fossil fuels. In some ICESs, electricity consumption may be greater than in conventional systems lacking heat pumps, but the total consumption of all forms of energy is lower.

SOLAR DISTRICT HEATING

ACESs and ICESs rely on heat pumps and storage systems, and need notable amounts of energy to operate. An annual storage solar district heating system could supply most of a community's annual space heating requirements with a minimum of nonrenewable energy.

An annual storage solar district heating system requires a heat store, a collecting area and a distribution system. The storage can be either an insulated earth pit or a below-ground concrete tank. Both have insulated concrete covers and are filled with water. Collectors are mounted on the cover of the storage tank and are rotated during the day so they always face the sun. During the summer, the collectors heat water for storage and for domestic hot water. During the winter, the collecting system heats water that is used directly for heating purposes. When additional heat is required, the hot water stored in the storage tank or pit is used. Water is removed from the top layers of the storage tank. The cooler used water is pumped back through the collectors or into the bottom of the storage tank.

These systems cannot provide air conditioning so they are mostly suited to northern climates. This is because over the course of a year even northern locations such as Canada receive as much sunlight per square foot as Saudi Arabia. The problem is that most of the sunlight falls in the summer when it is not needed for heating. In annual solar storage the system collects heat in the summer for use during the winter. A large rock cavern in Sweden provides district heating for 550 dwellings.

A housing project at Herley, near Copenhagen in Denmark, uses a central solar collector and a large insulated water tank buried in the ground. Solar heat provides most of the space heating requirements for 92 housing units. When the temperature of the heat store falls below 45°C, heat is transferred with a heat pump, powered by a gas engine, which boosts the temperature to 55°C. This process continues until the temperature of the heat store has fallen to 10°C, at the end of the heating season. Waste heat from the engine is also delivered to the heating system, and a gas boiler is used as a back-up. In summer, the main heating system is shut down and 90% of the domestic hot water requirements of the housing units are provided by additional solar collectors on each of the eight housing blocks. This type of system can also be implemented by a gas furnace. All of these systems operate in latitudes far to the north of American cities.

An annual storage solar district heating system is capable of supplying 90% of the annual heating requirements for the homes in a community. Depending upon the climate zone, the required collector area per house can range from 70 to 300 square feet. This can be reduced if residential heat loads are lessened through increased weatherization and the addition of passive solar features.

Solar district heating offers a number of advantages over conventional single-residence active systems. The collectors can be set aside in an open area and problems with access to the sun do not arise. The heat storage capacity is not constrained by space limitations in any one building and the storage tank can be as large as necessary. Since the system is equipped for annual storage, solar collection is not dependent on the day-to-day weather conditions.

HYBRID COOLING

Hybrid cooling plants may use a number of different technologies to provide cooling. These technologies include electric chillers, absorption chillers, engine-drive and/or dual-drive chillers, thermal storage systems and the use of a water-side economizer cycle. Most of these seek to provide some or all of the cooling without using electricity during the high cost, peak period. The electric rate structure is one of the primary determinants of the choice of cooling medium. Hybrid plants are generally a better option because the cost of cooling with electricity during some periods can be less than the cost of cooling with natural gas.

Absorption chillers, especially the double-effect type, are used for utility rate structures with high peak period demand. These include usage charges or rate schedules with ratchet clauses for the demand charges. There is a significant first cost premium for this equipment. Maintenance costs are generally comparable with electric chillers, but the absorption chiller requires more day-to-day maintenance. Engine-driven chillers provide an alternative to absorption chillers when natural gas cooling is desired. Engine-driven chillers utilize the same type of equipment as electric chillers for cooling, but replace the electric motor with a natural gas fueled engine. One problem with this equipment is that the maintenance and operation staff may be unfamiliar with the requirements of the engine. Especially for truck-derivative engines, maintenance costs are significant and must be accounted for in the operating costs. Noise and vibration are also concerns that must be addressed. A major benefit of engine-driven chillers is the opportunity to capture waste heat from the engine as a mechanical cogeneration systems. Another option is the use of dual-drive chillers with both an electric motor and a natural gas engine available to drive the chiller.

Thermal storage systems can be used to shift the cooling load from high cost periods to low cost times of day. The major design concern is allowing for sufficient storage and re-charging capacity to allow for some load and temperature increase for overnight periods. There is a significant danger of poor operation and the inability to fully transfer loads if some spare capacity is not provided.

Water-side economizers used in areas with low wet bulb temperatures, especially when the use of an air-side economizer cycle is not feasible. One problem that must be considered is the change-over from economizer operation to chiller operation since the low condenser water temperature can affect the operation of the chiller. The use of a water-side economizer also affects the cooling tower since there are collateral benefits in providing a larger cooling tower.

Primary-secondary chilled water distribution systems were developed to allow a constant flow through chillers, required by the chiller manufacturers, with variable flow for the load side of the system to improve efficiency. The main applications are in multibuilding systems or systems with larger variations in load. The emergence of variable speed drives and DDC control systems made the operation of these systems much more effective. Newer chillers with digital control panels are able to operate effectively and safely with variable flow. Another significant advantage of the primary-secondary system is the system flexibility that it offers. This type of system makes it easier to incorporate hybrid systems, as well as thermal storage systems and water-side economizers. Depending on the piping and valving arrangement, the system can load chillers evenly or sequentially. They also allow for the preferential loading of particular chillers as required in a hybrid system to gain the maximum benefit. The complexity of these systems requires a well developed sequence of operations to ensure that the control system will provide the proper operation.

Condenser water systems for electric chillers are usually designed with a 10°F temperature differential. Absorption chiller systems may operate with higher temperature differentials due to the greater amount of heat rejected from these units. There may be benefits for electric chiller systems in using a larger temperature differential for the condenser water system. The primary benefit is the reduction in the quantity of water to be pumped for the condenser water system to reject the same amount of heat. This allows the use of smaller piping and pumps. The higher temperature will improve the efficiency of the cooling tower, but will reduce the efficiency of the chiller. There is a reduction in first costs due to the smaller pumps and piping with no change required in the cooling tower or the chiller.

An oversized cooling tower is generally beneficial. Since it provides additional capacity and an allowance for equipment problems. For operating costs, there is a reduction in pumping energy, possibly a reduction in cooling tower energy, offset by an increase in chiller energy. The net impact depends on the size of the system, amount of pumping, climate and hours of operation, but generally results in a net reduction in energy consumption.

EXHAUST AIR

Exhausting air to outside is an effective way to provide a safe and comfortable working environment for industrial workers. Many exhaust systems are designed for peak demand and operate 24/7 with little or no controls. Normally, one fan controls several exhaust inlets. There are no dampers to close the inlets that are not in use. The fans are usually single speed and are not controlled by the building control system. They are manually turned on and run 24/7 in most cases. Most exhaust fans are in the range of 1/4-hp to 15-hp.

Since exhaust fans do not consume a lot of energy compared to other HVAC equipment in the building, many plant operators do not pay attention to their efficient operation. In manufacturing buildings, exhaust air needs to be made up by fresh outside air. Due to high air exhaust, some manufacturing buildings use almost 100% outside air during winter heating season. The supply system is used to create a comfortable environment in the plant and replace the air exhausted out by the exhaust system. The exhaust system removes contaminated air and reduces the heat concentration locally. The exhaust system can be divided into general exhaust and local exhaust. Local exhaust is more effective due to the fact it is close to the source of contamination.

Temperature and humidity are controlled to ensure worker comfort and product quality. When excessive exhaust occurs, the supply system would need to supply more outside air than the minimum required for proper ventilation, resulting in more heating and cooling energy.

One industrial facility that has done exhaust system retrofit is the Eldec Corporation, an aerospace electronic manufacturer. With the help of the local utility, Eldec implemented a control project to reduce exhaust air by up to 30% for the first shift and 60% for the rest of the time and achieved great savings with one year simple payback. The project closed the exhaust inlets with dampers and controlled the exhaust fan speeds with variable frequency drives (VFD). The exhaust fans are now monitored and controlled by the building direct digital controls (DDC) system to ensure proper operation and save energy.

The facility has three buildings with sizes ranging from 70,000 to 80,000 square feet (SF). The HVAC systems are variable air volume (VAV) systems. Minimum 30% relative humidity is controlled in the production buildings. All the three buildings have a similar operating schedule. One building is a two-story building with 70,000 SF. Two packaged units serve the majority of the building. Both units combined have a maximum supply air of 72,000 CFM and a minimum supply air of 44,000 CFM. Total exhaust CFM before retrofit was 34,650 CFM.

Before the retrofit, the exhaust system was manually controlled, by turning off fans. There were no dampers to close the inlets and no flow controls for the fans. Since these are local exhaust, heat recovery was not possible. Most inlets or hoods shared fans, so it was not possible to switch off a fan if any inlet was in use. The exhaust air volume was about the same as the minimum supply air. The floors are open spaces so the air moving around the floor was transferred from one floor to the other by pressure differences. Although there was a minimum outside air setting in the packaged units, outside air had to make up the exhaust by supply air from the packaged units and infiltration. The work schedule was flexible, so although the building operated on a one-shift schedule, workers could be in the building working any time of the day. The exhaust system ran constantly and due to exhaust, the HVAC systems had to operate the same way all the time.

The building had operated this way by for many years. During 2000-2001, the power rate increased dramatically due to the energy crisis on the West Coast and it became a high priority to reduce the power usage.

Since there were no dampers in most of the exhaust inlets and no automatic controls on the fans the exhaust air was very high and unnecessary. Modifications included easier operating dampers, using magnets to hold the dampers open and relocating the dampers so they would not obstruct normal operation. Visible warning lights were installed to indicate if the associated exhaust fans were on or off. The fans were controlled by variable frequency drives (VFD). The building had a direct digital control (DDC) system, so the VFDs were linked into the DDC system to schedule and monitor their operation. Workers were able to close dampers and turn off fans when they were not needed. The DDC system monitored the VFD operation and when the building was unoccupied, the VFDs were set to run at minimum. The building achieved a 30% energy reduction during occupied hours and 60% during unoccupied hours. Environmental safety standards were used to check if the exhaust amounts were adequate.

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Chapter 8

The Power and Transportation Future

As recently as 1978, gasoline sold for less per gallon, in constant dollars, than it had in 1960. Now prices jump upward as crude oil rises and supplies seem less secure. Until recently, making adjustments for inflation, gas prices were lower than they were during the oil crisis of the 1970s. The current prices are providing incentives for producers to pursue alternatives. When oil prices are high, there is a demand for alternatives. Although we will eventually run out of oil, coal, and other non-renewable energy sources, in the short term rising oil prices produce more of the hard to get oil with improved technology as well as other more expensive forms of energy.

There are large amounts of reserves that are too expensive to profitably develop when oil is below a certain price, as soon as the price rises above this threshold, a given oil field can be developed at a profit. Many older domestic fields with heavy crude are being developed using steam injection and recovery. Energy producers take advantage of higher prices to make use of their existing infrastructure to extract, refine, and distribute as much oil as possible. Current non-renewable energy supplies are still cheap but less expensive than they have been.

Before the 1970s, the typical American car was overweight at 22 times heavier than a 150-pound driver, overpowered, oversize, and very thirsty. In the late 1970s standard American cars downsized by trimming weight and exterior dimensions. This produced smaller and lighter vehicles with only half the cylinders of the once dominant V-8 engines. Front-wheel drive eliminated the shaft from transmission to rear differential and saved weight. More weight saving occurred in such areas as bumpers, hood, and body panels used plastic components. Heavy overdesigned frames were replaced by integrated frame-body shells similar to aircraft fuselages.

Even in smaller cars that use less petroleum, most of the energy released in combustion is wasted and only 12-15% is finally applied to move the car. The rest is lost due to the thermodynamic inefficiency of the engine, aerodynamic drag, rolling resistance of tires, transmission slippage, internal friction, idling and air conditioning.

Large frontal areas create air turbulence and drag and bodies designed from wind tunnel testing can provide a more smooth air flow around the vehicle. Automatic transmissions impose a mileage penalty of about 10% compared to manual gearboxes and continuously variable transmissions could provide better mileage. A stop-start engine that shuts down if a car is idling or coasting can cut gas consumption by about 15%. This is what happens in a hybrid vehicle as they shift to electric drive.

Better lubricants and bearings are reducing friction and microprocessors monitor engine conditions and make adjustments to keep operation at peak efficiency without actions by the driver.

As the price of petroleum for gasoline and diesel engines converges with that of alternate energy sources, new power systems will become more widely used. Battery-powered electric motors are quiet with low pollution and simplicity, the disadvantages of limited range between recharges (which are also limited), weight, and bulk reduce their market potential.

New battery systems could give better performance but they have not been forthcoming. Performance is limited by the lead-acid battery packs which are generally the most affordable option. More unfamiliar batteries like nickel metal hybride (NiMH) packs have also appeared.

The common 12-volt lead-acid battery has six cells, each containing positive and negative lead plates in an electrolyte solution of sulfuric acid and water. This proven technology is not expensive to manufacture and it's relatively long-lasting. But, the energy density of lead-acid batteries, the amount of power they can deliver on a charge, is poor when compared to NiMH and other newer technologies. The United States Advanced Battery Consortium (USABC) is a Department of Energy program launched in 1991. Since 1992, USABC has invested more than $90 million in nickel metal hybride batteries.

These batteries are much cheaper to make than earlier nickel battery types, and have an energy density almost double that of lead-acid. NiMH batteries can accept three times as many charge cycles as lead-acid, and work better in cold weather. NiMH batteries have proven effective in laptop computers, cellular phones, and video cameras.

NiMH batteries can power an electric vehicle for over 100 miles, but are still several times more expensive than lead-acid. NiMH batteries from Energy Conversion Devices were installed in GM's EV_I and S-10 electric pickup truck, doubling the range of each. Chrysler has also used

NiMH batteries, made by SAFT of France its Electric Powered Interurban Commuter (EPIC) vans, adding 30 miles to their range.

Other battery technologies include sodium-sulfur which was used in early Ford EVs, and zinc-air. Zinc appeared in GM's failed Electrovette EV in the late 1970s. Zinc-air batteries have been promoted by a number of companies, including Israel's Electric Fuel, Ltd. Zinc is inexpensive and these batteries have six times the energy density of lead-acid. A car with zinc-air batteries could deliver a 400 mile range, but the German postal service found that these batteries cannot be conventionally recharged.

The EFTC zinc-air battery system for electric vehicles uses a discharge-only zinc-air module with the exchange of batteries and zinc anode regeneration for battery recycling. A Zinc-Air Module is built from cells with replaceable zinc anode cassettes. There are 47 cells with an open circuit voltage of 67V and an operating voltage of 57-40V. The system has a battery capacity of 325 amp-hours and an energy capacity of 17.4-kWh with a peak power of 8-kW. The weight is 88-kg with an energy density of 200-Wh/kg and dimensions of 726x350x310 mm.

The cell uses a replaceable anode cassette made up of a slurry of electrochemically generated zinc particles in a potassium hydroxide solution with a collection frame and a separator envelope with two sides of oxygen reduction cathodes that extract oxygen from the air for the zinc-oxidation reaction. The discharged zinc-air module is refueled or mechanically recharged by exchanging spent cassettes with fresh cassettes.

Other battery types include lithium-ion, which is used in a variety of consumer products. Lithium batteries could offer high energy density, long cycle life, and the ability to work in different temperatures. However, like the sodium-sulfur batteries in the Ford Ecostar, lithium-ion presents a fire hazard since lithium itself is reactive. Plastic lithium batteries could prove to be very versatile. Bellcore is working on a lithium battery that is thin and bendable like a credit card for laptop computers and cell phones. Each cell is only a millimeter thick. The plastic batteries are lightweight and have been tested for automotive applications. Canadian utility Hydro-Quebec has been working with 3M on a lithium-polymer unit which may be the first dry electric vehicle battery. Like the Bellcore product, this dry battery uses a sheet of polymer plastic in place of a liquid electrolyte. Also working on this technology is a team at John Hopkins University. This is also a plastic battery that can be formed into thin, bendable sheets. These batteries also contain no dangerous heavy metals and are easily recycled.

LITHIUM ION BATTERIES

In the early 1970s, the first non-rechargeable lithium batteries became commercially available. Lithium is the lightest of the metals with the greatest electrochemical potential and the largest energy density for its weight. Attempts to develop rechargeable lithium batteries failed due to safety problems from the inherent instability of lithium metal. This work shifted to a non-metallic lithium battery using lithium ions. Although it is slightly lower in energy density than lithium metal, lithium-ion is safer, provided certain precautions are met when charging and discharging.

In 1991, Sony introduced the first lithium-ion battery and other manufacturers quickly followed. Lithium-ion is a low maintenance battery, there is no memory and no scheduled cycling is required to extend the battery's life. A protection circuit is used to prevent metallic lithium plating from an overcharge. Some capacity deterioration occurs after a year and lifetime is usually two or three years, but some lithium-ion packs are known to have served for five years in some applications.

Manufacturers are constantly improving lithium-ion units with new and enhanced chemical combinations introduced almost every six months. These revised batteries may last longer with higher energy densities.

The lithium polymer battery is different from conventional battery systems in the type of electrolyte used. The original design from the 1970s used a dry solid polymer electrolyte. This is a plastic-like film that does not conduct electricity but allows ion exchange. The polymer electrolyte replaces the traditional porous separator, which is soaked with electrolyte. The dry polymer design offers simplifications in fabrication with a rugged design and safety. However, the internal resistance is too high to deliver the current bursts needed for many applications.

A compromise is to add some gelled electrolyte. Commercial cells use a porous polyethylene or polypropylene separator filled with a polymer and gel filling with a liquid electrolyte. They offer improved safety with more resistant to overcharge and less chance for electrolyte leakage.

Battery system efficiency can also be increased by using flywheels to equalize power demands on batteries during acceleration and hill climbing.

NEIGHBORHOOD VEHICLES

Small neighborhood electric vehicles (NEVs) have been gaining popularity throughout the United States and in other parts of the world. There are several companies that manufacture and sell NEVs in the United States. Some of these employ solar-electric technology.

NEVs are also known as low speed vehicles (LSVs) and can legally be driven on any street with a posted speed limit no greater than 35 mph. This means that most urban environments, and many small, rural communities are appropriate locales for NEVs. As gasoline and energy costs escalate in the future, NEVs may become even more attractive. The batteries will need replacement perhaps every five years, but that is a large expense. In addition, thanks to recent legislation, NEV owners are now eligible for a federal tax credit.

In solar NEVs the solar-electric panels and the charge controller keep the batteries charged while not overcharging them. The owner can park the NEV in the sun and the vehicle will charge itself. If it is a cloudy day and the owner wants to charge the vehicle, it can be plugged into ordinary house current.

The shape of an NEV is free to take many forms, since it is not constrained by the conventional internal combustion engine's requirements for space. The electric motor is very small and the battery compartment is kept low in the vehicle for a low center of gravity, so it is often under the rear storage bay. Amorphous cell panels allow simple curved solar panels to be a part of the vehicle.

The Sunmobile SunVee is a solar neighborhood vehicle. Solar electric panels are integrated with the body to charge batteries which power an electric motor. The neighborhood range is about 30 miles with a top speed of about 25 miles/hour. The Sunmobile is based on a commercial four-wheeled, two person, pedaling bike, called a Rhoades Car.

The Sunmobile is charged solely with photovoltaic panels mounted as a roof canopy. It will travel at up to 30 mph with a range of up to 30 miles on a fully charged battery. A twist grip on the handlebars feeds information to a motor controller mounted under the chassis.

A digital meter shows the voltage and the amps being consumed or charging the batteries and the accumulated amp/hours. The amp/hour reading is comparable to a gas gauge, showing how much power has been consumed. The charge controller determines when and how much to charge the batteries from the solar panels. The Sunmobile weighs about

400 lbs. with a set of four deep-cycle marine batteries.

Cruise Car of Sarasota, Florida, also sells several models of solar electric vehicles. These are all low-speed, street-legal vehicles, suitable for neighborhood use. The Classic Cruise Car comes in two, four and six seat versions. The range for the four-seat model is 48 miles with a maximum speed of 20 mph. The body is composed of steel, plastic and fiberglass. It uses 6 or 8 standard lead/acid golf cart batteries and has a 5.5 hp motor with 4-wheel hydraulic brakes and spring suspension. It uses an onboard grid charger and solar panels.

The SunRay two-seat model has a 5.5 hp, 48V motor and uses 6 lead/acid golf cart batteries. It has a 180W solar panel and a 55 mile range with a maximum speed of 22 mph.

The Kudo Cruise Car comes in 2, 4, 6, 8, 11 and 14 seat models. The six-seat model has a 7 hp motor with a range of about 50 miles and a maximum speed of 25 mph. It uses 8 standard lead/acid batteries and has a 880W solar panel.

The Zap Xebra Xero Solar Option Truck has a speed of 40 mph (65 kmph) with a range of 25 miles per charge (40km). The Solar Bug features a light weight composite body with a speed of 25 mph and a range of 30 miles.

Sunnev offers kits for building solar electric vehicles that seat two with a 25 mph top speed a range of 20 miles. A small panel on the hood provides about 3 miles per day travel on a sunny day and larger panels on the roof bring that up to 12 to 16 miles per day.

The Venturi Eclectic solar vehicle has three seats and a 16-kW Asynchronous motor. It uses a hydride metal nickel 72V battery that provides 100 amp-hours and has an estimated 10-year life. It has regenerative braking and can be recharged in 5 hours from 16A grid power. There are 2.5 sqm of photovoltaic cells that provide 330W, with an estimated solar range of 7 km/day. It has a 50 km range with a 50 km/hour top speed. There is also an optional wind turbine for enhanced renewable energy generation.

The Venturi Astrolab is called a high-performance solar-electric commuter car. It has two seats in tandem for better balance on the road, a 16 kW asynchronous motor and a hydride metal nickel 72V battery that gives it a 110-km range and a 120 km/hour top speed.

Lee Iacocca's NEV, the luxury Lido 4-passenger sedan, can travel up to 25 mph with a 40 mile range and a 6-8 hour charge time. It has 13 inch tires and hydraulic brakes. It was available in 2 or 4 passenger and Runabout

Utility versions with a suggested retail price of $10,000 for the base model.

The Myers NmG three-wheeled electric car has a top speed of 70 mph. It is a single seat, three-wheeled electric car that runs on 156 volts DC with thirteen 12-volt batteries in series. It has a 1350 pounds curb weight with a 30-60 mile range and a price of $15,000-$17,000.

The Commuter Car Tango is a high-performance EV, that weighs over 3,000 pounds with its 20 batteries. It features two motors, one on each rear wheel. The range is between 40 and 160 miles, depending on the battery pack. The top speed is 150 mph and production models may cost between $18,000 and $108,000.

Global Electric Motor's two-seat GEM car is a NEV, with a top speed of 25 mph and a curb weight of 1100 pounds with batteries. A 72-volt shunt GE motor is used with front wheel drive. Six 12-volt deep-cycle batteries are used with hydraulic brakes, independent front wheel suspension, rack and pinion steering, aluminum welded space frame and composite and thermoplastic body. It seats two or four with a price of $7,000 to $9,000.

Ford's Th!nk NEV came in two and four passenger models with a range of 30 miles. It had a 72 volt battery with a 5,000 watt DC motor. The charging time was 4 to 8 hours and it had regenerative braking with hydraulic drum brakes. The price range was $8,000 to $10.000.

The Gorilla NEV is a 36 volt, 20-25 mph vehicle that uses three 12-volt batteries. It includes all required safety equipment for legality in California and 32 other states.

Nevco's Gizmo has a top speed of 40 mph with a motor 12 peak HP series DC motor and deepcycle lead acid batteries for a 48V electrical system. A fiberglass body is used with hydraulic disc brakes. The range is 45 miles per charge. The base configuration with the 45 mile battery pack is $8,650.

Nissan's Hypermini concept EV is a two passenger EV (electric vehicle) that can go 60 miles per hour and travel about 75 miles on a single charge. It uses a neodynium magnet synchronous motor, with a maximum output of 20 kW at 15,000 rpm, lithium-ion batteries and an inductive charging system. Rear-wheel 2WD is used with front independent struts and rear independent parallel-link struts. The brakes are ventilated discs with an anti-lock system.

India's Reva EV can travel at about 35 mph. The power system is eight 6-volt EV type lead acid batteries. The dent-proof body panels are made of high impact ABS (acrylonitrile butadiene styrene). It has side impact beams and electronic regenerative braking. The suspension is McPherson struts in front and coil springs in the rear. It is a two-door hatchback that can hold two adults and two children (227 kg). The driving range is 80 km with a charge time of 80% charge in 3 hours and 100% in 6 hours. A high-torque, separately excited DC motor of 13 kW peak output power is used. Microprocessor-based battery management is used with 48-volt, 200 amp-hour EV tubular lead acid batteries. The wheel base is 1710 mm with a curb weight of 754-kg.

The Tesla Electric sports car combines ithium ion battery technology with a unique battery pack design that is light and recyclable and is capable of delivering enough power to accelerate the Tesla Roadster from 0 to 60 mph in under 4 seconds. The battery stores enough energy for the vehicle to travel about 220 miles without recharging, with a 135 mpg equivalence. It has a two-speed transmission.

The Quaranta is a concept hybrid gas/electric vehicle with solar assist. The electric portion is made by Italdesign Giugiaro. The roof is a solar panel that charges the batteries and provides energy for the climate control system. The all wheel drive, mid-engined car accelerates from zero to 62 mph (100 kph) in 4.05 seconds and tops out at 155 mph. This is a three-seat high performance sports car.

In hybrid vehicles electric motors are paired with small combustion engines. Electric power is used for low speed city driving and combustion switches in for hills and highway passing. Power systems that run on compressed gases such as propane, methane, or hydrogen are possible but range may be limited since distribution systems are not in place and each station pump could cost $30,000.

So-called synthetic fuels could be used directly in engines or to generate electricity from fuel cells for electric motors. Other combustion engines such as the sterling motor could also become options.

The proper maintenance of roads can improve mileage 5% but funds are often spent elsewhere. Combustion engines operate best at about 45-MPH but traffic patterns are generally too slow in cities or too fast in the country.

A HYDROGEN FUTURE

The road to hydrogen vehicles and a hydrogen fueling delivery system may take many paths. Today, it may seem unlikely that market forces alone will result in the installation of thousands of hydrogen fueling stations across the country. But, this is exactly what happened with our present oil economy. Gasoline was originally available in small amounts often from hand pumps. As demand for gasoline for automobiles grew, so did fuel outlets. The federal government promoted alternative fuel vehicles in the 1990s, but there is a lack of interest in alternative fuels when gasoline is widely available.

The United States passed the Energy Policy Act in 1992. One goal was to reduce the amount of petroleum used for transportation by promoting the use of alternative fuels in cars and light trucks. These fuels included natural gas, methanol, ethanol, propane, electricity, and biodiesel. Alternative fuel vehicles (AFVs) can operate on these fuels and many are dual fueled also running on gasoline.

Another goal was to have alternative fuels replace at least 10% of petroleum fuels in 2000 and at least 30% in 2010. Part of the new vehicles bought for state and federal government fleets, as well as alternative fuel providers, must be AFVs. The Department of Energy (DOE) was to encourage AFVs in several ways, including partnerships with city governments and others. This work went to the Office of Energy Efficiency and Renewable Energy. By 2000, less than 1/2 million AFVs were in use which is less than 0.2% of all vehicles. In 2000, alternative fuels used by AFVs replaced about 350 million gallons of gasoline, about 0.3% of the year's total consumption. Almost 4 billion gallons of ethanol and methanol replaced gasoline that year in blended gasoline that was sold for standard gasoline engines.

The DOE has been developing clean energy technologies and promoting the use of more efficient lighting, motors, heating and cooling. As a result of these efforts and efforts by others, there have been savings by business and consumers of more than $30 billion in energy costs. Getting people to use alternative fuel vehicles has proven to be more difficult.

The GAO stated that the goals in the act for fuel replacement were not met because alternative fuel vehicles have serious economic disadvantages compared to conventional gasoline engines. These included the comparative price of gasoline, the lack of refueling stations for alternative fuels and the additional costs of these vehicles.

HYDROGEN COMBUSTION

Hydrogen powered internal combustion engines could promote the infrastructure for fuel cell cars. An internal combustion engine (ICE) can burn hydrogen with a few inexpensive modifications. Automakers, including Ford and BMW, have been working on hydrogen ICE cars which have the advantage over gasoline engines of very low emissions of urban air pollutants. But, there is the relatively high cost of today's hydrogen. Hydrogen engines are about 25% more efficient than gasoline units but they are likely to have a smaller driving range due to the problem of storing large volumes of hydrogen onboard. The higher price of hydrogen makes annual vehicle costs for mid-sized hydrogen vehicles almost one third higher than for gasoline vehicles. This is slightly lower than the estimated annual costs for fuel cell vehicles, according to a report by the Arthur D. Little firm.

Because of the energy used in generating hydrogen from natural gas or electricity and the energy required to compress hydrogen for storage, the total energy use of a hydrogen internal combustion engine can be higher than a gasoline engine. One study of ten different alternative fuel vehicles found that burning hydrogen from natural gas had the lowest overall efficiency on a total energy consumed basis.

The U.S. General Accounting Office (GAO) found that officials from federal agencies and state governments pointed to the lack of a refueling infrastructure more than any other reason to avoid alternative fuels.

Fleet use is one strategy for alternative fuel commercialization. It was the main strategy that the DOE used in the 1990s to meet the goals of the Energy Policy Act of 1992. Vehicle fleets are typically driven twice as many miles compared to private vehicles and make up about one fourth of all U.S. light-duty vehicle sales. Many fleet vehicles have fixed daily routes and are regularly fueled at one location, so less infrastructure is needed to support fleet-based vehicles.

A survey of almost 3,700 California fleets, found several reasons why central fueling may actually be a problem for alternate fuels. Light-duty fleets often reduce fuel costs by purchasing petroleum in bulk. But, hydrogen has been more expensive than gasoline on an equivalent energy basis. High travel demands do not match well with fuels that have shorter ranges and limited refueling stations. Gasoline or diesel vehicles provide a longer driving range and can also refuel at commercial gas stations.

About 80% of public fleets use central refueling, but only about one third of business fleets do and most of those also use commercial fueling stations. Most fleets that centrally refuel use outside sources for at least 15% of their refueling. The Environmental Protection Agency (EPA) has had major concerns over fuel leakage and underground water contamination in the last few decades. This has resulted in a significant reduction in the number of underground fuel storage tanks.

THE ELECTRIC AND HYBRID FUTURE

The internal combustion engine, running on gasoline, has been powering transportation for almost a century. Advances in engines and fuels, such as reformulated gasoline, have reduced the pollution of these engines. Competitors such as electric cars and natural gas vehicles have not been able to penetrate their dominance. The competition for fuel cell vehicles includes hybrid vehicles and diesels, which are seeing many advances today.

Hybrid gasoline electric-powered cars can be twice as efficient as internal combustion vehicles. An onboard energy storage device, which is usually a battery and sometimes a special capacitor (called a super capacitor), increases the efficiency greatly. Regenerative braking is also used to capture energy that is normally lost when the car is braking. The engine is turned off when the car is idling or decelerating. Gasoline engines have lower efficiencies at lower rpm so the gas engine operates only at higher rpms and is more efficient more of the time. In city driving, non polluting electric power is used.

The first-generation Toyota Prius had a city mileage of 52 miles per gallon (mpg) and a highway mileage of 45-mpg. The second-generation Prius, appeared in 2003 with improved mileage numbers. Toyota has been introducing other hybrid models along with most auto manufacturers that plan to produce hybrid vehicles.

DIESEL POWER

Another competitor for fuel cell vehicles could be the diesel engine. Diesel engines are used in large trucks and construction equipment for their high efficiency and durability.

Modern diesel engines are much different from the engines of the 1970s and 1980s. Advances have included electronic controls, high-pressure fuel injection, variable injection timing, improved combustion chamber design, and turbo-charging. They are 30 to 40% more fuel efficient than gasoline vehicles. The production and delivery of diesel fuel releases 30% less carbon dioxide than producing and delivering gasoline with the same energy content. Diesels emit higher levels of particulates and oxides of nitrogen. But, they are steadily reducing these emissions. A large amount of R&D is currently going into diesels and it is expected that they will be able to meet the same standards as gasoline engines in the near future.

Diesels are less than 1% of car and light truck sales in the U.S. But, they are more popular in Europe with its high gasoline prices. Their fuel taxes help to promote diesels and the emissions standards are less strict. Diesels are in almost 40% of the cars in Europe. By 2001 they were in most of the new cars sold in many European countries.

Most opinion polls show that the motorist's infatuation with automobiles does not include internal-combustion engines. Many drivers would trade in their current car for an electric vehicle, if it could perform as well and not cost any more. One poll of California new car buyers conducted by the University of California at Davis in 1995 found that almost half would buy an electric vehicle over a gasoline car, but they wanted a 300-mile range and a more reasonable price.

Most commuters have round-trips of 50-miles or less, but a longer distance is important for trips and visits. Accessories such as air conditioners, power windows and locks tend to limit an electric car's power and range even more.

Cost is always a problem when vehicles are made in limited numbers since the parts will cost more. The lithium ion batteries used in Nissan's Altra EV were reported to cost close to six figures. Since electric cars sell for $30,000 or more, a lease can soften the cost of the vehicle. It also isolates the user from expensive battery replacements. Even these subsidized leases required an extra $100 or more in monthly payments compared to a more conventional vehicle. Leasing allows the manufacturers to keep control of the vehicle for repairs and recalls. As the technology changes, a lease keeps customers from having a 2-3 year vehicle that is out of warranty with needing obsolescent, expensive parts.

ECOSTAR

The Ecostar van was Ford's first electric since the time of Thomas Edison and Henry Ford. The Ecostar was the first electric vehicle that resembled an actual production car instead of a conversion. It had a recharge port and a battery charging meter. The Ecostar provided a pleasant driving experience similar to a quiet luxury car. An electric powered vehicle can be extremely quiet and will appear to be as transparent to drivers as possible.

The Ecostar used high-temperature, sodium-sulfur batteries because of their range, but they also allowed the van to go from 0-60 in 12 seconds. The Ecostar had no trouble keeping up with gas vehicles, but Ford only built about 80 Ecostars. The sodium-sulfur batteries proved to be too sensitive to cold weather. They operated at 500° Fahrenheit and caused fires in several of the demonstrator cars.

U.S. Electricar built the lead-acid Electricar Prizm in Torrance, California, at Hughes Power Control Systems, a GM subsidiary that also designed the car's DC-to-AC inverter. Instead of a gas gauge there was a range meter. The batteries were in a covered tunnel underneath the car. Most electric vehicles have good low-end torque for excellent 0-60 acceleration, but the Prizm was a little sluggish initially but then picked up quickly. The car used a recharging paddle.

Detroit's electric cars have a shaky history since the market can change rapidly in the automobile industry, which is dependent on long lead times for new models. In 1975, when memories of the oil embargo were fresh, Detroit's cars were still growing in size, but it was a record sales year for the Volkswagen Beetle and sales of Toyotas and Hondas reached 100,000 that year. GM's profits dropped 35% and the company had to temporarily close 15 of its 22 assembly plants.

With nothing but full-sized cars in its inventory, GM launched a crash program to build an economy model, which resulted in the Chevette. It was based on GM's German Opel Kadett, a 4-cylinder, 52-horsepower compact with 35-miles per gallon economy. In 1976, GM sold almost 190,000 of the hatchback Chevettes and the market seemed right for electric vehicles. Small start-up companies had been offering electric conversions for commuter vehicles. The CitiCar was produced by Sebring-Vanguard, which for a short time was the fifth largest automaker in the United States.

GM built an electric vehicle (EV) called the Electrovette in 1980. It was a Chevette with a DC electric motor and zinc nickel oxide batteries. The Electrovette used a mechanical controller. The batteries were expensive and not much better than lead-acid power for extending the range of operation. The Electrovette had controller problems and GM let the project die.

In 1996 GM would launch the EV1. Almost every part of the EV1 is designed for energy efficiency. The steering wheel and seat frames are made of low-weight magnesium. The radio antenna is part of the roof to reduce drag. The tires are low-rolling-resistance, self-sealing Michelins which also saves the weight of the spare. The aerodynamic body sits only five inches off the ground and there are 2000 spot welds in the aluminum body. The cars came with air conditioning and CD players standard and were sold through Saturn dealers.

The EV1 assembly line was in the old Buick Reatta plant, next to the much larger and more automated facility that assembled Chevrolet Cavalier and Pontiac Sunfire convertibles. About 30 employees essentially hand built the cars on the line and traded off tasks.

GM built efficiency into their electric cars. They worked on reducing energy consumption, mass, and accessory loads, and improving aerodynamics, rolling resistance, and driveline efficiency. There was a 50-kilowatt fast charger, which could charge an EV1 in 10 minutes. An aluminum space frame allowed the body, without batteries, to weigh in at 1500 pounds. The 1300 pound battery pack sat on a 1500 pound body resulting in a total weight of about 2800 pounds. Getting the batteries to produce more power, weigh less, and take up less space was one of the goals in cars like this.

These same concepts could be used in fuel cell powered cars. Ultralight fuel cell vehicles are a part of the current generation of clean concept cars, sometimes called Green Cars. In 1996, when EV1 became available, it accelerated the development of the hybrid Toyota Prius and GM would show a number of alternative-fueled concept cars at the 1998 Detroit Show. Now every auto show has its alternative cars.

FUEL CELL ELECTRIC VEHICLES

A fuel cell car, bus or truck is in essence an electric vehicle powered by a stack of hydrogen fueled cells that operates like a refuelable battery. A battery uses chemical energy from its component parts, while a fuel cell uses an electrochemical process to generate electricity and receives its energy from the hydrogen fuel and oxygen that are supplied to it. Like the plates in a battery, the fuel cell uses an anode and cathode, attached to these are wires for the flow of current. These two electrodes are thin and porous.

Most automotive fuel cells use a thin, fluorocarbon-based polymer to separate the electrodes. This is the proton exchange membrane (PEM) that gives this type of fuel cell its name. The polymer provides the electrolyte for charge transport as well as the physical barrier to block the mixing of hydrogen and oxygen.

An electric current is produced as electrons are stripped from hydrogen atoms at catalysis sites on the membrane surface. The charge carriers are hydrogen ions or protons and they move through the membrane to combine with oxygen and an electron to form water which is the main by-product.

Trace amounts of other elements may be found in this water, depending on the cell construction. In most cells the water is very pure and fit for human consumption. Individual cells are assembled into modules that are called stacks.

PEM fuel cells can convert about 55% of the fuel energy fed into them into actual work. The comparable efficiency for IC engines is in the range of 30%. PEM cells also offer relatively low temperature operation at 80°C. The materials are used to make them reasonably safe with low maintenance requirements.

The emergence of commercial fuel cell cars will depend on developments in membrane technology, which are about one third of the fuel cell cost. Improvements are desired in fuel crossover from one side of a membrane to the other, the chemical and mechanical stability of the membrane, undesirable side reactions, contamination from fuel impurities and overall costs.

One breakthrough occurred in membrane technology when PolyFuel, in Mountain View, CA, produced a hydrocarbon polymer membrane with improved performance and lower costs than the current perfluorinated membranes. This cellophane like film has performed better than more common perfluorinated membranes, such as DuPoint's Nafion material.

The hydrocarbon membrane can also operate at higher temperatures, of up to 95°C, which allows the use of smaller radiators to dissipate heat. It also lasts 50% longer, while generating up to 15% more power and operating at lower humidity levels. Fluorocarbon membranes can cost about $300 per square meter, the PolyFuel materials cost about half of this. While hydrocarbon membranes may have to prove themselves to many, Honda's FCX fuel cell cars use them.

CATALYSTS

Another key part of a PEM membrane is the thin layer of platinum-based catalyst coating that is used. It makes up about 40% of the fuel cell cost. The catalyst prepares hydrogen from the fuel and oxygen from the air for an oxidation reaction. This allows the molecules to split and ionize while releasing or accepting protons and electrons.

On the hydrogen side of the membrane, a hydrogen molecule with two hydrogen atoms will attach itself to two adjacent catalyst sites. This frees positive hydrogen ions (protons) to travel across the membrane.

The reaction on the oxygen side occurs when a hydrogen ion and an electron combine with oxygen to produce water. If this is not controlled properly, highly corrosive by-products such as hydrogen peroxide can result, which quickly damage the internal components.

In a proton exchange membrane (PEM) fuel cell, protons travel through a film 18 microns thick which is the proton exchange membrane. Electrons are blocked by the film and take another path which provides the electric current flow. Over time and usage tiny holes can form on the film which reduces fuel cell performance. If the film is made thicker and stronger, then performance suffers.

FUEL CELL BUSES

Ballard Power Systems supplied one of the first fuel cell demonstration projects for British Columbia Transit. Ballard is a pioneer and major producer of fuel cells which it installed in several Vancouver, Canada city buses. The fuel cell powered New Flier buses are much cleaner than new diesels and they are not adding to Vancouver's smog problem. A similar demonstration has taken place in Chicago, where the modified city buses have been called the Green Machines.

The Vancouver pilot program was the world's first real test of fuel cell vehicles. The buses are quiet except for the whirl of their air compressors and have a range of 250 miles.

Ballard does not build cars, trucks, or buses. Its sole product is the fuel cell in all of its many applications, plus the auxiliary equipment to make them work. Since Ballard is a pioneer in modern fuel cells its technology is advanced and its fuel cell sales have made it one of the fastest-growing automotive suppliers in the world with alliance partners including DaimlerChrysler, Ford, Honda, Nissan, Mazda, Volvo, and Volkswagen.

The company started in 1979 building rechargeable lithium batteries for smoke detectors. Geoffrey Ballard had worked for the U.S. Department of energy. In 1983, he was approached by the Canadian Department of Defense who were interested in fuel cells. Since they were similar in operation to batteries, they thought Ballard might be interested in a developmental contract. There are now research operations in Germany and California as well as several facilities in Canada. Before Ballard actually made a profit (except under Canadian accounting rules), its stock made meteoric gains. Ballard is working to have a fuel cell ready for volume production with up to 250,000 annually.

Although many questions involve fuel cell availability and much is dependent on the auto industry, fuel cells are beginning to appear in a number of autos in limited production, even with the extremely limited infrastructure available now.

In Ballard's alliance with Ford, Volvo, and DaimlerChrysler, they will supply the other components of the vehicles from the car body to the electric motor drive. The fuel cell will function as the car's engine. It needs cooling, control and fuel processing.

Fuel cells typically have higher efficiencies at lower power, so a hybrid fuel cell vehicle with battery will not improve its efficiency as it does for a gasoline engine.

The high efficiency that hybrids have in urban settings could be particularly tough competition for fuel cell vehicles because, at least initially, fuel cell vehicles are likely to be used mainly for urban driving. Early models probably will not have the driving range of regular vehicles and will be used by fleets, which operate mainly in cities. The limited number of fueling stations early on will restrict long-distance travel.

A FUEL CELL FUTURE

A hydrogen-based economy could be the ideal scenario for personal transportation. The ultimate goal is a fuel cell car that is competitive in price and performance with the internal combustion vehicle. Some early users will pay a premium for new technology, but most drivers will not pay 20-30% more for similar performance.

A 2002 report for the DOE estimated that even with technology improvements, future fuel cell vehicles could cost 40 to 50% more than conventional vehicles. Hydrogen storage would be a large part of this extra cost. Estimates put the cost of compressed hydrogen at about $6,000 per vehicle, but complex hydrides reduces this to $4,000. Liquid hydrogen storage is estimated at $2-4,000 and chemical hydrides may range from $1.5-$2,000. The targets for practical fuel cell cars are $1,000 in 2010 and

$600 by 2015.

Hydrogen may not be more expensive than gasoline as oil prices soar upward. Hydrogen provided at fueling stations could cost about $4 or more per kilogram (kg) which is close to the equivalent-energy price of gasoline. A kilogram of hydrogen has almost the same energy as a gallon of gasoline. Ultimately, if hydrogen were to be the main transportation fuel, it would itself have to be taxed unless we find a new source for funding road projects.

Hybrid and clean diesel vehicles may cost more than current internal combustion engine vehicles. But, their greater fuel efficiency means that they may make up that extra up-front cost over the lifetime of the vehicle. This means that hybrids and diesels may have roughly the same annual operating costs as current internal combustion engine vehicles.

This also means that hybrids and diesels could reduce transportation CO_2 emissions at a lower cost per ton. The typical new car today generates about four to five metric tons of CO_2 per year. One reason for replacing gasoline engines is to lower that number. A fuel cell vehicle in 2020 might reduce CO_2 emission at a cost of more than $200 per metric ton, regardless of how the hydrogen was produced. An advanced gasoline engine could probably reduce CO_2 at lower cost.

MOVING HYDROGEN

Tanker trucks with liquefied hydrogen are typically used to deliver hydrogen today. This is the method NASA uses. It is popular for delivery in Europe as well as North America and works to supply distributed users with moderate hydrogen needs. It is currently less expensive than small on-site hydrogen generation and provides high purity hydrogen for industrial processes. Liquefaction has a high energy cost, requiring about 40% of the usable energy in hydrogen. Some automakers are using on-board storage with liquid hydrogen in their fuel cell vehicles. Liquid tanker trucks could be the least expensive delivery option in the near future. After delivery, the fueling station still has to use an energy-intensive pressurization system, which can consume another 10 to 15% of the usable energy in the hydrogen. This could mean that storage and transport alone might require as much as 50% of the energy in the hydrogen delivered. If liquefaction is to be viable, a less energy-intensive process is needed.

Pipelines can also be used for delivering hydrogen. Several thousand miles of hydrogen pipelines are in use around the world, with several hundred miles in the U.S. These lines are short and located in industrial areas for large users. The longest pipeline in the world is almost 250 miles long and goes from Antwerp to Normandy. It operates at 100 atmosphere of pressure which is approximately 1,500 psi.

Air Products plans on constructing a new hydrogen production plant in Port Arthur, Texas to supply 110 million standard cubic feet per day of hydrogen to Premcor Refining and others on Air Product's Gulf Coast hydrogen pipeline system.

Pipelines may be the least expensive way to deliver large quantities of hydrogen. Pipelines are the main choice for moving refined petroleum products across the country. They are less than 10% the cost of rail, road or water tankers. The U.S. has almost 200,000 miles of interstate pipelines for petroleum products. There is another 200,000 miles of interstate natural gas pipelines.

Hydrogen pipelines are expensive because they must have very effective seals. Hydrogen is also reactive and can cause metals, including steel, to become brittle over time. Hydrogen pipelines of 9 to 14 inch diameter can cost $1 million per mile or more. Smaller pipelines for local distribution cost about 50% of this. Siting major new oil and gas pipelines is often political and environmentally litigious. Political pressures may favor one location over another. Whether global warming concerns will be enough to override other considerations is still unknown. Pipelines are more likely to be used for hydrogen transport once there is real demand.

Trailers carrying compressed hydrogen canisters provide a flexible way of delivery suited for the early years of hydrogen use. This is a relatively expensive delivery method since hydrogen has a low energy density and even with high-pressure storage, not that much hydrogen is actually being delivered. Current tube or canister trailers hold about 300-kg of hydrogen which is enough to fill sixty fuel cell cars. It is estimated that with improved high-pressure canisters, a trailer could hold about 400-kg of hydrogen or enough for about 80 fuel cell cars. A tanker truck for gasoline delivers about 26 metric tons of fuel, or 10,000 gallons which is enough to fill 800 cars.

About one in 100 trucks on the road is a gasoline or diesel tanker. Replacing liquid fuels with hydrogen transported by tube truck means that about 10% of the trucks in the U.S. would be transporting hydrogen. Technology may provide better options in the future since there is significant R&D going into each of the storage and transportation technologies.

STATIONARY POWER POTENTIAL

Stationary power is the most mature application for fuel cells. Stationary fuel cell units are used for backup power, power for remote locations, stand-alone power plants for towns and cities, distributed generation for buildings, and cogeneration where excess thermal energy from electricity generation is used for heat.

Close to a thousand systems that produce over 10 kilowatts each have been installed worldwide. Most of these are fueled by natural gas. Phosphoric acid fuel cells (PAFCs) have typically been used for large-scale applications, but molten carbonate and solid oxide units also compete with PAFCs.

Thousands of smaller stationary fuel cells of less than 10 kilowatts each have been built and operated to power homes and provide backup power. Polymer electrolyte membrane (PEM) fuel cells fueled with natural gas or hydrogen are the primary units for these smaller systems.

A typical system that is commercially available in the United States is the 200 kilowatt (kW) PAFC unit produced by UTC Fuel Cells. This is the type of unit used to provide electricity and heat to the U.S. Postal Service's Anchorage Mail Handling Facility. In 2000, the Chugach Electric Association installed a 1 Megawatt (MW) fuel cell system at the U.S. Postal Service's Anchorage Mail Handling Facility. The system consists of five natural gas powered 200-kW PC25 fuel cells developed by UTC Fuel Cells.

The fuel cell station provides primary power for the facility as well as half of the hot water needed for heating. Excess electricity from the system flows back to the grid for use by other customers.

The fuel cell system emits much less carbon into the air than a combustion-based power plant. Less than one percent of the amount is produced from generating the same amount of power. The system is more expensive, costing several times as much per kilowatt-hour (kWh) of electricity produced than energy from a new natural gas fired turbine system.

The Town of South Windsor, CT, initiated a stationary fuel cell project in 2002. South Windsor used funding from the Connecticut Clean Energy Fund to install a natural gas powered 200-kW PC25 fuel cell system, from UTC Fuel Cells, at the South Windsor High School. The system provides heat and electricity to the high school along with learning opportunities for the students. The school has an extensive fuel cell curriculum for students and computer monitors allow students to track the operation of the fuel cell. South Windsor High School has also been designated as a regional emergency shelter and the fuel cell system will be able to provide power in the event of an electric power outage. UTC Fuel Cells intends to use the project as an international demonstration site for fuel cell technology.

The Department of Defense (DOD) Fuel Cell Demonstration Program is managed by the U.S. Army Corps of Engineers. It was begun in the mid-1990s to advance the use of PAFCs at DOD installations. Under this program, stationary fuel cells were installed at 30 facilities and locations in the Armed Services. The fuel cells are used for primary and back-up power as well as heat.

The DOD has also begun a residential fuel cell demonstration program using polymer electrolyte membrane (PEM) fuel cells ranging in size from 1 to 20 kilowatts. This will include twenty-one PEM fuel cells at nine U.S. military bases. The first units were installed in 2002.

The DOE's Distributed Energy and Electric Reliability Program involves a series of traveling road shows for building code inspectors, fire marshals and others on distributed energy technologies, including hydrogen and fuel cells.

ICELAND'S HYDROGEN ECONOMY

Iceland could become the world's first hydrogen economy. This island nation in the North Atlantic has many active volcanoes, hot springs, and geysers and is suited to a hydrogen economy because it has excess renewable energy.

Iceland uses its renewable energy for power generation and heating, so these sectors are nearly carbon-free. Carbon dioxide emissions are produced by the transportation, fishing, and industrial sectors, each of these contributes about one million tons of carbon dioxide (CO_2) per year.

Iceland shifted from fossil fuel to hydroelectric power very early and went to geothermal heating after World War II. But, to fuel its vehicles and fishing fleet, Iceland imports about 6 million barrels per year of petroleum. There are no sources of oil or other fuels other than some landfill methane on the island. Iceland has little fossil fuel resources but there is plenty of inexpensive, clean hydropower as well as geothermal energy. Energy is tapped from the hot water or steam in the ground to run turbine generators while lower temperature water is used to heat buildings or provide process heat for industries. Geothermal energy is used in 90% of the buildings for hot water or steam. Almost 9 million megawatt-hours (MWh) of thermal energy is used each year for heating and industrial uses.

In spite of its carbon-free electric power and the widespread use of geothermal heating, Iceland has high CO_2 emissions per capita. Typical developed countries emitted about 12 metric tons per capita in 1990, whereas Iceland emitted about 8.5 metric tons per capita. All forms of energy including renewables can affect the environment. Geothermal power can produce some emission of CO_2, about 100 grams (g) per kilowatt-watt hour (kWh), which is roughly 30% of the emissions of an efficient combined cycle natural gas plant.

Using some of its renewable energy would allow Iceland to produce hydrogen and replace all the oil used for the country's transportation and fishing industry. There would still be emissions from industrial processes such as aluminum and ferrosilicon production, but this plan would cut the country's fossil fuel use dramatically. Iceland has about 170 megawatts (MW) of geothermal electric power generation which provide more than 1.3 million MWh per year. Its hydroelectric plants have a capacity of approximately 1,000-MW and supply almost 7 million MWh per year of electric power. The current capacity at hydroelectric plants would allow significant hydrogen production.

The hydrogen could be produced during non-peak hours and stored until it is needed. This would allow Iceland to replace almost one fourth of the fossil fuels consumed by vehicles and vessels using its present generating capacity.

Iceland could also develop wind power with coastal or offshore facilities. A study indicated that 240 wind power plants could produce the electricity needed to replace fossil fuel from vehicles and fisheries.

Other studies suggest that only 17% of Iceland's renewable energy has been developed. This renewable electricity has been estimated at up to 50 million MWh per year for hydropower and geothermal. This represents six times the current renewable energy capacity.

In 1978, it was proposed that Iceland develop hydrogen. Support grew in the 1990s, because of advances in fuel cell technology and concerns about climate changes and a dependence on oil. By 1999, Shell, DaimlerChrysler, Norsk Hydro, an Icelandic holding company Vistorka hf (EcoEnergy) and others created the Icelandic Hydrogen and Fuel Cell Company, now called Icelandic New Energy Ltd. This group with the backing of the government and the European Union started Iceland on the path to hydrogen.

Since almost 65% of the population lives near the capital of Reykjavik a hydrogen infrastructure could be established with a few fueling stations in Reykjavik and nearby connecting roads. In 2003, Iceland opened the first public hydrogen filling station in the world, even though there were no privately owned hydrogen vehicles in the country.

A 2001 survey found that almost 95% of the population supported replacing traditional fossil fuels with hydrogen. Icelandic New Energy proposed a six-phase plan for hydrogen. Phase 1 started with the opening of a hydrogen fueling station in 2003. Three fuel cell buses which are 4% of the city's bus fleet have been in use in Reykjavik. This is known as ECTOS for Ecological City Transport System. Phase 2 will replace the Reykjavik city bus fleet with proton exchange membrane (PEM) fuel cell buses. Phase 3 will begin the use of PEM fuel cell cars, while phase 4 will demonstrate PEM fuel cell boats. Phase 5 will replace the entire fishing fleet with fuel cell powered boats and in the next phase Iceland will sell hydrogen to Europe and elsewhere. The last phase is expected to be completed by 2030-2040.

Iceland may start with methanol powered PEM vehicles and vessels. The University of Iceland is involved in research on the production of methanol (CH_3OH) from hydrogen combined with carbon monoxide (CO) or CO_2 from the exhaust of aluminum and ferrosilicon smelters. This would capture hundreds of thousands of tons of CO and CO_2 released from these smelters. If this is combined with hydrogen generated from electrolysis using renewable power, Iceland could cut its greenhouse gas emissions in half.

RENEWABLE ENERGY

Renewable energy has many attributes similar to those of fuel cells, including zero emission of urban air pollution, but some believe renewable sales have been slowed in the United States because of their high cost. Actually, renewable technologies have succeeded in meeting most projections with respect to cost. As costs have dropped, successive generations of projections of cost have either agreed with previous projections or have been less. Renewables should become important parts of the power generation mix in the U.S. They represent an important long-term success for government R&D.

Government R&D funding for renewables has been exceedingly successful, bringing down the cost of many renewables by a factor of ten in two decades, even though the R&D budget for renewables was cut by 50% in the 1980s and did not rebound to similar funding levels until the mid 1990s.

Renewable energy is about 13% of the world's energy while fossil fuels make up 80% and nuclear power 7%. Wind power has become a major part of power generation in Europe, with 20 to 40% of power loads in parts of Germany, Denmark, and Spain.

Photovoltaics has made much progress, but has had to compete with conventional generation. Traditional electricity generation costs dropped in the 1980s and 1990s rather than increasing, as had been projected in the 1970s. This occurred while reducing emissions of urban air pollutants. Utilities were also allowed to place barriers in the path of new projects while new technologies typically received little appreciation for the contributions they made in meeting power demand, reducing transmission losses or improving the environment. However, the competition from renewables does push the utilities to improve their performance.

A major part of the R&D conducted by DOE's office of Energy Efficiency and Renewable Energy involves energy-efficient technologies that reduce energy bills. More efficient devices include refrigerators, light bulbs, solid-state ballasts for fluorescent lights and improved windows. Many of these products have achieved significant market success.

The National Academy of Sciences found that they saved the U.S. $30 billion in energy. The products that were most successful had a good payback combined with similar or superior performance. Solid state ballasts can reduce energy use in half or more while providing a high quality light without the flicker of earlier fluorescent. They can provide a payback of less than two years.

WAVE ENERGY

Wave energy is a promising renewable source in maritime countries. As a wave travels forward in an up-and-down motion, its height is an indication of its power. Ocean waves could be providing large amounts of power for maritime countries. The energy potential has been estimated as being as much as 4,000 gigawatts (GW). The sea also has the potential to destroy wave-energy stations, but several nations have been designing more rugged small-scale wave power stations.

A wave power station must be able to withstand the power of the largest waves without being damaged. Two operating wave power stations, one in Scotland and one in Norway, have already been damaged by high waves. Wave energy was studied at the time of the French Revolution, but there has not much progress in turning this motion into useful energy until the last quarter century. A recent advance is the oscillating water column (OWC). This is a column that sits on the seabed and admits the waves through an opening near the base. As the waves rise and fall, the height of the water inside rises and falls pushing air in and out of a turbine which drives a generator. The turbine spins in the same direction regardless of the direction of the air flow.

Norway built a wave energy station on the coast near Bergen in 1985. It combined an OWC with a Norwegian device called a Tapchan (TAPered CHANnel). The waves move up a concrete slope where they fill a reservoir. As the water flows back to the ocean, it drives a turbine generator.

Wave power generators ranging from 100 kilowatts (kW) to 2 megawatts (MW) are now in use in more than a dozen countries. Scotland had a trial 75-kW OWC on the island of Islay for 11 years. This has been replaced by a 500-kW unit with plans for a 2-MW seagoing device called the Osprey. Portugal has been working on an OWC off the island of Pico in the Azores. An American company has worked on a 10-MW system on buoys 3 kilometers off the south coast of Australia. China, Sweden and Japan are also working on wave energy.

Wave energy is a capital-intensive technology, with most of the costs for construction. But, after 3 decades major breakthroughs are in sight and wave electricity should be part of the renewable mix in many countries before long.

Another technique used to harness energy involves the difference between sea levels. In Egypt, water running through an underground canal linking the Mediterranean to the El-Qattar depression could be used to generate electricity. In Israel, the same principle could be used in a canal between the Mediterranean and the Dead Sea which would descend 400 meters.

SOLAR POWER SATELLITES

Solar power satellites (SPSs) have promised to provide cheap, clean power for decades, but there has been very little progress on the concept in over 30 years. In 2004, a conference about space based solar power generation in Granada, Spain, provided progress reports from groups in Europe, the U.S., and Japan who are working on concepts and plans for building solar power plants in orbit that would beam power down for use on Earth. These concepts including building parts of the Solar Power Satellite from lunar and asteroidal materials while the conference focused the technological and political developments required to construct and employ a multi-gigawatt power satellite. It provided perspectives on the cost savings achieved by using extraterrestrial materials in the construction of the satellite. There were proposals and feasibility studies of lunar and high-orbital solar power stations, including assessments of the cost factors.

Power from space using solar power satellites would reduce reliance on burning hydrocarbons and would be one solution to our future energy needs. The Sun is constantly sending energy to the Earth. Any point on land is in the dark half of the time and during the day clouds can also block sunlight and power production. In orbit, a solar power satellite would be above the atmosphere and could be positioned so that it received almost constant direct sunlight.

There is no air in space, so the satellites receive intense sunlight, unaffected by weather. In a geosynchronous orbit an SPS would be illuminated over 99% of the time. The SPS would be in Earth's shadow for a few days at the spring and fall equinoxes. This would be for a maximum of an hour and a half late at night when power demands are at their lowest.

In many ways, the SPS is simpler than most power systems on Earth. This includes the structure needed which in orbit can be considerably lighter due to the lack of weight.

Some early studies considered solar furnaces to drive conventional turbines, but as the efficiency of the solar cell improved, this concept seemed less practical.

Another advantage is that waste heat is re-radiated back into space, instead of warming the biosphere as occurs with conventional sources. Some energy is lost in transmitting power to stations on the Earth, but this would not offset the advantages of an orbiting solar power station over ground based solar collectors.

The concepts of solar power satellites were being worked on in the 1960s, but there were a number of problems impeding them. The SPS concept was considered impractical due to the lack of an efficient method of sending the power down to the Earth for use. This changed in 1974 when

Peter Glaser was granted a patent for his method of transmitting the power to Earth using microwaves from a small antenna on the satellite to a much larger one on the ground, known as a rectenna. Glaser's work took place at Arthur D. Little. NASA granted them a contract to lead four other companies in a broader study in 1972. They found that while the concept had several major problems, chiefly the expense of putting the required materials in orbit and the lack of experience on projects of this scale in space, it showed enough promise to merit further investigation and research. Most major aerospace companies then became briefly involved in some way, either under NASA grants or on their own. At the time the needs for electricity were soaring, but when power use leveled off in the 1970s, the concept was shelved.

Recently the concept is of interest, due to increased energy demands and costs. At some point the high construction costs of the SPS become favorable due to their low-cost delivery of power and the rising costs of electricity. Continued advances in material science and space transport reduce the projected costs of the SPS.

Using solar panels on Earth is far less expensive, so much of the focus on solar energy is not on satellite systems. A major barrier is the high cost of launching. A significant investment would be needed to get a solar power satellite into orbit. Launch costs will need to come down before generating solar power in space makes economic sense. There may not be a financial reason to start building a solar power system unless we include the environmental costs of our current non-renewable sources of energy. A problem in opening any contemporary frontier is not usually a lack of engineering imagination or insight, but a lack of capital to finance the initial construction which makes the subsequent development possible.

A solar power system must also compete with other options which is a challenge for all renewable energy solutions. Among the barriers holding back solar power satellites are a lack of political will and insight to make the money available for further development.

There are also only a limited number of available slots in geosynchronous orbit where a satellite would be able to continuously beam power to a specific receiver. In areas with plenty of sun and available land, satellites may not compete with generating solar power locally. There would be more demand for beaming solar power to locations that couldn't generate it otherwise.

Some designs use solar arrays that are several kilometers long on each side. The largest solar panels in space are being used on the International

Space Station (ISS). They are 73 meters long and 11 meters wide. These panels make the ISS one of the brightest objects in the night sky.

A proof of concept satellite could use the station's solar panels. These solar panels are 14% efficient, but advances with solar cells and solar concentrators allow panels that are up to 50% efficient.

A solar power satellite in orbit uses microwave power transmission to beam solar power to a very large antenna on Earth. The system consists of three parts: a solar collector, made up of solar cells and a microwave antenna on the satellite, aimed at the Earth antenna to collect the power. The Earth-based receiver antenna called a rectenna would consist of a series of short dipole antennas.

Microwaves broadcast from the SPS would be received with about 85% efficiency. A conventional microwave antenna is even better, but the cost and complexity are much greater. Rectennas would be several kilometers across and crops and farm animals could be raised under the rectenna, since the thin wires used only slightly reduce sunlight. For best efficiency the satellite antenna would be between 1 and 1.5 kilometers in diameter and the ground rectenna around 14 kilometers by 10 kilometers. This would allow the transfer of 5 to 10 gigawatts of power.

The satellite would need 50 to 100 square kilometers of collector area using 14% efficient monocrystalline silicon solar cells. More expensive triple junction gallium arsenide solar cells with an efficiency of 28% would reduce the collector area by half. In both cases the solar station's structure would be several kilometers wide, making it much larger than most manmade structures on Earth. Building structures of this size in orbit has never been attempted before.

Although the advantage of placing the solar collectors in space is an unobstructed view of the Sun, the costs of construction are very high, and SPS may not be able to compete with conventional sources unless lower launch costs can be achieved, or unless a space-based manufacturing industry develops and they can be built in orbit from off-Earth materials.

A major problem for the SPS is the current cost of space launches. Current rates on the Space Shuttle are $3,000 to $5,000 per pound ($6,600/kg and $11,000/kg). Launch costs of less than $400-500/kg are thought to be necessary for SPS. Economies of scale on expendable vehicles could provide some large reductions in launch costs. Thousands of rocket launches could reduce the costs by ten to twenty times based on experience with similar technical achievements. This places the costs into the range where this system could be conceivably attempted. Large reusable vehicles could also help the launch problem, but these are not a well developed technology.

A typical solar panel mass is 20-kg-per kilowatt, then without considering the mass of the support structure, antenna or any significant mass reduction of focusing mirrors, a 4-GW power station would weigh about 80,000 metric tons. Although, this is huge, a space solar-panel would not need to support its own weight and would not be subject to earth's corrosive atmosphere. Some very lightweight designs could allow 1-kg/kW, or 4000 metric tons for a 4-GW station. This could require 40 to 800 launches to send the material to low earth orbit, where it would be turned into subassembly solar arrays and then ion-engine style rockets would move them to final orbit.

With the cost for a shuttle-based launch at $500 million to $800 million, total launch costs would range between $20 billion for low weight panels to $320 billion for heavy panels. This does not include the cost of assembly or materials and manufacturing. For each gigawatt rating, a SPS system can generate 8.75 terawatt hours of electricity per year. At $0.11 per kWh one gigawatt is worth about $1 billion per year. A 4-GW SSPS could generate over $40 billion each decade.

Prices for electricity fluctuate depending on the time of day. England has electricity costs of 22 cents per kilowatt hour and is further north than most inhabited parts of Canada and receives limited solar radiation over much of the year. This makes conventional solar power not very competitive at grid delivered costs. However, kilowatt hour photovoltaic costs have been in an exponential decline for decades, with a 20-fold decrease from 1975 to 2001.

In order to be competitive, SPS must cost no more than existing suppliers, this may be difficult, especially if it is deployed to North America. Either it must cost less to deploy, or it must operate for a very long period of time. Many proponents suggest that the lifetime is effectively infinite, but normal maintenance and replacement of less durable components makes this unlikely. Satellites do not, in our extensive experience, last forever.

One concept is to build the SPS in orbit with materials from the moon. Launch costs from the moon are about 100 times lower than from Earth, due to the lower gravity. This concept will work if the number of satellites to be built is near several hundred. Otherwise, the costs of setting up the production in space and mining facilities on the moon are as high as launching from Earth.

Asteroid mining has been seriously considered. A NASA design study produced a 10,000-ton mining vehicle to be assembled in orbit that would return a 500,000 ton asteroid fragment to geostationary orbit.

Currently the costs of solar panels are slowing their use, but the production of solar panels needed to build a SPS system could reduce the costs. The production of thin film solar panels called nanosolar could reduce production costs as well as weight.

The use of microwave transmission of power has been the most controversial item in SPS development, but the safety of anything which strays into the beam's path has been misrepresented. The beam's center is the most intense region and it is far below dangerous levels of exposure even if prolonged indefinitely. An airplane flying through the beam protects its passengers with a layer of metal, which will intercept the microwaves. Over 95% of the beam will fall on the rectenna. The remaining microwaves will be at low concentrations well within the standards for microwave emissions.

The intensity of microwaves at ground level in the center of the beam is likely to be comparable to that used by mobile phones. The microwaves cannot be too intense in order to avoid injury to wildlife, especially birds. Experiments with microwaves at reasonable levels have failed to show any negative effects even over multiple generations. Some designs locate rectennas offshore, but this presents other problems.

The proposed approach for fail-safe beam targeting uses a retrodirective phased array antenna/rectenna. A pilot microwave beam is emitted from the center of the rectenna on the ground to establish a phase front at the transmitting antenna, where circuits in each of the antenna's subarrays compare the pilot beam's phase front with an internal clock phase to control the phase of the outgoing signal. This allows the transmitted beam to be centered precisely on the rectenna and to have a high degree of phase uniformity, but if the pilot beam is lost (the transmitting antenna is turned away from the rectenna) the phase control system fails and the microwave power beam is defocused. Outside of the rectenna area the microwave levels rapidly drop off and nearby objects should be completely unaffected. But the long-term effects of beaming power through the ionosphere in the form of microwaves has yet to be studied.

A potentially useful concept to contrast SPS with is the constructing a ground-based solar power system that generates an equivalent amount of power. Such a system would require a large solar array built in a wellsunlit area. However, an SPS also requires a large ground structure. The rectenna on the ground is much larger than the area of the solar panels in space. The ground-only solar array would have the advantages of costing much less to construct and requires no significant technological advances.

But, such a system has its disadvantages. A terrestrial solar station intercepts only one third of the solar energy that an array of equal size could intercept in space, since no power is generated at night and less light strikes the panels when the Sun is low in the sky.

Some form of energy storage is needed to provide power at night, such as hydrogen or pumped storage hydroelectricity. Weather conditions would also interfere with power collection, and can cause greater wear on the solar collectors than the environment of Earth orbit. A sandstorm could cause much damage. Beamed microwave power can send the power near to the area where it is needed. A solar generating station on Earth may need to provide power to the other areas, where demand is relatively high. Ground-based power can be used on-site to produce hydrogen for transportation in a hydrogen economy.

Advanced construction techniques would make the SPS concept more economical and could make a ground-based system more economical. Many SPS plans are based on building the framework with automated machinery supplied with raw materials, typically aluminium. Such a system could also be used for Earth stations.

The use of microwave beams to heat the oceans has also been studied. Some research suggests that microwave beams would be capable of deflecting the course of hurricanes. NASDA (Japan's national space agency) has been researching this area and plans to launch an experimental satellite of 10-kW to 1-MW. Japan plans to assemble a space-based solar array by 2040.

THE FUTURE FOR ENERGY

Shell Energy has conducted extensive future energy studies. Shell has made major investments in renewable energy and hydrogen and has been a leader in reducing greenhouse gas emissions. From 1975 to 2000, the world gross domestic product (GDP) more than doubled while primary energy use grew by almost 60%. From 2025 to 2050 in one Shell future vision, the GDP almost doubles, but primary energy use grows by only

30%. This means that energy use would have to become twice as efficient. This future vision has natural gas consumption increasing through 2025 and then dropping due to supply problems.

As renewable energy grows, by 2020 a variety of renewable sources supply a fifth of the power in many developed countries. By 2025 biotechnology, materials advances and sophisticated power grid controls provide a new generation of renewable technologies. Its spread is aided by advances in storage technology.

Oil becomes scarce by 2040, but more efficient vehicles using liquid biofuels from biomass farms solve this problem with some help from super clean diesel fuel made from natural gas.

By 2050 renewables supply a third of the world's primary energy and most incremental energy. These are major increases in renewable energy and energy efficiency. Today, renewables supply about 13% of the world's energy, but in the U.S. renewables now only provide less than 1% of electric power generation.

BOTTLED FUEL

Another view of the future by Shell sees a technological revolution based on hydrogen. It is based on the development of bottled fuel for fuel cell vehicles. Two liter bottles hold enough fuel to drive forty miles and are distributed like bottled water through existing distribution channels including vending machines. A package of eight bottles can provide 320 miles of driving. Consumers would get their fuel anywhere and at any time.

By 2025, in this scenario, one-quarter of fleet vehicles use fuel cells, which make up half of new sales. Renewables grow quickly after 2025.

Almost a billion metric tons of CO_2 are sequestered in 2025. Then, hydrogen is produced from coal, oil and gas fields, with the carbon dioxide extracted and sequestered cheaply at the source. Large-scale renewable sources and nuclear energy are producing hydrogen by electrolysis come 2030.

Global energy use nearly triples from 2000 to 2050. World wide nuclear power production also nearly triples during this time. Natural gas use is large in this scenario, and its use more than triples over these 50 years. Renewable energy is also abundant.

By 2050, CO_2 sequestration is over 8 billion metric tons per year, one-fifth of emissions. The world is sequestering more CO_2 than the United States produces now from coal, oil and natural gas use.

Shell stresses that these are not predictions but conception exercises. Bottled fuel would have to be like liquid propane distribution today, but propane is liquid at a much higher temperature and lower pressure than hydrogen. The form of hydrogen contained would not be high-pressure storage, since that would be bulky, heavy, and certainly dangerous to distribute by vending machine. Metal hydrides would be even heavier. Chemical hydrides would be a possibility. Liquid hydrogen could not be dispensed in small, portable, lightweight bottles with today's technology. But, in the future something that could be easily used by the consumer to fuel a hydrogen vehicle would be a major breakthrough.

The Shell studies imply that fuel cell sales will start with stationary applications to businesses that are willing to pay a premium to ensure highly reliable power without utility voltage fluctuations or outages. This demand helps to push fuel cell system costs below $500 per kW, providing the era of transportation which drives costs to $50 per kilowatt. But, can the high-reliability power market really drive transportation fuel cell demand and cost reductions, especially for proton- exchange membrane (PEM) fuel cells?

By 2025 the world is sequestering 1 billion metric tons of CO_2 per year while simultaneously producing hydrogen and shipping it hundreds of miles for use in cars. This is equivalent to sequestering the CO_2 produced by more than 700 medium-sized generation units, about two-thirds of all coal-fired plants in the United States today.

The U.S. Department of Energy (DOE) has started the billion- dollar, FutureGen project to demonstrate a 275-megawatt prototype plant that cogenerates electric power and hydrogen and sequesters 90% of the CO_2.

The goal of the project is to validate advanced coal near zero emission technologies that by 2020 could produce electric power that is only 10% more costly than current coal generated power. This type of advanced system would grow to be 700 worldwide according to the Shell studies.

Advances can occur quickly in technology, these would be needed in hydrogen production and storage, fuel cells, solar energy, biofuel production and sequestration. Government and industry would need to spend hundreds of billions of dollars to bring these technologies to the marketplace. Those in industry commercializing these advances would reap the benefits while those with older technologies would be left behind.

Political obstacles to tripling nuclear power production would need to be set aside. Natural gas supplies would need to be increased.

Another problem is cost-effectiveness, hydrogen must be able to compete with alternative strategies including more fuel- efficient internal combustion engine vehicles. The Shell studies estimate that the cost in the U.S. to supply 2% of cars with hydrogen by 2020 is about $20 billion.

In the near term, hydrogen is likely to be made from fossil fuel sources. The annual operating costs of fuel cell power are likely to be higher than those of the competition in the foreseeable future.

The Kyoto treaty failed to pass in the U.S. Senate and the energy bill passed in 2005 hardly considered climate change. But in June of 2005, the U.S. Conference of Mayors adopted a resolution urging Congress and the states to meet the targets set by the Kyoto treaty and pledged to improve environmental practices in their cities. A number of states are also setting their own targets for emissions reductions.

Since 1990, University of California-Berkeley professor John Harte has been baking a Rocky Mountain meadow to investigate the effects of global warming. On a slope near Gothic, Colorado, Harte has set up an array of infrared heat lamps across 100 yards of grasses to create the effects of warming. In this ecosystem sagebrush is crowding out the other plants. Other experiments suggest that mountain meadows could become arid areas by the end of the century if warming continues.

Satellite data show the Arctic region warming more during the 1990s than during the 1980s, and Arctic Sea ice is now melting by up to 15 percent per decade. The loss of the Arctic Sea ice could alter ocean circulation patterns and trigger changes in climate patterns worldwide. Southern Ocean sea ice floating near Antarctica has decreased by almost 20 percent since 1950 and recent studies have also shown the worldwide acceleration of glacier melting. Across the world, farmers and climate scientists are finding that generations-old patterns of rainfall and temperature are shifting.

There are those who believe that global warming is the most potentially catastrophic environmental problem facing the nation and the planet this century and it is the problem that requires the most urgent action. They may advocate that spending money on building a hydrogen infrastructure would take away resources from more cost-effective measures. But, a hydrogen infrastructure may be critical in achieving a major CO_2 reduction in this century.

In the first half of the 21st century, alternative fuels could achieve greater emissions and gas savings at lower cost, reducing emissions in electricity generation. This is true for natural gas as well as renewable power in the near future. A natural gas fuel cell vehicle running on hydrogen produced from natural gas may have little or no net CO_2 benefits compared to hybrid vehicles. Natural gas does have major benefits when used to replace coal plants. Coal plants have much lower efficiencies at around 30% compared to natural gas plants at 55%. Compared with natural gas, coal has nearly twice the CO_2 emissions, while gasoline has about one third more CO_2 emissions than natural gas.

In the United States, vehicle emissions other than CO_2, have been declining steadily. Noxious emissions are being reduced by federal and state regulations and the turnover of the vehicle fleet. As the vehicles go out of service, they are replaced with newer and cleaner vehicles.

The federal Clean Air Act Amendments of 1990 appear to be working. In the 1990s, Tier 1 standards greatly reduced tailpipe emissions of new light-duty vehicles which includes cars and most sport utility vehicles.

By 2010, Tier 2 standards should further reduce vehicle emissions by extending regulations to larger SUVs and passenger vans. The use of gasoline with a lower sulfur content will also reduce emissions and it also makes it easier to build cars that can achieve further reductions. These standards should allow new U.S. cars to be extremely free of air pollutants. But, the Clean Air Act does not cover vehicle CO_2 emissions. Many new cars are called near zero emissions by their manufacturers and may have tailpipe emissions cleaner than some urban air. Hydrogen fuel cell vehicles will have almost no emissions besides some water vapor and would be much cleaner.

COAL AND NATURAL GAS

The U.S. has been building new natural gas power plants because they are more efficient and cleaner. By 2003, the nation had more than 800 gigawatts (gW) of central station power generation. One gigawatt is 1,000 megawatts (MW) and is about the size of a very large existing power plant or three of the newer, smaller plants. Almost 145 gigawatts were added from 1999 to 2002 and almost 96% of this was natural gas. This included 72 gigawatts of combined-cycle power and 66 gigawatts of combustion turbine power which are used generally when demand is high.

The Energy Information Administration predicts an increase in coal generated power. The EIA estimates that from 2001 to 2025, about 75 gW of new coal plants will be built. Over 90% of the coal plants are projected to be built from 2010 to 2025. The EIA forecast also predicts that existing coal plants will be used more often. From 2001 to 2025, the EIA estimates a 40% increase in coal consumption for power generation. This could increase U.S. greenhouse gas emissions by 10%.

The rising demand for natural gas already affects North American supplies and has pushed up prices. Canada is an important source of our imported natural gas, but it has little capacity left to expand its production. While not as energy-intensive a process as liquefying hydrogen, cooling natural gas to a temperature of about –260°F and transporting the resulting liquid has an energy penalty of up to 15%, according to the Australian Greenhouse Office. From a global standpoint, it might be better to use foreign natural gas to offset foreign coal combustion than to import it into the United States in order to turn it into hydrogen to offset domestic gasoline consumption.

The projected growth in global coal consumption could be an even bigger CO_2 gas problem than the projected growth in U.S. coal consumption. By 1999, there were over 1,000 gW of coal power generating capacity around the world. About one third of this is in the United States. From 2000 to 2030, more than 1,400-gW of new coal capacity may be built, according to the International Energy Agency of which 400-gW will be used to replace older plants.

These plants would need to use carbon capture equipment or their estimated carbon emissions could equal the fossil fuel emissions from the past 250 years. Carbon capture and storage (CCS) is an important research area but widespread commercial use may be years away.

Many of these plants may be built before CCS is ready and we will need to use our electricity more efficiently to slow the demand for such power plants, while building as many cleaner power plants as possible. Natural gas is far more cleaner for this power than coal. Generating hydrogen with renewables may be needed in order to avoid building coal-fired plants. More electricity from renewable power would reduce the pressure on the natural gas supply and reduce prices. The United States could have essentially carbon-free electricity before 2050 with hydrogen fuel playing a key role.

Some studies indicate that higher carbon savings can be achieved by displacing electricity from fossil fuel power stations. Abundant renewable power and the practical elimination of CO_2 emissions from electricity generation could take 30 years. The United Kingdom's power generation mix has less CO_2 emitted per megawatt-hour by one third compared to United States. The U.K. has moved away from extensive coal power generation in the past few decades and is aggressively pushing renewable energy and cogeneration.

Nuclear power is quietly reappearing in the United States and around the world. Major U.S. utilities have applied for site permits for new reactors, and interest is also growing through Europe.

The nuclear plants now operating in the U.S. are light water reactors, which use water as both a moderator and coolant. These are sometimes called Generation II reactors. In these Generation II Pressurized Water Reactors, the water circulates through the core where it is heated by the nuclear chain reaction. The hot water is turned into steam at a steam generator and the steam is used by a turbine generator to produce electric power.

The Generation III reactors Evolutionary Pressurized Reactor has expanded safety features such as 2 separate 51 inch thick concrete walls with the inner one lined with metal. Each of the walls is strong enough to withstand the force of a large commercial airplane.

The reactor vessel is on top of a 20 foot concrete slab with a leaktight core catcher. In the event of a meltdown the molten core would collect there and cool down. Four safeguard buildings are also used with independent pressurizers and steam generators. Each of these buildings is able to provide emergency cooling for the reactor core.

A dozen utilities around the country have started the process of applying to build nuclear plants. These would be Generation III and III+ designs.

In 2000, 10 countries including the U. S. evaluated more than 100 Generation IV designs and after 2 years picked six. Fourth generation nuclear plants replace the water coolants and moderators to allow higher temperatures with the potential to create hydrogen as well as electric power. Tests show that electrolysis is almost twice as efficient at the high temperatures.

One of the Generation IV designs is a melt-down proof pebble-bed reactor. It uses grains of uranium encased in balls of graphite for fuel. Helium gas is heated as it circulates through a vessel of the pebbles. It is then used to turn a turbine generator. A heat exchanger is used to transfer heat from the helium to produce hydrogen. This type of reactor is fail-safe, if the cooling system fails the reactor shuts down on its own. The hot helium gas is inert, so leaks are not radioactive. The heat could also be used to refine shale oil or desalinate water. Each day about 3,000 pebbles are removed from the bottom as some fuel is spent from the 360,000 pebbles, so there is no need to shut down the reactor to replace fuel. The pebbles are fireproof and extremely difficult to turn into weapons. If the fuel gets too hot, it begins absorbing neutrons, shutting down the reactor.

A modular 250-MW reactor of this type could be constructed off-site and then shipped by truck or train. This could shorten construction time by 2 years with corresponding cost savings. China and South Africa plan to build full-scale prototypes.

Three of the Generation IV designs under consideration are fast breeder reactors The fast neutrons in the core have no moderator to slow them down. When these fast neutrons collide with fuel particles, they can generate more fuel. These reactors use gas, sodium or molten lead for cooling.

The burning of coal and other fossil fuels is driving the concerns over climate change, but nuclear energy provides an alternative. The risks of atomic piles are manageable beside that of fossil fuels. Unlike global warming, radiation containment, waste disposal, and nuclear weapons proliferation are more manageable. The latest generation III+ reactors seems to be fuel-efficient, use passive safety technologies, and could be cost-competitive.

Four crucial factors could help to ease the leap from a hydrocarbon to a nuclear era: regulating carbon emissions, revamping the fuel cycle, revitalizing innovation in nuclear technology, and replacing gasoline with hydrogen.

This push is due to several factors and the most significant is the global-warming question. Large companies are now supporting greenhouse gas reduction and several of the world's major environmentalists now support nuclear power, noting that with the threat of warming, an emission-free power source is critical.

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