HIGHER ENERGY PRICES AND THE RESEARCH AND DEVELOPMENT OPPORTUNITIES THEY PRESENT

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Abstract

With the recent rise in demand, mostly because of increased demand in China and India, as part of expansion of their modern economy, coupled with the geopolitical aspects of the energy sector has caused record high oil and gas prices across the globe. As a result there is a renewed push for alternative energy technologies as well as technologies that can enhance recovery, transportation, and energy utilization and conversion efficiencies. In this article a review of current alternative energy technologies and their relevance in various energy sectors will be offered, including their most recent progress and the remaining challenges to overcome. Technology barriers and Research/Development opportunities for further growth in each category are outlined and future projected growth is discussed in brief.

KEYWORDS

Renewable Energy, Biomass, Solar Energy, Wind Energy, Hydrogen and Fuel Cells.

INTRODUCTION

Over the past two years we have witnessed substantial improvement in fossil fuel prices due a surge in demand, coupled with geopolitical aspects in the Middle East and else where in the world. The new energy prices have created a favorable atmosphere for other/alternative fuels and energy technologies. In general, we refer to renewable energy as energy that is derived from a broad spectrum of resources, all of which are based on self-renewing energy sources such as sunlight, wind, flowing water, the earth’s internal heat, and biomass such as energy crops, agricultural and industrial waste, and municipal waste. These renewable energy resources have served human being for a long time such as water wheels, windmills and biomass fuels during the industrial revolution. Modern efforts to harness these resources increase sharply after the oil crisis in 1970s, pushing significant technical and market advances to use these renewable sources to produce electricity for all economic sectors, fuels for transportation, and heat for buildings and industrial processes. Theoretically, renewable energy sources can meet many times the world’s energy demand. After two decades of dramatic technical progress, renewable energy technologies now have the potential to become major contributions to the global energy supplies. Some of the technologies are already well established and others needed further efforts in research, development and deployment to become economically competitive in traditionally fossil fuel dominated market. In this paper first, an introduction to the alternative energy technologies is given. Next, their potential impact and near term wider contribution to the energy supplies will be outlined. Finally, the Research and Development opportunities in the related Thermo fluids engineering will be discussed.

BIOMASS ENERGY

Biomass refers to green plants or almost any organic products derived from plants. Actually, it is another form of solar energy on earth to be collected and stored as chemical energy by green plants which can be suitable for conversion to more convenient types of energy forms (i.e., electric energy and thermal energy) or energy carriers' fuels in solid, liquid and gaseous states. Biomass is the only renewable energy resource like oil that can be converted to liquid fuels. Biomass is used in four major ways: direct combustion, electric power generation, conversion to gas for use as a fuel or chemical feedstock, and conversion to liquid fuels. There are abundant biomass resources, including trees and grasses, starch and oil seeds, sawdust, wood wastes, agricultural residues, food-processing waste, paper and municipal solid waste (MSW). Biomass energy commonly refers to both traditional biomass and modern biomass.

Traditional Biomass

Biomass is the directly converted chemical energy through combustion into thermal energy for heating and cooking that was the first application of renewable energy in the history, such as fuel wood, animal wastes, and crop residues burned in stoves. Using traditional biomass for energy has a long history since humans discovered fire. For example, wood and cow dung have been used for heating and cooking. Estimated 2.4 billion people in developing countries use biomass as their primary fuel for cooking and heating. Traditional biomass provides about 7-14 % of global primary energy supply and averages 30-45 % of the traditional biomass energy used in developing countries though some developing countries approach 90 % [1]. Today, new biomass stoves and heaters have improved efficiency. About 3 quads of energy are being provided in the U.S. today by wood, roughly half the contribution of nuclear power. MSW combustion also provides a small amount of process heat. At present, availability of low priced wood is key constraint for its market growth.

Modern Biomass

Biomass is converted by using related process facilities into electricity, transport fuels or chemicals (i.e., ethanol, methane and bodiesel). For example, China and India convert animal and plant wastes into methane for lighting, heating, cooking and electricity generation using bacteria to decompose biomass into biogas digesters. Modern biomass represents 20 % of Brazil's primary energy supply, aided by significant increases in the past 20 years in the use of ethanol fuels for vehicles and sugarcane waste for power generation. Global annual ethanol production from biomass is estimated at 18 billion liters, 80 % of which is in Brazil [2]. Gasification of biomass for production of methane may provide competitive source for the nation's natural gas market. Meanwhile, the conversion of a large portion of MSW and sewage sludge to methane via anaerobic digestion may provide an attractive alternative means of disposing of such wastes.

Transport Fuels

There are two kinds of biomass-derived liquid fuels for vehicles: ethanol fuel and biodiesel.

<u>Ethanol</u> Ethanol is an alcohol fuel traditionally fermented from corn kernel (corn alcohol) to meet a market demand. In 2002, 2.13 billion gallons of ethanol was produced in the US (up 20 percent from 2001), which was still a small amount (less than 2.6 %) of the U.S. oil imports. Ethanol can power specially designed vehicles that run on pure ethanol or is mixed with gasoline or diesel fuel as an additive for use in ordinary vehicles to boost combustion and reduce vehicle emissions. According to the U.S. Environmental Protection Agency, the use of ethanol blended with gasoline can reduce motor vehicle emissions of carbon monoxide by 25 to 30 % and also reduce ozone levels that contribute to urban smog. In addition, the combustion of ethanol produces 90 % less carbon dioxide than gasoline. A blend of 10 % ethanol and 90 % gasoline has been widely used throughout the nation for many years. Higher-level blends of 85 % and 95 % ethanol are being tested in government fleet vehicles, flexible-fuel passenger vehicles, and urban transit buses. Although there are nearly 50,000 such vehicles in operation, their use is expected to grow as federal, state, municipal, and private fleet operators seek to comply with the alternative fuel requirements of the Energy Policy Act of 1992 and the Clean Air Act Amendments of 1990. Market issues relate to ethanol production efficiency, cost competition with gasoline, the commercial viability and costs of specially designed ethanol only vehicles, fuel distribution infrastructure, and ratios of ethanol to gasoline in gasohol blending. However, corn requires high amounts of energy (as fertilizer and farm equipment fuel) to grow, harvest and process the grain by substantial coal-fire electricity. Some researchers showed that ethanol

consumed more energy than it produced when using traditional method from corn. Renewable energy research has transformed on a new biotech method producing ethanol – termed bioethanol – from cellulosic or biomass such as agriculture waste products and MSW. Feedstocks include corn husks, rice straws, rice hulls, wood chips, sugarcane, forest thinnings to prevent wildfires, waste newspaper, and grasses and trees cultivated as energy crops. Bioethanol could consume less energy to produce and use materials that are now burned or buried. Biological production of ethanol involves hydrolysis of fibrous biomass, using enzymes or acid catalysts, to form soluble sugars, followed by microbial conversion of sugars to ethanol. The cost of bioethanol production in the lab was decreased from \$3.60/gallon in 1980 to about \$1.20 in the 1990s (see Figure 6) due to technical breakthroughs, including genetic engineering of specialized enzymes and microbes. Ultimately, the goal is for bioethanol to become competitive with gasoline in price. Research focuses on low-cost production of enzymes to break down cellulose, improve microorganism performance, produce suitable energy crops, and demonstrate ethanol production from a variety of biomass feedstocks [3].

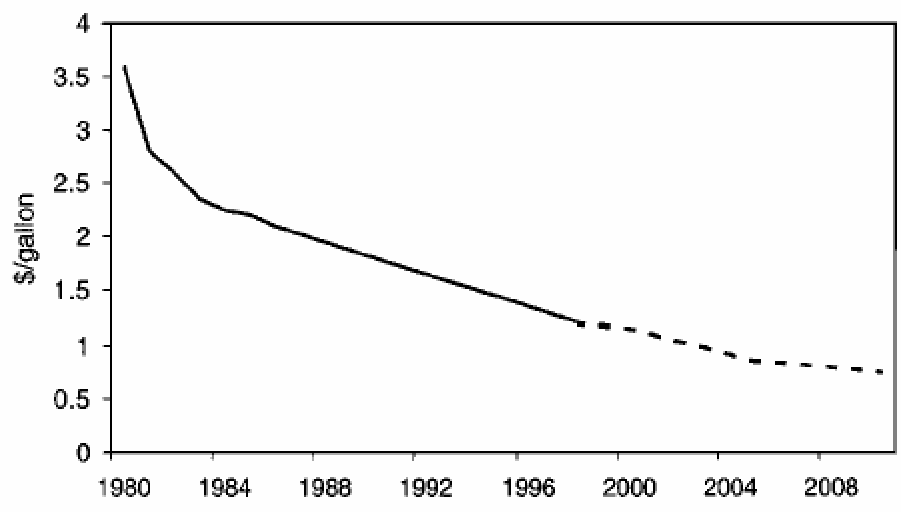

Fig. 1. Production cost trend of bioethanol [3]

However, the production of bioethanol from the laboratory to the highway has been slow. Though biomass is a renewable resource, ethanol is limited by available land. According to the recent DOE report [4], it would need 5 quads of bioethanol to provide 45 % of fuels used in gasoline vehicles, which would use current cropland and grassland to produce 63 % of bioethanol. Today, more than 60 % of Brazil's sugarcane production goes to produce ethanol. Technological advances have continued to improve the economic competitiveness of ethanol and gasohol relative to conventional gasoline, although the price of oil and competitive forces in global automotive technology greatly affect ethanol's prospects. In 2000, over 40 % of automobile fuel consumption and 20 % of total motor vehicle fuel consumption in Brazil was ethanol, displacing the equivalent of 220,000 barrels of oil per day. According to one estimate, about US\$140 billion would have been added to Brazil's foreign debt if ethanol had not been used as a fuel over the past 25 years, although this significant benefit has gone largely unreported and unnoticed by policy makers [5]. Moreover, ethanol is not the only fuel that can be produced from biomass. About 1.2 billion gallons of methanol, currently made from natural gas, are sold in the United States annually, with about 38 % of this used in the transportation sector. (The rest is used to make solvents and chemicals) Methanol can also be produced from biomass through thermochemical gasification.

Biodiesel Biodiesel is defined as the mono-alkyl esters of fatty acids processed from any vegetable oil or animal fat. Biodiesel is an alternative fuel for diesel engines that is receiving great attention around the world because it is renewable, and 100 percent biodiesel eliminates sulfur emissions and reduces particulate matter and other pollutants by 50 percent. However, it increases emissions of one smog-producing pollutant (nitrogen oxide, NO_X), which can be solved by adjusting engine timing. Biodiesel generally has a lower heating value that is 12 % less than No. 2 diesel fuel on a weight basis (16,000 Btu/lb compared with 18,300 Btu/lb). Since the biodiesel has a higher density, the lower heating value is only 8 % less on a volume basis (118,170 Btu/gallon for biodiesel compared with 129,050 Btu/gallon for No. 2 diesel fuel). Biodiesel can be used either pure or in blends with diesel fuel in diesel engines with no modification. In 2000, heavy trucks used 30 % as much fuel as light vehicles. In simple terms, biodiesel is the product when a vegetable oil or animal fat is chemically reacted with an alcohol to produce a new compound that is known as a fatty acid alkyl ester. In general, biodiesel can be made from several feedstocks:

1. In the United States, Soybean oil is the most popular feedstock, comprising over 75 % of the total national vegetable oil volume. Biodiesel from soybeans is sometimes called soydiesel, methyl soyate, or soy methyl esters (SME). Soybeans are a major U.S. crop and government subsidies may be available to make the fuel economically attractive to consumers who need or want to use a non petroleum-based fuel.
2. In Europe, most biodiesel is made from rapeseed oil and methanol and it is known as rapeseed methyl esters (RME). The most commonly used primary alcohol used in biodiesel production is methanol, although other alcohols, such as ethanol, isopropanol, and butyl, can be used. The University of Idaho has done considerable work with rapeseed esters using ethanol, which produces rapeseed ethyl esters (REE). [see http://www.uidaho.edu/bae/biodiesel/]
3. Other vegetable oils such as corn oil, canola (an edible variety of rapeseed) oil, cottonseed oil, mustard oil, palm oil, etc.,
4. Restaurant waste oils such as frying oils,
5. Animal fats such as beef tallow or pork lard,
6. Trap grease (from restaurant grease traps), float grease (from waste water treatment plants), etc.

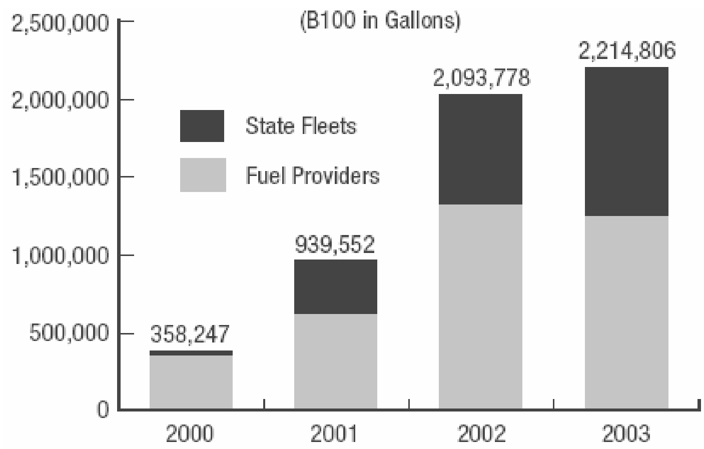

Fig. 2. Growth of biodiesel fuel use

Biodiesel is one good example of a form of biomass energy that has developed beyond R&D policy recommendations. Fueled by large agribusinesses, biodiesel has seen tremendous growth in the past few years (Figure 2). Based on data through the third quarter of 2002, biodiesel output is projected to grow by 8.2 million gallons per year until the subsidy expires at the end of 2006. Thereafter, biodiesel output is projected to grow by 1.8 percent per year [6].

SOLAR ENERGY

Although solar energy holds tremendous potential to benefit the world by diversifying energy supply, reducing the dependence on fossil fuels, improving the quality of the global environment, and stimulating the economy by creating jobs in the manufacture and installation of solar energy systems, However, its economic utility is limited by the finite rate at which the Sun's energy can be captured, concentrated, stored, and/or converted to be used in the highest value energy forms, and by the land areas that societies can dedicate to harness it. The amount of solar energy received across US latitudes is approximately 22 Quads per year per 4000 km^2 (about a million acres) on average [7]. Technologies based on this resource have the potential to become major contributors to our energy supplies [8]. Figure 11 illustrates how large a surface area of cells would be required to generate a particular amount of electricity. The left yellow region indicates electricity produced directly at the Photovoltaic (PV) cell (currently PV solar cells convert 10-20 % of incident radiation directly to electricity). The right blue region is a more realistic mapping and indicates the larger cell areas needed to cover the energy losses in transformers, transmission, power − equalization over time, and efficiency losses that occur for any conversion to gaseous or liquid fuels. Thus about 40-80 thousand km^2 of area – roughly 2-4 times the size of Massachusetts – could supply about 20 Quads, or 20-25 %, of today's US total energy requirements.

Solar Energy Perspective

The distributed, modular characteristics of solar energy offer tremendous flexibility for both grid-connected and off-grid electricity applications. Distributed energy technologies are expected to supply an increasing share of the electricity market to improve power quality and reliability problems such as power outages and disturbances. With improved technology supported by the US DOE, cost of solar energy has dropped substantially in the past decade and continued to decline. The projected costs (shown as dashed lines in Figure 16) are based on continuing the proposed budget support for the DOE Solar Program. The long-term cost goals are even more ambitious. For example, the goal for photovoltaics in 2020 is \$0.06/kWh, which will become economically competitive alternative to traditional fossil fuel energy.

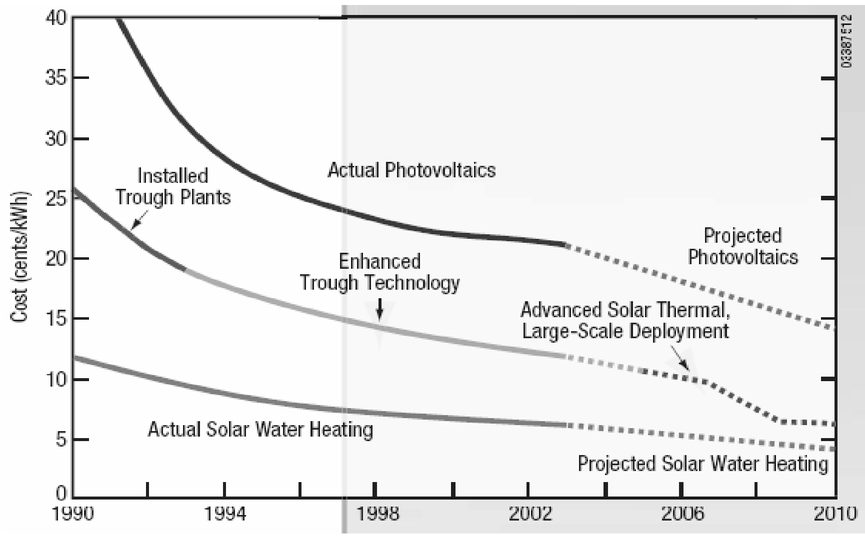

Fig. 3. The cost roadmap of solar energy technology [9]

WIND ENERGY

Wind is a form of solar energy. Winds are caused by the uneven heating of the atmosphere by the sun, the irregularities of the earth's surface, and rotation of the earth. Wind flow patterns are modified by the earth's terrain, bodies of water, and vegetation. Humans use this wind flow, or motion energy, for many purposes: sailing, flying a kite, and even generating electricity. The wind energy or wind power describe the process by which the wind is used to generate mechanical power or electricity. This mechanical power can be used for specific tasks (such as grinding grain or pumping water) or a generator can convert this mechanical power into electricity. Since early recorded history, people have been harnessing the energy of the wind. By the 11th century, people in the Middle East were using windmills extensively for food production; returning merchants and crusaders carried this idea back to Europe. Commonly called wind turbines that convert the kinetic energy in the wind into electricity through a generator, these machines appeared in Denmark as early as 1890. In the 1940s the largest wind turbine of the time began operating on a Vermont hilltop known as Grandpa's Knob. This turbine, rated at 1.25 megawatts in winds of about 30 mph, fed electric power to the local utility network for several months during World War II. The popularity of using the energy in the wind has always fluctuated with the price of fossil fuels. When fuel prices fell after World War II, interest in wind turbines declined. But when the price of oil skyrocketed in the 1970s, so did worldwide interest in wind turbine generators. The rapid progress in wind turbine technology has refined old ideas and introduced new ways of converting wind energy into useful power. Many of these approaches have been demonstrated in "wind farms" or wind power plants (groups of turbines), which feed electricity into the utility grid in the United States and Europe. Wind energy has expanded its role in electricity generation since the 1970s. The worldwide installed capacity of grid-connected wind power has now exceeded 40 GW, corresponding to an investment of approximately $40 billion [10]. A demand for clean, diverse sources of electricity, and state and federal incentives to stimulate the market has contributed to wind energy's growth in the United States. Utility-scale wind power plants are now located in 27 states. The average U.S. wind energy growth rate for the past five years is 24 %. This growth can be attributed to a greatly reduced cost of production (from 80 cents [current dollars] per kilowatt-hour [kWh] in 1980 to 4 cents per kWh in 2002). The global wind energy installed capacity has increased exponentially over a 25-year period, and in the process the cost of energy (COE) from wind power plants has been reduced by an order of magnitude with very close in cost to power from the modern combined-cycle power plants in some locations. According to the American Wind Energy Association, as much as 13 500 additional megawatts of wind capacity may be installed worldwide in the next decade. Wind energy is the world's fastest-growing energy source and will power industry, businesses and homes with clean, renewable electricity for many years to come.

Wind Energy Technology Development

Over the past two decades, the rapid progress in wind turbine technologies has led to more cost-effective wind turbines that more efficient in producing electricity, mainly motivated by the oil embargoes and fuel price escalations of the 1970s and recent environmental concern. The low speed technology targets development of cost-effective wind turbines for Class 4 sites (13-mph average annual wind speed) that can produce electricity onshore for $0.03/kWh and offshore for $0.05/kWh by the end of 2012. This will open up 20 times more land in the United States for wind energy development, and since many of these sites tend to be closer to urban load centers, the problem of transmission line expansion will be greatly simplified. But the current turbine designs are not well suited to low wind sites and have only limited potential to achieve lower costs of energy. If such technology can be successfully developed, the wind resources across the Great Plain states could potentially generate more electricity than is currently consumed by the entire nation. Although wind power plants have relatively little impact on the environment compared to other conventional power plants, there is some concern over the noise produced by the rotor blades, aesthetic (visual) impacts, and sometimes birds have been killed by flying into the rotors. Most of these problems have been resolved or greatly reduced through technological development or by properly siting wind plants.

HYDROGEN AND FUEL CELLS

Hydrogen is the simplest element; an atom consists of only one proton and one electron. It is also the most plentiful element in the universe. Despite its simplicity and abundance, it rarely exists as a free-floating element, which is always combined with other elements. Hydrogen is found in water, in hydrocarbon organic compounds that make up many of our fuels such as gasoline, coal, natural gas, methanol, and propane. Although President Bush called hydrogen a “pollution free” technology, extracting hydrogen from its most common source, water, requires electricity that could come from fossil fuels such as coal or nuclear energy. Although in many ways hydrogen is an attractive replacement for fossil fuels, it does not occur in nature as the fuel H_2. Rather, it occurs in chemical compounds like water or hydrocarbons that must be chemically transformed to yield H_2. Hydrogen, like electricity, is a carrier of energy, and like electricity, it must be produced from a natural resource that promises substantial contributions to global energy supplies and minimal environmental impact in the long term.

Hydrogen

Hydrogen is the simplest chemical fuel (essentially a hydrocarbon without the carbon) that makes a highly efficient, clean-burning energy carrier and a secondary form of energy that has to be produced like electricity. When hydrogen used to power a special battery called a fuel cell, its only waste product is water. Hydrogen-powered fuel cells and engines emerged as common as the gasoline and diesel engines of the late 20th century, which power cars, trucks, buses, and other vehicles, as well as homes, offices, and factories. It has the potential to fuel transportation vehicles with zero emissions, provide process heat for industrial processes, supply domestic heat through cogeneration, help produce electricity for centralized or distributed power systems, and provide a storage medium for electricity from renewable energy sources. Some envision an entire economy based on hydrogen called hydrogen economy in the future [11]. At present, most of the world's hydrogen is produced from natural gas by a process called steam reforming. However, producing hydrogen from fossil fuels would not welcome by the public acceptance of the hydrogen economy since steam reforming does not reduce the use of fossil fuels but rather shifts them from end use to an earlier production step; and it still releases carbon to the environment in the form of CO_2. Thus, to achieve the benefits of the hydrogen economy, the ultimately produce hydrogen must be produced more cost effectively from non-fossil resources, such as water, using a renewable energy source like wind and solar. Although the potential benefits of hydrogen economy are significant, many barriers to commercialization, technical challenges and otherwise, must be overcome before hydrogen will offer a competitive alternative for consumers.

Commercial Barriers Most of commercial barriers are: the high cost of hydrogen production, low availability of the hydrogen production systems, the challenge of providing safe production and delivery systems (i.e., economical storage and transportation technologies) and public acceptance.
*Hydrogen Production and Delivery***:** The high cost of hydrogen production, low availability of the hydrogen production systems, and the challenge of providing safe production and delivery systems are early penetration barriers. There are few data on the cost, efficiencies, and availabilities of integrated coal-to-hydrogen/power plants with sequestration options. Data on the high-temperature production of hydrogen from nuclear power are limited. Likewise, there is little operational, durability, and efficiency information for renewable hydrogen production systems. Hydrogen delivery options need to be determined and assessed as part of system demonstrations for every potential production technology. Validation of integrated systems is required to optimize component development. Hydrogen has a low energy density in terms of volume, making it difficult to store amounts adequate for most applications in a reasonable-sized space. This is a particular problem for hydrogen-powered fuel cell vehicles, which must store hydrogen in compact tanks. Other options are to store hydrogen at cryogenic liquid state or solid state.
*Gas/Liquid Storage: Hydrogen Storage***:** Current technology does not provide reasonable cost and volume for transportation or stationary applications. An understanding of composite tank operating cycle life and failure due to accident or neglect is lacking. Cycle life of hydride storage systems need to be evaluated in real-world circumstances. Hydrogen is currently stored in tanks as a compressed gas or cryogenic liquid. The tanks can be transported by truck or the compressed gas can be sent across distances of less than 50 miles by pipeline. In addition, the hydrogen production strategy greatly affects the cost and method of delivery. For example, the increased transport distances required for centralized hydrogen production significantly increase the delivery costs. In contrast, distributed production at the point of use eliminates the transportation costs but results in higher production costs because the economy of larger scale production is lost.
*Solid-State Methods***:** Technologies that store hydrogen in a solid state are inherently safer and have the potential to be more efficient than gas or liquid storage. These are particularly important for vehicles with on-board storage of hydrogen. High-pressure storage tanks are currently being developed, and research is being conducted into the use of solid-state storage technologies under investigation including metal hydrides (involve chemically reacting the hydrogen with a metal), carbon nanotubes (take advantage of the gas-on-solids adsorption of hydrogen and retain high concentrations of hydrogen), and glass microspheres (rely on changes in glass permeability with temperature to fill the microspheres with hydrogen and trap it there). However, statistical cost, durability, fast-fill, discharge performance, and structural integrity data of hydrogen storage systems will be needed to proceed with technology commercialization.

*Safety, Codes and Standards***:** Hydrogen, like gasoline or any other fuel, has safety risks and must be handled with due caution. Unlike familiar with gasoline, handling hydrogen will be new to most of consumers. Therefore, developers must optimize new fuel storage and delivery systems for safe everyday use, and consumers must become familiar with hydrogen's properties and risks. Codes and standards are needed to ensure safety, as well as to commercialize hydrogen as a fuel.
*Public Acceptance***:** The public acceptance of hydrogen depends not only on its practical and commercial appeal, but also on its record of safety in widespread use. Since the hydrogen economy will be a revolutionary change from the world we know today, education of the general public, training personnel in the handling and maintenance of hydrogen system components, adoption of codes and standards, and development of certified procedures and training manuals for fuel cells and safety will foster hydrogen's acceptance as a fuel. Hydrogen and fuel cell technologies must be embraced by consumers before its benefits can be realized. This is especially true for transportation, stationary residential, and portable applications, where consumers will interact with fuel cell technology directly. Key to public acceptance of hydrogen is the development of safety standards and practices that are widely known and routinely used –like those for self-service gasoline stations or plug – in electrical appliances. The technical and educational components of this aspect of the hydrogen economy need careful attention.

Technology Roadmap Technical challenges for hydrogen commercialization include cost-effective, energy-efficient production technologies and safe, economical storage and transportation technologies. The US DOE provided a national version of America's transition to a hydrogen economy to 2030 or beyond [12]. Technology roadmap will come in three steps. The first steps toward a clean energy future will focus on technology development and initial market penetration to build on well-known commercial processes for producing, storing, transporting, and using hydrogen. In the mid term, as hydrogen use increases and hydrogen markets grow, the expansion of market and infrastructure investment will make the cost of hydrogen and fuel cell economically competitive to traditional fossil fuels. For the long term, when market and infrastructure is becoming fully developed, widely uses of more cost-effective advanced technologies will be an important step toward a hydrogen economy [12].

Fuel Cell

Widespread use of hydrogen as an energy source in the world could help address concerns about energy security, global climate change, and air quality. Fuel cells are an important enabling technology for the future hydrogen economy and have the potential to revolutionize the way of power generation, offering cleaner, more-efficient alternatives to the combustion of gasoline and other fossil fuels. A conventional combustion based power plants typically generate electricity at efficiencies of 30-35 percent. When fuel cells are used to generate electricity and heat (co-generation), they can reach efficiencies up to 85 percent. Fuel cells promise to be a safe and effective way to use hydrogen for both vehicles and electricity generation. Vehicles using electric motors powered by hydrogen fuel cells are much more energy efficient, utilizing 40-60 percent of fuel's energy, while internal combustion engines in today's automobiles only convert less than 30 percent of the energy in gasoline into power that moves the vehicle. Although these applications would ideally run off pure hydrogen, in the near term they are likely to be fueled with natural gas, methanol, or even gasoline.

If the fuel cell is to become the modern steam engine, basic research must provide breakthroughs in understanding, materials, and design to make a hydrogen-based energy system a vibrant and competitive force. Fuel cell technology is not a new invention. Actually, fuel cell development predated the internal combustion engine but lacked commercialization until NASA decided to incorporate them in spacecrafts during the 1960s. Fuel cells convert hydrogen – as hydrogen gas or reformed within the fuel cell from natural gas, alcohol fuels, or some other source—directly into electrical energy with no combustion. Phosphoric acid fuel cells are already commercially available to generate electricity in 200-kW capacities selling for $3/W, using natural gas as the source of hydrogen; molten carbonate has been demonstrated at large (2-MW) capacities. A fuel cell works like a battery but does not run down or need recharging. It will produce electricity and heat as long as fuel (hydrogen) is supplied. A fuel cell consists of two electrodes – a negative electrode (or anode) and a positive electrode (or cathode) – sandwiched around an electrolyte. Hydrogen is fed to the anode, and oxygen is fed to the cathode. Activated by a catalyst, hydrogen atoms separate into protons and electrons, which take different paths to the cathode. The electrons go through an external circuit, creating a flow of electricity. The protons migrate through the electrolyte to the cathode, where they reunite with oxygen and the electrons to produce water and heat.

Technology Challengers for Hydrogen and Hydrogen Fuel Cells

Although hydrogen fuel cells have been used by NASA for space missions since 1960s, terrestrial applications are still in their infancy. The lack of an economical process for hydrogen production and suitable storage methods are two of the greatest obstacles to commercialization, especially in the transportation sector. Research goals include developing technologies to produce hydrogen from sunlight and water and biomass; developing low-cost and low-weight hydrogen storage technologies for both stationary and vehicle-based applications, such as carbon nanotubes and metal hydrides; and developing codes and standards to enable the widespread use of hydrogen technologies. However, cost is the greatest challenge to fuel cell development and adaptation, and it is a factor in almost all other fuel cell challenges as well. Statistical data for fuel cell vehicles that are operated under controlled, real-world conditions is very limited and often proprietary. Vehicle drivability, operation, and survivability in extreme climates, and emissions (hydrogen ICE) have not yet been proven. Development and testing of complete integrated fuel cell power systems is required to benchmark and validate for optimal component development. For example, some fuel cell designs require expensive, precious-metal catalysts, and others require costly materials that are resistant to extremely high temperatures. Another key technical challenge facing fuel cells is the need to increase durability and dependability. High-temperature fuel cells, in particular, are prone to material breakdown and shortened operating lifetimes. PEM fuel cells must have effective water management systems to operate dependably and efficiently. Finally, all fuel cells are prone, in varying degrees, to catalyst poisoning, which decreases fuel cell performance and longevity. Research into these areas is under way to test the durability of new components and designs.

RENEWABLE ENERGY PERSPECTIVE

It is less than 100 years that fossil fuels became the predominant sources of energy in the world with the discovery of oil, the development of natural gas fields, and the widespread distribution of electricity from coal-powered central power plants. From the dawn of human civilization to about 100 years ago, human and animal muscle and wood, with lesser amounts of solar, wind, hydro, and geothermal were the predominant sources of energy used by the mankind. Is there another major transition ahead for energy in the new millennium? Can the renewable resources that sustained early civilization be harvested more cost-effectively to meet a significant portion of the much higher demands of today's society? Although there is no fixed time frame for the world to make such dramatic transition, renewable energy technology has made great progresses in cost reductions, efficiency increases and reliability improvements over the past 30 years. Renewable energy has made increasing contributions to the world's energy supply. In 2000, the global electricity capacity generated by renewable energy source has accounted for about 30 percent (102 GW) in the total electric power capacity (Table 1). Most of the contribution comes from hydroelectric power. However, other non-hydro renewable energy resources such as biomass, alcohol fuel, wind, geothermal and solar have increased due to the technology innovations and cost reductions and are becoming viable, commercially competitive and environmentally preferable alternatives to the traditional fossil fuels. When the global resources of fossil fuels are facing gradual declining as well as increased environmental penalty by using fossil fuel energy such as the worsen GHG emissions and air pollutions, which will be more costly and difficultly solved if more strict mandatory emission reductions will be enacted.

Table 1. Renewable grid-based electricity generation capacity installed as of 2000 (megawatts) [2]

Technology	All countries	Developing countries
Total world electric power capacity	3,400,000	1,500,000
Large hydropower	680,000	260,000
Small hydropower[b]	43,000	25,000
Biomass power[c]	32,000	17,000
Wind power	18,000	1,700
Geothermal power	8,500	3,900
Solar thermal power	350	0
Solar photovoltaic power (grid)	250	0
Total renewable power capacity[d]	102,000	48,000

With continued R&D and deployment, many renewable-energy technologies are expected to continue their steep cost reductions such as wind, solar thermal and photovoltaics. The push to develop renewable and other clean energy technologies is no longer being driven solely by environmental concerns. These technologies are now becoming economically competitive (Figure 4). Several could become competitive over next decade or two, either directly or in distributed-utility. Wind turbines, in particular, could even become broadly competitive with gas-fired combined-cycle systems within next ten years in places where there are winds of medium or high quality. However, one disadvantage of renewable energy systems has been the intermittent nature of some sources, such as wind and solar. One solution is to develop diversified systems that maximize the contribution of renewable energy sources to meet the daily needs, but also use clean natural gas and /or biomass-based power generation to provide base-load power for the peak in energy use such as evening air conditioner or heating demand. Because of the changing U.S. electricity marketplace, remote or distributed markets for renewable electricity, as discussed above, appear to be more promising today than centralized electricity markets.

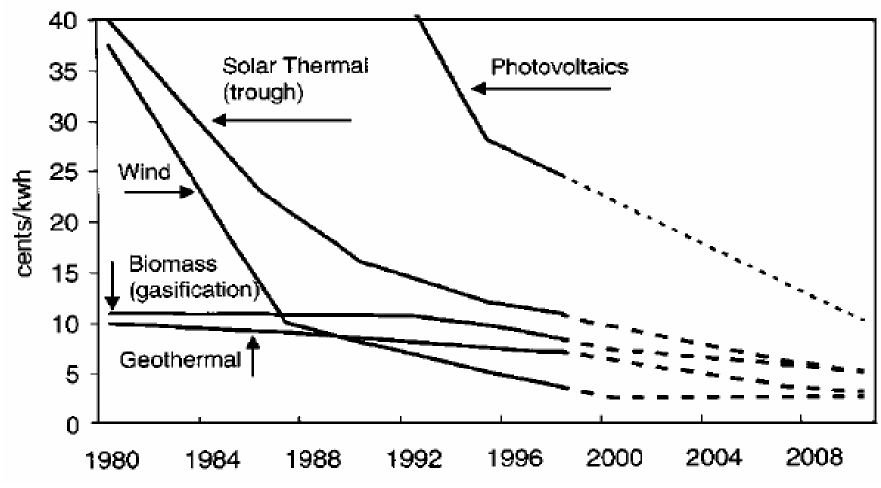

Fig. 4. The renewable electricity cost [13]

According to a fifty year perspective for future U.S. Highway Energy Use made by the US DOE in 2001 [4], which assumed the demand for world oil products growing at 2% per year and after 2020 when conventional oil production is assumed to peak once 50 % of ultimate resources have been produced and begin a continual decline, the gap between continuing demand growth and declining production could be around 50 billion barrels of oil equivalent (145 MBPD) by 2050, or almost twice current conventional oil production. Although there is considerable uncertainty, the report indicated that the U.S. should start transportation's energy transition immediately, since the time to fully implement a new vehicle technology in all vehicles on the road is 30 years or more, and the time to fully implement a new fuel would take even longer. The market penetration of the alternative renewable fuels such as biofuel/biodiesel or hydrogen (Table 2) are depended on their cost-effective production, storage, deliver, safety, customer acceptance as well as the related vehicle technology development such as HEVs, battery-electric vehicles and fuel cells [14].

Table 2. Comparisons of gasoline and alternative transport fuels [14]

	Gasoline	Biodiesel (B20)	Compressed Natural Gas (CNG)	Ethanol (E85)	Hydrogen
Chemical Structure	C_4 to C_{12}	Methyl esters of C_{16} to C_{18} fatty acids	CH_4	CH_3CH_2OH	H_2
Main Fuel Source	Crude Oil	Soy bean oil, waste cooking oil, animal fats, and rapeseed oil	Underground reserves	Corn, Grains, or agricultural waste	Natural Gas, Methanol, and other energy sources.
Energy Content per Gallon	109,000 - 125,000 Btu	117,000 - 120,000 Btu (compared to diesel #2)	33,000 - 38,000 Btu @ 3000 psi; 38,000 - 44,000 @ 3600 psi	~ 80,000 Btu	Gas: ~6,500 Btu @3k psi; ~16,000 Btu @10,kpsi Liquid: ~30,500 Btu
Price Per Gallon/ Gasoline Gallon Equivalent (GGE)	$1.99	$2.06	$1.40	$2.28	$5-11 (2003) $1.5-2.25 (2015)
Environmental Impacts of Burning Fuel	Produces harmful emissions; however, gasoline and gasoline vehicles are rapidly improving and emissions are being reduced.	Reduces particulate matter and global warming gas emissions compared to conventional diesel; however, NOx emissions may be increased.	CNG vehicles can demonstrate a reduction in ozone-forming emissions (CO and NOx) compared to some conventional fuels; however, HC emissions may be increased.	E-85 vehicles can demonstrate a 25% reduction in ozone-forming emissions (CO and NOx) compared to reformulated gasoline.	Zero regulated emissions for fuel cell-powered vehicles, and only NOx emissions possible for internal combustion engines operating on hydrogen.
Energy Security Impacts	Manufactured using imported oil, which is not an energy secure option.	Biodiesel is domestically produced and has a fossil energy ratio of 3.3 to 1, which means that its fossil energy inputs are similar to those of petroleum.	CNG is domestically produced. The United States has vast natural gas reserves.	Ethanol is produced domestically and it is renewable.	Hydrogen can help reduce U.S. dependence on foreign oil by being produced by renewable resources.
Fuel Availability	Available at all fueling stations.	Available in bulk from an increasing number of suppliers. There are 22 states that have some biodiesel stations available to the public.	More than 1,100 CNG stations can be found across the country. California has the highest concentration of CNG stations. Home fueling will be available in 2003.	Most of the E-85 fueling stations are located in the Midwest, but in all, approximately 150 stations are available in 23 states.	There are only a small number of hydrogen stations across the country. Most are available for private use only.
Maintenance Issues		Hoses and seals may be affected with higher-percent blends, lubricity is improved over that of conventional diesel fuel.	High-pressure tanks require periodic inspection and certification.	Special lubricants may be required. Practices are very similar, if not identical, to those for conventionally fueled operations.	When hydrogen is used in fuel cell applications, maintenance should be very minimal.
Safety Issues (Without exception, all alternative fuel vehicles must meet today's OEM Safety Standards)	Gasoline is a relatively safe fuel since people have learned to use it safely. Gasoline is not biodegradable though, so a spill could pollute soil and water.	Less toxic and more biodegradable than conventional fuel, can be transported, delivered, and stored using the same equipment as for diesel fuel.	Pressurized tanks have been designed to withstand severe impact, high external temperatures, and automotive environmental exposure.	Ethanol can form an explosive vapor in fuel tanks. In accidents; however, ethanol is less dangerous than gasoline because its low evaporation speed keeps alcohol concentration in the air low and non explosive.	Hydrogen has an excellent industrial safety record; codes and standards for consumer vehicle use are under development.

Although renewable energy technologies have advanced dramatically during the past 30 years, several independent entities forecasted that renewable energy would play a major role in the energy mix for the world, with increasing impacts beginning as early as 2000-2010 and major impacts by 2050 that renewable energy technologies, which will provide 30-50 % of world energy [15], which could have significant global impact on economic, environmental, and security problems. However, according to *International Energy Outlook 2004* (*IEO2004*) [16], world marketed energy consumption is projected to increase by 54 percent from 404 quadrillion British thermal units (Btu) in 2001 to 623 quadrillion Btu in 2025. Fossil fuels (such as oil, natural gas and coal) will continue to dominate in energy supply and oil will remain the world's foremost source of primary energy consumption throughout the 2001 to 2025 period, at 39 percent, despite expectations that countries in many parts of the world will be switching from oil to natural gas and other fuels for their electricity generation (Figure 5). Robust growth in transportation energy use – overwhelmingly fueled by petroleum products – is expected to continue over the 24-year forecast period. As a result, oil is projected to retain its predominance in the global energy mix, notwithstanding increases in the penetration of new technologies such as hydrogen-fueled vehicles.

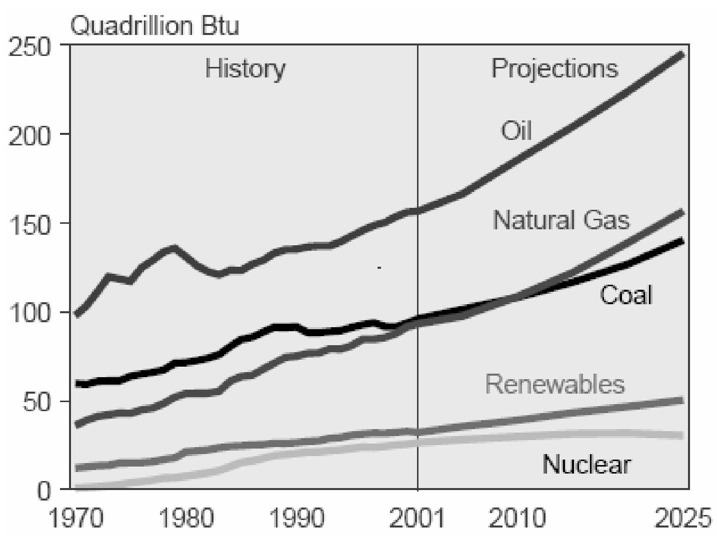

Fig. 5. World marketed energy consumption by energy source, 1970-2025 [16]

The same trend of slowly growing market in renewable energy can be found in the US in past five years. Renewable energy consumption in 2003 only grew 3 percent to 6.1 quadrillion Btu [17]. Current levels of renewable energy use represent only a tiny fraction of what could be developed. The US energy infrastructure is mainly based on the consumption of fossil fuels. As shown in Figure 6, solar and wind only account for 3 percent of total renewable energy use in 2003, less than 0.2 percent of the US energy supply in 2003.

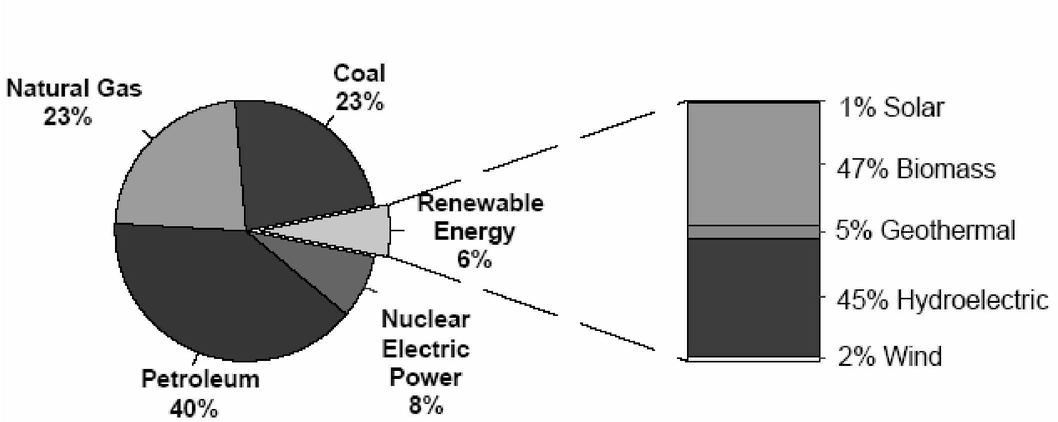

Fig. 6. Renewable Energy Consumption in the US's Energy Supply, 2003 [17]

CONCLUSIONS

Over past 30 years, there have been significant progresses in renewable energy technologies that have been viewed as alternative energy options to fossil fuels with unique environmental and social benefits. Many renewable energy technologies have been developed and some are already making large inroads in the marketplace, such as biomass, hydropower, geothermal, wind and solar power. Other technologies, perhaps those most beneficial to a sustainable future, require more efforts in research, development and deployment before they become economically viable and technically feasible. The world is now facing the reality that fossil fuels are a finite resource to be exhausted someday, that global consumption is outpacing the discovery and exploitation of new reserves, and that the global environment is becoming worse due to increasing GHG emissions by using traditional fossil fuels. To confront the distinguish of limited future availability of inexpensive fossil fuels, the world is now on the brink of a new energy transition from fossil fuels to clean renewable energy sources. However, the global energy infrastructure is mainly based on the consumption of fossil fuels with very little done to reduce dependence on these energy resources till now. Although in theory concept of renewable energy has been proven technically and economically feasible after three decades' efforts in the world, when the transition will occur will depend on the will of the customer and the government polices and the market drivers. The recently rising prices of conventional sources of energy gives the strongest economic argument in favor of the expanded market of renewable energy sooner rather than later. Substantial growth in use of alternative energy is expected to take a steeper growth slope in the years to come. Among the commonly known alternative energy technologies, wind energy is expected to be the fastest growing sector, followed by solar photovoltaics, fuel cells, and select alternative fuels. Collectively a 10-fold growth in clean energy use between 2002 and 2012 is expected. This paper briefly discussed technology barriers that need to be overcome with each of the alternative technologies to assure sustained fast growth. Although greater energy utilization efficiencies have proven to be effective conservation options to save energy consumption over past decades, they cannot, and should not be viewed as an ultimate remedy or solution. In the long run, renewable energy is the best option to meet the increasing clean energy demand.

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