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Technologies for Sustainable Energy Sources and Systems*

KunMo Chung
Energy Systems Research Center, Ajou University, Suwon, Korea

요 약

지속 가능한 개발을 위해서는 환경영향을 최소화하고 능률이 높은 에너지의 활용을 위한 기존 기술의 개선과 신기술의 창출이 필요로 하다. 이 논문에서는 현재 진행중인 화력발전기술 및 원자력발전기술의 연구개발 현황과 앞으로의 전마을 평가예측하고 기술개발에 있어서 중요한 과제를 어떻게 해결해야 하는가를 제시한다. 또한 대체에너지기술개발의 현황을 평가하고 앞으로의 개발 가능성을 분석한다. 에너지의 운송과 배분 및 저장 기술 중 주목을 끌고 있는 연구개발 사업을 평가하고 최종수요자가 사용하는 에너지소비기술개발에 있어서 주어진 과제들을 분석평가하고 앞으로의 성취 가능한 기술개발 목표를 제시하였다.

Abstract — It is essential to continue research and development for efficient energy conversion technologies and systems which produce minimal impact to the environment in order to maintain sustainable development. In this paper we present a technical assessment of electric generation technologies, both fossil and nuclear, and recommend the desirable approaches in resolving major issues of the current research programs. Also we discuss the potential of renewable energy resources as well as the technologies under development for energy transport, distribution and storage. End-use technologies for efficient energy consumption are reviewed in terms of achievable efficiencies and commercialization.

1. Introduction

The challenge for securing energy resources for sustainable development can be met by finding new and improving existing energy technologies to provide energy sources which are efficient while producing minimal impacts to the environment. Ever since the 1970's energy crisis, we have been accelerating research and development effort to achieve that goal. Although we have seen many breakthroughs in those activities, we certainly have not reached a satisfactory solution for long term sustainable energy sources and systems. At the 17^{th} World Energy Congress there were reports on the latest research results as well as some innovative ideas for the progress of appropriate energy technologies. The commercialization of these improved technologies will definitely make positive contributions to the global energy demand and supply system.

Technology options that may be of interest are very diverse and can range:

- from resource extraction to increasing end-use efficiencies;
- from highly centralized technologies such as large scale nuclear powered electricity production to decentralized household solar water heating;
- from those energy systems relying on commercial fuels such as petroleum to those employing noncommercial fuels.

Also technologies can be closely classified according to the kind of resources such as oil, oil shale, natural gas, coal, uranium, hydro-power or solar energy. In addition, technologies can be associated with various stages of the energy production, transportation/transmission, distribution, and end-use systems. However, the review of technologies for

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sustainable energy sources and systems at the 17th World Energy Congress is grouped into two categories: 'Generation Technologies and Issues' and 'Distribution and End-Use Technologies and Issues'.

The various technology options must be assessed and analyzed with respect to a number of issues of concern, potential impacts on the objective functions and consequences to the expected payoffs. For examples, the following issues should be addressed:

- Total fuel demand and optimization of fuel mix
- Reduction of the dependency on fossil fuels
- Potential to attain social goals
- Reduction of energy cost
- Minimization of capital requirement
- Improvement of reliability
- Favorable impacts on environmental issues such as air quality, use of arable land, water quality, occupational health, etc.
- Possibility for practical application

Technologies are in a state of continuous improvement and/or adaptation. Furthermore, the value of technologies varies from nation to nation and is subject to the specific characteristics of the total energy situation in that respective country. For example, the primary efficiency is defined by the ratio of the useful energy out of the process to the primary energy delivered. If a significant amount of ancillary energy of some other form can be used in certain nations, the value of primary energy can be changed in those nations. On the other hand, for end-use technologies, the relative effectiveness is more important rather than the primary efficiency.

In this overview paper, we present a view of the current state of technologies and technical developments mainly based on the areas of interest reflected by the papers submitted to the World Energy Congress.

2. Electricity Generation using Fossil Fuels

Electricity is the most important form of energy for modern society. The generation, transmission, and use of electricity sustain our economic productivity, elicit technological and scientific innovation, and profoundly influence the quality of our environment. In advanced countries more than one-third of the total primary energy resource is used for generating electricity. Scientific research and technological development activities to produce more efficient electricity generation, loss-free transmission, efficient end-use, minimum environmental impacts and higher reliability are key technical issues. Electricity is generated by converting potential energy of hydropower, chemical energy of fossil fuels such as oil, coal or gas, nuclear energy of fission, radiation energy of solar power, kinetic energy of wind power, or thermal energy of geothermal sources. We can also look ahead to the use of fusion for electrical generation purposes. Conversion processes of these energy resources into electricity require continuous technological improvements of conversion efficiencies, environmental controls, and operational protocols. This involves both improvements and innovations of technical process, design of hardware and software contents. At the World Energy Congress, the attention is focused on electricity generation by advanced thermal power technology, nuclear fission process, nuclear fusion process, direct conversion of solar radiation, wind power generation and the utilization of biomass for electric generation.

High quality fossil fuels such as oil and natural gas have been used extensively for the generation of electric power. Recently, electric generation using natural gas has been on the increase in advanced nations due to the advantages of less environmental impacts and shorter times for the construction of the gas-fired units. Employing the combined cycle technology, electricity generation using natural gas has been economically competitive where natural gas is readily available through pipelines. However, the problem is the finiteness of the reserves of oil and gas. At the present rate, they will be depleted within 50 to 60 years. In order to meet the increased demand of these fossil fuels, advanced technologies for exploration and production must increasingly be employed. Additional effort is given to those technologies for utilization of low-quality fossil fuels including liquidation and gasification of coal, gasification of residual oil and extracting 'imbedded' fossil fuels from oil shale or oil emulsions.

In terms of resource extension and conversion technologies for sustainable development, one of the most important future technologies for electricity generation is Integrated Gasification and Combined Cycle technology (IGCC) for utilizing low-grade fossil fuels. IGCC is converting coal, oil emulsions or residual oil into gaseous form of fossil fuels, which are more accessible for the clean-up process of removing environmentally polluting materials. The cleaned gaseous products can be combusted at higher temperatures to run gas turbines and then the residual heat can be fed into steam cycle engines. The overall efficiency of combined cycles is making the economics of IGCC very competitive. The efficient removal of pollutants also makes IGCC very favorable to the more stringent environmental control standards.

S. Hisa et el of Toshiba Corporation (1) report the recent progress of the Japanese IGCC development program. They expect that, by the year 2010, the thermal efficiency of IGCC plants will rise to 46~48%, which is 15~20% (relative) higher than today's plants burning pulverized coal. This will also result in a 15~30% reduction of CO_2 emission. IGCC plants can reduce SOx and NOx emissions significantly lower than conventional pulverized coal plants.

Typically, an IGCC plant consists of a gasifier, a gas-cleaner, a moisture separator and a combined cycle thermal plant. The combined cycle unit is composed of a high efficiency gas turbine, a heat recovery steam generator and a steam generator. There are a number of technologies for the gasifier under development. Also different clean-up technologies are under test. Japan is building an IGCC commercial 500 MWe capacity unit by year 2002. In Italy, two 500 MWe and one 230 MWe units are under construction with the completion date set for 2001. Both countries utilize the wet Texaco process that uses slurry of heavy residual oil. The gas clean-up process is also a wet low temperature process. In the US, the Tampa plant with a capacity of 300 MWe has been in operation over one year. In Netherlands, Buggenheim plant, using dry feeds, with a capacity of 300 MWe has been in operation over one and half years. Spain is also constructing a 300 MWe IGCC unit using the dry process. In Korea, research work is being conducted for an efficient dry process gasifier.

3. Nuclear Power Generation

Whereas IGCC is probably the most important electricity generation innovation technology using fossil fuels, the central issue of electricity generation for the coming century is probably the issue of nuclear power generation. We recall that the 1970's energy crises greatly accelerated the construction of nuclear power plants not only in developed nations but also in newly industrializing nations. France standardized its design of pressurized water reactor plants and succeeded in freeing herself from excessive oil dependency. In fact, France is exporting electricity generated by the nuclear power plants. Japan also built a large number of nuclear power plants using both pressurized water and boiling water reactor technologies. Nuclear power generation technology gave a high hope for supplying the bulk of electricity needed to sustain the advancing technological civilization. Unfortunately problems arose in connection with safety, safeguard and waste disposal for nuclear power generation. The TMI and Chernobyl accidents enhanced public anxiety over nuclear power generation. The NIMBY, 'not in my back yard', syndrome created serious difficulties in securing new sites for nuclear power generation facilities. The nuclear power generation option must confront some extremely difficult challenges, if it is to be seriously considered again as a major technology for future electricity generation.

There are over 440 nuclear power reactors providing roughly 17% of the electricity generated worldwide. The annual production of electricity by nuclear power reduces emission of carbon dioxide by 2,300 tonnes annually. This is a very important advantage over fossil fuels for the consideration of energy supply necessary for sustainable development. Nuclear power is a proven electricity generating technology that emits no sulfur dioxide, nitrous oxides, or greenhouse gases. Furthermore, the operating record of those nuclear power reactors has proven that the technology is practical for safety and reliability purposes if operated and maintained properly. But, in practice, there is no more new construction of nuclear power plants in North America, and nuclear activities in West Europe are reaching a state of saturation. Nuclear power plants in East Europe need substantial inputs for improvement. Only in Asia, nuclear technology is receiving a high priority for the provision of electricity in the coming century.

However, authors presenting papers on nuclear energy at the 17th World Energy Congress point out the importance of nuclear energy in meeting the energy demand of the future. B. Wolf declares that nuclear energy is the only practical solution to the pending world energy problems as many other proponents of nuclear energy have done for many years so far. In order to meet world energy needs by the middle of the next century, nuclear energy should provide half the needed energy. This would require the construction of about one hundred new nuclear plants a year for the next fifty years. Can this be feasible? Can those barriers preventing nuclear power from fulfilling its role be removed?

G. Watts of British Nuclear Fuels and A. J. Rastas of Finland discuss those barriers and some potential solutions to overcome those barriers. The major technological barriers are:

- ensuring nuclear safety
- implementing waste management
- increasing construction and maintenance efficiencies
- enhancing R&D activities for innovations
- maintaining technological expertise.

The recent report by the Atlantic Council entitled "An Appropriate Role for Nuclear Energy in Asia's Power Sector" (2) summarizes the feasible solutions to those barriers.

The future of nuclear power depends on the safe operation of all nuclear power plants as evidenced by the impact of the Chernobyl accident. Concern for safety pervades the entire nuclear power sector, from the design to construction stages as well as operation. In design and engineering, the required activities include adopting sound basic designs, adhering to appropriate codes and practices, using fully tested materials and components, providing adequate margins and fail-safe arrangements while facilitating maintenance and proper operation. Construction requires modern project management techniques and strict quality assurance practice. Standardization of nuclear power plant design would enhance safety and reliable operation through easier station management, staff training and maintenance.

Most incidents and accidents occur due to improper operational practices, human error and inadequate maintenance. In operation and maintenance, safety requires clear and correct procedures, manuals and records of all activities, and sound operating policies and practices, assuring work in conformance with operating policies and regulatory requirements and rigorous training. Stringent quality assurance and control is required in all processes. The workforce needs to be well trained and benefits from excellent training facilities, training materials, instruction, and on-the-job training. The human factor is critical in ensuring the safe and sound plant management which is necessary to develop a correct and robust safety culture. Both management and the work force must be trained in a strong and disciplined safety culture to follow well laid-out procedures. Officers, managers and supervisors must have in-depth technical and safety-related knowledge appropriate to their positions and responsibilities, and have clear lines of command to which they are held accountable.

Safety requirements, as well as technological methods, have continually made progresses. Although the main design bases are still valid and appropriate from the safety point of view, there are many improved design features applicable to the existing power plants. The 'evolutionary' processes on the major nuclear power plant designs are ongoing in a number of nations that have strong nuclear programs. Evolutionary modernization to improve the redundancy and robustness of safety systems to inherently prevent severe accidents shows great promises not only technically but also from the point of view of public acceptance. For example, the reduction of core-melt probability by a factor of 10 to 100 is necessary in order to increase the number of operating nuclear power plants. Such improvements of design are quite feasible by incorporating newly developed instruments and control technologies as well as fully employing modern probabilistic safety assessment methods. New knowledge and up-graded techniques are available for the improvement of nuclear power plant design. Work is also going on for the development of revolutionary designs of future nuclear power plants, although their commercial utilization is still some years away.

Waste management is a difficult issue for any industry, but particularly so for the nuclear industry because of widespread anxiety by the public and the long-term nature of radioactive wastes. Although advanced countries operate interim storage and conversion facilities of nuclear wastes; there is no permanent repository for highly radioactive wastes. Because many nuclear nations have not settled their plans to handle spent fuel and radioactive wastes, over 100,000 tonnes of spent fuel is currently safely stored waiting for the final societal decision. Discharges of spent fuel from world nuclear power plants were estimated to be about 32,000 tonnes in 1997, and are expected to rise by about 10,000 tonnes annually to a possible 220,000 tonnes by the year 2015. The present scheme of storing spent fuel in the on-site pools only buys limited time for the permanent solution. There should be technological demonstration and convincing actions by the joint authority of the government and private sector in order to convince the public of the safety and the appropriateness of the waste management. As of today, the safe storage of radioactive wastes has proven to be the most intractable global barrier for nuclear power generation, and could potentially inhibit further development of nuclear power in the future if not satisfactorily addressed.

Increasing efficiency of nuclear power generation is an important issue. In order to improve the competitiveness of nuclear power, we need to standardize the design, shorten the construction time, increase the operating capacity factors and improve the conversion efficiency of thermal energy into electricity. France, for example, succeeded in making nuclear power generation economically competitive in a relatively short time period. The Korean nuclear power program has a strong emphasis on standardization and its strategy has already started to pay off. Standardization of the plant design also shortens the construction time. In the economy of electricity generation, interest cost during construction is a major expense item. Utilizing a highly rationalized project administration practice, the construction time of large size power plants can be reduced to less than sixty months, possibly even fifty months. Good maintenance and operational practice technically improve the capacity factor of the plant. A high capacity factor is often related to the total quality assurance of plant operation. Also improving the fuel cycle efficiency and thermal conversion efficiency reduce the generating cost of nuclear electricity.

For a long time, nuclear power plants had been based on 'physicist's designs'. However, in recent years, the design has transformed into 'engineer's designs'. The nuclear power technology has two distinctive features: it is a system technology and it is rather young. Although the nuclear power technology is a system technology, the available nuclear power plant designs have not been fully benefited from systems engineering. Since the mid-1970s three reactor designs have accounted for over 80% of operating reactors: PWR, BWR and PHWR. In 1995, there were 246 operating PWRs, 93 BWRs and 32 PHWRs including CANDUs.

Although governments' support for the nuclear technology has been declining, there are more opportunities to improve nuclear power technologies. Better instrumentation and control systems, improved coolant chemistry and its controls, preventive maintenance techniques, optimization of refueling, increased burn-up, extension of plant life and safety inspection techniques are items which can pay off handsomely by R&D activities. Also advanced reactor technologies such as passive safety features, increased modularization, new types of fuels such as MOX, thorium-based fuel cycles and accelerator breeders are calling for active research investment and technical leadership.

In order to make nuclear energy as a candidate of energy source for sustainable development, the most important issue in the final analysis is how to maintain the technical base and expertise during the present largely inactive days for research, engineering and construction activities. Today, there are only about 30 nuclear power plants under construction worldwide. Many advanced nuclear engineering programs are being closed down or are merging with other engineering disciplines. There is no global leadership that can generate enthusiasm for the nuclear option. The serious question is whether there are reasonable chances for a nuclear renaissance in the 21st century. To maintain a reasonable chance, we have to maintain the current expertise and educate the next generation experts who can utilize the valuable knowledge basis and further improve the engineering and design packages of nuclear power generation.

The public acceptance of nuclear technology will be boosted as we understand more about the seriousness of the global warming by greenhouse gases emitted due to extensive use of fossil fuels. The recent development of public awareness of climate changes tells us what we should maintain and improve the nuclear power technology for the future and coming generations.

4. Alternative Energy Technologies

Since the energy crises, there have been a number of major R&D programs for alternative energy sources such as solar, nuclear fusion, biomass, wind energy, etc. Photovoltaic conversion of solar radiation energy into electricity, solar space and water heating, controlled thermonuclear fusion energy, extensive biomass energy production, electricity generation by wind power, hydrogen fuel production, fuel cells, synthetic fuel production, and geothermal energy extraction have drawn research support by many public and private research funds.

Because of its intrinsic 'renewable' nature, solar energy has been the subject of intensive research for the major energy supply for the coming century. The focal points of the solar energy research are:

- how to produce economically competitive solar cells which are reliable and maintenance-free for the long term,
- collect low intensity solar energy for production of high intensity central thermal power, which can be used for electric gene- ration, and
- supplement with efficient and economic energy storage systems.

Impressive solar energy R&D results have been achieved, but practical commercialization has so far been limited. Yet, photovoltaic generation of electricity is making an increasing contribution to the supply of energy services and emerging as an economic alternative for peak-power supply. The efficiency of single-crystal silicon photovaltaic cells has increased to over 23%, while costs have declined by a factor of 2 or more. L. Vronicke et el of Israel report the successful operation of high temperature solar energy collectors and propose integrated energy systems which can make solar energy more attractive economically. Solar energy for space and water heating is ideal in developing countries where low intensity heat supplies are needed for daily life. Both wind energy and geothermal energy are of low intensity and also limited geographically.

Liquid fuel production from biomass is an important renewable energy. Liquid fuels from biomass include:

- methanol produced by gasifying biomass;
- ethanol fuels derived from grains, crops or wood;
- hydrogen fuels derived from biomass by gasification or from water by electrolysis or by chemical membrane reactions;
- gasoline derived from biomass through refining; and
- diesel fuel produced from vegetable oils and microalgae oils.

These biofuels burn cleanly and plants grown as feedstocks for these fuels absorb greenhouse gas. Currently, however, only ethanol fermented from corn is produced in commercial quantities. Blending with gasoline in concentrations of 10%, the resulting gasohol is sold commercially.

The use of renewable energy resources generally benefits the environment. Renewable energy technologies contribute little or nothing to environ- mental pollution or to the potential for global climate change. The price of energy from renewable technologies is dropping. As emerging renewable technologies become mature, renewables should penetrate the energy markets more broadly. However, investment in renewable energy systems is currently hampered for several reasons. First, lack of experience in utilizing renewables, compared to the experience in using fossil and nuclear power plants, makes energy planners hesitant. Reliability, operating lifetime, maintenance requirements and availability of renewables are not well known. Also the infrastructure for renewables is at the beginning stage and the existing infrastructures for fossil fuels and nuclear are competing. Furthermore, some renewable energy facilities require much more capital outlays. Although the long term economics of renewables are competitive, financial markets prefer the lower risks associated with low capital cost facilities. Finally some renewable energy technologies are constrained by excessive regulatory requirements and environmental considerations.

Synthetic fuel production technologies received great attention in the past and R&D programs for synthetic fuels are still conducted. Techno-economic analyses of these technologies have not yet predicted advantages over more advanced exploration and extraction technologies of natural fossil fuels. The main barrier is the price competitiveness. Technology is available but the present economic situation is not favorable for commercialization. Fuel cell technologies have some distinctive advantages over the conventional power generation technologies from the environmental aspect. Of the various types of fuel cells produced throughout the development of the technology, three appear to be more promising than others. They are phosphoric acid fuel cell (PAFC), molten carbonate fuel cell (MCFC) and solid oxide fuel cell (SOFC). Each technology is distinctly different from a fabrication and engineering point of view. The PAFC is most advanced and commercially available. The MCFC technology, second generation fuel cell, has a potential for a higher efficiency conversion because of the potential for adding a bottom cycle and is less sensitive to the environmental gases. The SOFC technology is most attractive but requires substantive materials and engineering development. Although important developmental milestones have been reported, commercial application requires further progress in reliability and efficiency. USA, Japan and EU have very active development programs.

Controlled thermonuclear fusion energy research has been conducted for more than 40 years. Initial optimism has been faded due to the realization of poor understanding of fully ionized plasmas. There are basically two approaches; magnetically confined fusion and inertial fusion. Heating to the fusion temperature has been demonstrated, but confinement time is too short to engineer the production of steady fusion power. The recent reduction of funding by participating nations in the international cooperative fusion research also delays more ambitious construction of engineering or demonstration fusion devices. At the present, we can say that the scientific feasibility of fusion power is established, the engineering feasibility of practical fusion power has yet to be demonstrated and the economic feasibility is far from proven. Fusion power could be a long-term proposition for the coming century.

5. Distribution and Storage Technologies

Very often, the load centers of energy consumption are located far away from the centers of energy production. For examples, the east coastal region of China is one of the fastest growing heavy energy consumption load centers but it is located far from coal mines, oil and gas fields or the large hydro power plants under construction. Western Europe needs a large supply of natural gas and Russian gas has to be pipelined for a long distance from the production field to the consumers. Safe and economic transportation and transmission of energy over long distances are major issues of energy technologies. It involves transformation of energy resources, dedication of transportation means, controls and measurements of energy flow, and interconnections of distribution networks. Both the hardware and software of technologies in a number of disciplines are required to set up the needed infrastructure and logistics. Introduction of new high technologies is often necessary to design and ensure the delivery and implementation of the end products.

Kucherov and his co-authors of Eastern European nations discuss the possibility of creating the trans-European synchronized interconnected power system. In Europe, there are two large power grids; UCPTE connects and operates synchronous power systems for 15 states of the Western continental part of Europe and UPS unites the power systems of 11 Eastern European nations. The proposed trans-

European power system will provide major economic benefits such as reduction of the stocks and reserve capacities, relief of energy shortages in a number of European nations, and optimization of power production and maintenance activities. However, there are technical and management issues: resolution of uneven technical parameters and qualities of electricity sources, reliability of generation and transmission subsystems, maintenance of the overall reserves at all time, emergency coordination, etc. Nevertheless, such interconnection is feasible and forthcoming in the trans-European gas pipelines.

Similar propositions have been discussed in Asia, although the Asian case is far from realization. There are huge oil and gas reserves in remote areas in Asia such as Eastern Siberia; whereas energy consumption centers are located at the Western Pacific Rim areas of the Northeastern Asia. For the supply of energy and development, pipelines for gas transportation and connected grids would provide great energy supply impact in the coming years. Unlike the European example, the Asian interconnection requires concurrent development of energy sources. An immense amount of investment is necessary. The electrical grid of the future, with highly decentralized power sources and substantially higher capacity than today's systems, will not be possible without major breakthroughs in electrical power engineering. The grid will consist of both AC and DC technology with various switching devices. Furthermore, new components and materials are introduced to increase efficiency and reliability. The system's viability is also a significant technical challenge.

Transportation of oil and liquefied gas via ocean shipping has been in operation for many years and the technology is mature. However, considerable transport accident probability which could cause great environmental damage still exists. Major oil spills have occurred and will occur again. For shipping LNG, major capital investment is needed for liquefying and receiving base stations as well as for safety engineered LNG ships. After regasification, the pipelines transport natural gas to the consumers. Safety provisions are necessary to avoid major accidents due to leakages and breaks of pipelines. Advanced sensor technology and integrated monitoring systems are installed to prevent major accidents.

Transportation infrastructure, particularly railroad, is the limiting factor for coal utilization. Coal mines are normally located considerable distances away from load centers. In China and India, where coal is the major energy resource, coal transportation is the biggest business for railroads. In China, coal accounts for 75% of the power supply. The volume of coal transported from Shanxi province, one of the key coal producing regions in China, increased 20 times during the past 30 years but the capacity of railroad increased only fivefold. Because of lack of transportation capability, the authority limited the production capacity of coal. The energy shortage for the eastern coastal region, which is the fastest developing economic area in China, is caused by the inadequate transportation facilities. Coal can also be transported in slurry form. Although the slurry transport feasibility has been well established, economics of the technology has not been demonstrated.

Whereas distribution technologies connects the production of energy with consumption centers separated by long distances; energy storage technologies resolve the time separation of energy production and consumption. The ideal energy storage system should be inexpensive, convenient and safe to use, quickly available on demand, compact, and non-polluting. Batteries, which store electrical energy, are important for both regeneration of electricity and electric vehicle propulsion. The most widely used lead acid batteries are very useful for low current applications while new lithium batteries show promise for heavy-duty applications such as electrical vehicles. However, pumped-hydro, compressed air, and batteries are available today for energy storage purposes. Pumped hydro systems are most economical in large size (over 1 GWe) and are best suited for baseload duty. Compressed air storage systems cost much less. Battery systems are most appropriate for providing peak power. These technologies are proven and used commercially. Although technical progress will gradually reduce their costs, no major breakthrough in cost reduction is expected.

For renewable energy systems, hydrogen-based systems are expected to be the most economical and efficient means for collecting, storing and transporting energy. Hydrogen is also the cleanest and recyclable. Solar and wind energy systems gain competitiveness by being connected to hydrogen production, storage and distribution systems. Winter and Nitsch concluded that solar energy could become a commercial commodity and would, as a component of the hydrogen energy economy, provide a challenge to conventional electricity production.

Storage of mechanical energy using flywheels is useful on automotive crankshafts. Storing heat or cold is another mechanism to store energy. At the 17th World Energy Congress, H. Paksoy of Turkey reported the feasibility study of underground thermal energy storage technology: storage in pits, tanks and rock caverns; storage in aquifers; and storage in ducts. Underground thermal energy storage provides a mechanism that can enhance sustainable development in developing countries.

6. End-Use Technologies

Technologies for improving the efficiency of energy use or changing the fuels used span a wide range of technical research and development endeavors. In transport, better engines can improve fuel efficiency. Alternative fuels including methanol, ethanol, natural gas, electricity or hydrogen are possible. Also developments of batteries, gaseous storage systems or small-scaled fuel cells can be used for powering efficient electric vehicles. New jet engine designs and improvement of older ones save energy and reduce energy consumption in air transport, which requires huge amounts of high grade fossil fuels. Similarly, advances in electric motor drives can improve efficiencies in a wide variety of electric motor applications, which may be amplified by the better optimization of systems. Household appliances are continually improved energy-wise. For example, refrigeration efficiency can be improved through better motors, advanced power electronics, improvement of insulation, and system designs. New lighting technologies and control mechanisms can also reduce energy consumption.

The largest energy consumption sector is industry. A wide range of improved industrial processes is available. In industry, the distillation process is very energy-intensive and new technologies for separating fluids can reduce energy consumption significantly. Electrothermal techniques using microwaves or radio-frequency waves can deposit intense energy (heat) at particular locations on surfaces or within materials for relatively less energy inputs. New catalysts are developed to accelerate chemical reactions consuming less energy. New materials can replace older energy-intensive materials so that the overall energy intensity can be substantially reduced without sacrificing the quality of products or facilities. For example, strong plastics can replace energy-intensive metals or smoother materials can reduce frictional energy loss. If high temperature superconducting materials become available, revolutionary energy savings will be feasible and the resultant potential for energy saving is beyond imagination.

Improving end-use efficiencies is the best way to reduce energy consumption and mitigate the environmental consequences of energy use. This view is based on analyses of the technical probabilities for improving current efficiency levels, and economic costs of such improvements were compared to the alternative of expanding the energy supply. Improving current end-use technologies, as well as those that may be possible via fundamental redesign and reorganization of the technologies and systems which provide those energy related services can be a significant contributor to energy savings and should not be overlooked.

Let us now review some of important end-use energy technologies and their recent progresses. The first item is energy technology for transportation. Energy consumption for transport is growing faster than in any other sector of the global economy. Cars are the major consumers of fossil fuels and many technological options are available for improvement of energy efficiency. Those options include modified and improved engine design and controls, improved powertrains including continuously variable transmission, reductions in weight, and reductions of rolling and air resistance. Available technology could deliver up to 40% improvement in average fuel economy by the year 2010 at little extra cost and without loss in performance while incorporating the more stringent emission controls.

Since the 1970's oil crises, fuel efficiencies of motor vehicles have been improved markedly. Most of the improvements occurred between 1975 and 1985 when oil prices were rising and the automobile market looked for fuel saving cars. The new car fuel economy was improved by about 20% in Europe and over 35% in the USA during that period. Improvement in fuel consumption can be made through economic power production for propulsion and minimization of the power required to propel the vehicle. The world average fuel consumption is about 10 litres/100 km. It has been estimated that about 75% of the fuel energy is used in the engine, 15% in the transmission, and only 10% turns the wheels. Precision cooling, reduced engine friction, reduced pumping losses, direct injection, electronic engine management, automated manual transmission, continuously variable transmission, weight reduction, aerodynamic improvements, improved tyres, lubricants and accessories can improve the fuel economy of automobiles. Cars capable of travelling at an average of 4.4 litres/100 km have been on the market since the early 1990s.

There are substantial opportunities for saving electricity by improving the design of major household appliances, which consume over 30% of total domestic electricity in developed countries. For example, refrigeration appliances can be designed to use only one third the current electricity required in the better models in the market. Experts claim that domestic consumers could save up to 25% of their electricity consumption at net economic savings by purchasing energy saving household appliances.

Lighting accounts for about 15% of total electricity consumption in the developed countries. Recent advances in lighting technology, especially improvements in fluorescent lamps, could reduce projected energy consumption for lighting by 30% without a decrease in lighting quality. The most important technical options are replacing filament lamps by compact fluorescent lamps in the home and using high frequency fluorescent lighting instead of conventional fluorescent lighting in commercial applications. Advanced control systems tailored to the service requirements can also save substantial energy. Although there have been continuing improvements for filament lamps such as the development of the tungsten halogen lamp, metal halide lamp and the high pressure sodium lamp; the replacement of filament lamps with high efficiency fluorescent lamps offers a great energy saving opportunity. Also fluorescent lamps being operated at higher frequencies can save energy and the recent developments in electronics provide technical solutions for the use of high frequency fluorescent lamps. There are three main opportunities for saving energy through need-based controls; integration of lighting with daylight, task-related regulation of lighting and presence-detector control of lighting. By incorporating these measures, energy savings in lighting can be realized from at least 20% to a maximum of 90%.

Nearly one half (30~50%) of all energy consumed in industrialized countries is used in buildings. The total energy used in a building depends on the efficiency of the various end-uses such as heating, lighting and air conditioning. Energy saving is available by improving the overall management and coordination of energy use in buildings. Building energy management systems exploit modern computing, control and sensor technologies to manage energy uses in buildings more efficiently. Control is the key to energy management. The advent of microelectronics and sensors has greatly increased the ability to control services such as heating, air conditioning, ventilation, lighting and running appliances. Control can be a simple on/off switching system for a small house to an integrated computer based system for controlling a wide range of functions in a large commercial building. Distributed intelligence systems are also applicable for a set of separate sites linked by a communications network to a central supervisor unit. This communicated data provides key information for energy management and related automated systems can be installed to provide substantial energy savings (20~40%).

At the 17th World Energy Congress, a few papers were presented in connection with end-use energy savings technologies. Y. Chen discusses the energy issue of the Chinese transport system whereas Maillard of SNCF presents a paper on the energy implications of the railroad transport system. Similarly, D. Bennet discusses the constraint issues of energy and environment in air transport. Klein and McKay of the Netherlands present a long-term view on the future of electric road transport based on renewable energy.

7. Concluding Remarks

There are a large number of opportunities for technological innovation in how we supply and use energy. There are high tech solutions such as IGCC, passively safe fission nuclear power plants, or new photovoltaic systems. At the same time, there are low-tech solutions such as more efficient end-use devices or transportation systems. The solution for sustainable energy sources and systems would require combinations of both high and low-tech solutions in a systems engineering environment. In practice, a sustainable global environment requires multiple solutions; each matched to achieve optimal performance between the energy source and the end-use systems. We must not only improve the efficiency of fossil fuel utilization to reduce emission of polluting and greenhouse gases but also seek non-fossil fuel new energy sources which will fill the increased energy demand. Energy saving technologies are of particular importance since saving one joule of energy means a savings of more than one joule of supply energy, sometimes this supply savings may be about three times the end-use reduction in the case of electricity production.

However, we have to be aware that technical solutions will not be attainable without the proper investment of human and financial resources. The governments will have to create a conducive environment for new technical solutions to be integrated into the overall energy systems. Incentive measures and regulatory enforcements are necessary for increasing efficiencies and increasing energy savings through the commercialization of new technical solutions. We must also keep in mind that education and training plays a critical role in the achievement of these goals. Providing and maintaining competent professionals to carry out research and development activities as well as energy engineering tasks are absolutely essential for formulating and implementing successful technical solutions.

References

1. Papers quoted in this overview are presented in Sessions 4.1 of the 17th World Energy Congress at Houston on September 15, 1998.
2. The Atlantic Council has been reviewing the issue of nuclear power. In June, 1997, it held the seminar on nuclear power in Asia in Seoul, Korea. The proceedings were published in February 1998 under the title, "An Appropriate Role of Nuclear Energy in Asia's Power Sector". The follow-up seminar to discuss the global issue of nuclear power was held in Cannes, France during the first week of May 1998.
3. An excellent review of end-use energy technology is given in the book entitled "Emerging Energy Technologies: Impacts and Policy Implications" published by the Royal Institute of International Affairs in 1992.