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New Energy Sources: Technological Status and Economic Potentialities

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New Energy Sources: Technological Status and Economic Potentialities

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Abstract- There are different types of energy sources: traditional, commercial, primary, renewable and the new energy sources. The new energy sources, from the perspective of this paper are those that have been innovated in the recent past and are still being innovated by the scientists and technologists to meet the energy challenges. The availability of the fossil fuels or the commercial sources: coal, oil and gas is finite. Human beings have already used a considerable portion of the reserves. The reserves are maturing. Besides, these sources cause environmental pollutions: particulates, acid rains, toxic pollutants, particularly greenhouse gases. The greenhouse gases are warming up the globe with consequent climatic changes. Global warming and climatic change is presently one of the major challenges before human race.

New energy sources are important to meet the ever growing need of energy for smooth transition from the present day predominantly finite sources to pseudo unlimited energy sources like fusion or solar energy. In order to achieve the goal of sustainable development, national as well as international commitment and coordinated efforts are essential to harness the new: nuclear, solar, wind, tidal, geothermal, biomass, hydrogen and other new renewable sources optimally.

The paper tried to focus on the technical status and economic potentialities of a number of the new energy techniques or sources that appear to suit sustainable development.

I. Introduction

Energy is one of the key elements for economic development of a country. There are various types and forms of energy sources. The sources are evolving from predominantly traditional sources like firewood, vegetable wastes, cow dung etc. to commercial sources e.g. coal, oil and gas and now though slowly, to new sources e.g. nuclear, photovoltaic, LNG, CNG, hydrogen, wind turbine, geothermal etc.

The human knowledge is expanding. The technology is becoming more and more sophisticated. There are continued and consistent efforts among the scientists, technologists and researchers to move towards more efficient and cost effective energy sources. The new energy sources are the outcome of the application of the new knowledge, research findings and innovated technology.

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The availability of the sources, end uses and environmental considerations and finally the cost effectiveness are the deciding factors in the selection of the type of source.

The reserves of the presently dominant primary sources: coal, oil and gas are maturing. Nature took about three million years to produce these sources. Much more exploration efforts are now required to find new reserves and the growth of consumption rates lags the discovery rate.

At some stage of future date people will have no option other than to use the new sources particularly fissile and renewable sources till pseudo infinite source like fusion become technically and economically cost effective. Yet, the new energy sources are increasingly used from the perspective of cost, accessibility and environmental considerations.

Strong political will, continued R& D, public awareness will be required to harness the benefit of new energy sources optimally.

II. New Energy Sources

a) *Perception*

The universe consists of fundamentally of mass and energy. Energy and mass are always conserved. Neither of the two can be created but the conversion from one to other is possible. In fact most of the energy sources are not new. The techniques of using the energy sources and or conversions from one form of the source to other form of energy are new. The techniques are becoming more and more sophisticated with the passage of time and as the human knowledge is expanding and the capability is increasing.

The new energy sources, from the perspective of this paper are those sources or techniques that have been *evolved or innovated lately from the consideration of efficiency, cost optimization, environment, user friendliness etc*.

From the aforesaid perspectives, an improved oven which uses firewood or vegetable wastes is a new technique. While the biogas produced out of cow dung for domestic use may be termed as, at least from the perspective of this paper, a new source. The new technique and the source are more efficient, user friendly and less polluting.

There are many such devices or techniques and the sources. The paper will touch only a few ones. Out of these only the important and the promising ones will be discussed further in the subsequent presentations of the short course.

b) *Fundamental Forces*

Energy is required to do work. Work is defined as force multiplied by distance. For any work at least equal amount (at 100% efficiency, which is practically impossible) of energy is required. *There are three fundamental forces: electromagnetic force, gravitational force and the strong nuclear force*. Any one of these three forces is involved in the process of work and the delivery of energy or conversion of the same.

i. *Electromagnetic Force*

Energy is produced out of commercial energy sources: coal, oil and gas or traditional fuels through interactions of electromagnetic forces. The interactions take place by *chemical reactions* during burning.

ii. *Gravitational Force*

The source of hydropower is *gravitational force* converted to potential energy. The energy produced depends on height and quantity of flow that can be sustained. The commercial hydropower is being used for about 140 years. But the pumped storage hydro power station is relatively new and may be termed as new source. Pumped hydropower stations are used for peak loads of electrical power system from economic considerations. The number and cumulative capacity of such stations are increasing.

iii. *Strong Nuclear Force*

Strong nuclear force is the force that holds the particles in the nucleus i.e. neutron and proton. It is also called gluon. The root of solar energy is *fusion. The fusion energy is the result of interactions of strong nuclear force.* The nuclei of two lighter atoms usually of hydrogen, deuterium and tritium are fused together to produce a heavier atom releasing enormous amount of energy.

Energy produced from nuclear power stations also come from the strong nuclear force. Here the process is reverse. Energy is produced when a heavy nucleus, usually of uranium or thorium, breaks (*fissions*) to form two lighter atoms and the release of particles. Enormous amount of energy is also produced during the process of fission.

c) *Solar Energy*

The source of the most of the renewable energy sources: solar, wind, tide, biomass, ocean current etc is the sun. Solar energy falls in the group of traditional energy as long as it is used for drying of crops, clothes etc. in traditional way. But the photovoltaic, innovated solar cooking devices or solar thermal power stations etc. fall into the category of new energy techniques or sources.

d) *Wind Energy*

Traditional use of wind power for sailing, processing of crops fall in the category of traditional energy source. But the wind turbine that generates electricity can be termed as new energy technique or source.

e) *Geothermal Energy*

The origin of geothermal energy is the heat trapped in the interior of the earth during its formation. *Some scientists believe that the source of the trapped heat is nuclear fission*. The fission is still taking place in the core of the earth where heavy atoms of uranium and thorium were concentrated due to the gravitational force at the time of formation of the earth.

f) *Nuclear Energy*

The *fissile energy sources*: *uranium* (Ur^{235}, Ur^{233}) *and Plutonium* (Pu^{239}) fall under new energy sources. The source of *fusion energy is hydrogen, deuterium, tritium and helium*. Nuclear energy is generated by *fission or fusion through interactions of strong nuclear forces.*

g) *Category of New Energy*

The new energy techniques or sources can be categorized under three broad groups-

- Renewable;
- Nuclear; and
- Advanced technologies.

III. Technical and Theoretical Potential

The technical and theoretical potentials of the renewable and fissile sources are extremely large. The summary of the potentialities of the global fossil and nuclear sources are shown at Table-1 and that of renewable sources are shown at Table-2 .

Table 1 : Summary of the Global Fossil & Nuclear Energy Sources, Source [1. p.166]

Summary Of Global Fossile And Fissile Resourses (Thousands Of Exajoules)						
Resource	Consumed by end 1998	Consumed in 1998	Reserves	Resources	Resource base[a]	Additional occurrences
Oil	5.14	0.14	11.11	21.31	32.42	45
Conventional	4.85	0.13	6.00	6.07	12.08	
Unconventional	0.29	0.01	5.11	15.24	20.35	45

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Gas	2.38	0.08	14.88	34.93	49.81	930
Conventional	2.35	0.08	5.45	11.11	16.57	
Unconventional	0.03	0.00	9.42	23.81	33.24	930
Coal	5.99	0.09	20.67	179.00	199.67	
Fissile total	**13.51**	**0.32**	**46.66**	**235.24**	**281.89**	**975**
Uranium						
Open cycle in thermal reactors[b]	n.e.	0.04	1.89	3.52	5.41	7.1[c]
Closed cycle with fast reactors[d]	-	-	113	211	325	426[b]
Fossile and fissile total[e]	**n.e.**	**0.36**	**48**	**446**	**575**	**1,400**

n.e. Not estimated. – Negligible.

a. Sum of reserves and resources. b. Calculated from the amount in tones of uranium, assuming 1 tonne = 589 terajoules (IPCC, 1996a). c. Does not include uranium from seawater or other fissile materials. d. Calculated assuming a 60-fold increase relative to the open cycle, with 1 tonne = 35,340 terajoules. e. All totals are rounded. Source: Author's calculations from previous chapter tables.

N.B. *Sea water contains less than 3 parts per billion of uranium. But the quantity of uranium is about 4.5 billion tons or 700 times of known terrestrial resources recoverable at a cost of $ 130/Kg. Uranium from sea water can be extracted at $ 300/Kg. Some recent studies reveal that it can be produced at cost as low as $ 80 to 100/Kg. [].*

Table 2 : Summary of the Technical Potential of Global Renewable Energy Sources, Source [1. p. 168]

Summary of the Renewable Resource Base (Exajoules A Year)			
Resource	Current use[a]	Technical potential	Theoretical potential
Hydropower	9	50	147
Biomass energy	50	>276	2,900
Solar energy	0.1	>1,575	3,900,000
Wind energy	0.12	640	6,000
Geothermal energy	0.6	5,000	140,000,000
Ocean energy	n.e.	n.e.	7,400
Total	56	>7,600	>144,000,000

n.e. Not estimated. a. The electricity part of current use is converted to primary energy with an average factor of 0.385. Source: Author's calculations from previous chapter tables.

The principal reasons for the minimal use of the vast potentials of the renewable energy sources are:

- Technologies are yet to be cost effective;
- Low energy density;
- Time dependence;
- Season dependence;
- Others

The primary reason for under use of nuclear power is geopolitics. There are of course the issues of safety, proliferation, waste management and safeguards that have to be properly addressed by the United Nations and the community of the states.

IV. New Renewable Energy Source Status

a) Background

The renewable sources supplied 56 ± 10 exajoules or about 14% of world primary energy consumption in 1998 [2]. Out of the total 38 ± 10 exajoules came from biomass. Hydropower and modern biomass contributed 9 and 7 exajoules respectively [2].

Renewable energy sources depend on energy flows through the earth's ecosystem out of the insolation (solar radiation) of sun and the geothermal energy of the earth [2]. From prehistoric period people used renewable energies in many ways for cooking, heating, processing crops, sailing boats and ships etc. The sources can be sub-grouped into the following:-

- Biomass energy;
- Hydro;
- Wind energy;
- Solar energy;
- Marine energy; and
- Geothermal energy.

The renewable energy sources have enormous potentiality and can meet many times the present world energy demand. If the sources are applied in a modern way, these may effectively help in attaining, environmental, social and economic goals.

The sources are briefly outlined in this paper. These will be further elaborated in the subsequent six lectures to presented under *Module-5: Renewable Energy*. The current status of renewable energy is shown at Table-3.

Table 3 : Current Status of Renewable Energy Technologies, Source [2]

Technology	Increase in installed capacity in past five years (percent a year)	Operating capacity, end 1998	Capacity factor (percent)	Energy production 1998	Turnkey investment costs (U.S. dollars per kilowatt)	Current energy cost of new systems	Potential future energy cost
Biomass energy Electricity Heat[a] Ethanol	≈ 3 ≈ 3 ≈ 3	40 Gwe >200 GWth 18 bin litres	25-80 25-80	160 TWh (e) >700 TWh (th) 420 PJ	900-3,000 250-750	5-15 ¢/kWh 1-5 ¢/kWh 8-25 $/GL	4-10 ¢/kWh 1-5 ¢/kWh 6-10 $GL
Wind electricity	≈ 30	10 Gwe	20-30	18 TWh (e)	1,100-1,700	5-13 ¢/kWh	3-10 ¢/kWh
Solar photovoltaic electricity	≈ 30	500 Mwe	8-20	0.5 TWh (e)	5,000-10,000	25-125 ¢/kWh	5 or 6-25 ¢/kWh
Solar thermal electricity	≈ 5	400 Mwe	20-35	1 TWh (e)	3,000-4,000	12-18 ¢/kWh	4-10 ¢/kWh
Low-temperature solar heat	≈ 8	18 GWth (30 min m^2)	8-20	14 TWh (th)	500-1,700	3-20 ¢/kWh	2 or 3-10 ¢/kWh
Hydroelectricity Large Small	≈ 2 ≈ 3	640 Gwe 23 Gwe	35-60 20-70	2,510 TWh (e) 90 TWh (th)	1,000-3,500 1,200-3,000	2-8 ¢/kWh 4-10 ¢/kWh	2-8 ¢/kWh 3-10 ¢/kWh
Geothermal energy Electricity Heat	≈ 4 ≈ 6	8 Gwe 11 GWth	45-90 20-70	46 TWh (e) 40 TWh (th)	800-3,000 200-2,000	2-10 ¢/kWh 0.5-5 ¢/kWh	1or 2-8 ¢/kWh 0.5-5 ¢/kWh
Marine energy Tidal Wave Current OTEC	0 - - -	300 Mwe exp.phase exp.phase exp.phase	20-30 20-35 25-35 70-80	0.6 TWh (e) - - -	1,700-2,500 1,500-3,000 2,000-3,000 -	8-15 ¢/kWh 8-20 ¢/kWh 8-15 ¢/kWh -	8-15 ¢/kWh - 5-7 ¢/kWh -

a. Heat embodied in steam (or hot water in distric heating), often produced by combined heat and power systems using forest residues, black liquor, or bagasse.

b) *Biomass Energy*

Biomass has very large energy potential. The solar to biomass conversion efficiency is less than 1%. The production of biomass as such requires large area of land.

i. *Heat*

A vast global population, mostly living in rural areas of underdeveloped and developing countries use biomass for cooking and heating. Greater use of improved ovens for cooking and heating will have great beneficial impact on the lives of these people. The improved ovens possess higher burning efficiency and produce less undesirable emissions.

ii. *Electricity*

Electricity can be produced through thermo-chemical conversion of biomass. Total installed capacity of such power plants is 40 Gwatt [1]. The plant size and efficiency ranges from 20 to 100 MW and 20 to 40% respectively.

iii. *Gasification*

Demonstration gasification plants with 40% efficiency have been built. Presently a biomass integrated gas (BIG) combined cycle (CC) 30 Mwe power plant costs about US $ 2800 to 5000 per Kw. Additional R& D works are required to develop economically viable BIG/CC power plant.

iv. *R&D*

Additional and continued R& D activities are required on the biogas production, production of liquid and gaseous biomass based fuels (bio-oil and bio-crude). Oil seeds and rapeseeds can be converted to esters to replace diesel. R& D works are going on to produce methanol, hydrogen and hydrocarbon.

v. *Environmental Impacts*

Large biomass production is associated with soil erosion and increased water usage. It also causes pollutions out of the use of agrochemicals and fertilizers. Further studies and research are required to reduce the adverse effects and cost of production and also to balance the negative effects with beneficial outcome.

c) *Hydro Energy*

i. *Background*

Hydropower uses gravitational force for the production of energy. The precipitation is stored at higher natural storage enhanced by dam. The potential energy of the stored water at high altitude is converted to kinetic energy and runs turbine to produce electricity. The theoretical and technical potential of hydropower are 147 and 50 Exajoules per year respectively. Current use is 9 exajoules per year [1].

The first commercial hydropower station was commissioned at Appleton, Wisconsin, USA in 1882. The technologies are improving and getting diversified. The pumped storage hydropower stations are new. The hydropower stations can be of the following types: *runoff river plants, runoff with pondage and reservoir plants (most common type).*

ii. *Present Status*

Among the renewable sources hydropower stations are by far the largest contributor (17% of the total) to the generation of global electricity. Canada with installed capacity of 66954 Mwe is the largest producer of hydroelectricity. *Rest of the renewable sources contribute only 2% of the global electricity.*

Norway gets 99% of electricity out of hydropower. The size of hydropower station ranges from a few Kw (micro hydropower station) to 12600 Mwe (super large) at Brazil/Uruguay. The Gorges dam in China will have installed capacity of 18,300 Mwe (planned to be commissioned in 2009).

iii. *Negative Factors*

A hydropower station in the past used to be considered as environment friendly. The notion has changed. The plant causes dislocation of communities and bio-species. " Ecosystem impacts usually occur downstream and range from changes in fish biodiversity and the sediment load of the river to coastal erosion and pollution" [2]. The plants also cause greenhouse emissions. The hydropower station usually is very much capital intensive with long construction and amortization periods and therefore becoming less attractive for the investors. The possible dam failure may cause havocs in the down stream.

d) *Wind Energy*

i. *Background*

The theoretical and technical potential of global wind energy is about 6000 and 640 exajoules per year respectively. The current use is only about 0.12 exajoules [2]. Wind power had been used for mechanical power long before the industrial revolution in Europe and other parts of the globe. The progress was barred with the advent of commercial fuels: coal and oil and the invention of steam engine. Recently wind energy is again drawing attention of the technologists and the entrepreneurs. Considerable progress has been achieved lately in the design and production of the wind turbines.

The first wind turbine grid connection was accomplished in 1980. The installed capacity of grid connected wind turbine rose to about 13500 Mwe in 2000. Besides, more than a million wind pump are in operation to supply water for the livestocks. Tens of thousands of wind generators are being used for charging batteries in China, Mongolia and Central Asia.

The minimum wind energy density of 400 watt per square meter at a height of 30 meters above ground is required for the plant to be viable.

ii. *Technical Development*

Wind energy turbines are becoming larger. The average size of a wind turbine was 30 Kw in mid 1970s. The size increased to 200 Kw and 700 Kw in 1992 and 1999 respectively. The average size now is about 1200 Kw. The higher the size the more is the efficiency.

The present day wind turbines are more controllable and grid compatible. Fewer number of components are being used to improve reliability and maintainability and also to reduce cost. Improved materials are being used for the manufacture of turbine blades and other parts. Works are in progress to build special offshore wind turbines.

iii. *Negative Factors*

Wind flow is mostly intermittent. The wind speed varies with time, season and geographical locations. The capacity factor of a wind turbine based power plant as such is quite low. The environmental effect of wind turbine is primarily limited to noise and aesthetics (as it obstructs free vision).

e) *Solar Energy*

i. *Background*

The theoretical and technical potential of solar energy is 3,900,000 and 1575 Exajoules per year respectively. The current usage is only about 0.1 Exajoules per year. The principal reason for the minimal use is low energy density. The maximum solar energy density occurs near equator. The density is about 1Kw

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per square meter. The average energy density ranges from 100 to 300 watt per square meter. The new use of solar energy can be categorized into two broad heads:

solar photovoltaic; and

solar thermal electricity.

Table –4 shows the forecasts of potential contribution of solar energy to world energy consumption by different studies.

Table-4 : Solar Energy Contribution Forecasts. Source: [2]

Potential Contribution Of Solar Energy Technologies To World Energy Consumption According To Different Studies (Exajoules Of Electricity)			
Study	2020-2025	2050	2100
WEC, 1994 a,b	16		
IIASA and WEC, 1998	2-4	7-14	
RIGES, 1993 (solar and wind)	17	35	
Shell, 1996	<10	200	
Greenpeace and SEI, 1993 (solar and wind)	90	270	830
Reference: total world energy consumption	400-600	400-1,200	

ii. *Photovoltaic*

Edmond Becquerel discovered the photovoltaic effect in 1839. AT&T first demonstrated PV cell in 1954. The first solar power satellite, Vanguard 1 was launched in 1963. The efficiency of solar PV is improving. The cost per watt peak of solar panel has gone down from several hundred to about 4 US $. The PV based energy supply systems are becoming more and more cost effective for isolated electrical demands of a few Kws depending on the location and the operating loads.

There are different types of PV panels with varied characteristics. *These are: single crystal silicon, multi crystalline silicon, amorphous silicon, crystalline silicon films on glass, cadmium telluride, copper-indium/gallium diselenide etc.* The efficiency varies between 9 to 24%.

The photovoltaic market expanded at the rate of over 15% per year between 1983 and 1999. The market is presently growing even at a faster rate. The solar PV domestic units are becoming popular and cost effective in areas isolated from the grid to meet electrical energy needs for lighting and appliances like radio and television. More than 50,000 such units are now operating in Bangladesh.

The rooftop based PV panels are now being connected to the grid. The energy payback time of these systems are shown at Table-5. The PV potentialities will be covered in greater depth in *Module –5*.

Table-5 : Payback Time for Grid Connected Rooftop Photovoltaic Systems. Source: [2]

Estimated Energy Payback Time Of Grid-Connected Rooftop Photovoltaic Systems (Years)			
	State of the art	Near to medium term (<10 years)	Long term
Modules			
Crystalline silicon	3-8	1.5-2.5	<1.5
Thin film	2-3	0.5-1.5	<0.5
Balance of system	<1	0.5	<0.5
Total system			
Crystalline silicon	4-9	2-3	<2
Thin film	3-4	1-2	<1

Note: Based on an insolation of 1,500 kilowatt-hours per square metre a year.

Source: Alsema, Frankl and Kato, 1998.

iii. *Solar Thermal Electricity*

The operating capacity of solar thermal based electric power plants in 1998 was 500 Mw. The capacity is lagging far behind compared to the wind turbines. Several types of solar thermal electricity are presently being considered. These are outlined below:-

a. *Parabolic Trough System*

The parabolic trough (solar farm) consists of long parallel rows of identical concentrator modules, typically using trough-shaped glass mirrors. Tracking the sun from east to west by rotation on one axis, the trough collector concentrates the direct solar radiation onto an absorber pipe located along its focal line. A heat transfer medium, typically oil at temperatures up to 400 degrees Celsius, is circulated through the pipes. Generating systems connected to the grid in southern California since the mid-1980s, parabolic troughs are the most mature STE technology (Pilkington, 1996). There are more than 100 plant-years of experience from the nine operating plants [2].

b. *Central Receiver/Power Tower*

The solar central receiver or power tower is surrounded by a large array of two-axis tracking mirrors-termed heliostats- reflecting direct solar radiation on to a fixed receiver located on the top of the tower. Within the receiver, a fluid transfers the absorbed solar heat to the power block where it is used to heat a steam generator.

Advanced high-temperature power concepts are now under investigation, heating pressurized air to more than 1,000 degrees Celsius to feed it into the gas turbines of modern combined cycles. (Solar One) operated with steam from 1982-88. After modification of the complete plant in 1996, it operated as Solar Tower for a few thousand hours, with molten salt as the heat-transfer and energy storage medium, delivering power to the electricity grid on a regular basis (Pacheco and others, 2000) [2].

c. Dish/Engine Power Plants

Dish/ engine power plants. Parabolic dish systems consist of a parabolic-shaped point focus concentrator in the form of a dish that reflects solar radiation onto a receiver mounted at the focal point. These concentrators are mounted on a structure with a two-axis tracking system to follow the sun. The collected heat is often used directly by a heat engine, mounted on the receiver.

Several dish/engine prototypes have operated successfully in the last 10 years, including 7-25 kilowatts-electric units developed in the United States. But there has not yet been a large-scale deployment. In Spain six units with a 9-10 kilowatts-electric rating are operating successfully. Australia has demonstrated a 400 square metre, 10 kilowatts-electric 'big dish' at the Australian National University in Canberra (Luzzi, 2000) [2].

e) Marine Energy

The oceans cover more than two-thirds of the Earth's surface. The oceans have an enormous energy resource potential which is vastly more energy than the human race could possibly use. The energy of the seas is stored partly as kinetic energy from the motion of waves and currents and partly as thermal energy from the sun.

The theoretical potential of ocean energy is about 7400 exajoules per year. Although most marine energy is too diffuse and too far from where it is needed to be economically exploited, in special situations it can be effectively captured for practical use.

The principal marine energy resources can be summarized, in order of maturity and use, as below:-

Tidal barrage energy;
Wave energy;
Tidal/marine currents;
Ocean thermal energy conversion (OTEC);
Salinity gradient/osmotic energy; and
Marine biomass fuels.

The current status of marine renewable energy technologies is shown at Table-6.

Table-6 : Current Status of Marine Renewable Energy Technologies, Source [2]

Current Status of Marine Renewable Energy Technologies				
Technology	Maturity	Load factor (percent)	Installed capital cost (dollars per kilowatt)	Unit cost of electricity (dollars per kilowatt-hour)
Tidal barrage	Virtually abandoned	20-30	1,700-2,500	0.08-0.15
Wave-shoreline OWC	Experimental	20-30	2,000-3,000	0.10-0.20
Wave- near shoreline OWC	Commercial 2002-05	25-35	1,500-2,500	0.08-0.15
Wave-offshore-point absorber	Commercial 2010 or later	30-60	2,500-3,000	0.06-0.15
Tidal current turbine	Commercial 2005-10	25-35	2,000-3,000	0.08-0.15
OTEC	Commercial 2005-10	70-80	Unclear	Unclear

g) Geothermal Energy

i. Background

Human beings had been using geothermal energy for bathing and washing for thousands of years. But it is only in the 20th century that it has been harnessed on a larger scale for space heating, industrial energy use, and electricity production. The theoretical and technical potential of geothermal energy is 14,000,000 and 5,000 exajoules per year [1]. These are extremely large quantities.

ii. Development

Prince Piero Ginori Conti initiated electric power generation with geothermal steam at Larderello in Italy in 1904. The first large municipal district heating service started in Iceland in the 1930s.

Geothermal energy has been used commercially for some 70 years, and on the scale of hundreds of megawatts for 40 years, both for electricity generation and as source of heat for direct use. Its use has increased rapidly in the past three decades-at the rate of about 9% per year during 1975-95 for electricity and, about 6% a year for direct use. Geothermal resources have been identified in more than 80 countries, with quantified records of geothermal use in 46.

iii. *Electricity production*

The growth of the total generation capacity in 1990-98 was about 40%, with the largest additions in the Philippines (957 megawatts), Indonesia (445 megawatts), Japan (315 megawatts), Italy (224 megawatts), Costa Rica (120 megawatts), Iceland (95 megawatts), the United States (75 megawatts), New Zealand (62 megawatts), and Mexico (43 megawatts) [2].

iv. *Heat Pumps*

Geothermal heat pumps are rated among the most energy-efficient space conditioning equipment available in the United States. Reducing the need for new generating capacity, they perform at greater efficiencies than conventional air source heat pumps used for air conditioning.

The summary of the global geothermal electricity generation and direct use for the year 1997 is shown in Table-8.

Table-8 : Summary of Electricity Generation and Direct Use of Geothermal Energy in 1997, Source [2]

Electricity Generation and Direct use of Geothermal Energy, 1997						
Region	Electricity generation			Direct use		
	Installed capacity (giga watts-electric)	Total production		Installed capacity (giga watts-thermal)	Total production	
		Terawatt-hours (electric)	Percent		Terawatt-hours (thermal)	Percent
European Union	0.75	3.8		1.03	3.7	
Europe, other	0.11	0.5		4.09	16.1	
Total Europe	0.86	4.3	10	5.12	19.8	52
North America	2.85	16.2		1.91	4.0	
Latin America	0.96	6.9				
Total Americas	3.81	23.1	53	1.91	4.0	10
Asia	2.94	13.0	30	3.08	12.2	32
Oceania	0.36	2.9	6	0.26	1.8	5
Africa	0.05	0.4	1	0.07	0.4	1
World total	**8.02**	**43.8**	**100**	**10.44**	**38.2**	**100**

Source: Based on Stefansson and Fridleifsson, 1998.

V. Nuclear

a) *Background*

Albert Einstein's epoch making theory of relativity (1905) led to the famous mass energy conversion equation- $E= mc^2$. Chadwick discovered neutron in 1932 and Livingstone and Lawrence, proton in the same year. German scientists Otto-Hann, Strassman and Myers demonstrated fission in 1938. Enrico Fermi demonstrated sustainable chain reaction on 2nd December1942 at the University of Chicago.

The atom bomb explosions in Nagasaki and Hiroshima in August 1945 made the people of the world stunned about the tremendous potentiality of nuclear power. President Eisenhower of USA placed his proposal of "Atom for Peace" in the United Nations ( ) and assured full support and cooperation for the peaceful use of nuclear power for the benefit of humanity. The International Atomic Energy Agency was established in 1957 with the full support and active cooperation of the USA.

Nuclear power industry mainly flourished during 50s to early 70s. Then the development stuck up on the issues of proliferation, safeguards, safety and waste managements. The issues are in fact more political than technical. The recent oil price hike and the global warming issues are again drawing attentions of the world leaders towards nuclear energy. Nuclear power can help substantially in addressing the greenhouse and sustainability issues.

b) *Nuclear Energy*

Energy is released when the nuclei of the fissile atoms of Ur^{235} or Ur^{233} or Pu^{239} are fissioned by the striking neutrons. This has been elaborated in Fig. 1.

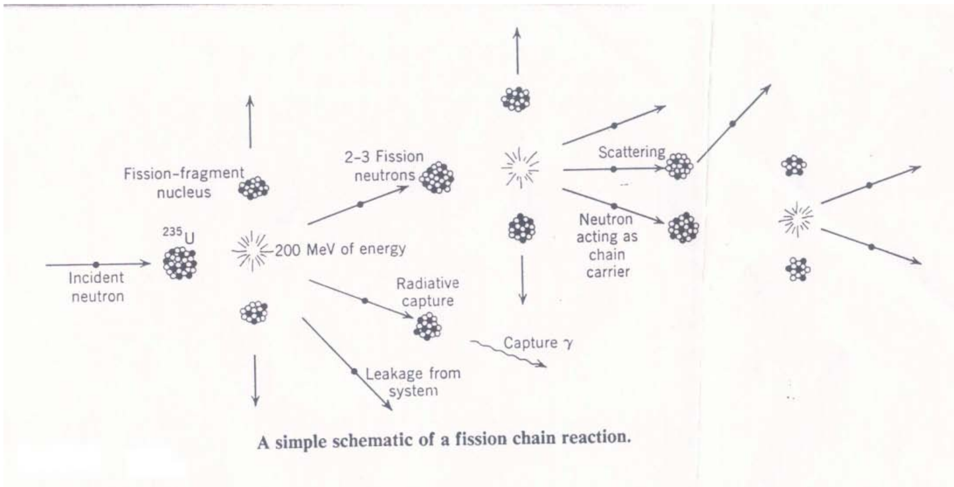

Fig. 1 : Fission Chain Reaction

c) Nuclear Materials

Nuclear materials consist of uranium, thorium and plutonium. These materials are grouped into: *fissile and fertile materials. The fissile materials are those atoms that can be fissioned by thermal neutrons. The fertile materials are the ones that can be converted to fissile materials through nuclear interactions. The fertile materials are:* Ur^{238} , $Ur^{236,}$ $Ur^{234,}$ Th^{232} etc. Most of the present day power reactors are thermal reactors and use Ur^{235} as the fuel. The uranium that is obtained in the nature contains only 0.71% Ur^{235}. The remaining is primarily Ur^{238}.

The trading of nuclear materials can only take place under strict regulatory control and IAEA observations in pursuant to the international treaties, conventions and protocols.

d) Present Status

Today nuclear power plants generate 17% of the global electricity. Annex-1 shows the nuclear power status and the nuclear share of electricity generation.

Cost of electricity generated form the nuclear power plants are very competitive as may be seen at Fig. 2.

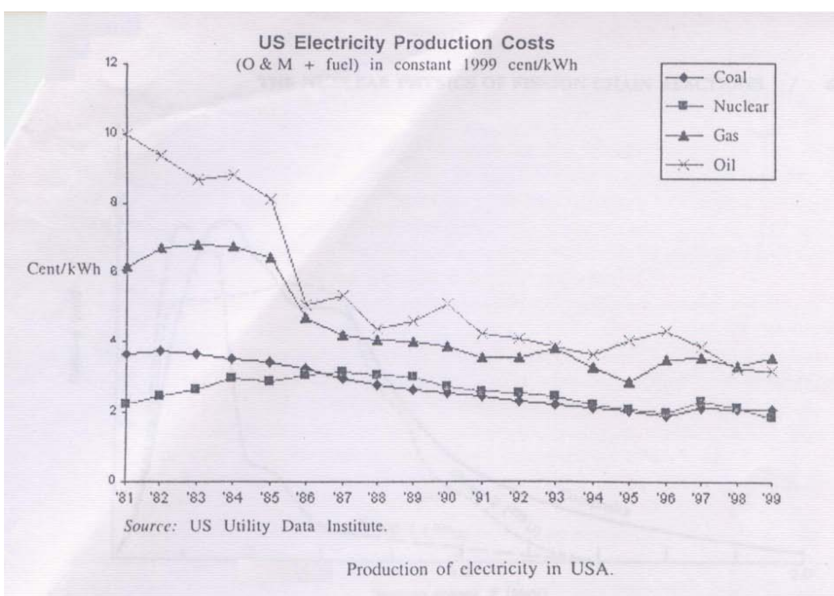

Fig.2 : Comparison of Electricity Production Costs from Different Sources

All the present day power plants are thermal reactors. There are different types of nuclear power plants: PWR, BWR, GCR, HWR and the advanced versions of these four basic types.

The nuclear power systems are basically of two types: open cycle and closed cycle. Annex-II elaborates the two cycles. At present the open cycle options is mostly pursued. But from the point of view of source conservation and other related aspects closed cycle option should be critically reviewed for future developments.

e) Special Features

Nuclear power cycle produce very little greenhouse gases and particulates. The system is environmentally much more cleaner compared to other alternatives (**Annex-III**).

The amount of fuel required for production of electricity is much less compared to the fossil fuel fired plants. A 1000 Mwe nuclear power plant requires only about 30 tons of fuel per year compared to 1.1, 1.4 and 2.2 million tons of fuel for a similar capacity gas, oil and coal fired power plants respectively (**Annex-IV**). The nuclear power option, therefore, can relieve enormous pressure from the communication system. Plant capacity factor of nuclear plant is high (70 to 80%)compared to the fossil fired plants.

f) Breeder Reactors

The fertile materials that is Ur^{238} or Th^{232} is used as a blanket surrounding the reactor core in breeder reactors. The fertile materials are gradually converted to fissile materials by neutron activations. The newly breed fertile materials after the processing, are again used for production of electricity. The energy potential of nuclear materials thus is increased at least by 60 times. Considerable works were carried out by Japan and France to develop breeder reactors. The R& D works on breeder reactors should be pursued. The nuclear reactors will be covered in more details under Module – 4 of the course.

VI. Advanced Technologies

a) Development Trend

The technological revolutions are underway in power generation to achieve the sustainability goal of near zero air pollutant and greenhouse gas emissions. The technological revolution is under way in power generation. Advanced systems are gradually replacing steam turbine technologies as part of the long term goal. Natural gas fired combined cycles with efficiency of 55% are becoming cost effective. Cogeneration is usually more efficient and can play an important role in energy economy. R& D works are going on in syngas (mixture of CO and H^2), synthetic liquid fuels, coal gasification, and hydrogen as energy carrier.

The fuel cycle and hydrogen will be covered exclusively in L 3.3. Development works are going on for conversion of hydrogen from coal, gas and biomass, liquefaction and gasification of coal etc.

b) Fusion

Fusion is the fusing of two light nuclei to form a heavier nucleus [Fig .3]. Fusion takes place at plasma state, at an ambient temperature of the order of 10^8 C. A large amount of energy is released during the process of fusion. The fusion equations are shown below:-

- ${}_1H^2 + {}_1H^2 \longrightarrow {}_2He^3 + {}_0n^1 + 3.2$ Mev
- ${}_1H^2 + {}_1H^2 \longrightarrow {}_2He^3 + {}_1p^1 + 4$ Mev
- ${}_1H^2 + {}_1H^3 \longrightarrow {}_2He^4 + {}_0n^1 + 14.1$ Mev
- ${}_1H^2 + {}_2He^3 \longrightarrow {}_2He^4 + {}_1p^1 + 18.3$ Mev

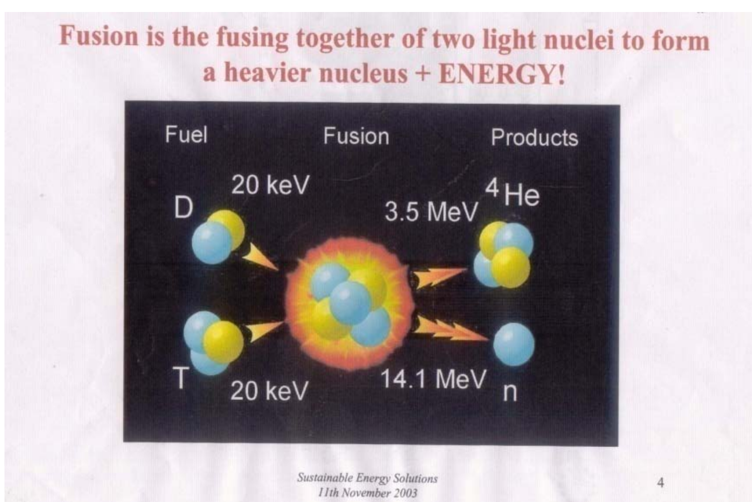

Fig. 3 : Fusion Reaction

The fusion reactions do not emit any greenhouse gas and there is little waste burden for the future generation. The possibility of large accident is also low. The amount of deuterium available in seawater is sufficient to meet the energy demand for billions of years and as such may be termed as pseudo infinite source.

The physics of fusion is quite well known. The technology is developing. It started with Tokmac process. The EU, Japan, USA, Russia, Canada, China and other countries are collaborating to develop the process. It appears to be a long way to go for the real technological break through to harness fusion energy. The time schedule is dependent on many factors, and as such is not reliably foreseen.

Experts and the associated scientists believe, “In the long term, nuclear fusion could provide power generation from abundant fuel source with zero carbon emissions and without the problems associated with long term highly radioactive wastes”. They also believe that “ technical feasibility of fusion power generation could be demonstrated within 25 years given adequate resource….” [11]

VII. Need and Importance

Electricity is the most preferred from of energy. The growth rate of electricity is the highest compared to other forms of energy. The Fig. 4 shows the future growth scenarios of different type of energy sources.

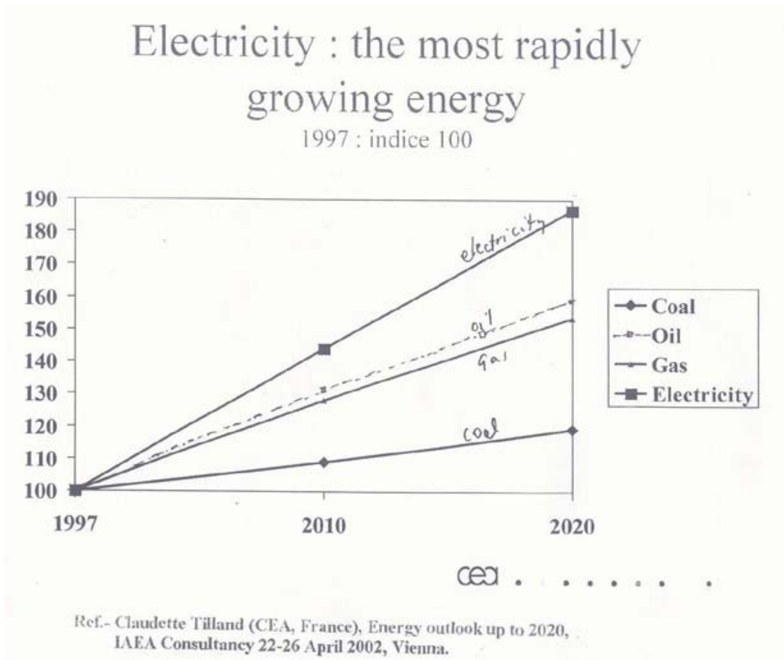

Fig. 4 : Growth Scenarios of Different Energy Sources

The share of world primary energy by different source for the global production of electricity is shown at Fig. 5. The share of the different types of fossil fuels is shown in Fig 6.

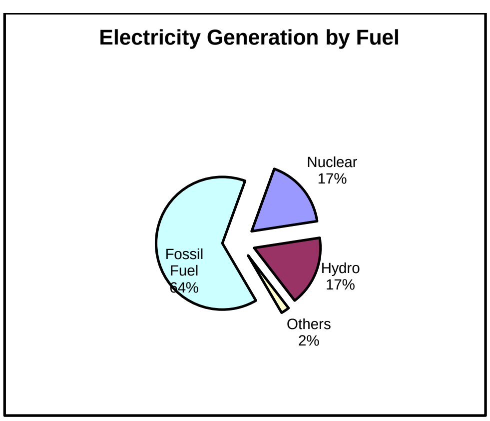

Fig. 5 : Global Electricity Generation by Sources

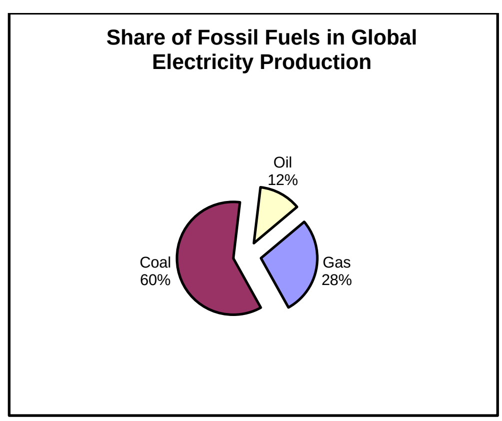

Fig. 6 : Share of Fossil Fuel in Global Electricity Generation

The prime importance of the new sources is to achieve the sustainability goals. But most of the new sources are yet to mature and become economically competitive. These have the limitations for operation as base loads.

But nuclear power is technically proven and economically competitive source. It can play an effective role in addressing the issue of greenhouse gas as well as in achieving the goals of sustainability and millennium development commitments.

VIII. Future Strategy

The new renewable energy sources are yet to be cost effective. Continued R& D will be required to make the sources economic. Besides, the sources are dependent on geographical locations, time, season, and other factors. The sources as such cannot be used as base load power supply stations. A possible strategy for optimizing the share of renewable sources is shown at Fig. 8. Continued R&D and collaborative works will also be required to expedite the development of the renewable sources. A logical flow diagram for the development activities is highlighted in Fig.9.

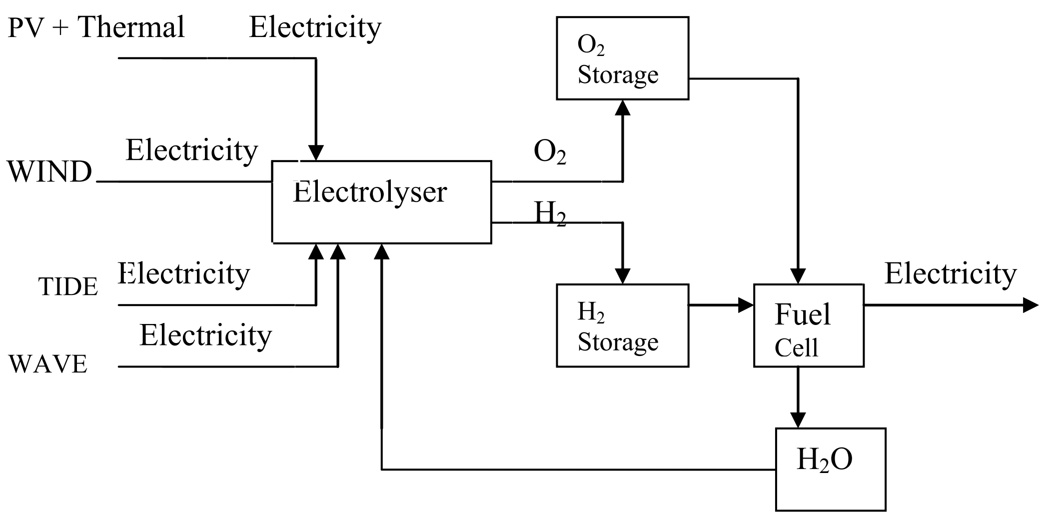

Fig . 8 : Possible Strategy for Optimizing Use of Renewable Sources

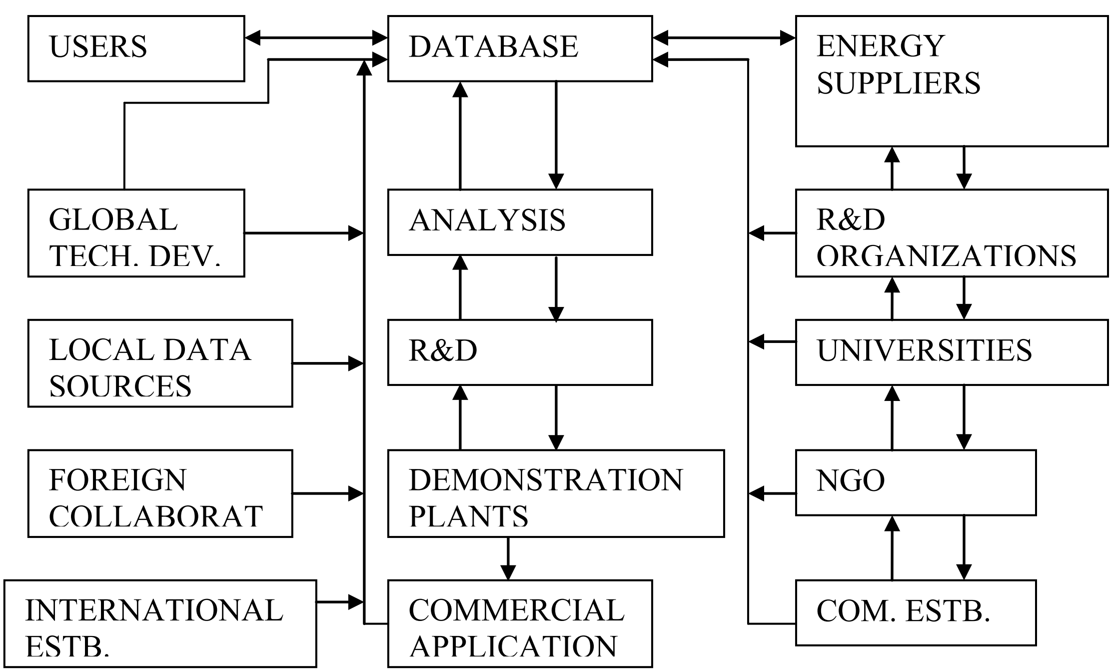

Fig. 9 : Proposed Flow Diagrams for Development of New Sources

IX. Conclusion

Energy is key for economic development as well as for the improved quality of life. The demand of different forms of energy particularly electricity are increasing and it will continue to increase. The energy sources have to be sustainable, accessible and affordable for the global population particularly those living in the least developing and developing countries.

The 2.5 billion deprived population of the world who live on less than $ 2 a day use solid fuels. The solid fuels are harmful for health and environment. Improved ovens, biogas and solar photovoltaic can meet the basic needs of fuel for cooking and electricity for lighting.

The current path of energy system is not compatible with the sustainable development objectives. The present energy system has to be remodeled with the combination of more efficient and less polluting new energy technologies and sources. The future sources will have greater share of the renewable and new energy sources.

Many of the new and renewable energy sources and the technologies are still in the process of R&D and are yet not cost effective. The R&D works have to be pursued with more intensity and clear objectivity.

Nuclear power can assist in addressing the issues of greenhouse gas and sustainability provided the world leaders cooperate in resolving the existing barriers.

Strong political will and cooperation among the states, multinational companies, R&D institutions universities, NGOs, media, civil societies and the communities at stakes will be required to achieve the goals of sustainable development and the millennium development goals.

Annexes

Annex-I: Nuclear Power Status Around the World
Annex-II:Nuclear Fuel Cycle
Annex-III: Greenhouse Gas Emissions from Electricity Production Chains
Annex-IV: Fuel Requirements for a 1000 Mwe Power Station

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