Energy Sources and Electricity

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ABSTRACT
Necessity is the mother of invention. A need encourages creative efforts. The history of world is the history of mankind determined from various disciplines such as archaeology, genetics, anthropology, linguistics etc. Sun has always been the source of energy in the form of heat and light. Ability to produce fire and use it to burn biomass were the main milestones in the history of mankind. Man depended on the power from manual labour and animals. Invention of watermills and then windmills emerged as the means to utilize natural sources of energy. The pace of inventions and discoveries of conventional and renewable sources of energy and their usages picked-up in last few centuries. The ways of transportation and communication were evolved. In the last few decades, environmental concerns and climate uncertainty are compelling the trends of usage of environment friendly sources of energy.

I SOURCES OF ENERGY

Energy sources may be classified as primary and secondary. Primary sources are suitable for end use without conversion to another form. Examples are wind power, solar power, wood fuel, fossil fuels such as coal, oil and natural gas, and uranium. The secondary sources are obtained in desired form of energy after substantial conversion of primary source e.g. electricity, hydrogen, or other synthetic fuels. The trends in the usage of energy sources have been changing since the beginning of the human civilization. Shift in the usage of energy sources is directly linked with the economy and technological developments. The trend has been to adopt the sources available locally with higher energy density. The present trend is primarily driven by the concerns caused by the climate change. The shifts in energy sources in the past and emerging trends are broadly given below:

- Since the beginning of civilization and up to the industrial revolution of 18th century, the sources for carrying out the work were men and animals. Wood used to be burnt for heating and cooking purposes.
- Development of watermills and subsequently windmills provided alternative sources of energy which were limited mainly to grind the flour and water pumping.
- With the advent of steam engine there was a major shift in energy sources in the mid 19th century. Steam engine triggered the industrial revolution in Europe and coal fired thermal power plants emerged as the main source of electrical energy.
- In the early 20th century, process of refining of the crude petroleum oil was developed that attracted the use of oil, a source with high energy content. The use of oil accelerated with the invent of internal combustion engine for oil powered road transport, sea transport and also power generation.
- The use of petroleum based energy sources continued to increase rapidly in the late 20th century. With the advancement of technology, natural gas came in use as more efficient sources of fossil fuels.
- Nuclear fission is considered as clean source of energy in spite of radiation hazards. The stringent standards and practices evolved over the decades minimised the risk of accidents.
- Hydroelectric power is a renewable source of energy and has been adopted by several countries as a part of water management system for flood control, irrigation, industries and domestic uses.
- The oil shocks of 1973, uncertainty in oil supply and environmental concerns forced to tap alternative sources of energy, such as wind, solar, geothermal etc., though their share remained marginal till 20th century.
- The 21st century has started observing major shifts in energy sources. The pace of fossil fuel based power generation is subsiding with a focus on efficient 'clean coal' technologies. The share of renewable sources of energy is picking-up rapidly. Development of fusion based nuclear energy, green energy in transport sector are also increasing. A potential transition is expected in hydrogen as a source for fuel cells to power vehicles, small power generation etc.

A brief overview of historical evolution of energy sources and their usage by mankind, starting from discovery of fire and agriculture is given next:

(a) Sun: The ultimate source of energy - Sun is the ultimate source of energy for earth. Sun is a star and is powered by the fusion reaction of hydrogen isotopes taking place in the sun and forming the heavier atoms. In the fusion process, hydrogen atoms combine to form helium atoms and release huge amount of energy. The fusion reaction continues till fusion material gets exhausted. After all the

hydrogen atoms are used up, the fusion of helium atoms starts. The solar energy is radiated in all directions in the forms of heat, visible light and UV radiations. Even after travelling hundreds of kilometres through atmosphere, solar radiation reaches earth with adequate energy. The average solar insolation entering the atmosphere is 1,366 W/m^2. The major portion of the solar radiation is absorbed by earth, clouds, and atmosphere whereas remaining is reflected as shown in Figure-1. The average insolation that reaches earth's surface is 684 W/m^2.

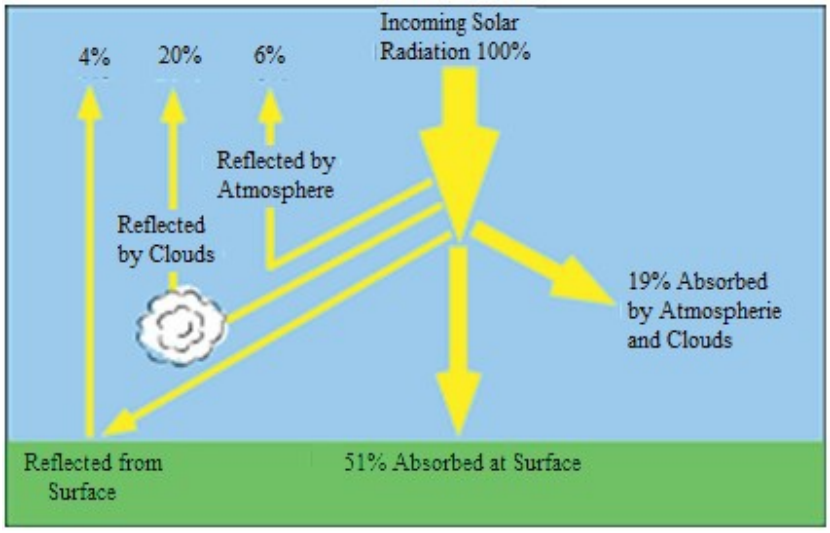

Fig.1 Solar insolation [1]

The renewable sources of energy are direct (solar heat and light) and indirect (wind, water, etc.) which are originated by the solar energy. The solar energy warms the earth's surface and oceans and causes weather patterns, air flow, and ocean currents. The evaporation of water caused by solar heat energy initiates the water cycle causing rainfall. The potential energy of the stored water in reservoirs is converted into electrical energy in a hydroelectric power plant.

(b) Photosynthesis - Photosynthesis is the process by which plants make their own food called glucose in the presence of sunlight, water, and carbon dioxide as shown in Figure-2.

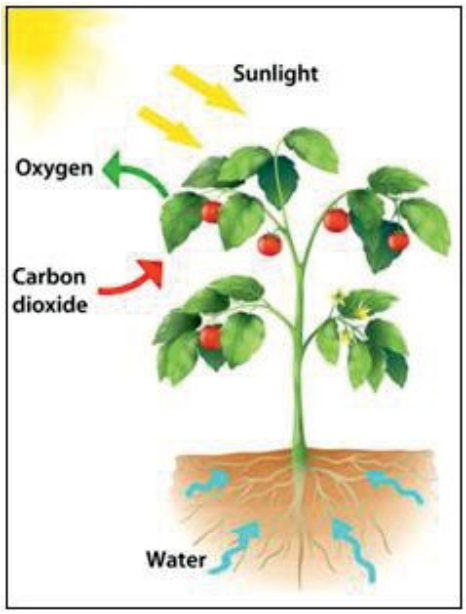

Fig.2 Photosynthesis process [2]

The photosynthesis takes place in the presence of sun light. In the chemical reaction, oxygen is formed and released into the atmosphere as can be seen from the equation (1):

$$\underset{\text{Carbon diaoxide}}{6CO_2} + \underset{\text{water}}{6H_2O} \xrightarrow{\text{Light energy}} \underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6O_2} \quad (1)$$

Some of the glucose that plants produce during photosynthesis is stored in fruits and roots. The source of energy for the growth, development and physical activity is the plants. The men and animals eat the plants to get energy whereas plants get energy from glucose made during photosynthesis process.

The major sources of energy for power generation and transportation have been the fossil fuels i.e. coal, oil, and natural gas which were made in millions of years from the remains of dead plants and animals which got their energy from photosynthesis. Photosynthesis also maintains the balance between oxygen and carbon dioxide levels in atmosphere.

(c) Fire - Lakhs of years ago, the ability to make and regulate fire was a major jump in the evolution of energy. It helped our ancestors to remain warm in the cold season. The fuel used was naturally the biomass, mainly wood. The availability of biomass for cooking and lighting improved safety in human and facilitated the process of habitation. The cooking helped to consume hard plants with comparative ease and with higher nutrition content required for growth. The burning eventually led to discovery of ovens which made it possible to refine metals from ore and produce tools and pottery.

Fig.3 Use of fire in iron age [3]

(d) Water power and wind power - The watermill was invented about 2,500 years ago. Using watermills, humans managed to master the water power to produce flour, oil, tanning of leather, smelting of iron, sawing the wood, and so on. Later in the first century AD, windmill was invented and was used for various applications such as milling (grinding), rolling, or hammering. These processes were used in the manufacture of paper, textiles, rolling, wire drawing, and metal products.

(e) Fossil fuels - Fossil fuels are the buried deposits of organic materials for millions of years in the crust of earth. These materials are plants and animals that get converted into crude oil, coal, natural gas, or heavy oils due to heat and pressure. The utilization of fossil fuels has enabled large-scale industrial development which largely replaced water-driven mills and burning of wood for heat.

(f) Agriculture - During evolution of human civilization, wild grains were collected and eaten. Agriculture was a revolutionary milestone in the history of mankind. Agriculture began in different parts of the world independently and included diverse crops. The food grains like wheat, barley, peas, vetch, lentils, chick peas, rice, and flax were cultivated initially. The cultivation of sugarcane, sorghum, bananas, cotton, and some root vegetables were developed later. The agriculture resulted in food security and paved the way for permanent human settlements. The animals were used for agriculture also and hence, domestication of

animals increased. The agricultural waste became animal waste became the main sources of fuel.

(g) **Industrial Revolution in Europe -** In the 18th century, cost of wood-fuel increased substantially and wood was replaced by coal in several industries. The invention of steam engine in the 18th century was instrumental in initiating industrial revolution. For almost 200 years it was the main source of power for industry and transport sectors. The steam engine was introduced in 1712 by Thomas Newcomen at Dudley Castle coal mine and was the work-horse of industrialisation. Richard Trevithick, a British engineer, demonstrated that in place of very low pressure adopted by James Watt, steam could be safely used at much higher pressures. Trevithick stimulated the development of locomotive steam engines. James Watt, a Scottish engineer, refined the governor to control the speed of engine, and parallel motion device which kept the piston upright in the cylinder. With these refinements, the engine became efficient and was a great success which led to an era of 'The Industrial Revolution'. In the 19th century, steam engine dominated in industries, land as well as sea transport. The steam engine proved to be one of the most successful and useful inventions of all times.

Fig.4 America built locomotive of mid-19th century [4]

New era started with the successful development of internal combustion engine for application in automobiles and aviation at the beginning of the 20th century.

(h) **Petroleum fuels -** These are hydrocarbons of different molecular weights and organic compounds. A fossil fuel, petroleum is formed when dead organisms, usually zooplankton and algae, are buried underneath sedimentary rocks under high temperature and pressure for millions of years. Petroleum is a yellow-to-black thick natural viscous fluid called crude oil. The petroleum is refined to break it into fractions with different boiling points, using a fractional distillation. The use of refined oil suited well for internal combustion engine. The development of process for refining crude oil laid the foundation for oil age. The use of natural gas increased rapidly after Second World War.

(i) **Nuclear fission -** In nuclear fission is a process of splitting heavy atoms of fissionable materials, either uranium or plutonium. It was first developed in the 1940s and then attention was paid on controlling the fission reaction for power generation. The first nuclear power stations commenced operation in the 1950s. By December 2017, there were over 448 nuclear power reactors in operation in 31 countries, with cumulative installed power capacity of over 391,720 MWe and generating over 11% of the world-wide power generation. There are about 60 reactors under different stages of construction. The nuclear power is reliable and suits well to meet base load demand without emission of GHGs. There are 180 nuclear reactors to power around 140 ships and submarines. There are about 250 research reactors in 55 countries.

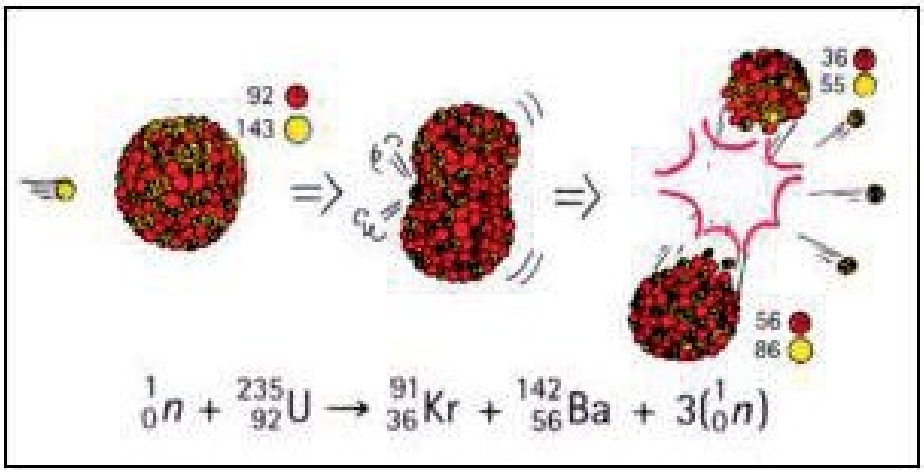

Fig. 5 Nuclear fission reaction [5]

USA, France, Russia, South Korea, China, are the world leaders in nuclear power generation. India stands 12th globally in installed nuclear power capacity of 6780 MWe.

(j) **Oil shocks and alternate sources of energy -** An oil embargo in 1973 imposed by members of the Organization of Arab Petroleum Exporting Countries (OAPEC) led to fuel shortages and sky-high prices. In the wake of oil shocks, self-sufficiency in energy was identified as the major driver for the new and renewable sources of energy in India. The fluctuations in the prices of crude oil, uncertainties associated with its supply and its impact on the Indian economy led to the formation of a Commission for Additional Sources of Energy (CASE) under the Department of Science & Technology in March 1981. A new department, named Department of Non-Conventional Energy Sources (DNES) was created in 1982. In 1992, a new ministry named, 'Ministry of Non-Conventional Energy Sources' was formed. In October 2006, the ministry was re-named as the Ministry of New and Renewable Energy.

II CLIMATE CHANGE AND ENERGY PATTERN

Climate change or to be more appropriate, climate uncertainty is one of the biggest challenges of the 21st century. The burning of fossil fuels by the humans is the dominating cause of emission of green house gases which contributes to global warming. Climate change is a threat to sustainable development. Increasing temperatures, rising sea levels and frequent weather extremes have become a global and regular phenomenon. It is assessed that global average temperature could increase by 0.3° C to 4.8° C by the end of the 21st century. Rapidly changing climate puts many coastal areas, food security, human health and ecosystems at risk and may intensify further. To avoid such devastating consequences, the international community has committed itself to limit the mean global temperature rise to 2° C above pre-industrial levels. Man-made GHG emissions are primarily due to burning of fossil fuels in power plants, transport and domestic sectors. In agriculture sector, methane and nitrous oxide are emitted which have 25 and 298 times warming potential than carbon dioxide. Natural sources of GHG emission are forest clearing and waste decay in landfills.

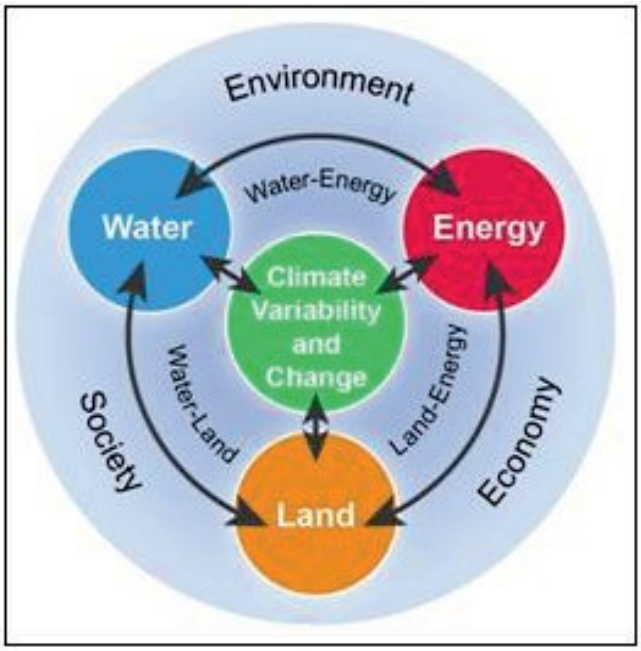

Fig.6 Energy, water, land and climate [6]

The main focus areas of a sustainable energy sector are:

- Energy conservation and
- Shifting over from fossil fuels to renewable sources of energy

III FUTURISTIC SOURCES OF ENERGY AND TECHNOLOGY

In the 21st century, there is an intense necessity to adopt environment friendly and smart technologies of power with a focus on conservation of natural resources in order to minimize fossil fuel based grid power. A brief overview of the emerging scenario is given next:

The process of electricity reforms was initiated with the enactment of Electricity Act-2003 by the Ministry of Power. As a part of reforms, the transmission and distributed losses are minimized. In view of the challenges imposed by climate change, energy conservation is considered an important tool to manage demand. The Energy Conservation Act-2001 was enacted by the Government of India which focuses on demand side management. Public awareness is the key to success of any program including energy conservation. The demand of energy could be minimized by the use of energy efficient appliances for which star rating system was introduced by the Bureau of Energy Efficiency, Ministry of Power, for easy understanding of the general public. The measures like low price sale of LEDs, installation of solar water heating system in large buildings such as hotels, hospitals etc. are some examples. The energy intensive industries have been identified and bench marks for specific energy consumption are set.

Coal fired power generation is mainly responsible for climate change but it cannot be stopped suddenly but could be gradually phased out. Clean coal technology aims to reduce GHG emissions by improved burning of coal and capturing of the SO_X and NO_X gases. The new power plants are installed with the boilers based on supercritical technology which are more efficient and emit less GHGs.

Nuclear power generation all over the world is based on controlled fission process in which heavy atoms of uranium are split into 2 or 3 lighter atoms and huge amount of energy is released. There are safety hazards, health issues, and challenges in disposing radioactive waste. In view of these, nuclear fusion process is being developed in which lighter atoms join to form heavier atom and release lot of energy. The fusion is quite safe and being developed by few countries including India. A 500 MW experimental fusion reactor is being developed for installation in France. Once developed successfully, it will play major role in meeting the energy requirement. In the Indian context, fast breeder reactor is very important as its fuel, thorium' is abundantly available indigenously. A 500 MW indigenously developed prototype fast breeder reactor 'Bhavini' has been installed and is likely to be commissioned in 2019 at Kalpakkam in Tamil Nadu. It will operate with uranium as a nuclear fuel and its experience will be utilised in developing thorium based reactor.

India stands fourth in the world in installed capacity of onshore wind power projects. Offshore has great wind power potential. India has issued 'National Offshore Wind Energy Policy-2015' and prepared a roadmap by assigning the job to FOWIND, a GWEC led consortium.

In order to capture high wind at heights, flying turbines are being developed which do not need tower and yawing mechanism. However, several challenges are to be overcome. In order to exploit low speed wind energy, different versions in vertical axis wind turbines are developed on innovative concepts. The future trend will be for hybrid wind-solar power plants so as to utilize empty space between the wind turbines. **Energy storage ????**

Hydrogen has great potential as source of energy but safety hazards in transportation and storage are the main hurdles. Once these hurdles are overcome, hydrogen will play vital role in transportation sector in the form of fuel cell and small power generating stations. The fuel cells overcome the shortcomings of batteries of low energy storage capacity. Extraction of bio-diesel from ethanol obtained from sugarcane bagasse and biodiesel from Jatropha, Karanj, Pine etc. is likely to be an important source of green energy in transport sector.

IV EVOLUTION OF ELECTRICAL ENGINEERING AND POWER SYSTEMS

The evolution of electrical engineering and electrical power system are a result of dedicated efforts of the scientists and engineers. Since early civilization static electricity and magnetism were experience but they could not distinguish between the two. A Greek scientist around 600 BC discovered the phenomena of attraction when amber was rubbed with cloth. It was due to static electricity. The gradually acquired knowledge of magnetism, electricity and the interaction between them led to revolutionary inventions.

The history of evolution of electricity and power system are given next:

1492 Christopher Columbus, an Italian Navigator discovered variation in declination of compass needle around the globe.

1729 Stephen Gray, a British chemist, experimentally discovered electric conduction and insulation.

1733 Charles Francois, a French, discovered two types of electric charges, named positive and negative. He established that similar charges repel each other and opposite charges attract.

1752 Benjamin Franklin, USA proved that electric charges and lightning were the same. He invented lightning rod for protection of buildings from lightning strikes.

1800 First electric battery was invented by Alessandro Volta, an Italian. The unit of electric potential is named 'Volt' in his honour.

1808 Humphry Davy, a British chemist invented an 'arc lamp'. The 4-inch arc was created between carbon rods that glowed when electric power was supplied by a battery.

1820 Independent experiments conducted by Hans Christian Oersted - a Danish, A.M. Ampere – a French Physicist, and a French physicist Francois Arago. It established the relationship between electricity and magnetism.

- Ampere developed a formula, known as Ampere's law, to calculate magnetic field strength when an electric current flows through a conductor.

1821 The first electric motor was invented by Michael Faraday, a British.

1826 Georg Ohm, a German physicist, defined the relationship between power, voltage, current and resistance in 'Ohm's Law'. The unit of resistance is named 'Ohm' in his honour.

1831 Michael Faraday, a British proved that electromotive force (EMF) is induced by changing electromagnetic field. Faraday's experiments demonstrated working of an electric generator.

1832 Based on Faraday's principles, a French instrument maker Hippolyte Pixii built the first 'dynamo' capable of delivering power to industry.

Fig.7 Michael Faraday, A great scientist [7]

1833 Russian physicist Heinrich Lenz formulated Lenz's law for electromagnetism that upholds the principle of conservation of energy.

1835 Joseph Henry, USA invented an electromagnetic relay.

1837 Thomas Davenport, USA invented the electric motor, an invention that is used in most electrical appliances.

1839 Sir William Robert Grove, a British developed the first fuel cell, a device that produces electrical energy by combining hydrogen and oxygen.

1841 James Prescott Joule, a British showed that energy is conserved in current flowing electrical circuits, thermal heating, and chemical transformations. The unit of thermal energy, 'Joule', was named after him.

1853 William Thomson, a British mathematically formulated R-L-C circuits.

1860s James Clerk Maxwell, a Scottish published mathematical theory of electromagnetic fields. His four equations unified magnetism, electricity and light which led to the invention of electric power, radios, television, and communication.

1876 Charles F. Brush, Ohio, USA invented the 'open coil' dynamo that could produce a steady electric current.

1878 Joseph Swan, a British invented the first incandescent light bulb. His light bulb burned out quickly.

- Charles Brush developed an arc lamp that could be powered by a generator.
- Edison Electric Light Co. was founded in New York by Thomas Alva Edison.

1879 Thomas Edison, USA invented an incandescent bulb and continued experiments to extend its life.

- Electric lights (Brush arc lamps) were first used for street lighting, in Cleveland, Ohio.
- California Electric Light Company Inc., San Francisco: the first company to sell electricity to public. The company supplied power to arc light lamps.

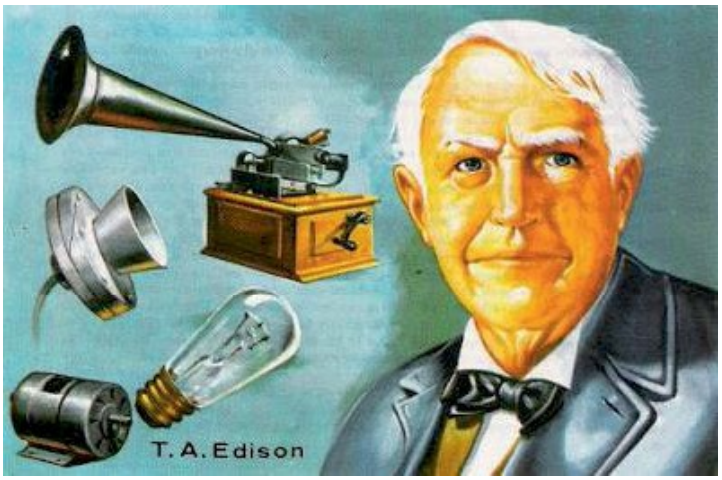

Fig.8 Thomas Alva Edison: A great scientist [8]

1882 Coal fired power plant: Pearl Street Station, Manhattan, New York built by Edison Illuminating Company was the first electric power plant of the world. The station was powered by custom-made Porter-Allen high-speed steam engines designed to provide 175 HP at 700 rpm. It was the first ***cogeneration*** power plant also as the steam was supplied to the local manufacturers and warming the nearby buildings in the same block. It was a direct current (DC) power system and could supply power to light about 500 customers.

- The first hydroelectric station of the world: 1 x 12.5 kW Vulcan Street Plant on Fox River was commissioned on 30th September in Appleton, Wisconsin, USA.
- First DC transmission line: 2 kV, 57 km Munich-Miesbach commissioned.

1883 Nikola Tesla, a Serbian-American invented the 'Tesla coil'. It is a resonant transformer circuit which produced high-voltage, low-current, high frequency alternating-current.

1884 Nikola Tesla invented an electric alternator that produced alternating current (AC).

- Steam turbine generator for bulk power generation was invented by Sir Charles Algernon Parsons.

1886 William Stanley, USA developed first practical transformer which spurred the development of AC power. He also developed an improved electric meter.

1888 Nikola Tesla for the first time demonstrated complete 'poly-phase' electrical system of power generation. Westinghouse Electric Company, USA obtained the patent rights of AC system.

- The first wind turbine to generate electricity: 12 kW at Cleveland, Ohio. Its power was used to charge the batteries.

1891 First 3-phase AC power transmission line was commissioned between Lauffen and Frankfurt, Germany.

1893 The Westinghouse Electric Company used an alternating current (AC) system to light the Chicago World's Fair.

- A 22 mile (35 km) AC power line was commissioned to transmit electric power from Folsom Powerhouse in California to Sacramento.

1896 First power line, 11 kV, 3-phase, 20 mile (32 km) transmission line was commissioned between Niagara Falls to Buffalo, New York.

1897 India's first hydroelectric power station: 2 x 65 kW Sidropong Hydroelectric Power Station, Darjeeling, was commissioned.

1899 India's first thermal power project: Emambagh Lane was commissioned (The Calcutta Electric Supply Corporation Limited).

Fig.9 Hydro power station at Darjeeling [9]

1902 5-MW turbine for Fisk St. Station, Chicago, USA was commissioned.

1903 World's longest and highest voltage transmission line: 50 kV, 136 km from Shawinigan Power Station to Montreal was commissioned.

1904 World's first geothermal power plant was commissioned at Larderello, Italy.

1909 First pumped storage plant was commissioned in Switzerland.

1912 First 110 kV-overhead power transmission line was commissioned.

1921 Lakeside Power Plant in Wisconsin became the world's first power plant to burn only pulverized coal.

- Geothermal power plant: 1517 MW, The Geysers, California, USA, the largest in the world was commissioned.

1923 World's first 220 kV transmission line was commissioned between hydroelectric plants in the Sierra Nevada to the San Francisco Bay Area.

- Big Creek – Los Angeles lines were upgraded to the 220 kV.

1925 Peat fired power plant: 1,500 MW Shatura, Russia, the highest capacity in the world was commissioned.

1936 Highest steam temperature of 900 degrees Fahrenheit was attained in early 1920s.

- Boulder (Hoover) Dam was completed.
- A 287 kV, 266 miles (428 km) transmission line was laid to transmit 240 MW power from Hoover Dam to Los Angeles.

1938 Nuclear fission process: discovered by Otto Hahn and Fritz Strassmann, German radio-chemists

1939 First industrial gas turbine: 4 MW was commissioned at Neuchatel, Switzerland. It was manufactured by Brown Boveri.

1942 World's first nuclear fission reactor with controlled chain reaction was designed and developed by Enrico Fermi in USA.

1953 First 345 kV, 3-phase AC transmission line was commissioned by American Electric Power, USA.

1954 World's first nuclear power plant commissioned in Russia.

First high voltage direct current (HVDC) line (20 MW, 1900 kV, 96 km).

1957 Shippingport Reactor in Pennsylvania became the first nuclear power plant to provide electricity to customers in USA.

1967 Highest transmission voltage: 765 kV line was commissioned in Russia, USA and Canada.

1973 Oil shale fired power plant: 1,615 MW, the largest capacity in the world was commissioned in Eesti, Estonia.

1974 Solar Photo Voltaic cell for harnessing light energy of sun was developed by Joseph Lindmayer, USA.

1977 Nuclear power plant: 6384 MW, the largest in the world was commissioned at Bruce, Canada.

1979 Run-of-the river power plant: 2,620 MW, the largest in the world was commissioned at Chief Joseph, USA.

1980 World's first wind farm with 20× 30 kW turbines was commissioned in New Hampshire, England.

1981 Solar One, commissioned first large scale, 10 MW pilot solar thermal power plant in Daggett, California.

1982 First 1,150 kV transmission line between Elektrostal and power station at Ekibastuz, Soviet Union was commissioned.

1985 Pumped Storage hydro power plant: 3,003 MW Bath County, USA, the largest in the world commissioned

1987 Coal fired power plant: 4,760 MW Vindhyachal, Madhya Pradesh, the largest in India was commissioned

1988 Natural gas power plant: 5,597 MW Surgut-2, Russia, the largest in the world commissioned

1990 India's first commercial wind turbine: 250 kW Kattadimalai, Muppandal, Tamil Nadu was commissioned.

1991 Floating wind farm: 11 x 450 kW, Vindeby, Denmark, world's first was commissioned. (dismantled in 2017)

1992 Coal fired power plant , 5,500 MW Taichung, Taiwan, the largest in the world was Commissioned.

1999 First 1,000 kV transmission line with double circuit between Kita and Iwaki, Japan.

- Oil refinery: 1,97,000 m^3/day, Jamnagar, India, the World's largest commissioned

2001 Biomass power station: 265 MW Alholmens, Finland, the world's largest commissioned

2008 Wave power plant: 2.25 MW Agucadoura Power Plant, Portugal, the largest in the world

- Onshore wind power project: 1,500 MW Muppandal, Tamil Nadu, the largest wind park in India was commissioned

2011 Tidal power plant: 254 MW Sihwa Lake, South Korea, the largest in the world was commissioned

- Solar PV Concentrated power plant: 60 MW Golmud-2, China, the largest in the world

2012 Hydro power plant: 22,500 MW, Three Gorges, China, the largest in world commissioned

- Onshore wind park: 5,160 MW, Gansu, China, the largest in the world

2013 Concentrated solar thermal generating system: 377 MW, Carolina, South Mojave desert. Ivanpah, California, the largest in the world commissioned

- HVDC line: 600 kV, 7.1 GW, 2385 km, Rio Madeira transmission link, Brazil, the longest in the world

2014 Oil fired power plant: 5,600 MW and desalination complex at Shoaiba in Saudi Arabia, world's largest commissioned

- Offshore wind farm: 630 MW London Array, United Kingdom, the largest in the world commissioned
- Zero emission coal power plant: 229 MW GutureGen 2.0 Illinois, USA, the first in the world is under construction (retrofitting the old Meredosia Power Station).

2015 OTEC (Ocean Thermal Energy Converter) power plant: 100 kW, Hawai, USA, the largest in the world

Fig.10 Largest solar power plant of India at Kamuthi [10]

2016 Largest unit rating wind turbine: 8 MW of MHI Vestas model V164-8.0 MW for offshore is the largest unit rating turbine in operation. It has a 164 m rotor diameter and a hub height of 138 m. Two turbines were installed in Esbjerg, Denmark.

2016 Solar PV Power Plant, 1547 MW Tengger Desert Solar Park, Zhongbei, Ningxia, China commissioned, the largest in the world.

2016 Solar PV Power Plant, mega solar park: 648 MW Kamuthi, Ramanathapuram district, Tamil Nadu, India commissioned, the largest in India.

2017 Floating offshore wind farm: 30 MW Hywind Project, Scotland, the largest in the world.

V GROWTH OF CONVENTIONAL POWER IN INDIA

Power Sector in India has grown significantly since independence both in the installed electricity generating capacity and transmission & distribution (T&D) system. The total power generating capacity of (utilities & non utilities) has increased from 1362 MW in 1947 to 349.29 GW (including renewable energy) by December, 2018. The per capita electricity consumption which was mere 16.3 kWh in1947 has increased to 1149 kWh by March 2018. Despite this, the growth of electricity demand has surpassed the power supply and our country has been facing power shortages during peak electricity demand in spite of the manifold growth over the years. Government of India lays special emphasis on reduction of T&D losses and demand side management to optimally utilize the limited energy resources. Central Electricity Authority (CEA) has taken a lead and immensely contributed in the national endeavour of development of power sector by introduction of new technologies, techno-economic clearance of projects, generation & transmission planning including green energy corridor and operation & construction monitoring of projects, design & engineering and dissemination of data & information. The information covers plan wise pattern of growth accomplished for various important indicators like installed generating capacity, hydro electric potential, state-wise forecast of electricity demand of the country as well as forecast of electricity demand of mega cities, electrical energy generation, transmission & distribution network, power supply position, captive power plants, pattern of electricity consumption of the country as well as per capita consumption and maps showing State-wise Installed Electricity Generating Capacity. The growth of installed power capacity in India is given in Table 1.

Table 1
Growth of installed conventional power capacity in India: 1947 to 2018 [11]

Status as on	Thermal (MW)				Nuclear (MW)	Hydro* (MW)	Total (MW)	Growth# (%)
	Coal	Gas	Diesel	Total				
31Dec 1947	756	-	98	854	-	508	1362	-
31Dec 1950	1004	-	149	1153	-	560	1713	25.77
31 Mar 1956	1597	-	228	1825	-	1061	2886	68.48
31 Mar 1961	2436	-	300	2736	-	1917	4653	61.23
31 Mar 1966	4417	137	352	4906	-	4124	9030	94.07
31 Mar 1974	8652	165	241	9058	640	6966	16664	84.54
31 Mar 1979	14875	168	164	15207	640	10833	26680	60.11
31 Mar 1985	26311	542	177	27030	1095	14460	42585	59.61
31 Mar 1990	41236	2343	165	43744	1565	18307	63616	49.39
31 Mar 1997	54154	6562	294	61010	2225	21658	84893	33.45
31 Mar 2002	62131	11163	1135	74429	2720	26269	103418	21.82
31 Mar 2007	71121	13692	1202	86015	3900	34654	124574	20.46
31 Mar 2012	112022	18381	1200	131603	4780	38990	175373	40.78
31 Mar 2017	192163	25329	838	218330	6780	44478	269588	53.72
31 Dec 2018	197452	24937	638	223027	6780	45399	275206	2.08

*Hydro power plants of above 25 MW capacity are only considered.
#Growth is calculated over the previous value of total conventional installed power capacity.

VI POWER GENERATION BY VARIOUS SOURCES OF ENERGY

Total electrical power generation in India was 13,00,499 GWh during 2017-18. Figure 11 shows break-up of power generation from various sources of energy.

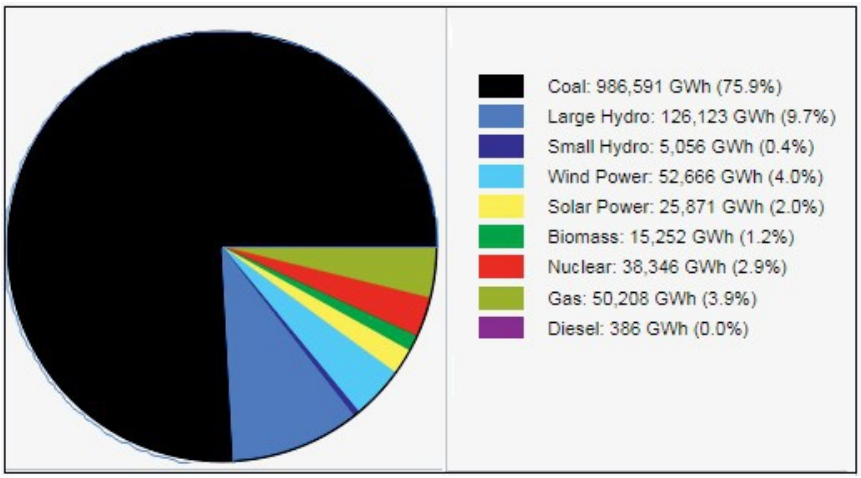

Fig.11 Power generation from various sources of energy in 2017-18 [11]

The year 2016-17 was significant as for the first time, new installed power capacity of renewable energy in India surpassed installations based on fossil fuels. The Central Electricity Authority (CEA) declared on 29th March 2017 that for the first time India had become net exporter of electricity. India exported 5,798 GWh energy to neighbouring countries, against an import of 5,585 GWh.

VII PER CAPITAL ELECTRICITY CONSUMPTION

Energy is a basic need in our daily life and is a backbone for economic and social development. Therefore, per capita energy consumption is an indicator of economic development of a country. Table 2 gives growth in per capita electricity consumption and change from previous value.

Table 2
Growth in per capita electricity consumption in India [11]

Status as on	Per capita consumption (kWh)	Change (%)
31Dec 1947	16.3	-
31Dec 1950	18.2	11.66
31 Mar 1956	30.9	69.78
31 Mar 1961	45.9	48.54
31 Mar 1966	73.9	61.00
31 Mar 1974	126.2	70.77
31 Mar 1979	171.6	35.97
31 Mar 1985	228.7	33.28
31 Mar 1990	329.2	43.94
31 Mar 1997	464.6	41.13
31 Mar 2002	671.9	44.62
31 Mar 2007	559.2	-16.77
31 Mar 2012	883.6	58.01
31 Mar 2017	1122	26.98
31 Mar 2018	1149	2.41

VIII CONCLUSION

The adoption of various sources of energy has been influenced by the economic and technological considerations since ages.

The sun has been the very first source of energy for heat and light and also it is the source of other energy sources. Developing the ability to ignite fire by burning biomass and use the same for light and heat was a major milestone. Man took lakhs of years to harness energy from wind and water and use the same for various applications such as pumping, grinding, transportation and much later for generation of electricity.

Wood has been and still is the main fuel for cooking and heating globally in rural areas. In 19th century, the invention of steam engine triggered 'industrial revolution' in which wood was burnt to generate steam which was later replaced by coal. Steam engine was extensively used in industries and for transportation. Besides coal, fossil fuel sources viz. oil and natural gas are also used. The use of electricity started in the late 19th century and with the development of power distribution and transmission systems, the demand of electricity continues to rise. Nuclear and hydro power have been contributing significantly in electric power generation in many countries.

In the past few decades, environmental concerns and climate uncertainties have emerged as the dominating factors for which emission of greenhouse gases due to burning of fossil fuels is mainly responsible. Hence, the trend is to minimise the use of fossil fuels and adopt renewable sources of energy. In future also, the trend of energy sources will be guided by not only technology and economics but also by environmental and climatic factors.

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