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Thermal Energy and Power Production: Impact on the Global Environment

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Abstract: Thermal energy is energy that comes from a substance whose molecules and atoms are vibrating faster due to a rise in temperature. In thermodynamic terms, Thermal energy is the internal energy present in a system in a state of thermodynamic equilibrium by virtue of its temperature. Thermal energy cannot be converted to productive work as easily as the energy of the systems that are not in thermodynamic equilibrium.

Matter is made up of molecules and atoms that are constantly moving. The increase in temperature causes these particles to move faster and collide with each other. The hotter the substance, the more its particles move, and the higher its thermal energy. Thermodynamics is the branch of physics that deals with the relationships between heat and other forms of energy.

That is, thermodynamics involves measuring thermal energy.

➢ In this paper we will be talking about the primary concepts of thermodynamics related to the formulation of thermal energy and then explain the correlation between thermal energy and thermal power. We also have included a CASE Study on the adverse Environmental effects of Thermal power production.

I. THERMAL ENERGY

A. What is Thermal Energy?

Thermal energy refers to the energy contained within a system that is responsible for its temperature. Heat is the flow of thermal energy. A whole branch of physics, ***thermodynamics***, deals with how heat is transferred between different systems and how work is done in the process.

B. First Law of Thermodynamics

The first law of thermodynamics states ***that energy can neither be created nor destroyed, only altered in form***. It is a version of the law of conservation of energy, adapted for thermodynamic processes, distinguishing two kinds of transfer of energy, as heat and as thermodynamic work, and relating them to a function of a body's state, called internal energy. According to the FLOT, one of the two major kinds of energy transfer is heat, and the quantity of heat is referred to as the flow of thermal energy.

$$\Delta U = Q - W$$

ΔU= Change in internal energy.
Q= Heat.
W= Work done by the system.

In the context of mechanics problems, we are usually interested in the role thermal energy plays in ensuring conservation of energy.

Almost every transfer of energy that takes place in real-world physical systems does so with less than 100% and results in some thermal energy.

This energy is usually in the form of *low-level* thermal energy. Here, low-level means that the temperature associated with the thermal energy is close to that of the environment. It is only possible to extract work when there is a temperature difference, so low-level thermal energy represents 'the end of the road' of energy transfer. No further useful work is possible; the energy is now 'lost to the environment'.

C. *Thermal Energy from Friction*

Consider the example of a man pushing a box across a rough floor at a constant velocity as shown in the figure. Since the friction force is non-conservative, the work done is not stored as potential energy. All the work done by the friction force results in a transfer of energy into thermal energy of the box-floor system. This thermal energy flows as heat within the box and floor, ultimately raising the temperature of both of these objects.

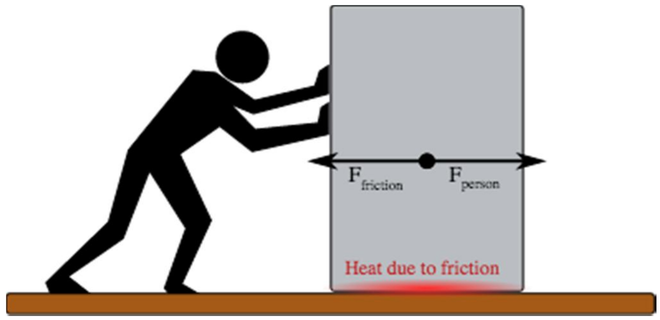

Fig: Man pushing a box on a rough surface

The thermal energy of the box-floor system is represented by ***ET*** and the change in total change in the thermal energy of the system is denoted by **Δ*ET***

Finding the change in total thermal energy of the box-floor system can be done by finding the total work done by friction as the person pushes the box.

$$W = F \cdot d$$
$$\Delta ET = F\, friction \cdot d$$

the coefficient of kinetic friction is μk ;

$$\Delta ET = \mu k\ Fn\ d$$

D. *Thermal Energy from Drag*

The force of *drag* on a moving object due to a fluid such as air or water is another example of a non-conservative force.

When an object moves through a fluid, some momentum is transferred and the fluid is set in motion. If the object were to stop moving there would still be some residual motion of the fluid. This would die down after some time. What is happening here is that the large scale motions of the fluid are eventually re-distributed into many smaller random motions of the molecules in the fluid. These motions represent an increased thermal energy in the system.

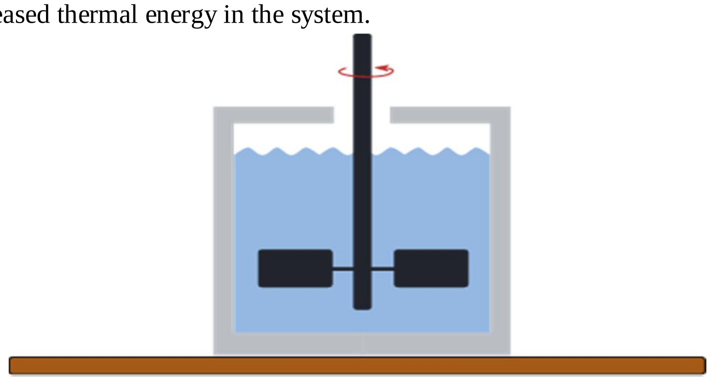

Fig: A rotating paddle wheel in an enclosed water tank

The figure above shows a system in which a thermally insulated water tank has a shaft suspended in it. Two paddles are attached to the shaft which is set to rotate on its axis. In this system, any work done in rotating the shaft results in a transfer of kinetic energy to the water. If the drive force is removed from the shaft after some time, there will still be some residual motion. However, the motion will eventually die down and result in an increase in thermal energy of the water.

II. THERMAL POWER

Thermal power describes how fast heat is produced. For most energy systems such as a gasoline engine, thermal power is equal to the rate of fuel converted into heat. These heat engines create this heat to achieve useful work. Most common use of thermal power refers to the heat input to a boiler in a power plant in order to generate electricity. While in other contexts, it can be a measure of the output—like the radiant heat given off by the Sun.

A. Correlation between Thermal Energy and Power

Thermal Energy (as mentioned in pg.3) refers to the energy contained within a system that is responsible for its temperature, while Thermal Power discusses about how fast the heat or flow of thermal energy is produced. It deals with the utilization of Thermal Energy to do some viable work.

B. Power Production

Power production is done in a facility known as a power plant. A power plant is an industrial facility that generates electricity from primary energy. Most power plants use one or more generators that convert mechanical energy into electrical energy in order to supply power to the electrical grid for society's electrical needs. The exception is solar power plants, which use photovoltaic cells (instead of a turbine) to generate this electricity.

The type of primary fuel or primary energy flow that provides a power plant its primary energy varies. The most common *fuels* are coal, natural gas, and uranium (nuclear power). A substantially used primary energy *flow* for electricity generation is hydroelectricity (water). Other flows that are used to generate electricity include wind, solar, geothermal and tidal.

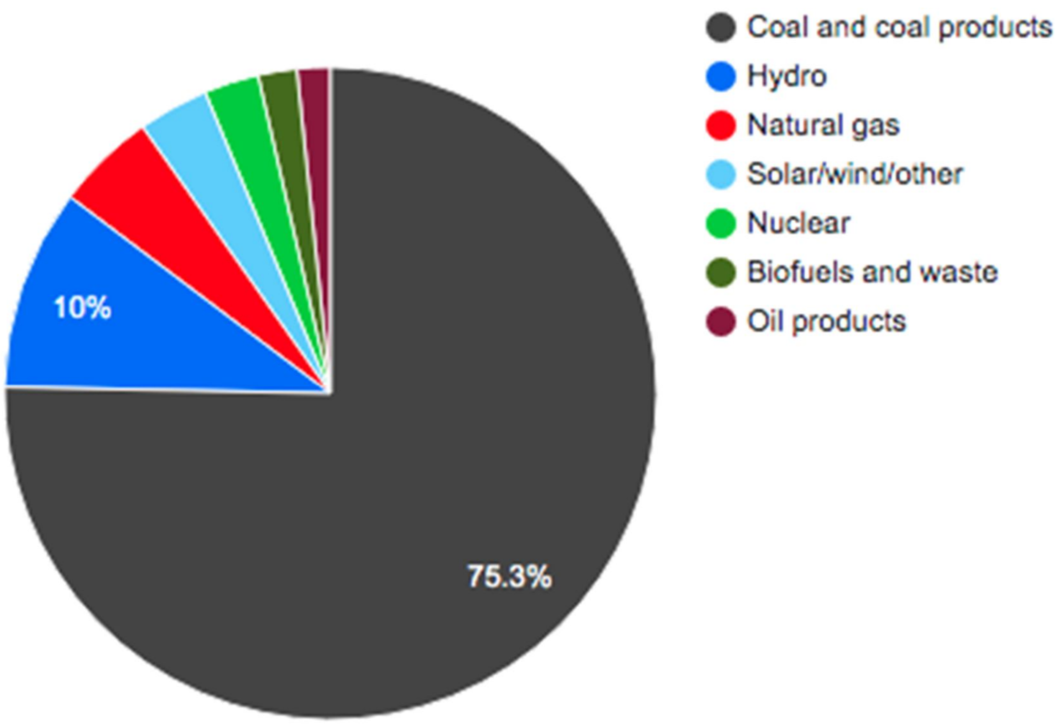

Fig: Power Energy Source of India as per IEA World Energy Stats (2015-2020)

Different countries get their electricity from different types of power plants. For example, in our country India, looking at the data given in the graph above, it is clear that more than 75% of the country's electricity and power needs are met by Thermal Power Production methods utilizing majorly fossil fuels for the producing electricity.

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C. Thermal Power Production

Most thermal power plants use fuel to heat up water from a reservoir, which generates steam(usually at a high pressure). The highly pressurized steam then travels through pipes to rotate the fan-like blades of a turbine. As the turbine begins to spin, it causes giant wire coils inside the generator to turn. This creates relative (continuous) motion between a coil of wire and a magnet, which pushes electrons and starts the flow of electricity.

D. Types of Thermal Power Plants

There are 3 major types of thermal power production units (plants), all characterized by the type of fuel they use. The different types of power plants are;

1) Fossil fuel power plants burn their fuel in order to create the thermal energy to run their external heat engines. A simple cycle gas plant does *not use steam* like the others: it works similar to a jet engine where natural gas is ignited and burned and the heat creates pressure that turns the turbine. Combined cycle gas plants use both the heat and steam as well. Types of fossil fuel plants include coal-fired power plants and natural gas power plants—accounting for the largest producers of electricity around the world.
2) Nuclear power plants use fission processes to generate electricity. In these plants, uranium nuclei are split which creates the thermal energy needed to create steam. It then works just like fossil fuel power plants where the steam spins a turbine, generating electricity. The power plants require the use of nuclear reactors to carry out these fission processes.
3) Solar thermal power plants use heat from the sun's rays to create the steam that is needed to rotate the turbine.

E. Primary Energy Source of the World

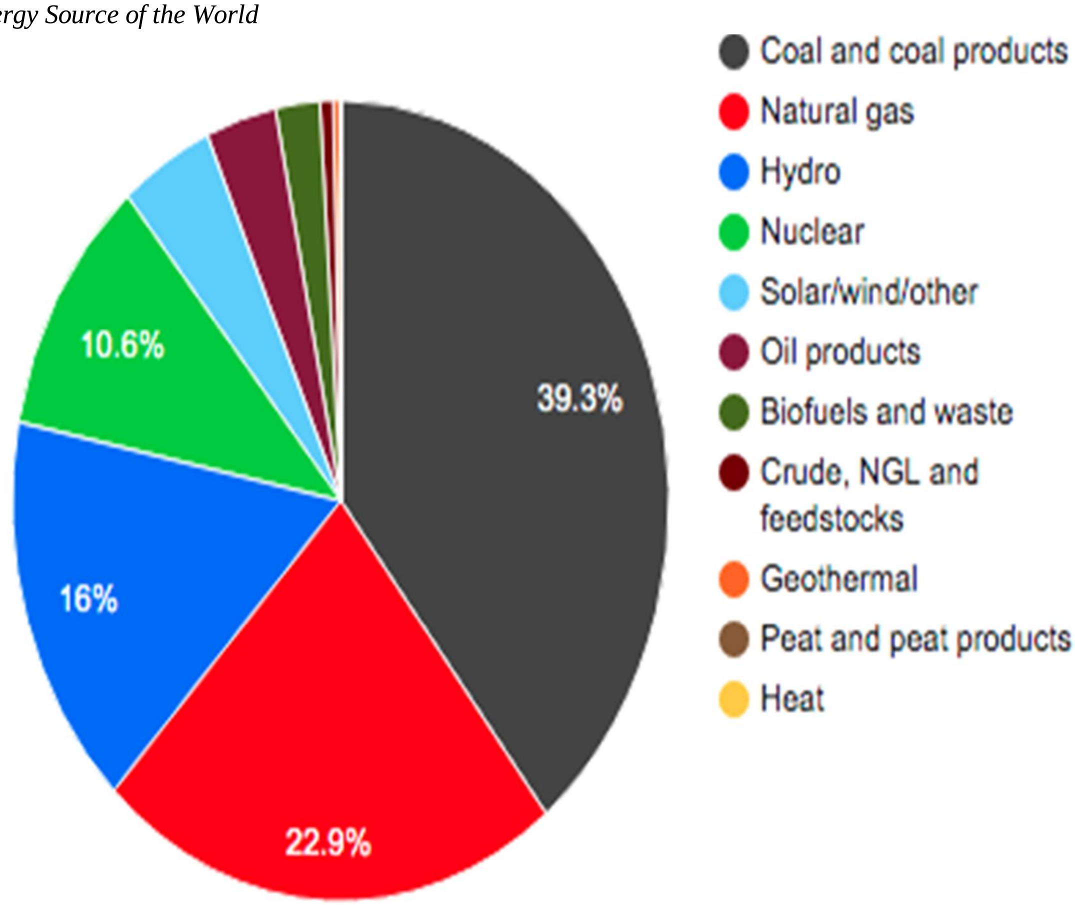

Fig: Power Energy Source of the world as per IEA World Energy Stats (2015-2020)

From the data representation above it is clear that more than 52% of the world's energy requirements are met by Thermal power plants which use fossil fuels as their primary fuel source to generate thermal energy.

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III. METHODS OF THERMAL POWER GENERATION USING FOSSIL FUELS

As discussed above we know that a majority of the countries of the world rely on Thermal power production methods which use fossil fuels as their primary source of energy, some of the well known generating facilities are;

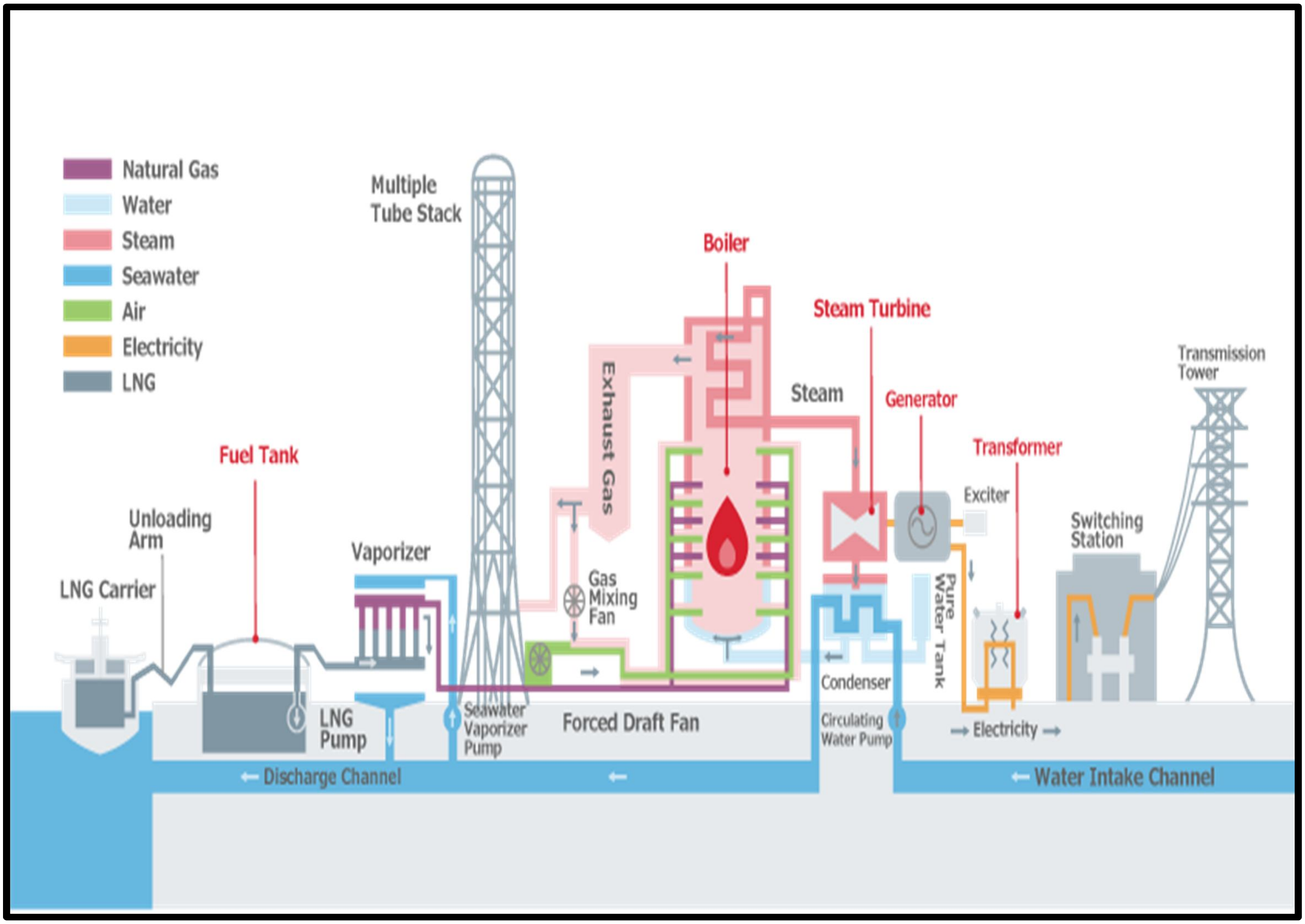
A. Steam Power Generation

Steam power generation is a way of generating electricity that makes use of the expansion power of steam. Hot and high-pressure steam is generated from heat by burning heavy crude oil, LNG (liquefied natural gas), coal, etc. This steam rotates the impeller in a turbine, which then powers a generator connected to the turbine, which generates energy.

Almost all coal, nuclear, geothermal, solar thermal electric power plants, waste incineration plants as well as many natural gas power plants are steam-electric. Natural gas is frequently combusted in gas turbines as well as boilers. The waste heat from a gas turbine can be used to raise steam, in a combined cycle plant that improves overall efficiency.

Worldwide, most electric power is produced by steam-electric power plants, which produce about 89% of all electric generation.

Diagramatic Representation of a Steam Power Generation Plant



Reference: https://www.jera.co.jp/thermal-power/type

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B. Combined Cycle Power Generation

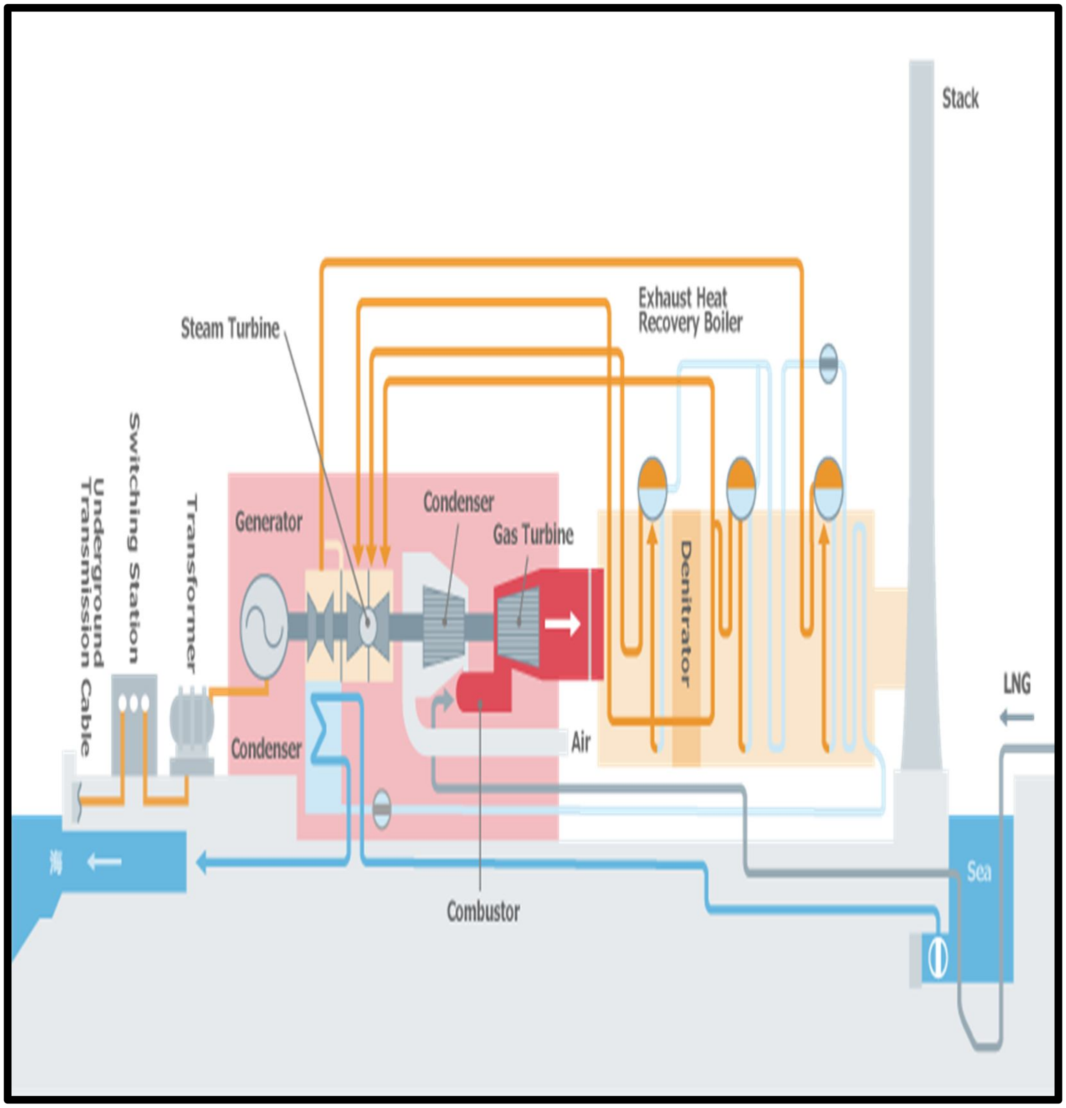
A combined cycle power plant combines a gas turbine and a steam turbine to generate electricity.

High thermal efficiency can be achieved by combining two methods of power generation, which are Gas Turbine power generation and Steam power generation.

Gas turbine power generation from rotating a generator utilizing expansion power by generating combustion gas via burning fuels in the compressed air, and steam power generation from rotating a steam turbine collecting the residual heat of the exhaust gas. In addition, as combined cycle power generation comprises small gas turbines and steam turbines, operation /stoppage can be immediately switched and can be operated in response to changes in demand.

By generating power from multiple streams of work, the overall efficiency of the system can be increased by 50–60%. That is, from an overall efficiency of say 34%, to as much as 64%. Heat engines can only use part of the energy from their fuel, so in a non-combined cycle heat engine, the remaining heat from combustion is wasted.

Diagramatic Representation of a Combined Cycle Power Generation Plant



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IV. CASE STUDY

A. Environmental Impact of Thermal Power Production

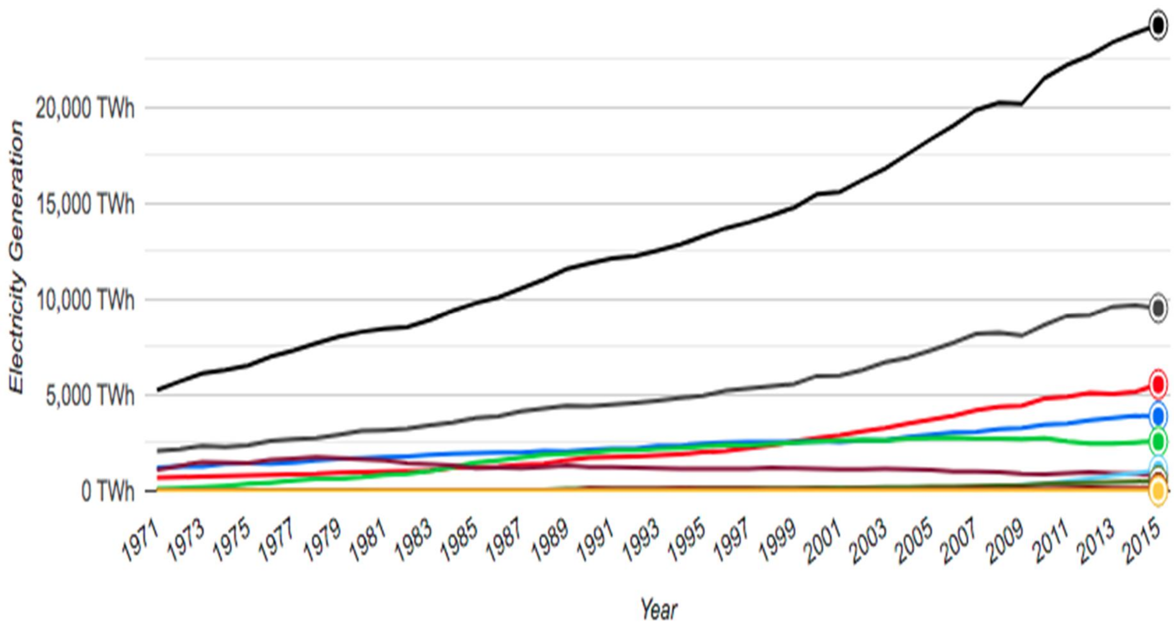


Fig: Power Generation v/s Year Graph as per IEA World Energy Stats (1971-2015)

➢ As it is clearly visible from the data represented in the graph above, over the years the power production has increased drastically all over the world to cater the increasing demand for electricity.

➢ This increase in the power production has led to an overall increase in the global CO2 and other greenhouse gas emissions.

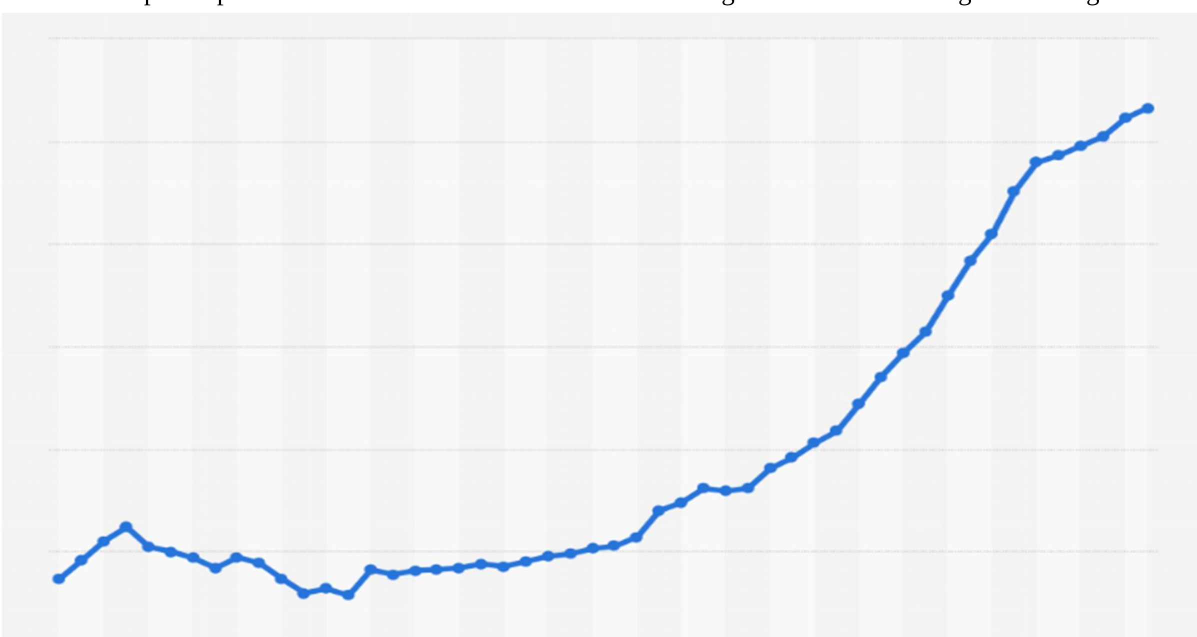


Fig: Carbon Emissions v/s Year Graph as per IEA World Energy Stats (1971-2015)

➢ This increase in the global carbon footprint has many adverse effects on both the Atmosphere and the Local Environment.

B. *Impact on the Atmosphere*

Thermal power plants are known to pump out a lot of greenhouse gases and ash, which are by-products of burning fossil fuels. Whilst some thermal power plants do use solar or nuclear energy, they are heavily reliant on fossil fuels.

Carbon dioxide is one of the main gases that is released from the burning of fossil fuels and is known to be a greenhouse gas and a contributor of global warming. Sulfur dioxide is another gas that is released from power plants. Whilst it is technically not a greenhouse gas, it is known to have indirect effects on the atmosphere because it can affect the scattering of incoming sunlight, the formation of clouds and precipitation patterns. So, in many cases, it is considered an indirect greenhouse gas. Sulfur dioxide also forms sulphuric acid in the atmosphere. This can then return to Earth as acid rain and impact various ecosystems. Thermal power plants are the largest emitters of sulfur dioxide worldwide.

Thermal power plants are also one of the biggest contributors to the global nitrogen oxide levels. Unlike nitrous oxides, nitrogen oxides are again not technically greenhouse gases, but they do have an indirect effect on the atmosphere. Nitrogen oxides are known to present visibility and respiratory issues, and they can also combine with other atmospheric gases and moisture to form acid rain and smog.

The other big pollutant to the atmosphere is ash. Ash often contains harmful particulate matter, as well as heavy metals. Ash can have multiple effects; it can get into waterways and soil wherever it falls (it doesn't have to be the local environment) and change the alkalinity of the soil/water, which can render the soil unusable for agricultural purposes and the water undrinkable, and it can cause visibility issues.

C. *Impact on the Local Environment*

When the water in a power plant is no longer usable, it often gets discharged into a local waterway. This wastewater generally has a higher temperature than the local natural water, so it can increase the temperature of the water, which in turn can have a negative impact on the local ecosystem. Moreover, this wastewater often contains metals and metalloids which have dissolved—such as boron, arsenic and mercury—which can also affect the balance of the local ecosystem.

The discharged ash can contain radioactive nuclides (radionuclides). Whilst a lot of radionuclides remain within the power plant, some can escape, and because they are radioactive, they can affect many aspects of the local environment—from the waterways, to the soil, vegetation, and any human and animals living in the local vicinity of the plant.

The land required to build these power plants has a significant effect on the local habitats before the power plant processes even begin—and can destroy many habitats, local ecosystems and local food chains without even releasing any pollutants.

D. *Solution*

1) India is a country which has about 60% of its population employed in the Primary Sector, ie; Agricultural related work.

2) So our solution to the environmental impacts caused by the Energy Production based on conventional methods, revolves around the concept of making use of the agricultural practices to reduce the dependence of our rural areas on the Electricity generated in power plants. Our present solution involves the work which was carried out to study the performance of a Savonius rotor for small-scale hydropower generation by a group of professors at NITK. It has been observed that some of the irrigation channels available in the rural areas are having enough bed slope to generate kinetic energy, which can be harnessed through a Savonius rotor.

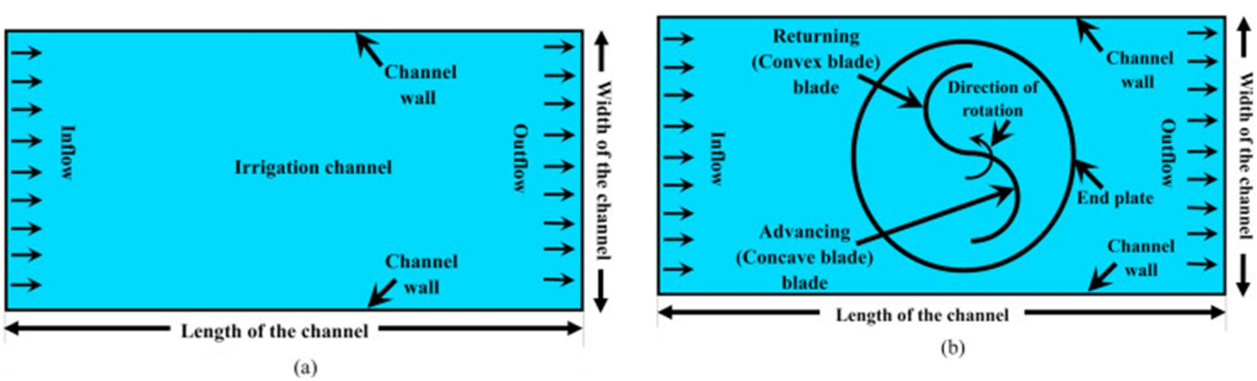
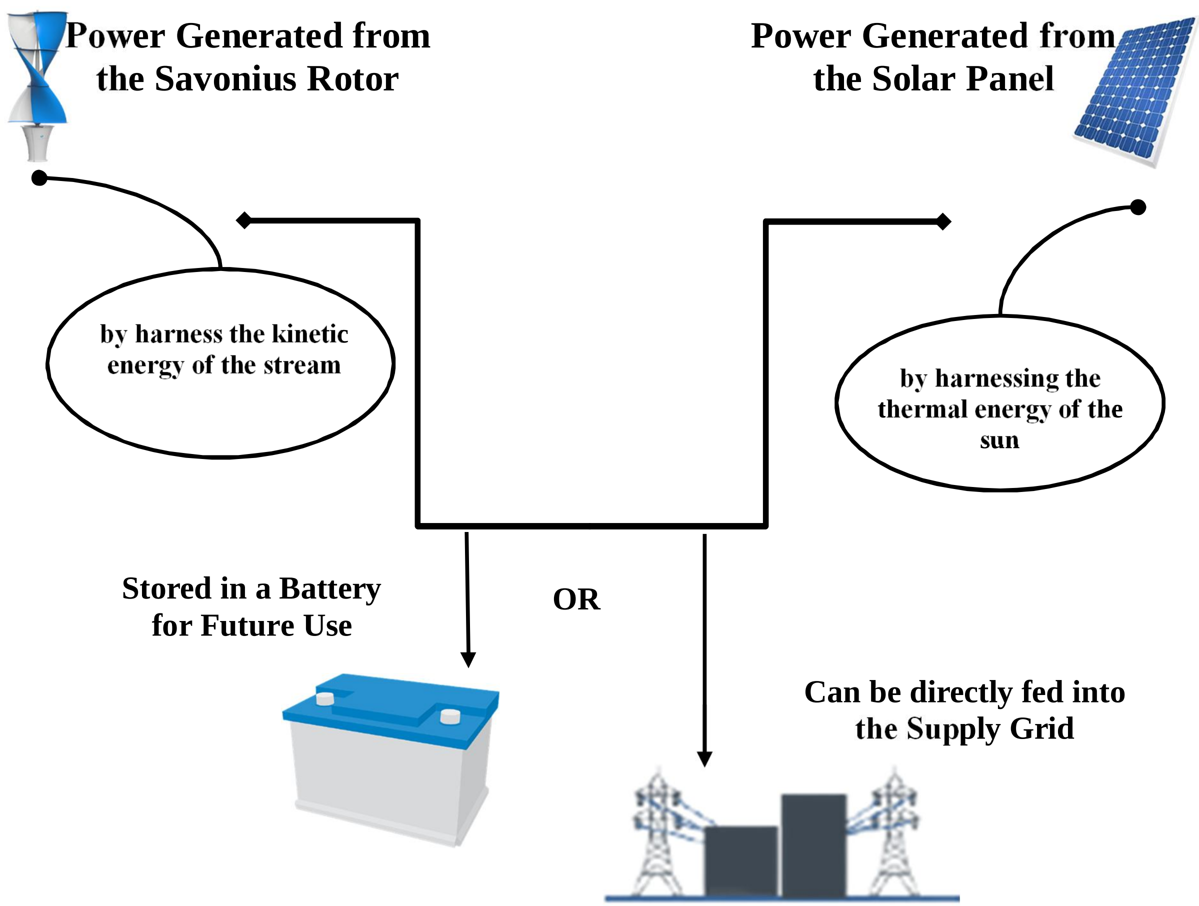


Fig: (a) and (b) placement of the Savonius Rotor in the channel

A fabricated scale-down model of the Savonius rotor when tested at an inclination of 0°, 0.5°, 1.0°, 1.5° and 2.0° to determine performance under controlled conditions. It is observed that at the tip speed ratio of 0.92 and channel inclination of 0.5° compared to 0° inclination, the coefficient of power and coefficient of torque improved to 40% and 10%, respectively. Furthermore, it is found that the torque and power developed by the turbine are maximum at a bed slope of 2.0° owing to the maximum available energy.

➢ We also plan on integrating a solar panel to the above mentioned design to increase the amount of electricity generated which can be either stored for future use or be directly fed back to the supply grid.

Diagrammatic Representation of Proposal (Flow-chart)



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[9] Reference of Pg. 13 and 15 Diagrams mentioned below the diagrams itself