

# **Power Plant Engineering**

## **Lecture 1**

### **Introduction**

**Lecturer: Dr. Melaku Desta**

# ***Lecture learning outcomes:***

At the end of this lecture, you will be able to:

- i. Identify and classify raw energy resources such as fossil fuels, nuclear, solar, wind, hydro, and geothermal sources.
- ii. Explain the environmental and economic impacts of utilizing various raw energy resources.
- iii. Describe the principles of direct energy conversion systems, including thermoelectric, photovoltaic, and fuel cell technologies.
- iv. Compare direct and indirect energy conversion methods in terms of efficiency, scalability, and application.
- v. Understand the working principles of indirect energy conversion power plants, such as steam turbines, gas turbines and internal combustion engines.

# Content

1. Fundamentals of Power Plant
2. Classifications of Power Plant
3. Raw Energy Resources
4. Energy Conversion Systems
5. Direct Energy Conversion Systems
6. Indirect Energy Conversion Power Plants

Summary

References

# 1. Fundamentals of Power Plant

- **Power Plant Engineering** is a specialized branch of energy engineering that deals with the design, construction, operation, and maintenance of power plants used for electricity generation [1].
- It is assembly of systems or subsystems to generate electricity, i.e, to produce power with economy and requirements.
- So the power produced must be:
  1. **Economically useful**
  2. **Environmental friendly to society**
- In general, power plant can be defined as:

“A machine or assembly of equipment that generate and deliver a flow of mechanical or electrical energy.”

# 1. Fundamentals of Power Plant

Cont...

- Power Plant is a highly **interdisciplinary** field that combines principles from:
  - **Mechanical Engineering** (thermodynamics, fluid mechanics, heat transfer, turbine design)
  - **Electrical Engineering** (power generation, transformers, grid integration, control systems)
  - **Civil Engineering** (structural design of dams, building foundations, cooling towers)
  - **Chemical Engineering** (combustion, emissions control, water chemistry)
  - **Environmental Science** (pollution control, waste management, sustainability)

# 1. Fundamentals of Power Plant

Cont...

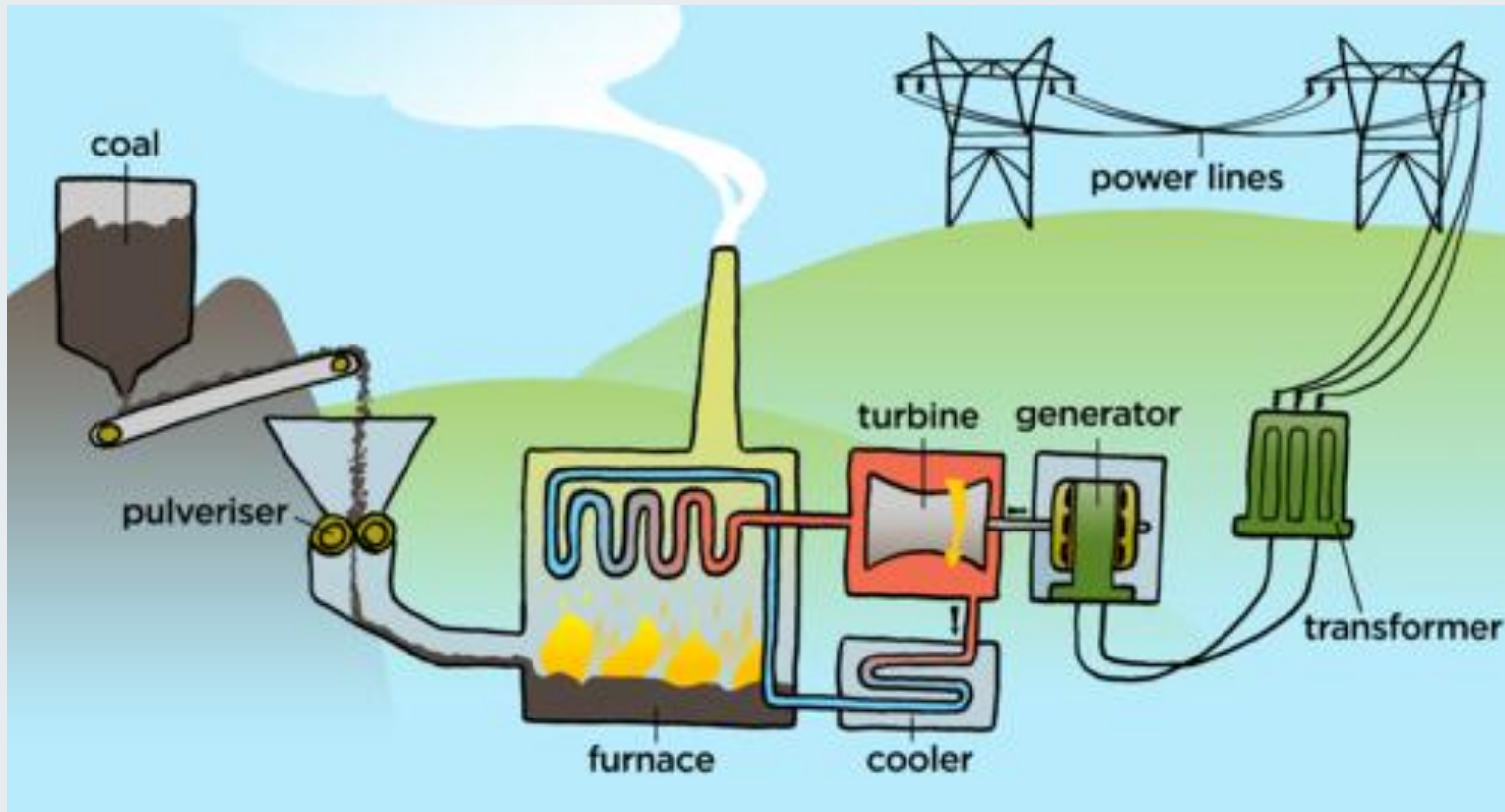
- The fundamental process that power plant engineering manages is the **energy conversion chain**. i.e. all power plants are energy conversion systems.

**Primary Energy Source** → **Thermal/Mechanical Energy** → **Electrical Energy**  
(Input Energy)                      (Conversion Process)                      (Output Energy)

- This process can be broken down as follows:
  - Energy Release
  - Mechanical Work
  - Electricity Generation
  - Transmission & Distribution

# 1. Fundamentals of Power Plant

Cont...



**Figure 1.** Fundamental Processes of Power Plant. Siyavula Education, n.d.

url: <https://www.siyavula.com/read/za/natural-sciences/grade-7/the-national-electricity-supply-system/images/gr7ec06-gd-0005.png>

## 2. Classifications of Power Plant

- Understanding the classification of power plants helps in **selecting** the appropriate type for specific applications, optimizing efficiency, cost, and environmental impact [2].
- Power plants can be classified based on several criteria, including:
  - The **primary energy source** used
  - The **energy conversion method**
  - The **type of load** they serve
  - Their **operational strategy**, and
  - The **technology they employ**

# 2. Classifications of Power Plant

Cont...

## 1. Based on Primary Energy Source

- This is the most common method of classification.

### i. Thermal Power Plants

- Use **heat energy** (from coal, oil, natural gas, or nuclear reactions) to produce steam that drives turbines.

**Examples:** Coal-fired, Gas turbine, Nuclear power plants.

### ii. Hydroelectric Power Plants

- Use **potential energy** of stored or flowing water to drive turbines.

**Example:** Dam-based or run-of-river hydro plants.

## 2. Classifications of Power Plant

Cont...

### iii. Renewable Energy Power Plants

- Utilize naturally replenished sources.
  - **Solar Power Plants:** Convert sunlight using photovoltaic cells or solar thermal systems.
  - **Wind Power Plants:** Use wind turbines to generate electricity.
  - **Biomass Power Plants:** Use organic materials as fuel.
  - **Geothermal Power Plants:** Extract heat from the Earth's crust.

## 2. Based on Energy Conversion Method

### i. Direct Energy Conversion Systems

- Convert primary energy directly into electrical energy **without intermediate** mechanical processes.

**Examples:** Fuel cells, Solar PV, Thermoelectric generators.

### ii. Indirect Energy Conversion Systems

- Convert primary energy into **thermal/mechanical energy** first, then into electricity.

**Examples:** Steam turbines in coal, nuclear, and geothermal plants.

## 2. Classifications of Power Plant

Cont...

### 3. Based on Prime Mover Used

- Steam Turbine Plants
- Gas Turbine Plants
- Hydraulic Turbine Plants
- Internal Combustion Engine Plants

# 3. Raw Energy Resources

- Energy sources are systems or materials capable of **delivering sufficient** energy in a usable form over extended periods.
- Raw energy sources are **natural sources of energy** used directly or after minor processing to produce electricity [3].
- The primary sources of energy, excluding human and animal power, include **fossil fuels** (such as petroleum, natural gas, and coal), **biomass, geothermal energy, nuclear power, wind, and solar energy**.
- Raw energy resources can be **renewable** or **non-renewable** energy sources.

## Classification of Raw Energy Sources

### 1. Non-Renewable Energy Sources

- Non-renewable energy sources are those that exist in **finite quantities** and **cannot be replenished** within a human timescale.
- Once consumed, they take millions of years to form again-making them unsustainable in the long run.

#### Examples:

- Coal
- Petroleum (Oil)
- Natural Gas
- Nuclear (Uranium, Thorium)

# 3. Raw Energy Resources

Cont....

## Classification of Raw Energy Sources

### 2. Renewable Energy Sources

- Renewable energy sources are those that are naturally replenished on a human timescale and can be used to generate electricity, heat, or fuel **without depleting the Earth's resources**.
- They have **low environmental impact** and increasing role in sustainable power generation.

#### Examples:

- Solar Energy
- Wind Energy
- Hydro Energy
- Biomass Energy
- Geothermal Energy

## 1. Non-Renewable Energy Sources

### i. Coal

- Coal is a combustible black or brownish-black sedimentary rock formed from the fossilized remains of ancient plants.
- Most widely used in thermal power plants
- Coal comes in four main types, also known as ranks based on its carbon content, i.e., **Lignite, Bituminous, Subbituminous, Anthracite**
- While it boasts a **high energy density**, its combustion releases substantial **pollutants**, making it a major contributor to climate change.

# 3. Raw Energy Resources

Cont....

## ii. Petroleum (Oil) and Natural Gas

- Petroleum (also called **crude oil**) and natural gas are two of the most important fossil fuels.
- They're formed from ancient organic matter, i.e., plants and animals, that was buried under layers of sediment and subjected to heat and pressure over millions of years.
- They are used in **gas turbines** and **diesel** power plants
- They offer **high energy efficiency** and **rapid start-up** capabilities, but are hindered by **price volatility** and **finite reserves**.

# 3. Raw Energy Resources

Cont....

## iii. Nuclear Energy

- Nuclear energy is the power released from the **nucleus** of an atom-the dense center made up of **protons** and **neutrons**.
- It's one of the most concentrated forms of energy.
- The principal fuel types used in nuclear energy are **Uranium-235** and **Thorium-232**.
- Nuclear energy offers a **high energy output** with **minimal greenhouse gas emissions**, but its drawbacks include the **generation of radioactive waste** and significant **safety concerns**.

## 2. Renewable Energy Sources

### i. Solar Energy

- Solar energy is the radiant energy emitted by the **Sun**, which can be harnessed to produce **heat, electricity**, or drive **chemical reactions**.
- It's the most **abundant energy** source on Earth and a cornerstone of renewable energy technologies
- Solar energy is captured using two main methods:
  - **Photovoltaic (PV) Systems**
  - **Concentrated Solar Power (CSP) Systems**
- Solar energy faces challenges due to its reliance on **weather conditions** and time of day, along with the **high upfront cost** of installation.

# 3. Raw Energy Resources

Cont....

## ii. Wind Energy

- Wind energy is a form of renewable energy that harnesses the **kinetic energy** of moving air to generate electricity.
- It's **clean, sustainable, scalable technology**, and one of the fastest-growing energy sources globally.
- Wind turbines are primarily categorized into two types:
  - Horizontal-axis wind turbines (HAWT) and,
  - Vertical-axis wind turbines (VAWT)

# 3. Raw Energy Resources

Cont....

## iii. Hydro Energy

- Hydro energy, also known as **hydroelectric energy**, harnesses the power of moving water-typically from rivers, streams, or dams-to generate electricity.
- Hydropower plants can be classified by size into **large-scale** and **small or micro-scale** systems.
- Hydropower plants offer **clean, renewable** energy with **low operating costs** and reliable electricity generation, especially in regions with abundant water resources.
- However, they can cause significant **environmental disruption**, including **habitat loss**, and often require **high initial investment**.

## iv. Biomass and Geothermal

- **Biomass energy** is derived from organic materials-such as wood, crop residues, animal waste, and even food scraps.
- When these materials are burned or biologically processed, they release energy that can be used for electricity, heating, or biofuels like ethanol and biodiesel.
- **Geothermal energy** harnesses the heat from beneath Earth's surface.
- This heat originates from the planet's core and can be accessed through wells that bring hot water or steam to the surface to drive turbines and generate electricity.

# 3. Raw Energy Resources

Cont....

## What are the Key Factors in Source Selection?

- Cost and availability
- Environmental impact
- Energy demand
- Plant location
- Technological maturity

# 4. Energy Conversion Systems

- An energy conversion system refers to the process and machinery that transforms **raw energy sources**-like coal, natural gas, nuclear fuel, solar radiation, or wind-into usable **electrical energy** [4].
- These systems are the **heart of any power plant**, and they operate based on principles of **thermodynamics**, **fluid mechanics**, and **electrical engineering**.
- Each system has unique conversion paths, efficiencies, and environmental impacts.
- Energy conversion systems are central to **power generation**, **industrial processes**, and **sustainable energy development**.

## Components of Energy Conversion Systems

- The main components of energy conversion system in power plants are:
  - **Energy Source:** Raw input (coal, gas, uranium, sunlight, wind, etc.)
  - **Prime Mover:** Converts energy into mechanical work (e.g., turbines, engines)
  - **Generator:** Converts mechanical energy into electrical energy
  - **Auxiliary Systems:** Boilers, condensers, cooling towers, control systems
- Energy conversion system is divided into two:
  - Direct energy conversion system
  - Indirect energy conversion system

# 5. Direct Energy Conversion Systems

- Direct energy conversion refers to the **transformation** of one form of energy (e.g., chemical, solar, nuclear) **directly** into electrical energy **without intermediate mechanical steps** [5].
- However, traditional conventional power plants use mechanical systems (e.g., turbines) to convert thermal energy into electricity. Direct systems skip this step.
- This offers potential for:
  - **Higher efficiencies** (not limited by Carnot efficiency).
  - **Higher reliability** and longer life (no moving parts to wear out).
  - **Quiet operation** and minimal maintenance.
  - **Modularity and portability**.

# 5. Direct Energy Conversion Systems

Cont...

## Types of Direct Energy Conversion Systems

### i. Thermoelectric Generators (TEGs)

- Thermoelectric generators (TEGs) are fascinating devices that convert **heat** directly into **electricity** using a principle called the **Seebeck Effect** [6].
- The Seebeck Effect is the phenomenon in which a voltage (electromotive force, or EMF) is generated across the junction of two different conductors or semiconductors when there is a **temperature difference** between them.
- Unlike conventional power systems that rely on turbines and moving parts, TEGs are solid-state, meaning they have no moving components, making them quiet, durable, and ideal for highly specific applications.

# 5. Direct Energy Conversion Systems

Cont...

## Applications of Thermoelectric Generators (TEGs)

- Spacecraft
  - Automotive
  - Industrial
  - Remote Sensors
  - Waste Heat Recovery
- However, TEGs have very low efficiency, typically **5-8%**.

# 5. Direct Energy Conversion Systems

Cont...

## ii. Photovoltaic Cells (Solar Cells)

- Photovoltaic (PV) cells, commonly known as **solar cells**, are semiconductor devices that convert sunlight directly into electricity using the **photovoltaic effect**.
- They're the fundamental building blocks of solar panels and play a central role in harnessing solar energy.
- Some of its advantage are:
  - Renewable, abundant and clean energy source
  - Reduces dependence on fossil fuels
  - Scalable for both small and large installations
  - Key to global decarbonization efforts

# 5. Direct Energy Conversion Systems

Cont...

## Application areas of photovoltaic cells

- Rooftop solar panels for homes and businesses
- Solar farms for utility-scale power
- Portable solar chargers and calculators
- Spacecraft and satellites

# 5. Direct Energy Conversion Systems

Cont...

## iii. Fuel Cells

- Fuel cells are electrochemical devices that convert the chemical energy of a fuel directly into electricity, without combustion.
- They operate much like **batteries** but with a key difference: they continuously generate electricity as long as fuel and oxidizer are supplied.
- Fuel cells are used in powering spacecraft, electric vehicles, backup systems, and even submarines.
- They're a cornerstone of clean energy innovation.

# 5. Direct Energy Conversion Systems

Cont...

## Advantages of Fuel Cells

- High Efficiency
- Clean and Quite
- Reliable
- Flexible and Scalable

## Application areas of fuel cells

- Transportation
- Stationary Power
- Portable Power

# 6. Indirect Energy Conversion Systems

- An indirect energy conversion system is one where the energy from a source is **not transformed directly** into **electricity** (or useful work).
- Instead, it is first converted into an **intermediate form** of energy, almost always **thermal energy (heat)**, which is then used to produce the final desired form of energy, typically **electrical energy**.
- In short, indirect energy conversion refers to the **multi-step process** of converting energy.
- Unlike direct conversion systems (e.g., solar PV or fuel cells), these systems rely on **thermal** and **mechanical processes** before producing usable energy.

# 6. Indirect Energy Conversion Systems

Cont...

## Key characteristics of indirect energy systems:

- **Multi-stage conversion:** Energy is transformed through heat, mechanical work, and finally electricity.
- **Thermodynamic cycles:** These systems operate based on cycles like Rankine, Brayton, Otto, or Diesel.
- **High power output:** Suitable for large-scale applications like power plants and industrial facilities.

# 6. Indirect Energy Conversion Systems

Cont...

## Types of Indirect Energy Conversion Systems

### 1. Steam Power Plants

- A Steam Power Plant (also known as a thermal power plant) is a facility that converts **heat energy** from **fuel combustion** into **mechanical energy**, and then into **electrical energy** using a steam-driven turbine and generator [1].
- It operates on the **Rankine cycle**, which involves boiling water to produce steam, expanding it through a turbine, and condensing it back to water.

### Application Areas

- Electric Power Generation
- Industrial Heating

# 6. Indirect Energy Conversion Systems

Cont...

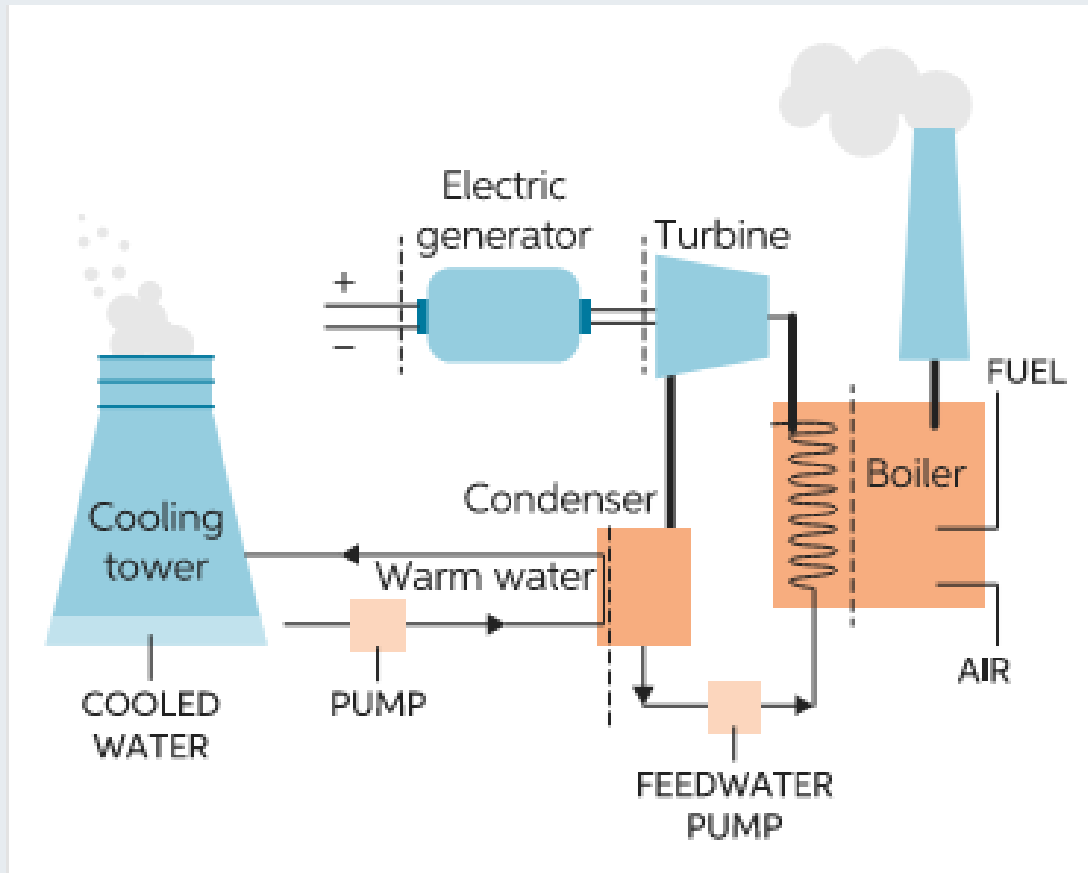
## Main Components Steam Power Plants:

- **Boiler**-Converts water into high-pressure steam using heat from fuel combustion
- **Steam Turbine**-Converts thermal energy of steam into mechanical energy
- **Generator**-Converts mechanical energy into electrical energy
- **Condenser**-Condenses exhaust steam from the turbine back into water
- **Feed water Pump**-Pumps condensed water back into the boiler

# 6. Indirect Energy Conversion Systems

Cont...

## Main Components of Steam Power Plants:



**Figure 2.** Harvesting Fusion Power – Main components of steam power plant." EDN Network, n.d  
url: [https://www.edn.com/wp-content/uploads/Power-Points-Blog-151\\_harvesting-fusion-power\\_Fig2.png?w=375&resize=375,297](https://www.edn.com/wp-content/uploads/Power-Points-Blog-151_harvesting-fusion-power_Fig2.png?w=375&resize=375,297)

# 6. Indirect Energy Conversion Systems

Cont...

## 2. Gas Turbine Plants

- A gas turbine power plant is a type of thermal power station where **air is compressed, mixed with fuel, and ignited** to produce high-temperature gases that spin a turbine connected to a generator [1].

### Application Areas

- Electricity generation
- Aircraft propulsion
- Marine engines
- Industrial mechanical drives

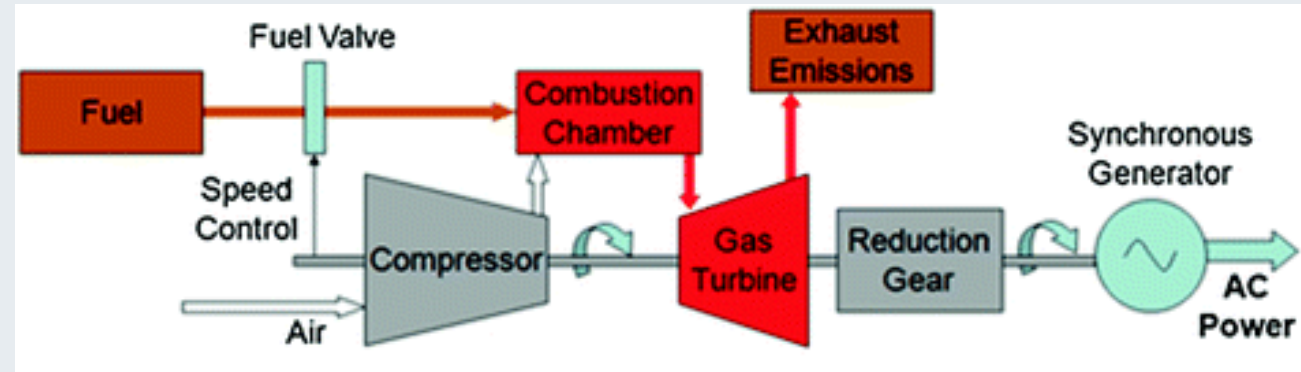
# 6. Indirect Energy Conversion Systems

Cont...

## Main Components of Gas

## Turbine Power Plants

- Compressor
- Combustion Chamber
- Turbine
- Generator
- Auxiliary Systems



**Figure 3.** Main Components of Gas Turbine Electric Power Plant.” GEMCO Pellet Mills, n.d.

url: <http://www.gemcopelletmills.com/uploads/allimg/gas-turbine-electric-power-generation.jpg>

## Types of Gas Turbine Cycles

- **Open Cycle:** Air enters and exits the system once.
- **Closed Cycle:** Working fluid is recirculated.
- **Combined Cycle:** Integrates a steam turbine for higher efficiency.

# 6. Indirect Energy Conversion Systems

Cont...

## 3. Internal Combustion Engine

- An Internal Combustion Engine (ICE) is a heat engine where the **combustion of fuel** occurs with an **oxidizer** (usually air) inside a combustion chamber.
- The expanding gases directly apply force to engine components, converting chemical energy into mechanical work.

### Application Areas

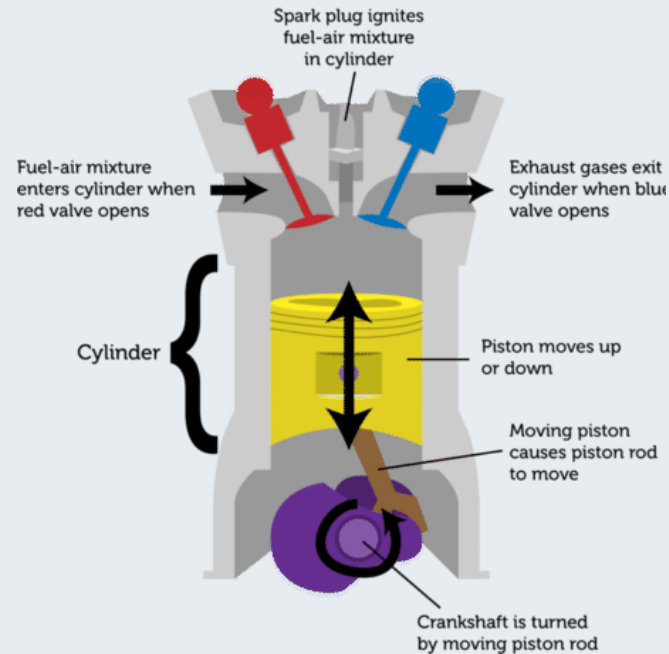
- Automobiles and motorcycles
- Aircraft and ships
- Power generators
- Agricultural and construction machinery

# 6. Indirect Energy Conversion Systems

Cont...

## Main Components of Internal Combustion Engine

- Cylinder
- Piston
- Crankshaft
- Valves
- Spark Plug
- Camshaft



**Figure 4.** Main components of internal combustion engine

url: [https://encrypted-tbn0.gstatic.com/images?q=tbn:ANd9GcTFI5uFYgispIThpxBFOPZMirjvkk4HpGF9mA1u09VJfz\\_KavCqCiTd59z4&s](https://encrypted-tbn0.gstatic.com/images?q=tbn:ANd9GcTFI5uFYgispIThpxBFOPZMirjvkk4HpGF9mA1u09VJfz_KavCqCiTd59z4&s)

According to the combustion process, IC Engines can be classified:

- **SI Engine:** Uses spark plug to ignite air-fuel mixture
- **CI Engine:** Air is compressed to high temperature; fuel is injected

and auto-ignites

## 4. Hydro Electric Plant

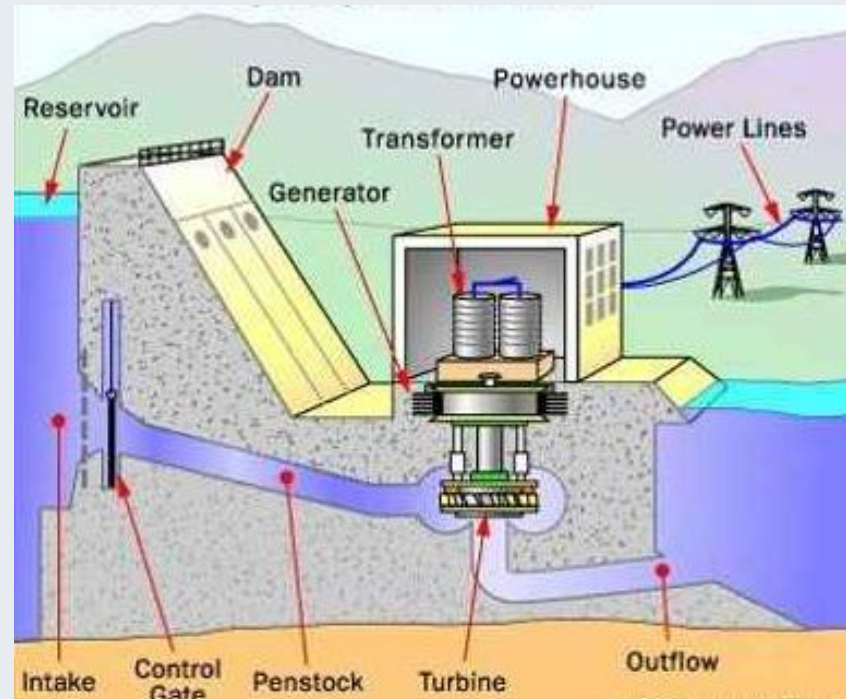
- A hydroelectric power plant converts the **kinetic** and **potential energy** of flowing or falling water into **mechanical energy**, which is then transformed into **electrical energy** using a generator [2].
- **The key features of hydro electric plant are:**
  - Renewable and clean energy source
  - High efficiency (up to 90%)
  - Long operational lifespan

# 6. Indirect Energy Conversion Systems

Cont...

## Main components of hydro electric energy:

- Dam
- Reservoir
- Penstock
- Turbine
- Generator
- Transformer



**Figure 5.** Main components of hydro electric power  
url: [https://encrypted-tbn1.gstatic.com/images?q=tbn:ANd9GcSOaD180Hl bwdmcOsLmk-Ae\\_T6YEhmjQoLWRECcuq5RicY6YKdyg](https://encrypted-tbn1.gstatic.com/images?q=tbn:ANd9GcSOaD180Hl bwdmcOsLmk-Ae_T6YEhmjQoLWRECcuq5RicY6YKdyg)

# 6. Indirect Energy Conversion Systems

Cont...

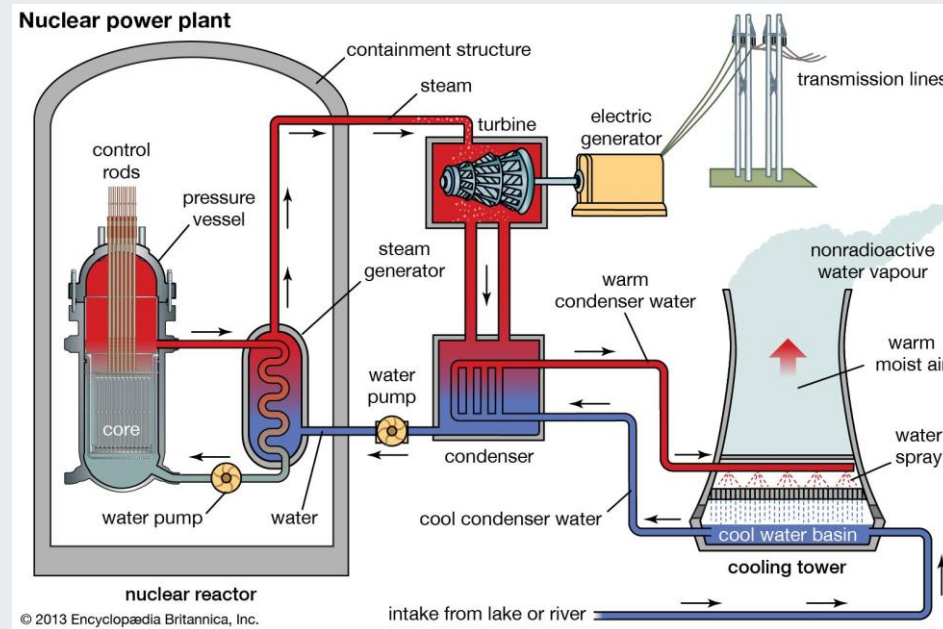
## 5. Nuclear Power Plant

- A nuclear power plant generates electricity using **heat** produced by **nuclear fission**, a process where the nucleus of an atom splits into smaller parts, releasing a tremendous amount of energy [1].
- **The key features of nuclear power plant are:**
  - High energy density
  - Low greenhouse gas emissions
  - Reliable base-load power source

# 5. Indirect Energy Conversion Systems

## Major components of nuclear power plant:

- Reactor Core
- Control Rods
- Coolant
- Steam Generator
- Turbine and Generator
- Containment Structure



**Figure 6.** Main components of nuclear power plant Reactor.” Encyclopædia Britannica, Inc., n.d.

url: <https://cdn.britannica.com/62/162162-050-586ADA35/diagram-nuclear-power-plant-reactor.jpg>

# Summary

- Power plants convert various forms of energy into electrical energy using mechanical systems and thermodynamic principles.
- Power plants are categorized as thermal, hydroelectric, nuclear, solar, wind, and diesel based on energy source and conversion method.
- Raw Energy Resources include conventional (coal, oil, natural gas) and renewable (solar, wind, hydro, biomass) sources used to fuel power generation.
- Direct Energy Conversion Systems are technologies like fuel cells, thermoelectric generators, and solar PV convert energy directly into electricity without mechanical motion.
- Indirect Energy Conversion Power Plants are systems like steam turbines and gas turbines that convert thermal energy into mechanical energy, then into electricity.

# References

- [1]. Power Plant Engineering, Larry Drbal, Kayla Westra, and Pat Boston, Springer, 2011.
- [2]. Power Plant Engineering, R.K. Rajput, 3rd Edition, 2011.
- [3]. The role of renewable energy in the global energy transformation, D. Gielen, F. Boshell, D. Saygin, M.D. Bazilian, N. Wagner, R. Gorini, Energy Strategy Reviews, 2021, <https://doi.org/10.1016/j.esr.2019.01.006>
- [4]. A comprehensive review of hybrid renewable energy systems: Modeling, optimization, and applications, Khalid, F., Duan, J., Ouyang, T., & Naqvi, S. A. A. (2023). Energy Reports, 9, 5251–5282. <https://doi.org/10.1016/j.egyr.2023.04.332>
- [5]. Thermoelectricity: Direct Energy Conversion from Heat to Electricity, D.M. Rowe, Institute of Physics Publishing, 2018.
- [6]. Thermoelectric Generators: A Review of Applications, D. Champier, Energy Conversion and Management, 2017, <https://doi.org/10.1016/j.enconman.2017.02.070>

Thank you !