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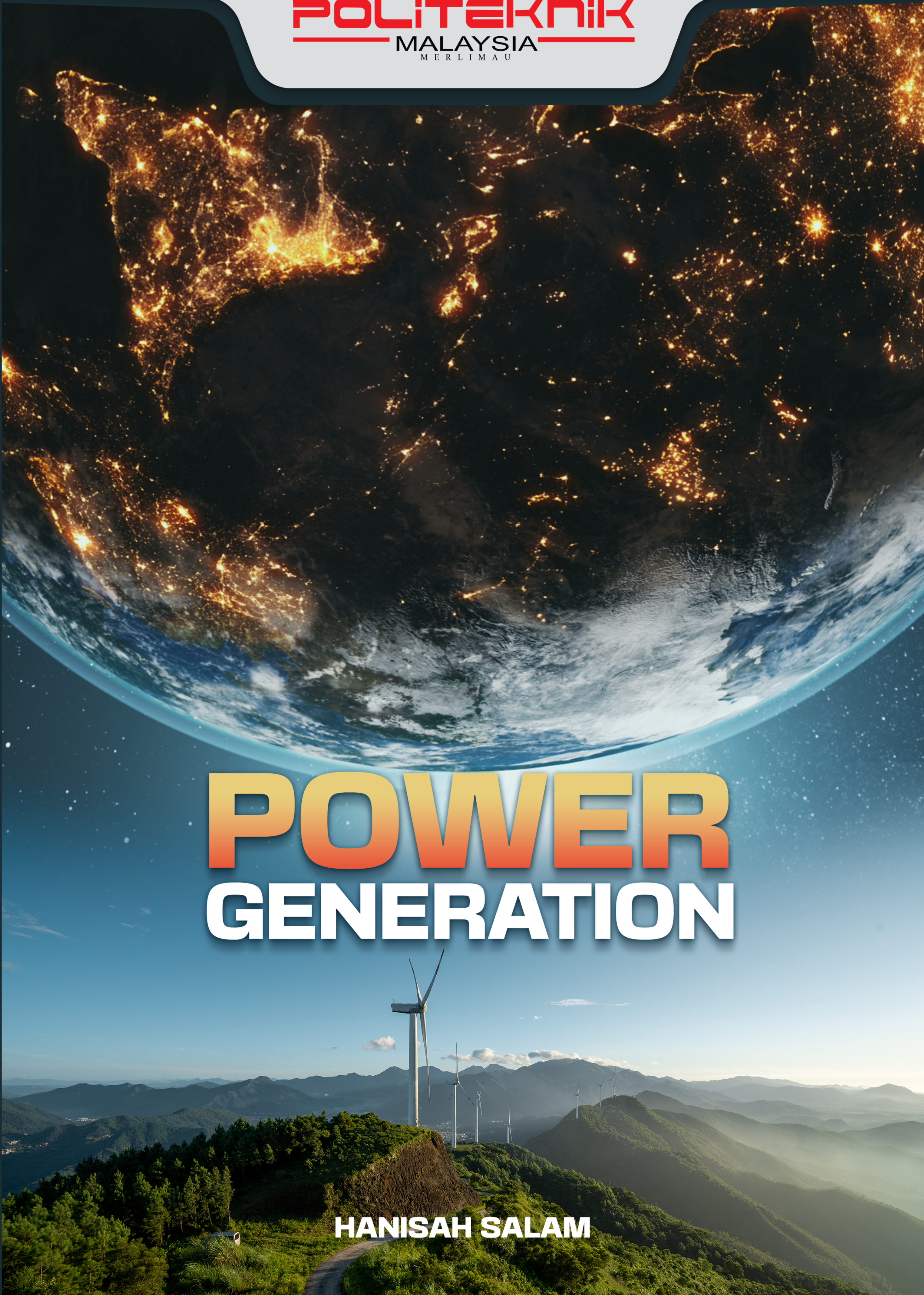

POWER GENERATION

HANISAH SALAM

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In the name of Allah, the Most Gracious and the Most Merciful

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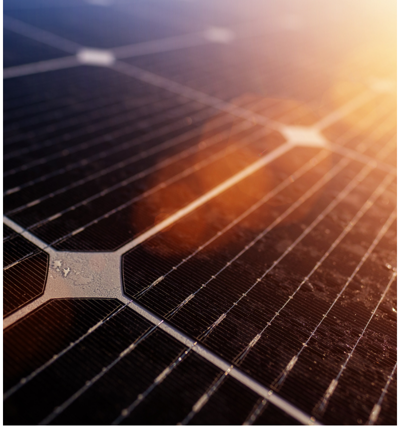
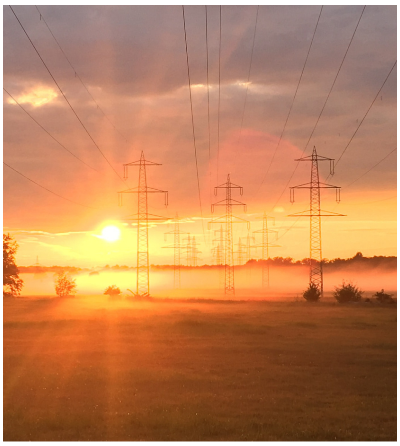
PREFACE

This eBook is one of the additional reference sources for all students who learn Power System or who are interested in this topic.

The uniqueness of this eBook is displayed in the form of easy-to-understand text in a compact form to make it easier for students and readers to make references. The eBook is illustrated with pictures related to the topic discussed, with aims to ensure that the students can relate to the real situation.





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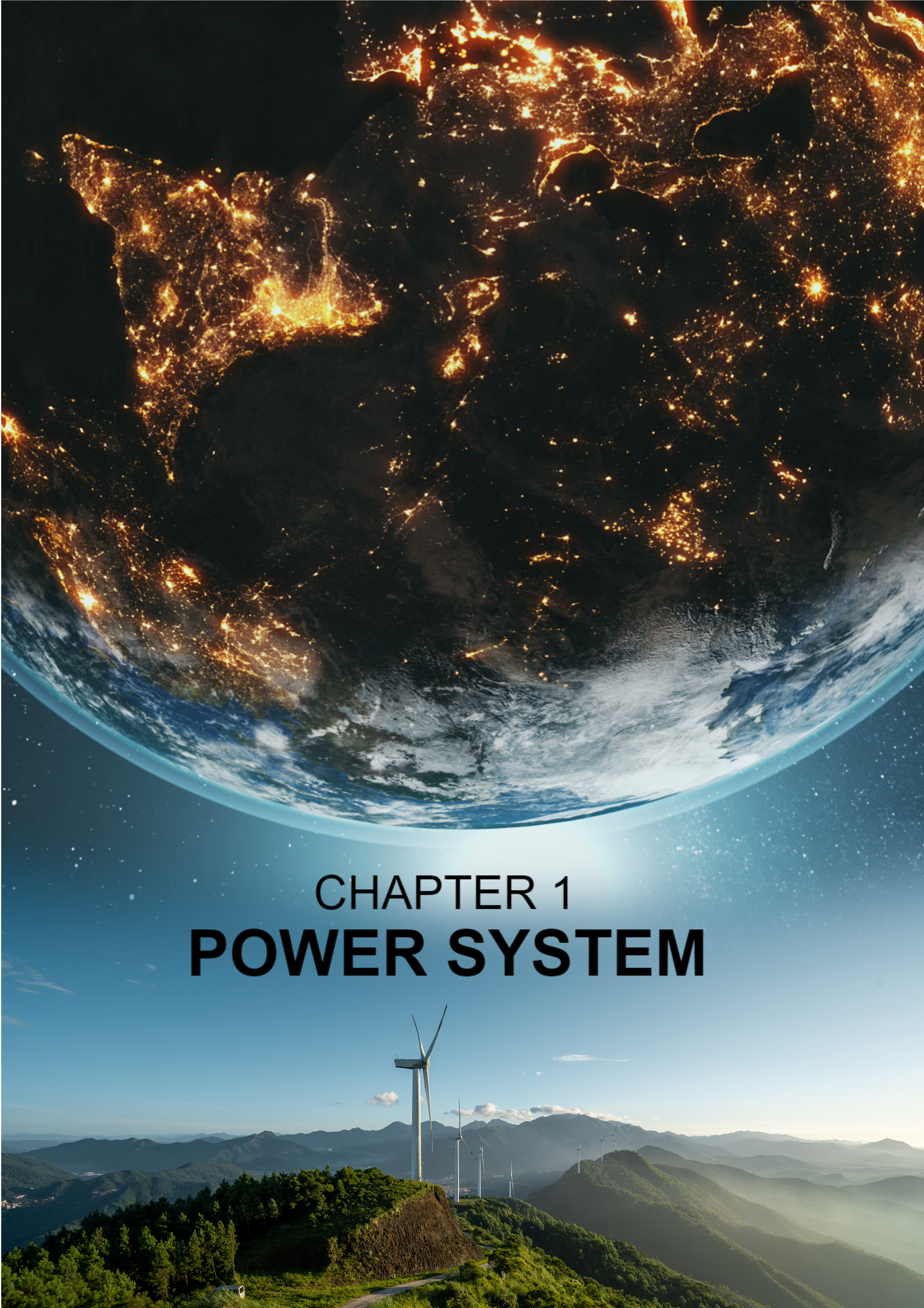

CHAPTER 1
POWER SYSTEM

CHAPTER ONE

POWER SYSTEM

Electric Power System is a composite component that converts other types of energy (like coal and water) into electrical energy and delivers it to the consumers.

It consists of generation, transmission and distribution system. It also comprises components like the synchronous generator, motor, transformer, circuit breaker, cable, and others that are connected to the system.

Why we need to generate electricity?

Benefits of Electricity

CHEAPNESS
Much cheaper than other forms of energy.

CONVENIENT FORM
Easily converted into other forms of energy such as electrical energy into heat (heater) and electrical energy into light (bulb).

EASY CONTROL
The electrically operated machines have simple and convenient starting, control and operation such as an electric motor can be started or stopped by turning on or off a switch.

CLEANLINESS
Free from smoke, fumes or poisonous gases.

GREATER FLEXIBILITY
Easily transported from one place to another with the help of conductors.

HIGH TRANSMISSION EFFICIENCY
Can be transmitted conveniently and efficiently from generation center to the consumers with the help of overhead conductor (transmission line).

SOURCE OF ENERGY

"THE FUTURE IS GREEN ENERGY, SUSTAINABILITY AND RENEWABLE ENERGY"

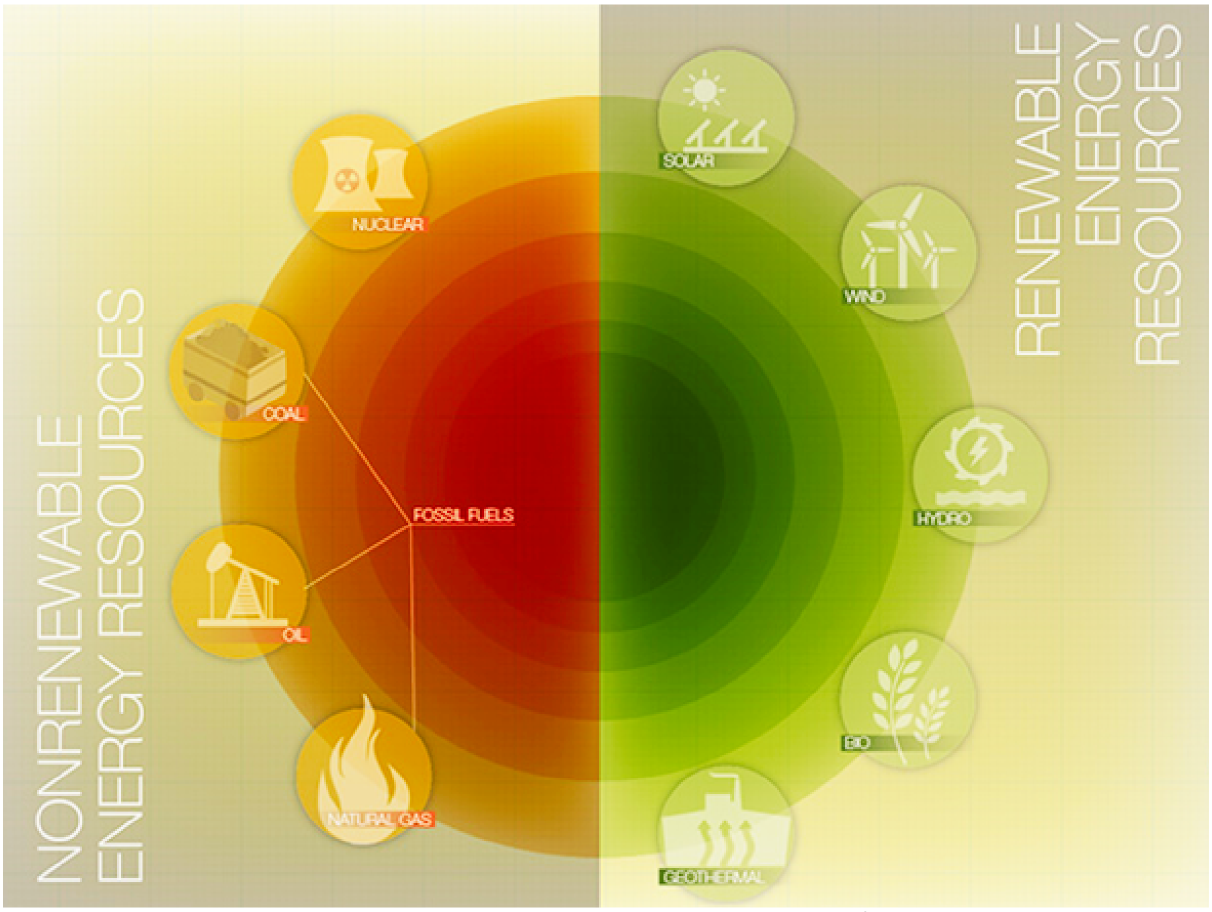

Figure 1.1: Non-renewable and renewable energy sources for power generation.

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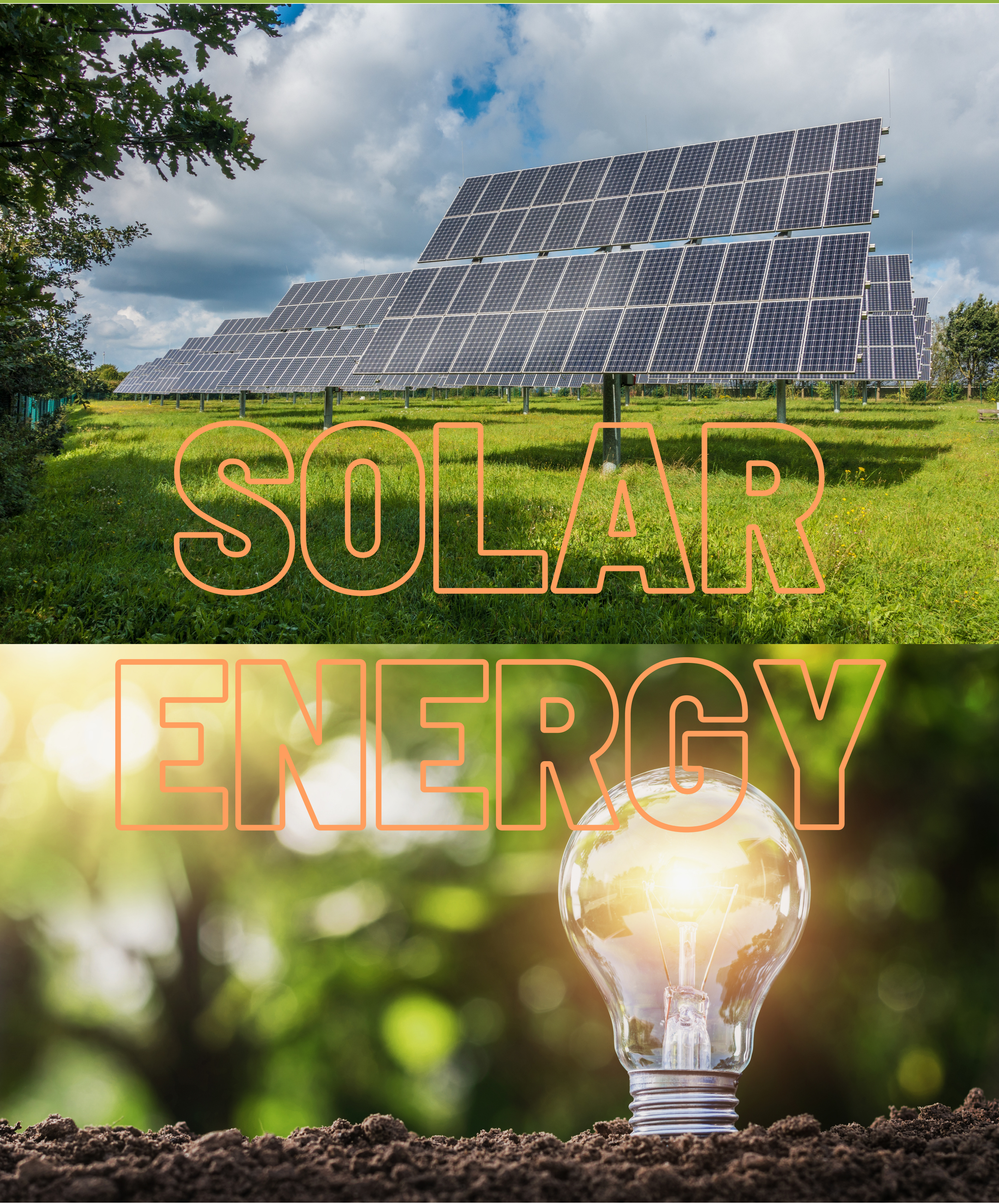
RENEWABLE ENERGY

Renewable energy is described as energy derived from natural resources (sunlight, water, wind, and tidal) that are not depleted or destroyed when used.

It is a replacement for conventional energy, which is based on fossil fuels. It is also less hazardous to the environment.

Solar, wind, hydro, biomass, biofuel, and geothermal power plants are all examples of renewable energy power plants.


SOLAR
ENERGY

SOLAR ENERGY

Sunlight is the source of solar energy. Photovoltaics convert the heat energy emitted by the sun into electrical energy (PV).

Figure 1.2: TNB largest scale solar project uses 230,000 solar panels installed on 98 hectares of land in Mukim Tanjung 12, Sepang

How it works?
A photovoltaic system turns sunlight into electrical direct current (DC), which is subsequently converted to alternating current (AC) with the use of inverters.

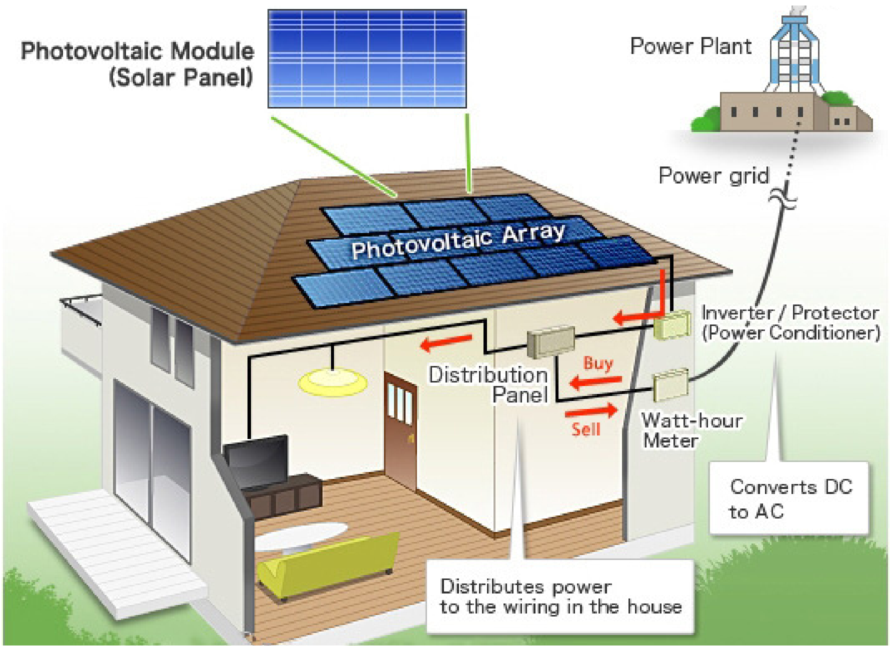
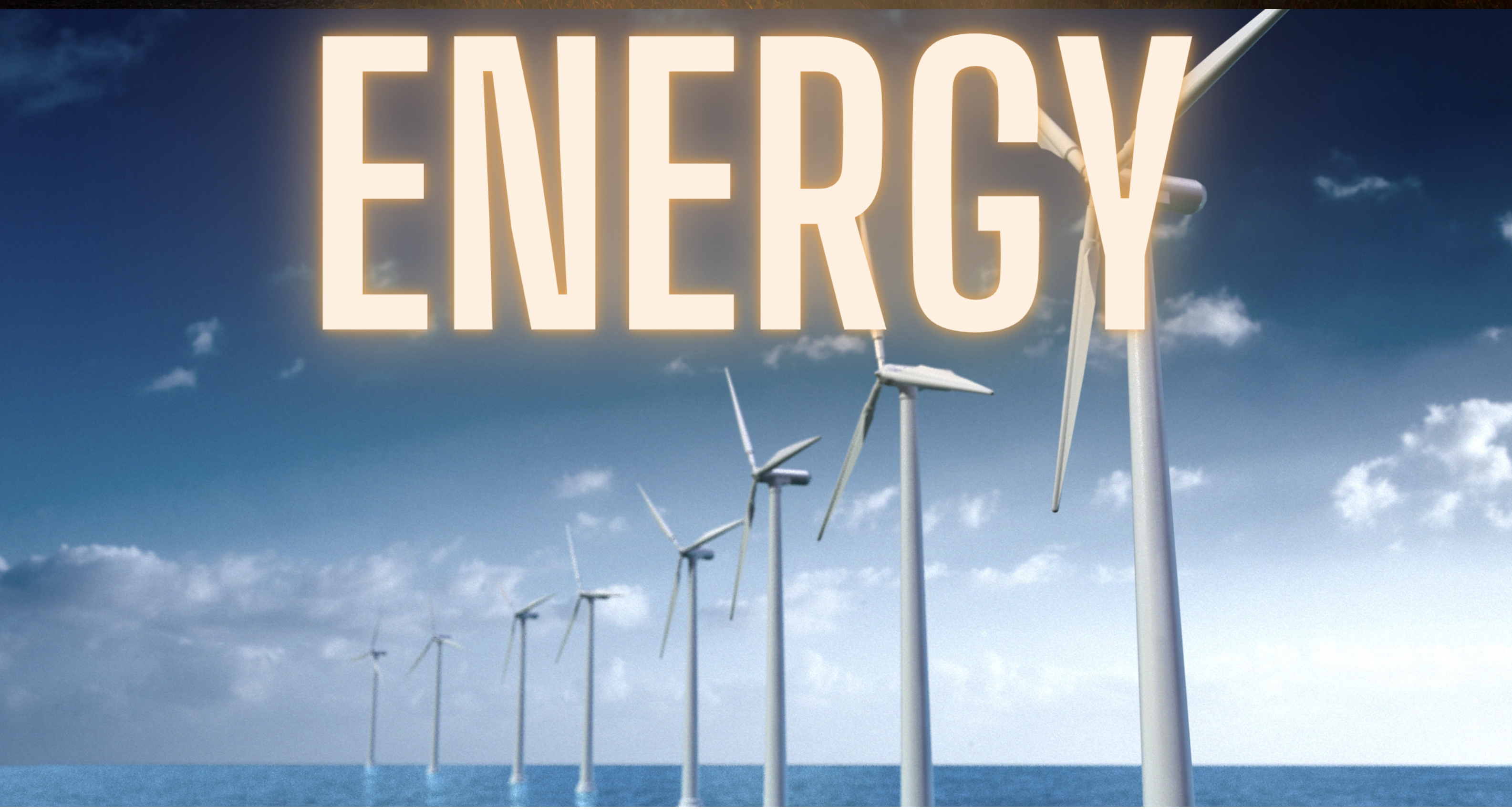


Figure 1.3: A small home solar power system

WIND ENERGY



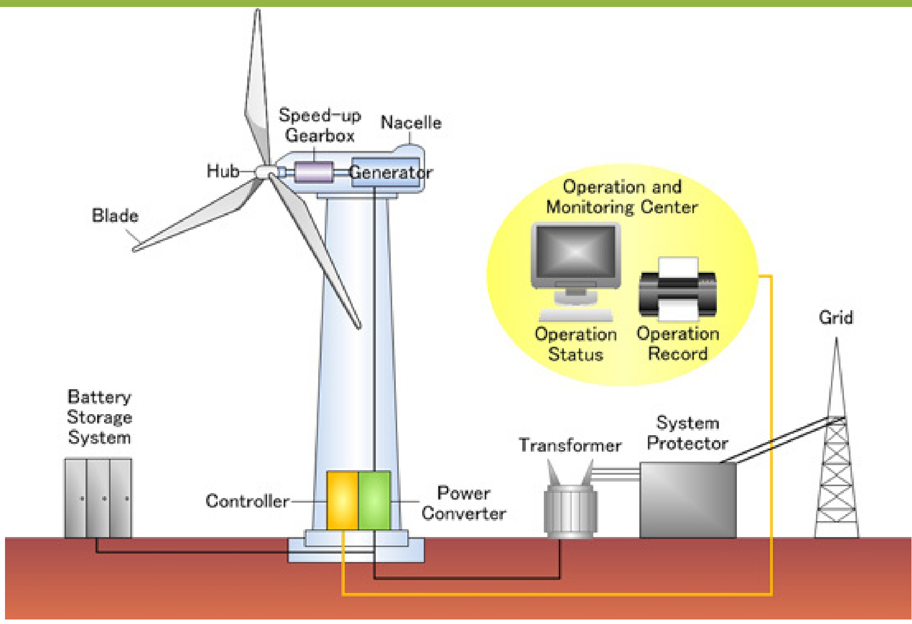


Figure 1.4: Wind Power by Yokogawa Electric Coorporation

WIND ENERGY

Wind energy is generated by blowing wind using wind turbines to produce mechanical power output which drives an electric generator to obtain electrical energy.

How it works?

Wind spins the shaft and turns the turbine blades. After that, electricity is produced. An inverter is a device that converts DC electricity into AC electricity. Electricity is either directly connected to the grid or stored in a battery.

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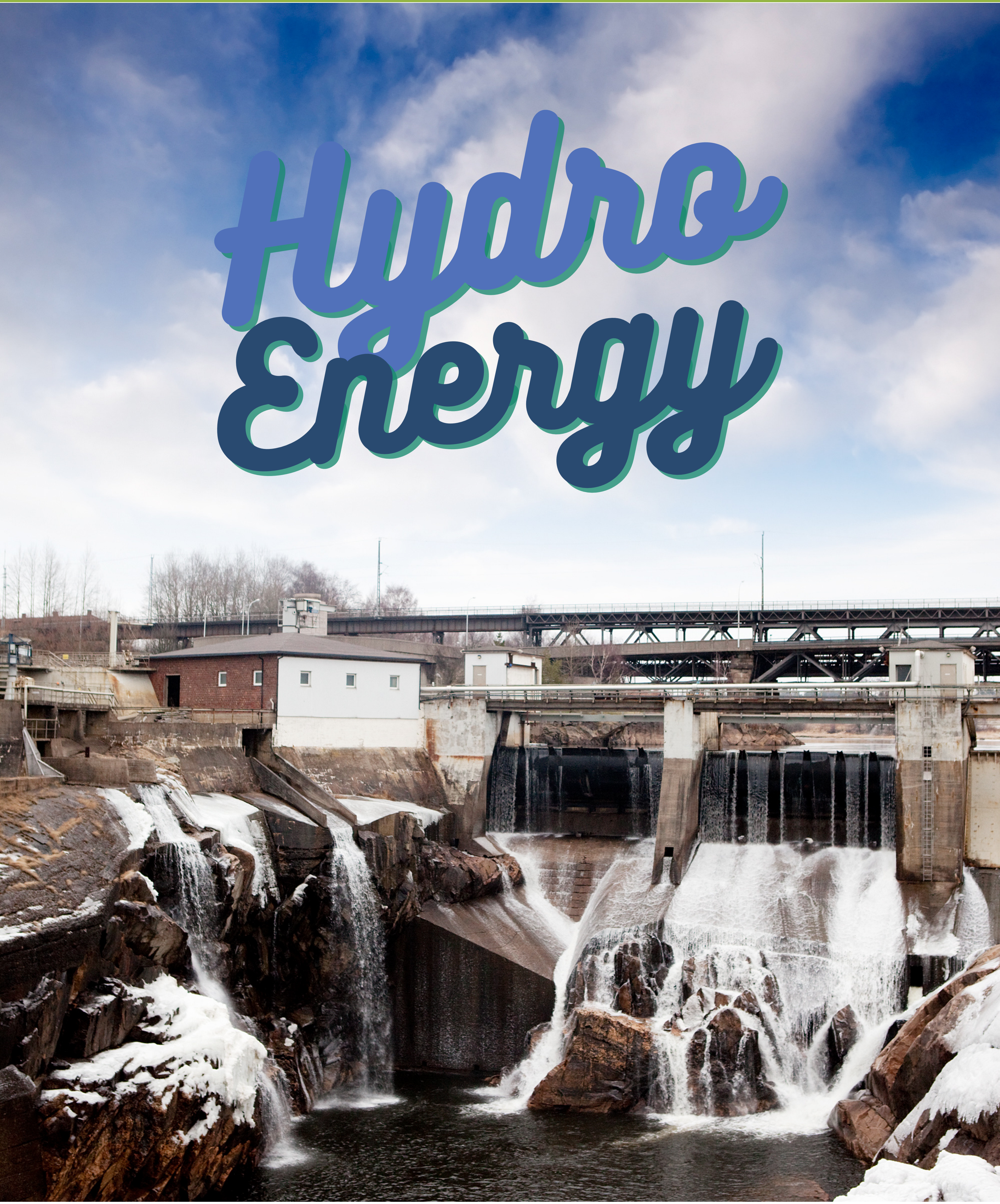
Hydro Energy



HYDRO ENERGY

How does it work?

Falling water from reservoirs is directed via the intake near the bottom of the dam, which generates hydro energy. Water flows through the penstock to the turbine when the intake door is opened. The turbine is turned by the water, which then turns the generator shaft. The water is pumped back into the river after being used to create electricity. Transmission wires run from the power plant to the homes and businesses.

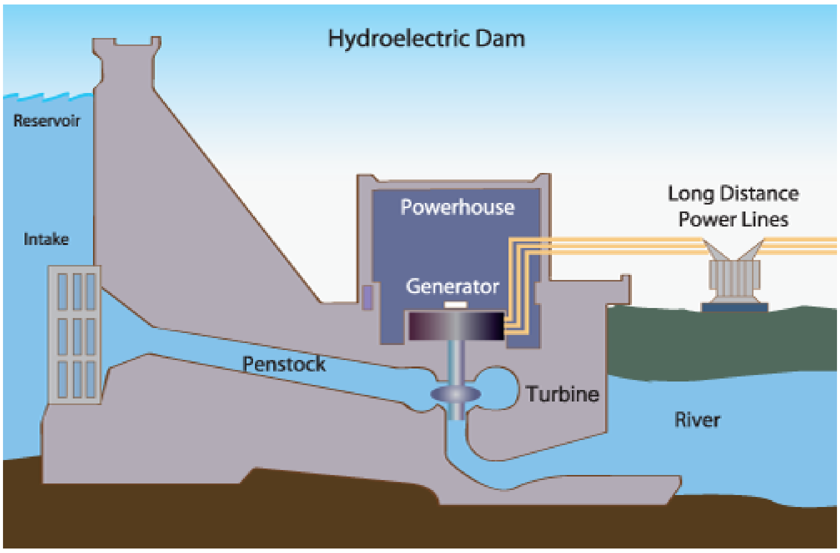


Figure 1.5: Hydroelectric Diagram

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BIOMASS



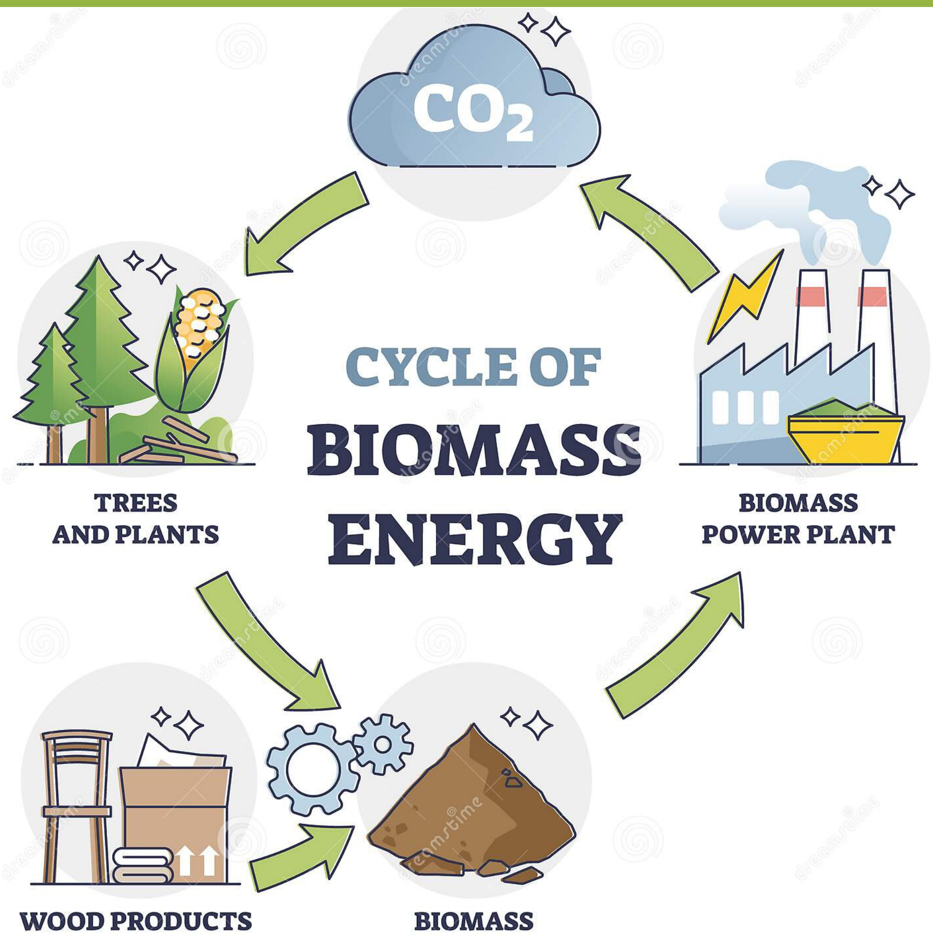

Figure 1.6: Cycle of Biomass Energy

BIOMASS ENERGY

The sources to generate biomass energy are wood waste, rice husks, animal waste, algae, oil palm residue waste, etc.

How it works?
The biomass source is fed into a furnace where it is burned to produce steam. The steam turns a turbine and which then turns the shaft of generator to produce electricity.

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BIOFUEL ENERGY

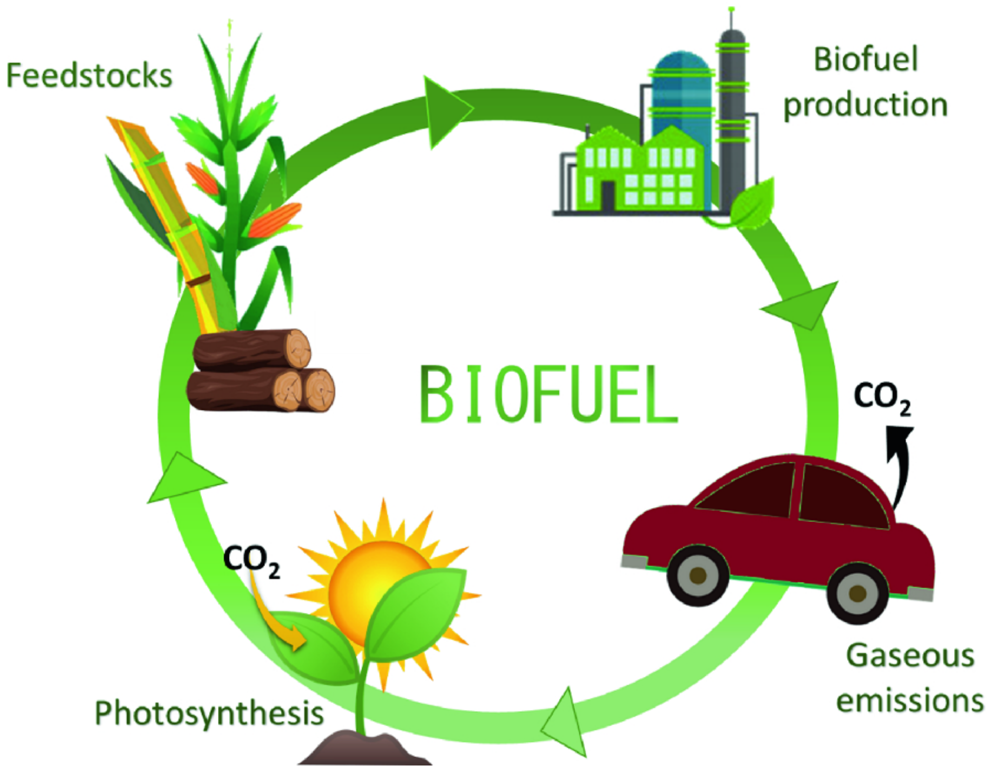

Figure 1.7: Cycle of Biofuel Energy

For our transportation needs, biomass may be readily transformed into liquid fuels (biofuels) (cars, trucks, buses, aeroplanes, and trains). Ethanol and biodiesel are basically two forms of biofuel.

How it works?

Ethanol is generated by fermenting any biomass that contains a lot of carbs (starches, sugars, or celluloses) in a similar way to producing beer. Biodiesel is created by mixing vegetable oil, animal fat, or recycled cooking greases with alcohol (typically methanol).

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Geothermal Energy

The Sarulla Geothermal Power Plants in Indonesia

GEOTHERMAL ENERGY

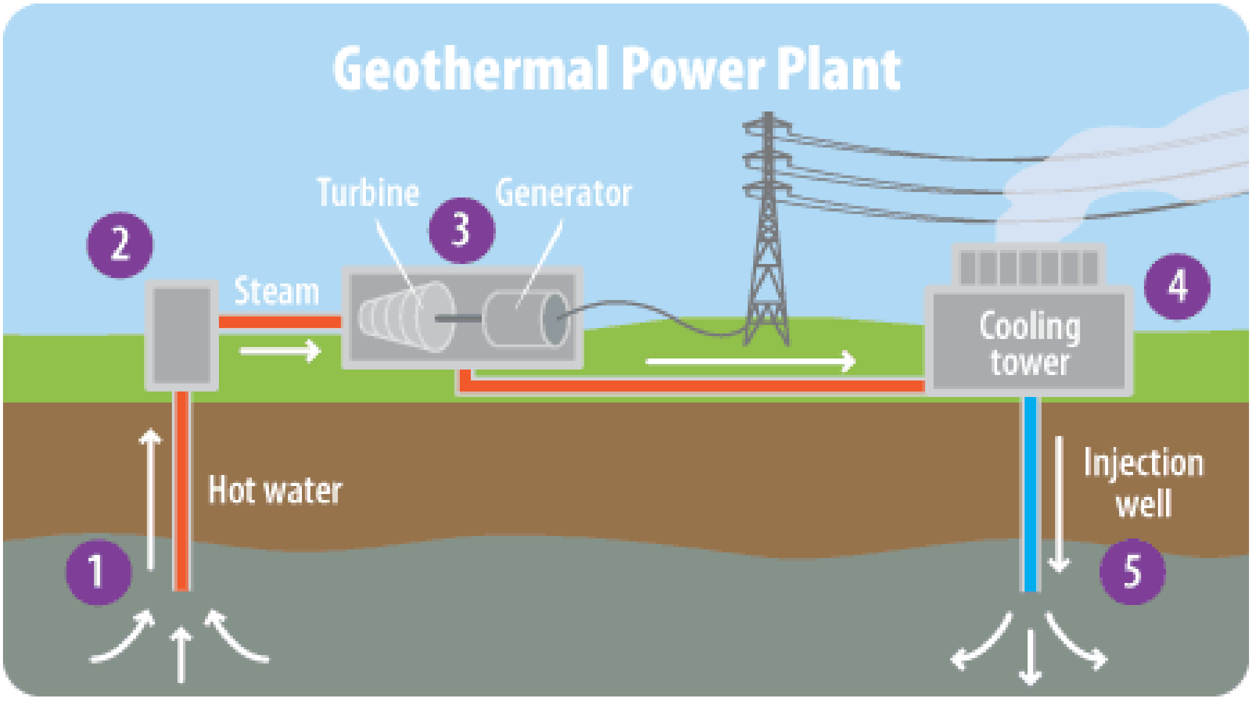


Figure 1.7: Cycle of Geothermal Power Plant

Geothermal energy comes from the heat in the ground.

How does it work?

- Hot water is injected from deep underground through a well under high pressure.
- As the water approaches the surface, its pressure drops, leading it to transform into steam.
- The steam spins a turbine, which is connected to a generator of energy.
- Steam cools and condenses back to water in a cooling tower.
- To restart the process, the cooled water is pushed back into the ground.

THE IMPORTANCE OF RENEWABLE ENERGY

There are few or no greenhouse gas emissions.

Enhances both public health and environmental quality.

A large and endless source of energy.

Increases economic growth and job chances.

" THE POTENTIAL OF RENEWABLE ENERGY IS IMMENSE. "

~Tulsi Tanti~

Advantages of RENEWABLE ENERGY

- Easy to generate and renewable.
- Facilities require less maintenance than traditional generator.
- Produces little or no waste products / minimal impact to the environment.
- Boosts economic growth and increases job opportunities.

Disadvtanges of Renewable Energy

1) It's difficult to create as much electricity as a typical generator.

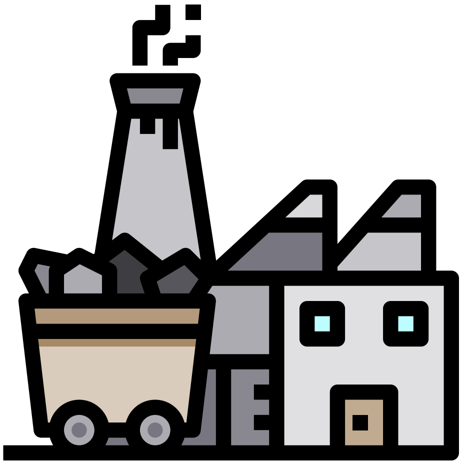
2) Depends on weather for its source of power thus reducing its reliability.

3) Extremely requires large capital cost.

4) Unpredictable and inconsistent.

2 2

NON RENEWABLE ENERGY



NON-RENEWABLE ENERGY

NATURAL GAS

Reservoirs store natural gas underground. Natural gas is used in a boiler to heat water and produce steam, which is then used to power a turbine to generate electricity.

FUEL

Prime movers transform the heat energy of burning fuels into mechanical energy, which drives the generator, which then converts mechanical energy to electrical energy.

NUCLEAR

Nuclear energy comes from uranium and plutonium. The heat energy released as a result of fission is utillised to boil water, which is then converted to steam. To generate energy, steam rotates a turbine, which powers generators.

COAL

The heat generated by the burning coal is utillised to heat the water. The steam drives turbines, which in turn drive electricity generators.

ADVANTAGES OF NON-RENEWABLE ENERGY

(1) The energy sources are easy to be transported from one area to another.

(2) Coal is a relatively cheap energy source.

(3) The energy sources can be found in many places in the world.

(4) The energy sources took million of years to form and will run out one day.

Exercise

(1) List THREE (3) types of power plants with their energy sources.

(2) Write the differences between hydro and thermal (coal-fired) power plant based on the installation cost, location, environmental impact and output power.

(3) List THREE (3) advantages of solar energy.

(4) State FOUR (4) renewable energy sources.

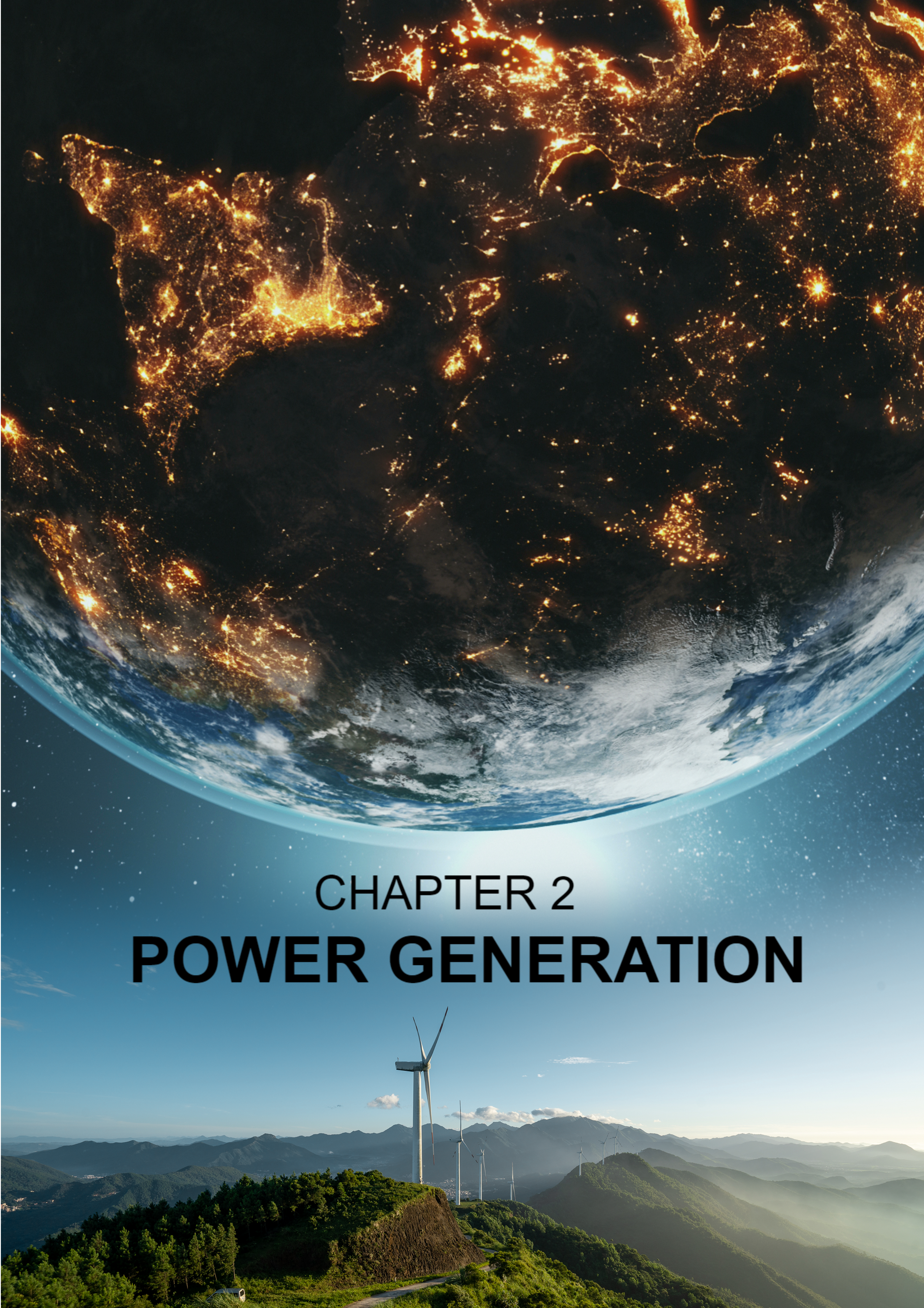
(5) Explain the importance of renewable energy.

(6) Explain TWO (2) advantages and TWO (2) disadvantages of a solar power plant.

(7) Explain FOUR (4) types of generation power plants.

(8) Construct the operational block diagram of a hydro power plant.

(9) List THREE (3) types of conventional power station.



CHAPTER 2

POWER GENERATION

SINGLE LINE DIAGRAM ELECTRICAL POWER GENERATION

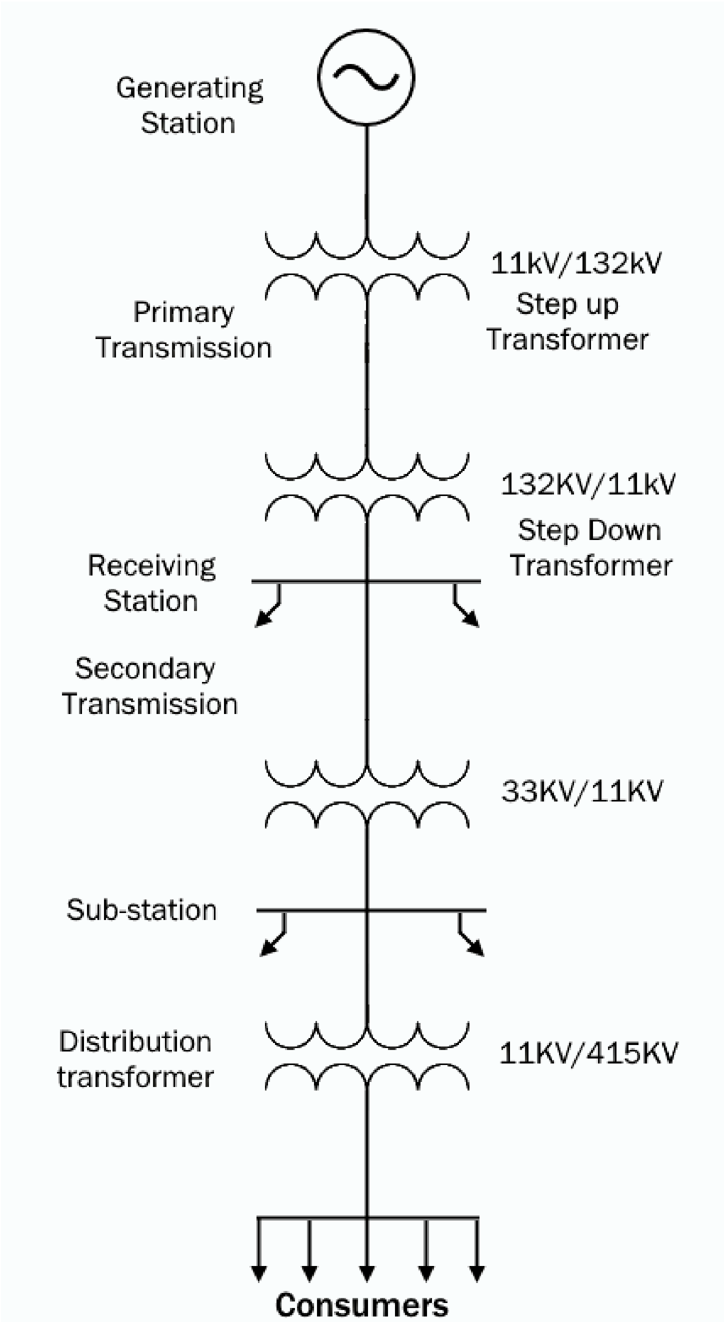


Figure 2.1: Single Line Diagram for Power Generation

TYPES OF POWER GENERATION

1. Hydro Power Generation
2. Thermal Power Generation
3. Wind Power Generation
4. Solar Power Generation

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HYDRO POWER

GENERATION

STRUCTURE OF HYDRO POWER GENERATION

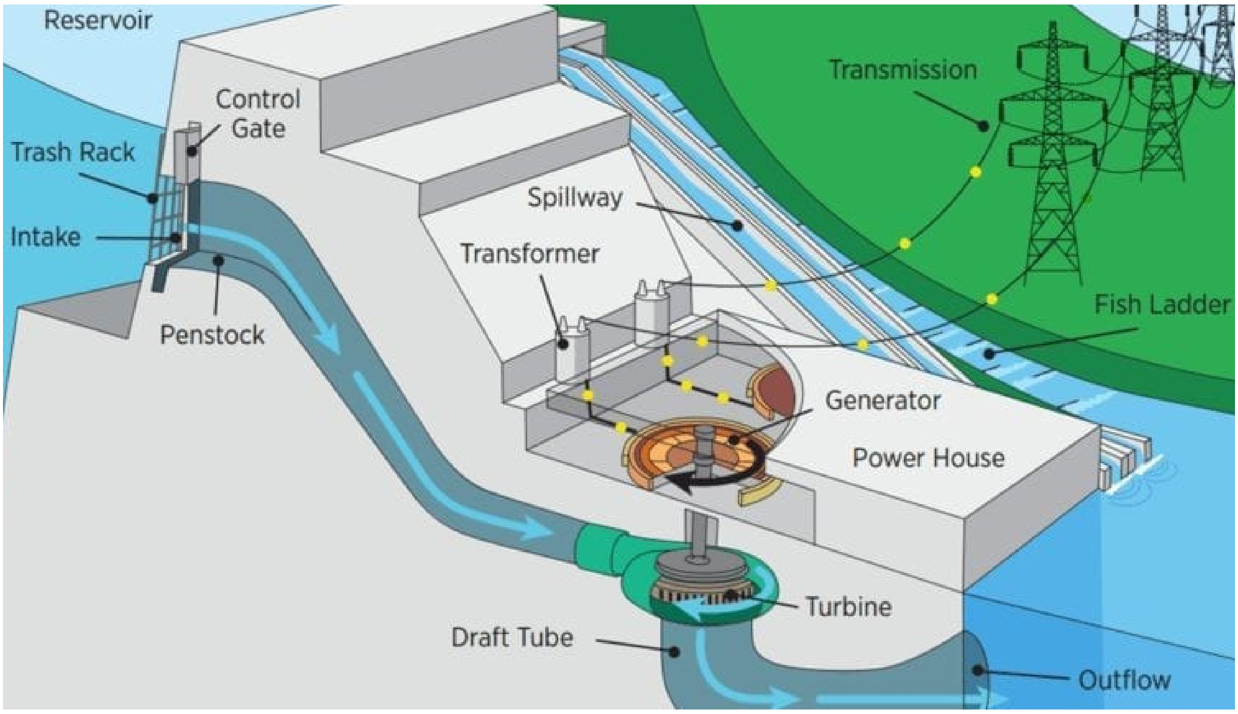

Figure 2.2: Cycle of Hydro Power Plant

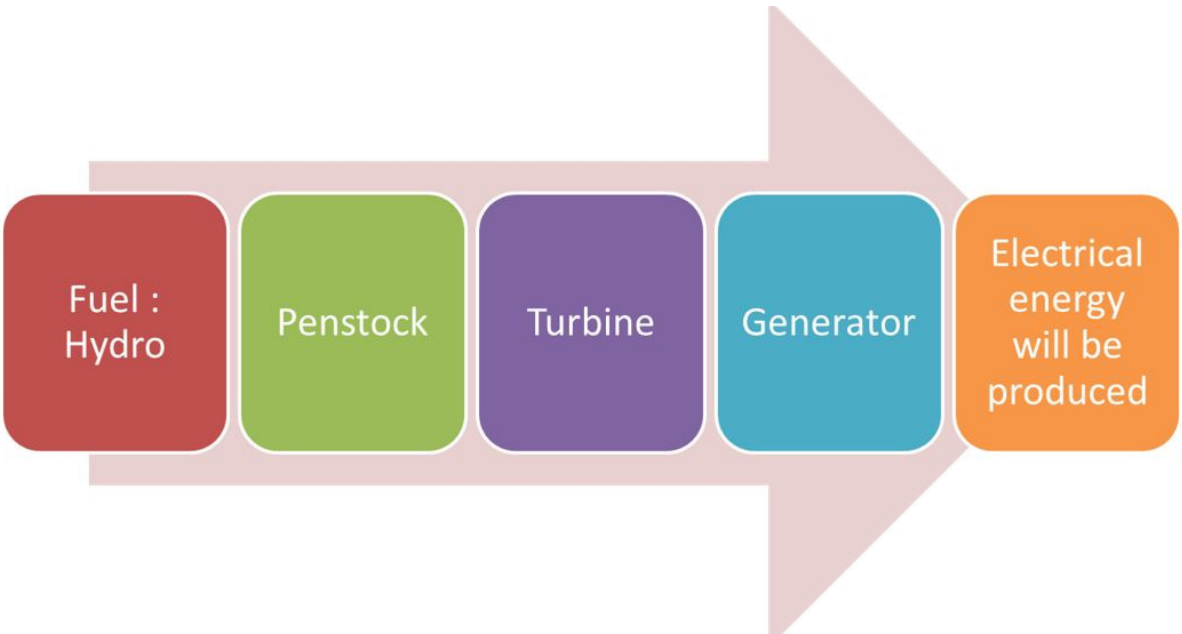

Figure 2.3: Block Diagram of Hydro Power Plant

GENERAL PRINCIPLE OF HYDRO POWER GENERATION

(1) The DAM is constructed on a big river with a significant drop in height.

(2) It has a RESERVOIR behind it that stores a lot of water.

(3) WATER INTAKE is placed near the dam's bottom. When the door opens, water will flow into the turbine's path.

(4) Water is flowing through the PENSTOCK inside the dam due to gravity.

(5) The water rotates the TURBINE, which rotates the GENERATOR shaft.

(6) Electricity is created and delivered to users via POWER LINES.

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THERMAL POWER GENERATION

STRUCTURE OF THERMAL POWER GENERATION

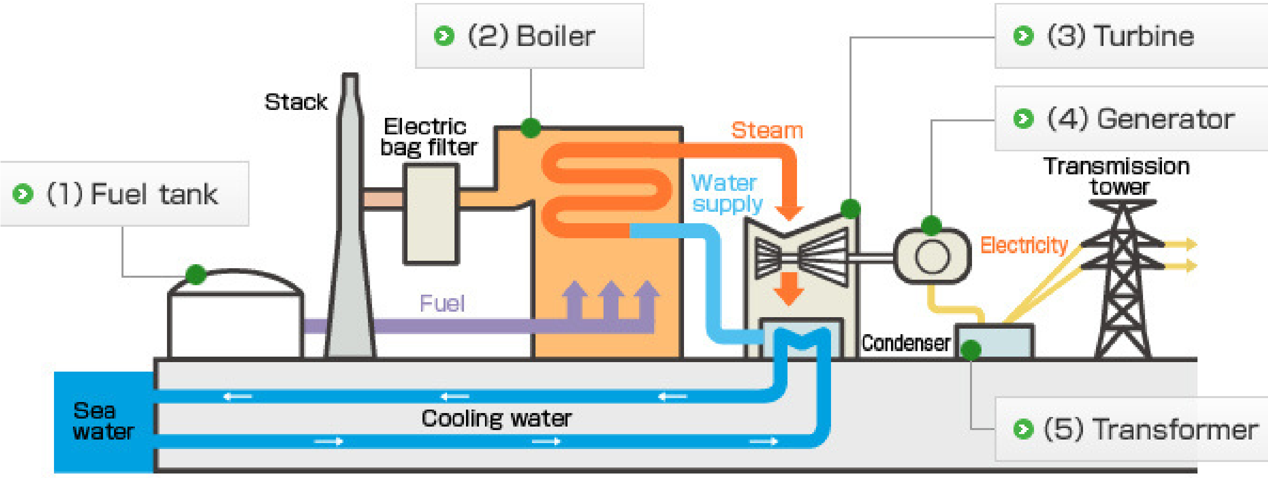

Figure 2.4: Cycle of Thermal Power Plant

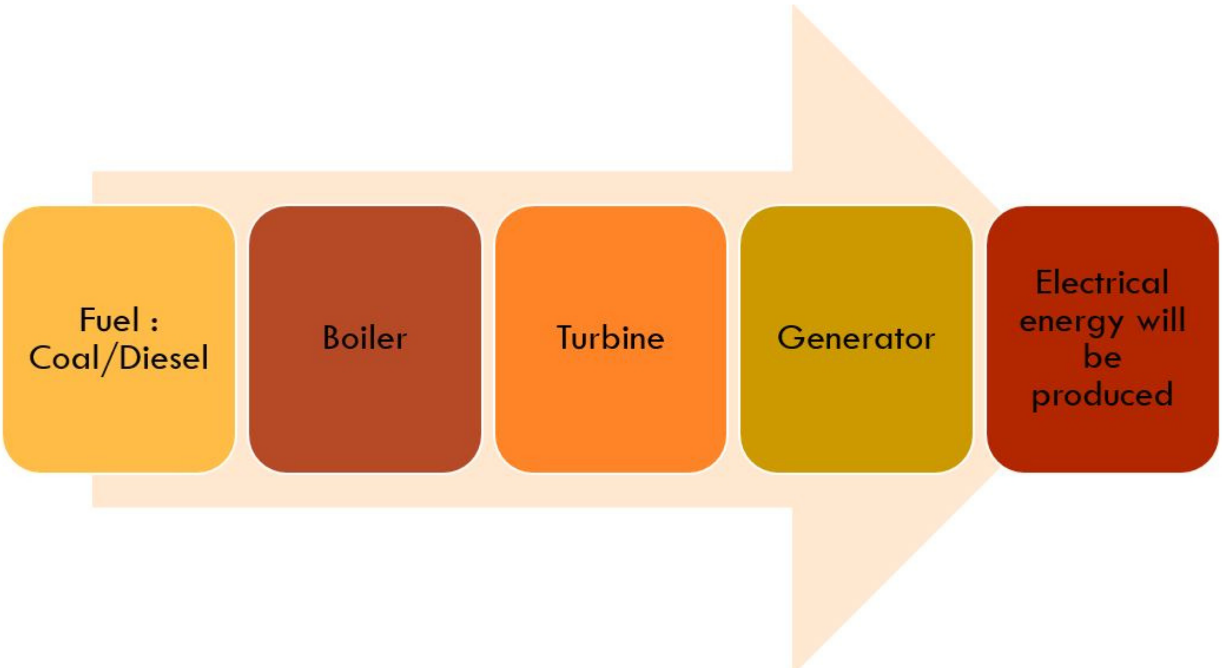

Figure 2.5: Block Diagram of Thermal Power Plant

GENERAL PRINCIPLE OF THERMAL POWER GENERATION

1

FUELS

Coal or diesel is used as fuel for the generation of heat energy.

As the water in the boiler evaporate due to the intent heat, it becomes high pressure steam.

BOILER

The steam is passing through a conduit and it forces its way through the turbine thus rotating the turbine.

2

TURBINE

The turbine is connected to the generator.

As the turbine is rotating (from the force of steam), electrical energy is being produced.

3

GENERATOR

After the steam passes through the turbine, it enters the condenser, the steam changes back to its liquid and returns to the boiler. The process is being repeated.

4

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WIND POWER GENERATION

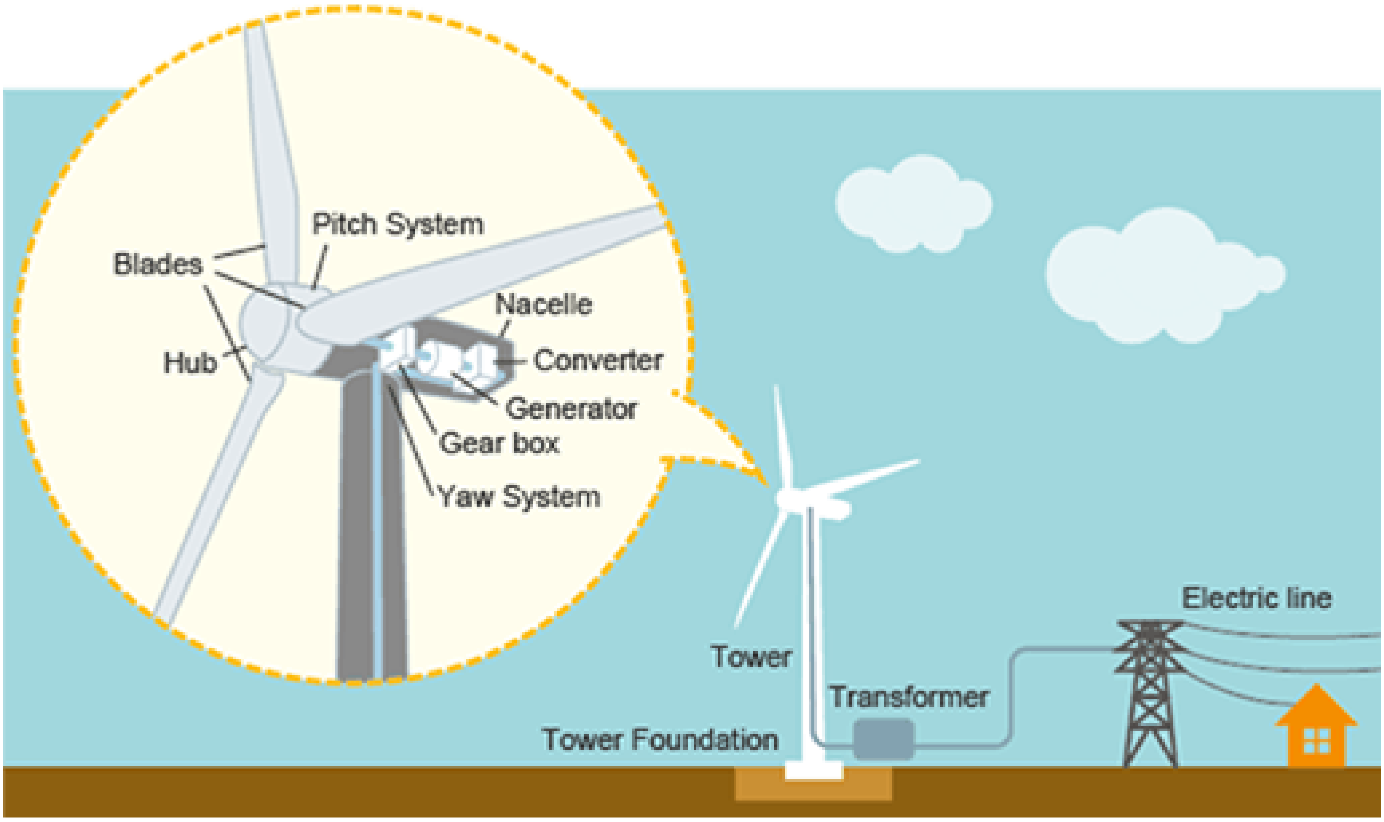

Figure 2.6: Structure of Wind Power Plant

GENERAL PRINCIPLE OF WIND POWER GENERATION

- Wind Turbine: A wind turbine converts wind energy into mechanical energy. It increases the speed and transmits it to the generator rotor through the gear system and linkage.
- Generator: A generator is a device that converts rotational energy to electrical energy.
- Controller: Wind direction, wind speed, generator output, and temperature are all sensed by the controller, which then sends out relevant control signals to act quickly.

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SOLAR POWER GENERATION

SOLAR POWER GENERATION

Photovoltaic (PV) and concentrated solar power are the two primary types of solar energy technologies (CSP).

Photovoltaic (PV)

When the sunlight passes on a solar panel, the sun's energy is absorbed by the photovoltaic cell in the panel. This energy causes electricity to flow by forcing electrical charges to shift in response to an internal electric field in the cell.

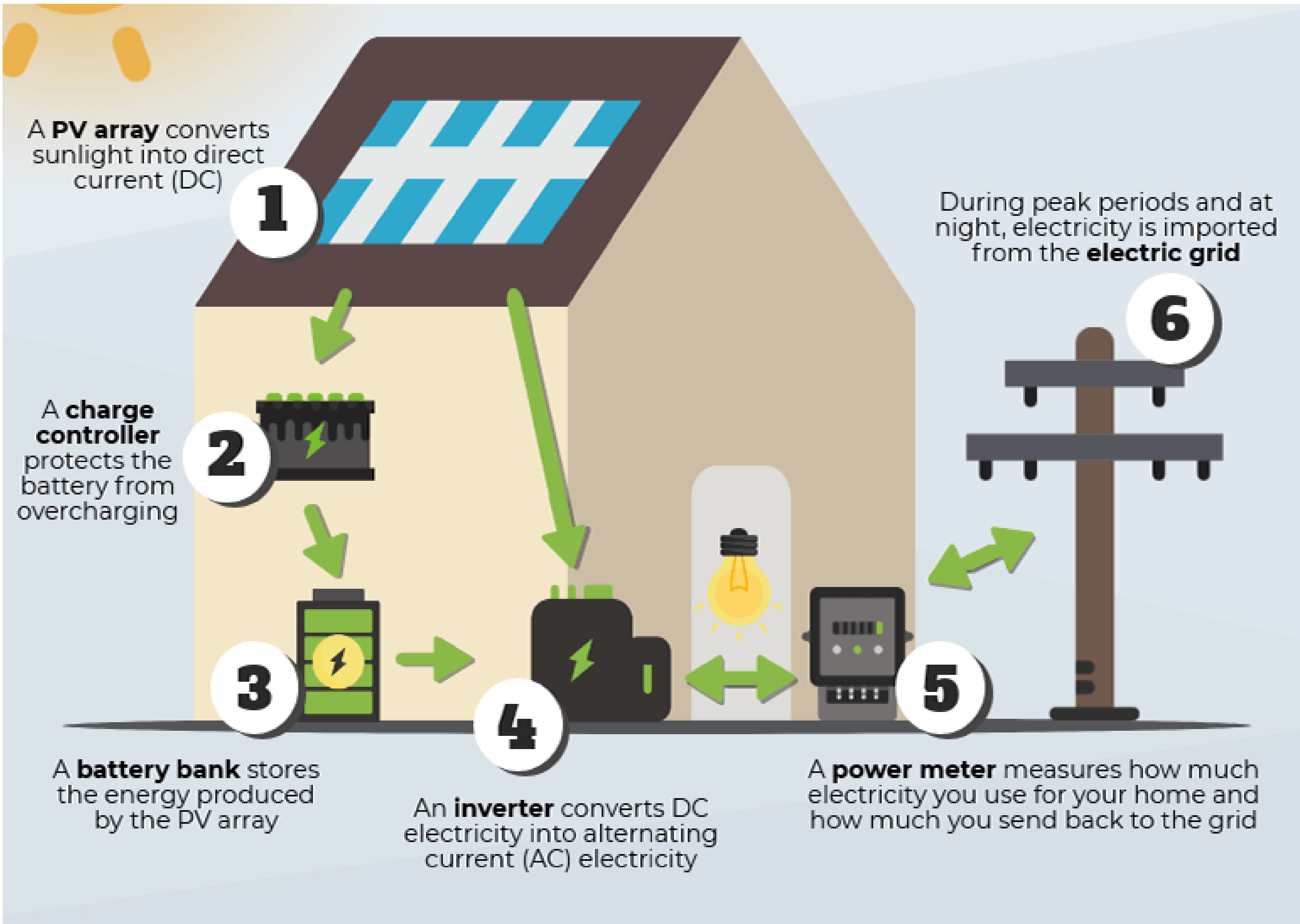
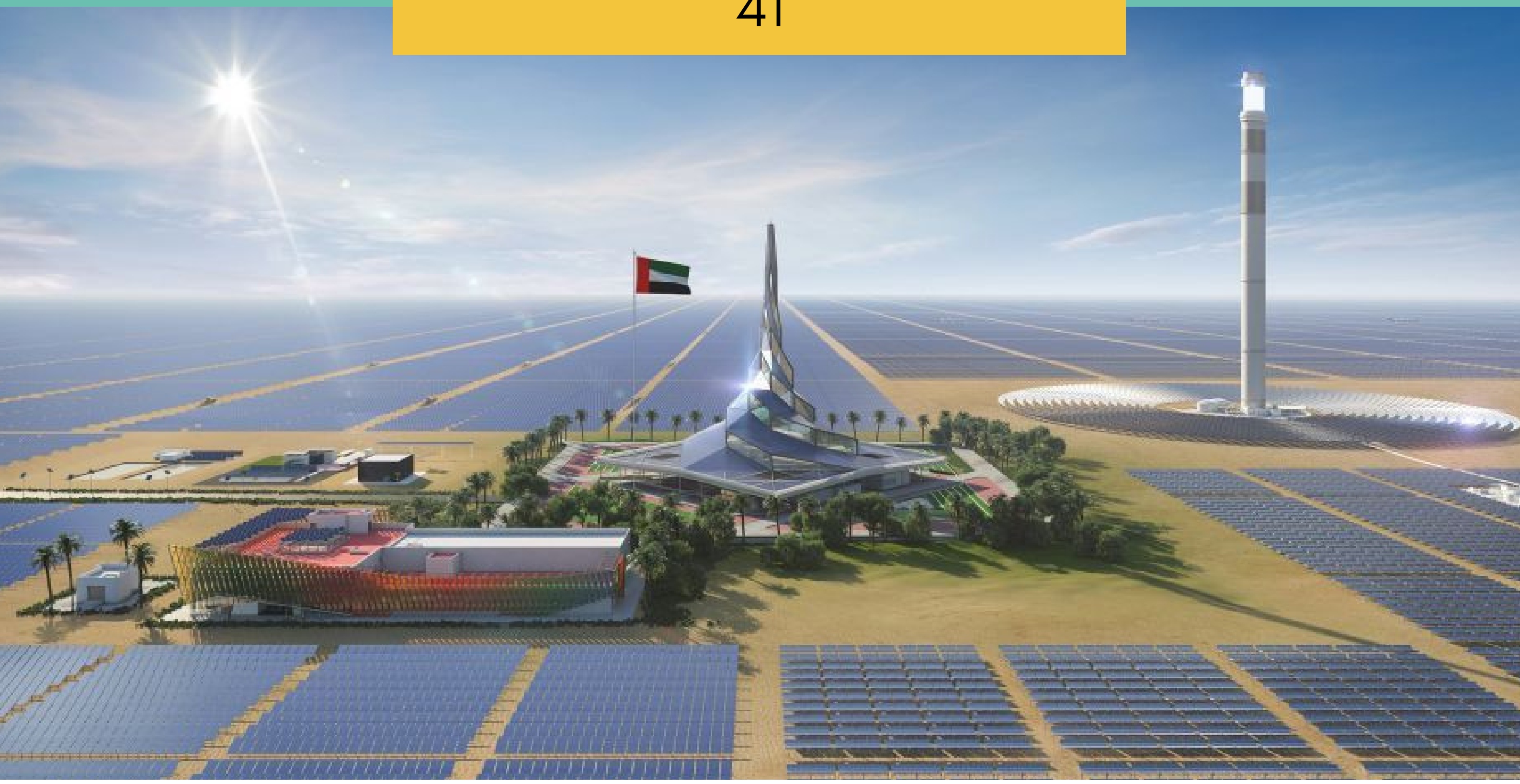


Figure 2.7: Structure of Solar Power Plant



SOLAR POWER PLANT

Concentrated Solar Power (CSP)

CSP uses mirrors to focus a vast region of sunlight onto a tall thin tower (receiver). These concentrated light sources heat fluid, producing steam, which powers a turbine and creates energy.

To generate electricity, CSP is employed in large-scale power facilities.

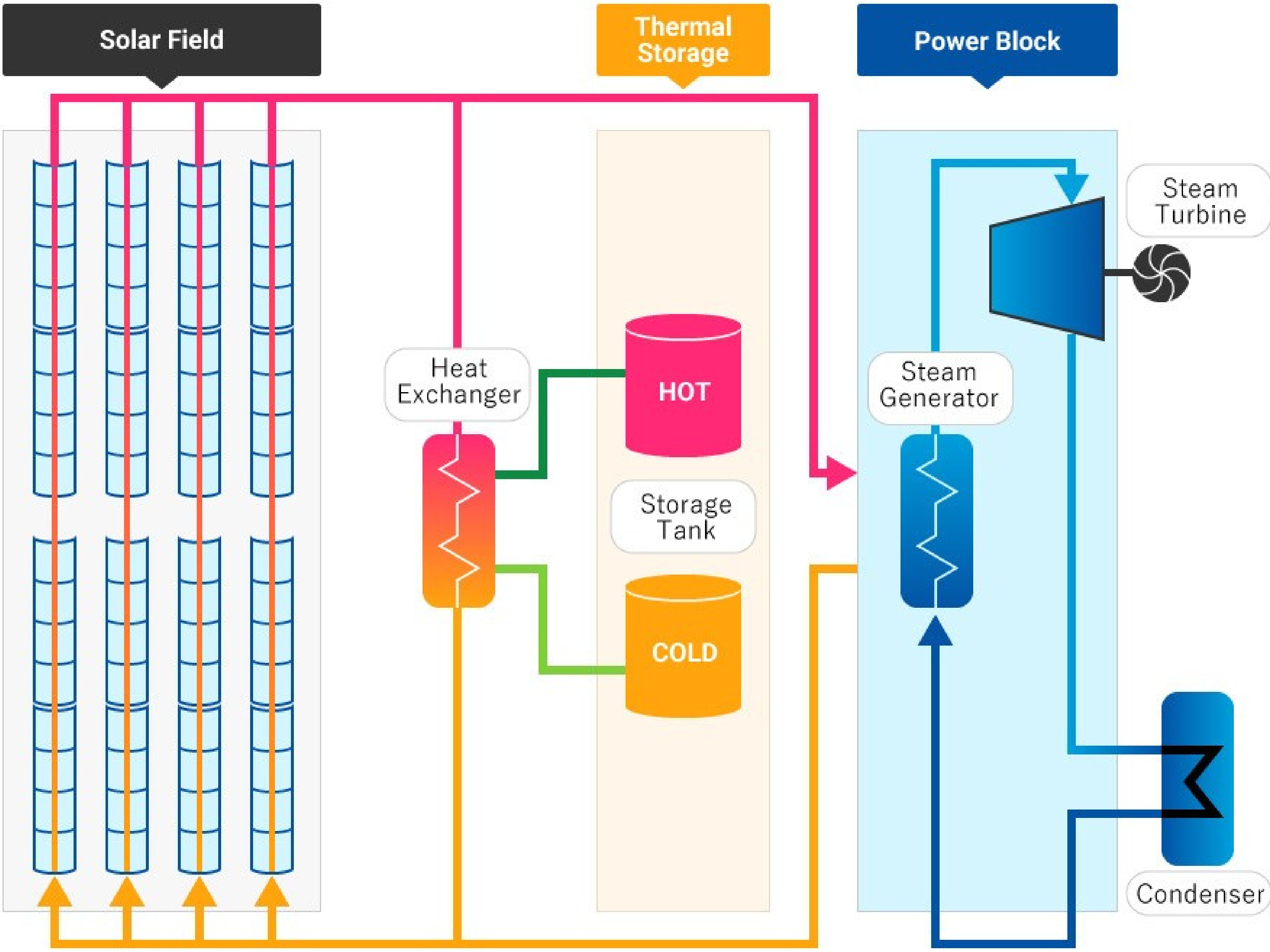
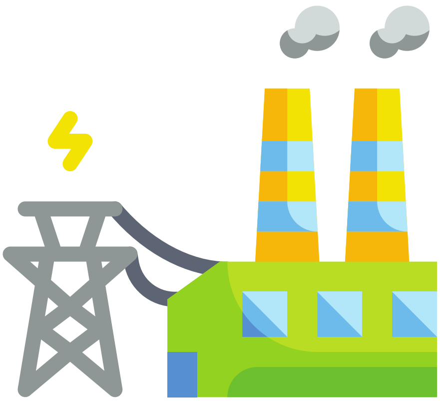


Figure 2.8: Structure of Concentrated Solar Power Plant

ADVANTAGES & DISADVANTAGES OF POWER PLANT GENERATION

Table 2.1: The Differences of The Power Plant

No	Item	Hydro-electric power plant	Steam power station	Wind power plant	Solar power plant
1	Intallation cost	High	Lowest	Low	Highest
2	Maintenance cost	Low	High. Skilled staff required.	Low. Generation and maintenance cost are negligible	Low. Generation and maintenance cost are negligible
3	Availability	Not limited reserves. Not dependable because of wide variations in the rainfall every year.	Limited reserves.	Not limited reserves.	Not limited reserves.
4	Location	Located where large reservoirs can be obtained by constructing a dam such as in hilly areas.	Located at a place where ample supply of water and coal is available. Transportation facilities are adequate.	Located at any place but require large space of land	Located at any place but requires a large space of land
5	Environmental impact	No air/water pollution But changing the environment and affecting land use, homes, and natural habitats in the dam area.	High pollution. Air pollution because of ash and sulfur dioxide.	-No air/water pollution -Noise produced by the rotor blades, visual impacts, and deaths of birds and bats that fly into the rotors (avian/bat mortality).	Little pollution. Some toxic materials and chemicals are used to make the photovoltaic (PV) cells that convert sunlight into electricity.
6	Output power	Large output power.	Very large output power.	Small output power.	Small output power.



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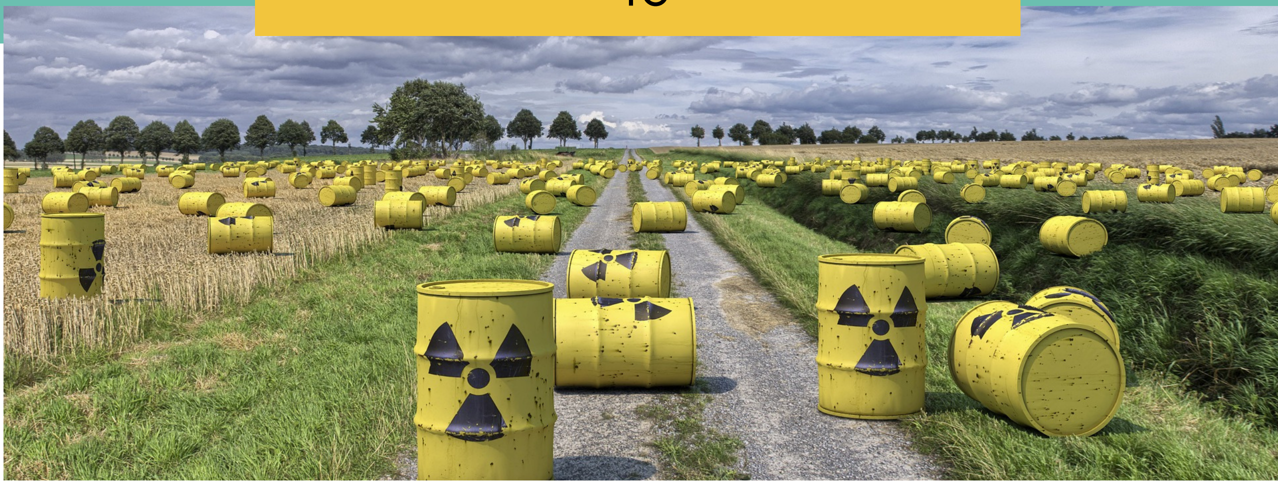
ECO-FRIENDLY METHODS TO TREAT POWER PLANT WASTE

ECO-FRIENDLY METHODS TO TREAT POWER PLANT WASTE

1. Near surface disposal (nuclear)
2. Deep geological disposal (nuclear)
3. Flow gas desulfurization (fuel, gas and coal)
4. Electrostatics precipitator (coal and biomass)
5. Heat recovery steam generator (gas)



NEAR SURFACE DISPOSAL (NUCLEAR)

- For low and intermediate-level radioactive waste, near-surface disposal is the most common option.
- Its facilities are either on the surface or 10 meters below.
- At near-surface disposal facilities at ground level, the disposal packages are housed in shallow constructed concrete vaults up to the approximate level of the ground surface. No radioactive material reaches the surface because the vaults are sealed with a specially built lid that keeps rains out and unforeseen incursions at the range away.
- Drift can be employed to get to disposal sites that are ten meters below the surface of the Earth. Shallow disposal necessitates the excavation of subsurface caves, hence surface excavation is done.

DEEP GEOLOGICAL DISPOSAL (NUCLEAR)

- Nuclear power facilities generate high-level nuclear waste (HLV) that can no longer be used to generate energy.
- They'll be kept in water pools for five to ten years to cool down.
- The radioactive wastes are placed in a solid steel container near the nuclear reactor.
- The containers are delivered to the storage locations.
- Excavated vaults are buried at depths ranging from 250 meters to 1000 meters, whereas boreholes are buried at depths ranging from 2000 meters to 5000 meters.

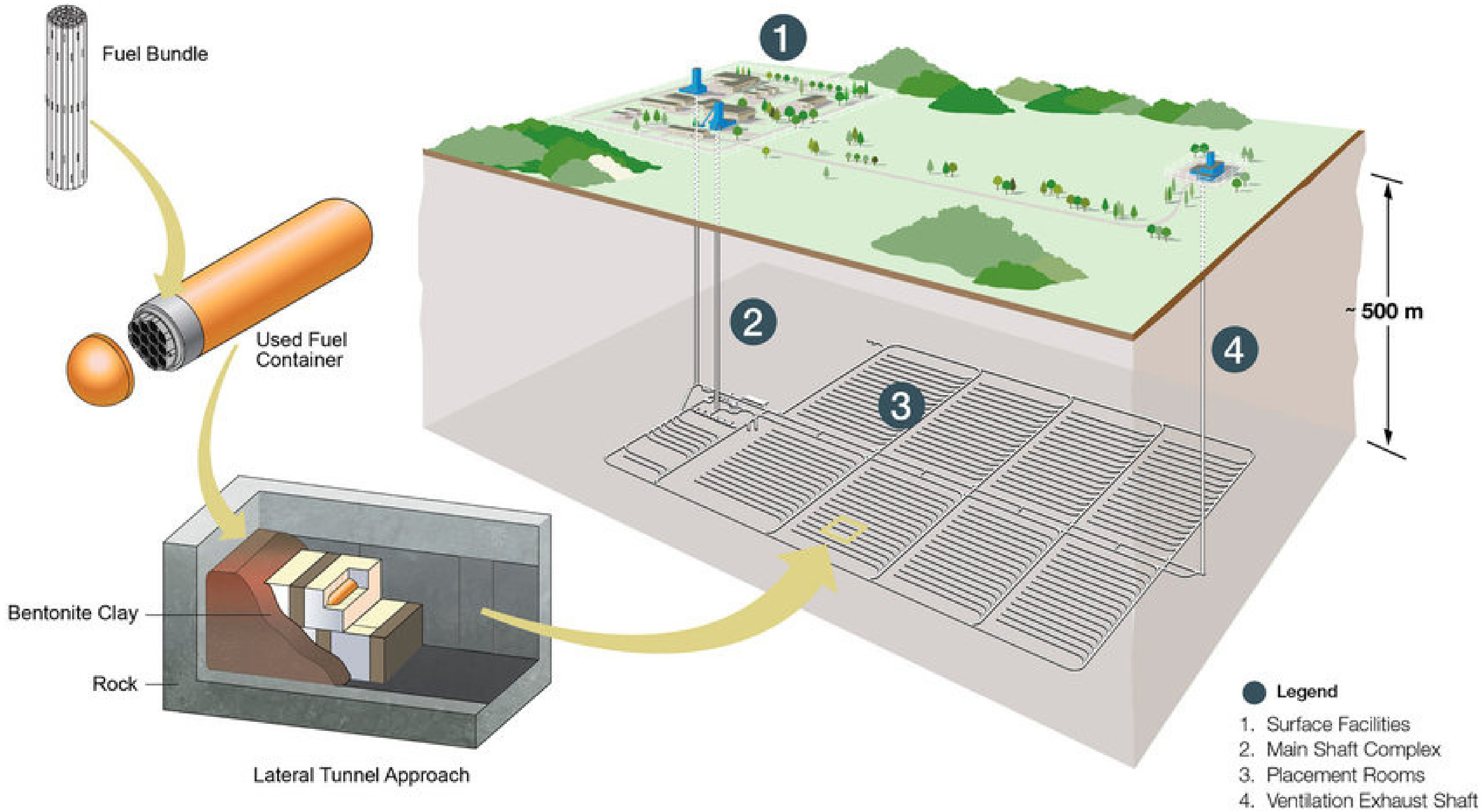


Figure 2.9: Structure of Deep Geological Disposal

FLUE GAS DESULFURIZATION (FUEL, GAS AND COAL)

- Sulphur dioxide (SO 2) is removed from the exhaust flue gases of fossil-fuel power plants, as well as other sulphur oxide generating operations such as garbage burning.

- There are two types of FGD processes: wet and dry. Wet FGD systems account for more than 75% of all FGD systems used in power generation.

- Lime (calcium oxide) and limestone are the most commonly utilised reagents in FGD systems (CaCO3).

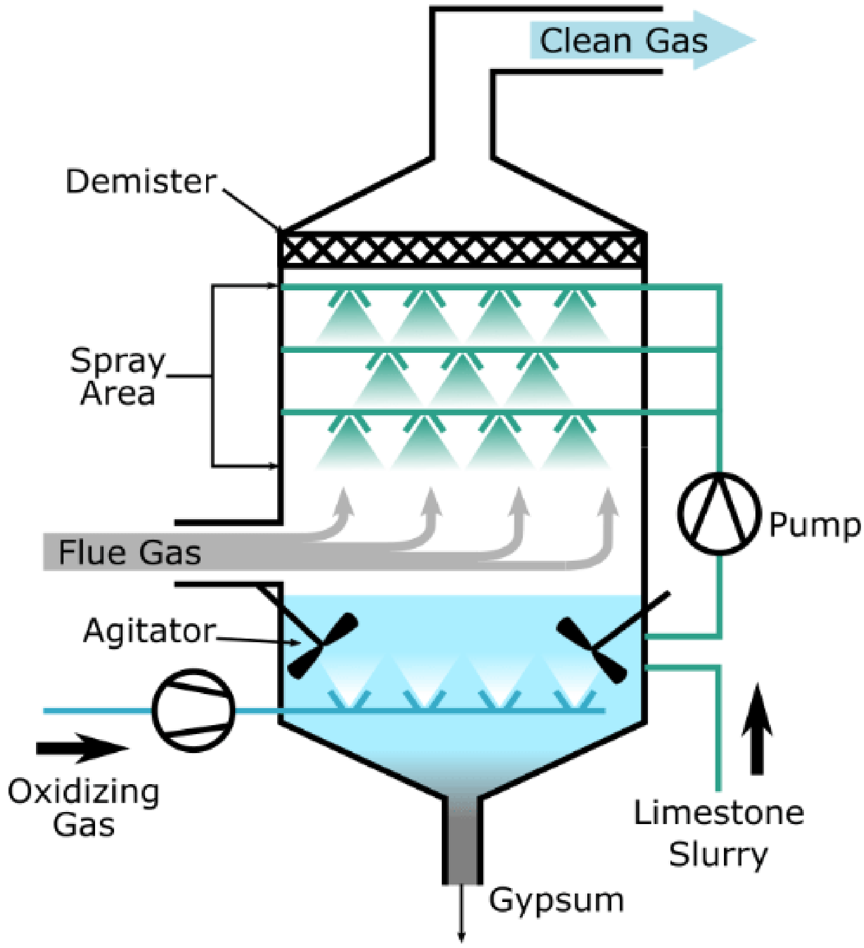
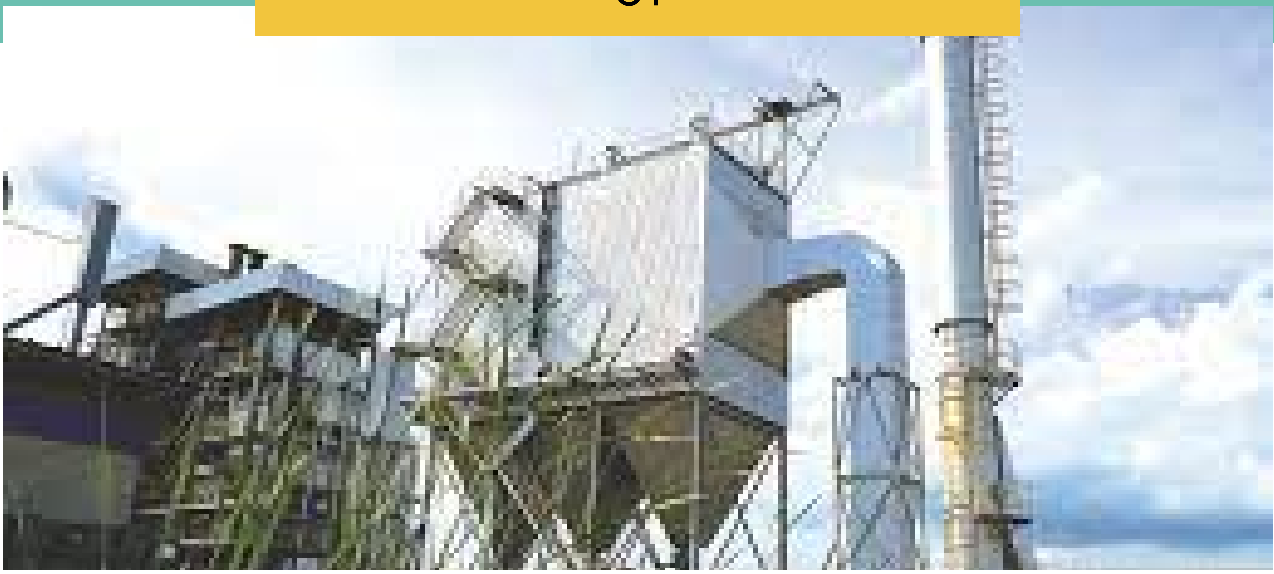


Figure 2.10: Structure of Wet Flue Gas Desulphuriser



ELECTROSTATICS PRECIPITATOR (BIOMASS AND COAL)

- Negative electrodes are either rods or wire mesh. Plates are used for positive electrodes.
- The discharge electrode is subjected to a high voltage, resulting in a corona discharge that creates negative ions.
- An electrical field collects the electrically charged dust on the collecting electrode.
- The dust is cleared with a rapping hammer (dry ESP), a scraping brush (dry ESP), or water flushing (wet ESP).
- After passing through the electrostatic precipitator, the flue gases are practically free of ash particles and are eventually expelled into the atmosphere through the chimney.

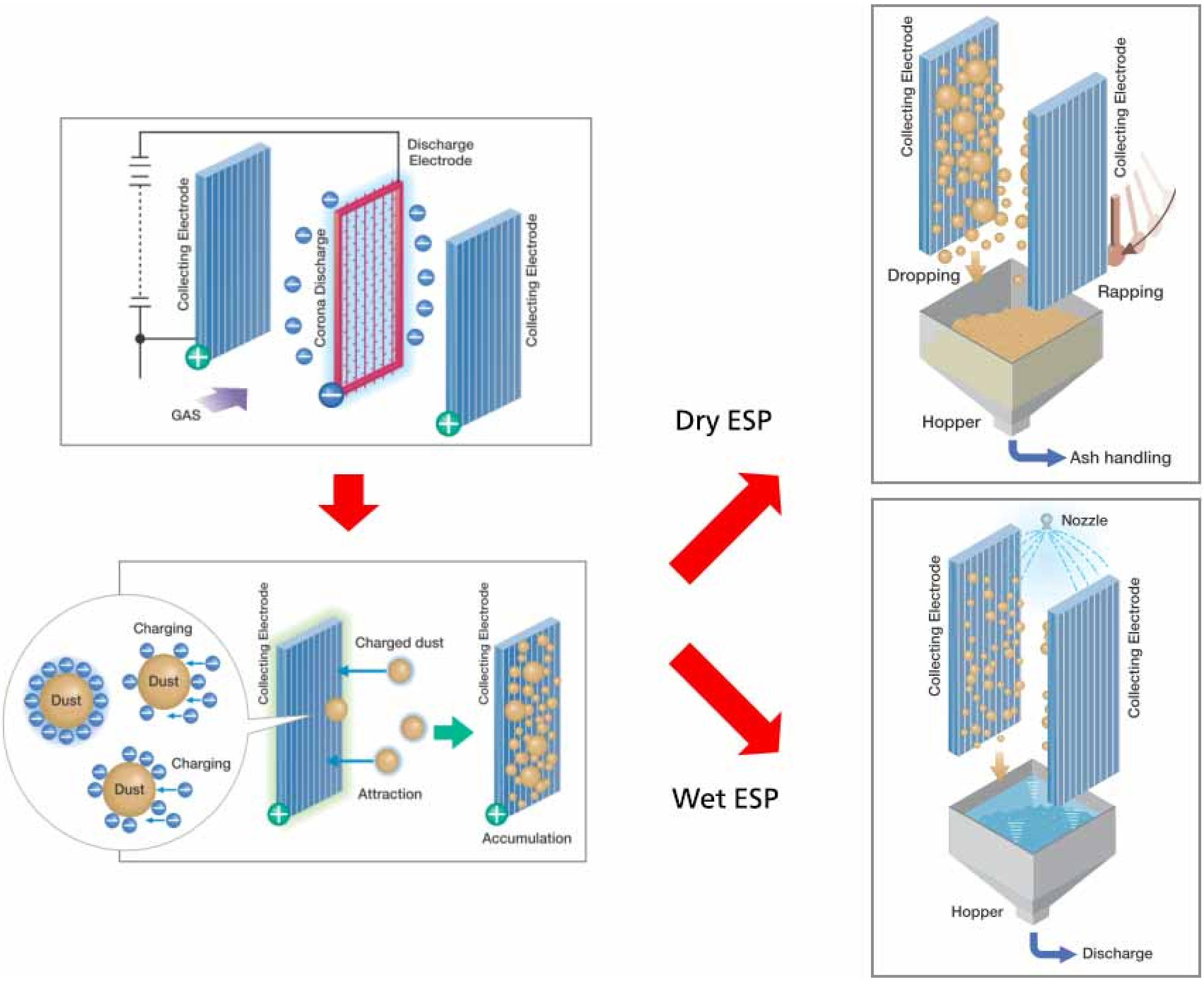


Figure 2.11: Electrostatics Precipitator Process

HEAT RECOVERY STEAM GENERATOR (GAS)

- One of the most essential components of a gas turbine is the heat recovery steam generator (HRSG), which combines the cycle power plant with high thermal efficiency and low CO2 emissions.

- HRSG is a boiler that heats water and converts it to steam, which is then used to power steam turbines, using the heat energy from residual exhaust gases from a gas turbine.

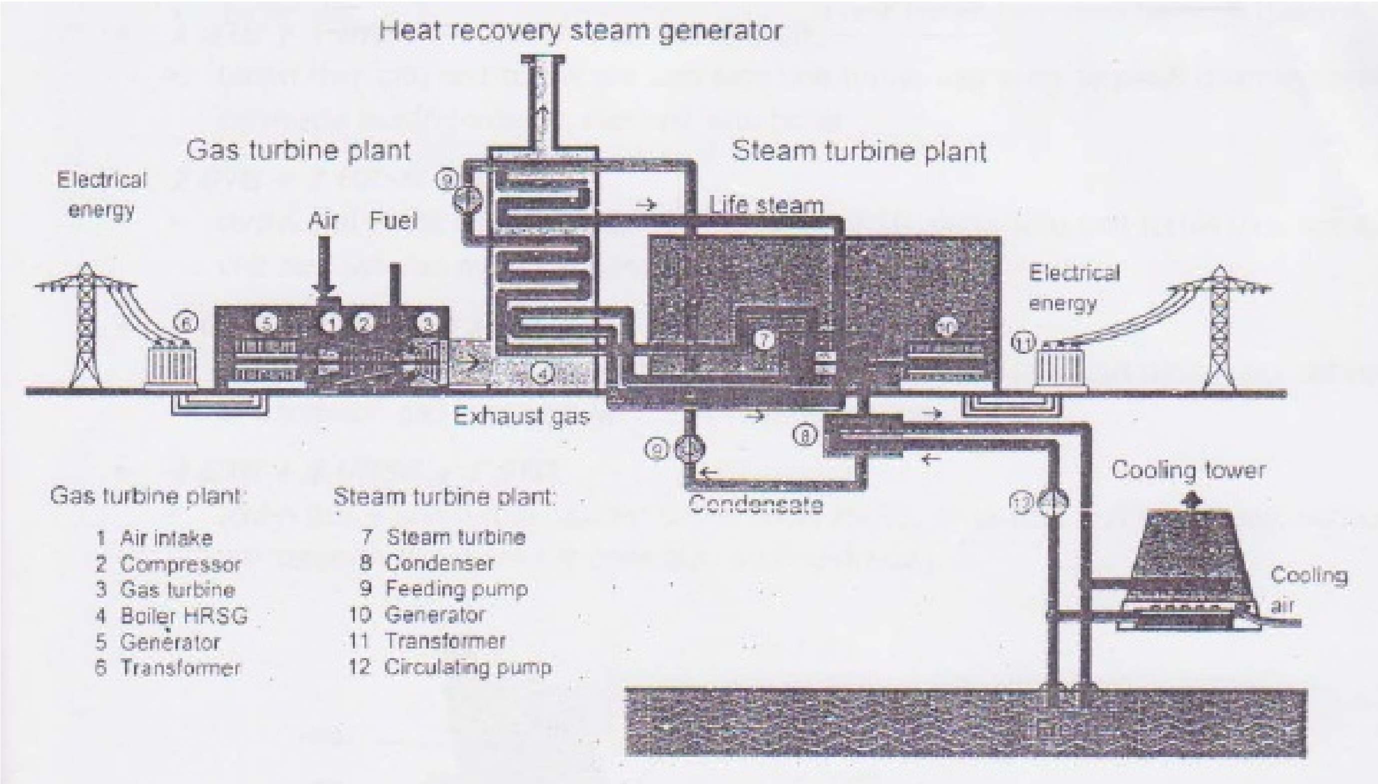


Figure 2.11: Combined Cycle Power Plant

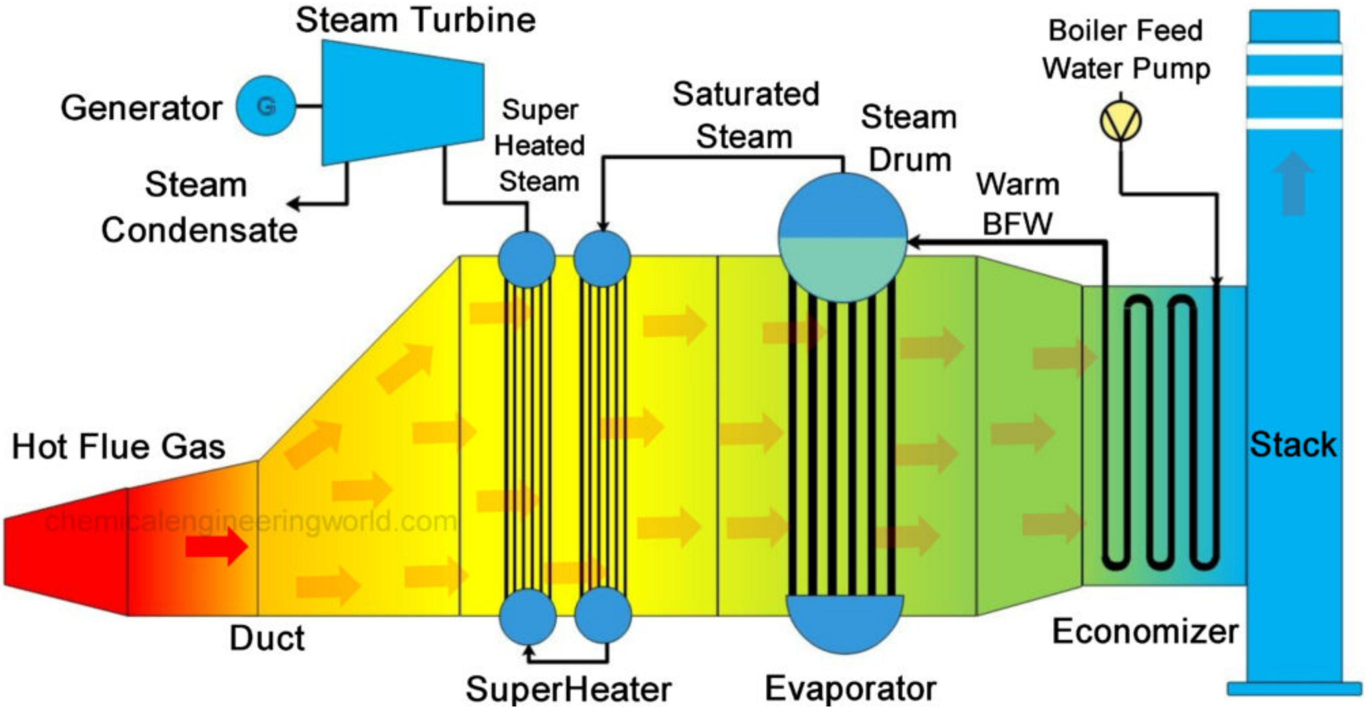


Figure 2.12: Heat Recovery Steam Generator

Exercise

(1)State TWO (2) differences between fuel power plant and nuclear power plant.

(2) Hydro power station is one of the most important power stations in Malaysia.

(i) Illustrate the diagram structure of a hydro power station

(ii) Explain the operation of the hydro power station

(3) Radioactive waste is stored to eliminate any possibility of humans being exposed to radiation or pollution. Explain the TWO (2) methods used to treat the nuclear power plant waste. Draw the operational block diagram for the BEST method used to treat the high-level radioactive waste.

(4) Contrast the differences between steam power plant and hydro power plant based on:

(i) types of sources

(ii) fuel cost

(iii) weather dependent

CHAPTER 3
CONSUMERIZATION

POWER QUALITY

Power Quality Problem

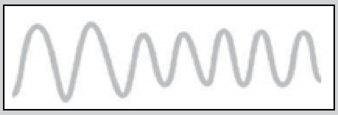
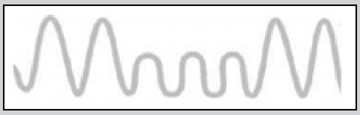
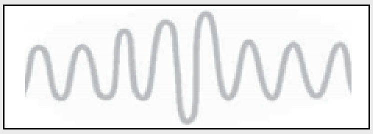
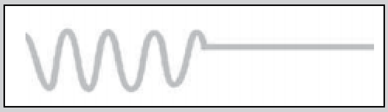
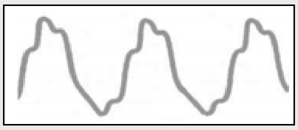
Any power faults that result in voltage, current, or frequency variations which cause customer equipment to malfunction or stop working.

Importances of Power Quality

- Deliver high-quality electric power so that end-use equipment meets its design requirements.
- It should be reliable enough for the user of end-use equipment to be able to work without interruption.

POWER QUALITY FACTORS

Table 3.1: Types of Power Quality Factors

Power Quality Factors	Waveform
Under Voltage: A decrease in the rms ac voltage to less than 90 percent at the power frequency for a duration longer than 1 min.	
Over Voltage: An increase in the rms ac voltage greater than 110 percent at the power frequency for a duration longer than 1 min.	
Sags: A decrease to between 0.1 and 0.9 pu in rms voltage or current at the power frequency for durations from 0.5 cycle to 1 min.	
Surge Voltage/Swell: An increase to between 1.1 and 1.8 pu in rms voltage or current at the power frequency for durations from 0.5 cycle to 1 min.	
Blackout: A short or long-term loss of the electric power to an area.	
Harmonic Distortion: The presence of harmonics in electrical systems means that current and voltage are distorted and deviate from sinusoidal waveforms.	

METHODS TO ENHANCE POWER QUALITY

(1) Surge Protector

- To prevent voltage spikes in electrical devices.
- Any undesired voltages above a safe threshold are either blocked or shorted to ground to limit the voltage delivered to an electric equipment.

Figure 3.1 Surge Protective Device

METHODS TO ENHANCE POWER QUALITY

(2) Uninterruptible Power Supply (UPS)

- To provide back-up power to equipment in case of sudden power failure.
- Computers, data centres, telecommunications equipment, and other electrical equipment are all types of hardware that must be protected.

Figure 3.2 A Small Free-Standing UPS with One IEC 60320 C14 Input and three C13 Outputs

METHODS TO ENHANCE POWER QUALITY

(3) Backup Generator

- A back-up electrical system that operates automatically.

(4) Passive Filter

- A set of inductors, capacitors, and resistors that are used to cancel out one or more harmonics.

Figure 3.3 A Backup Generator

ELECTRICAL ENERGY DEMANDS

Table 3.2: The Differences Between Demand and Consumption

Demand	Consumption
The rate at which electricity is consumed.	The amount of electricity that has been consumed over a certain time period.
Measured in kilowatts (kW).	Measured in kilowatt-hours (kWh).

Example:

1000 watt-hours (1 kWh) are consumed by a 100-watt light bulb when it is turned on for ten hours. It takes or "demands" 100watts or 0.1kW from the utility for the entire time it is on. That indicates your utility must be prepared to provide that 0.1 kW anytime the client turns on the light.

DEMAND CURVE

- A curve displaying the variation of power station load over time.
- The curve is plotted over a time period of 24 hours.

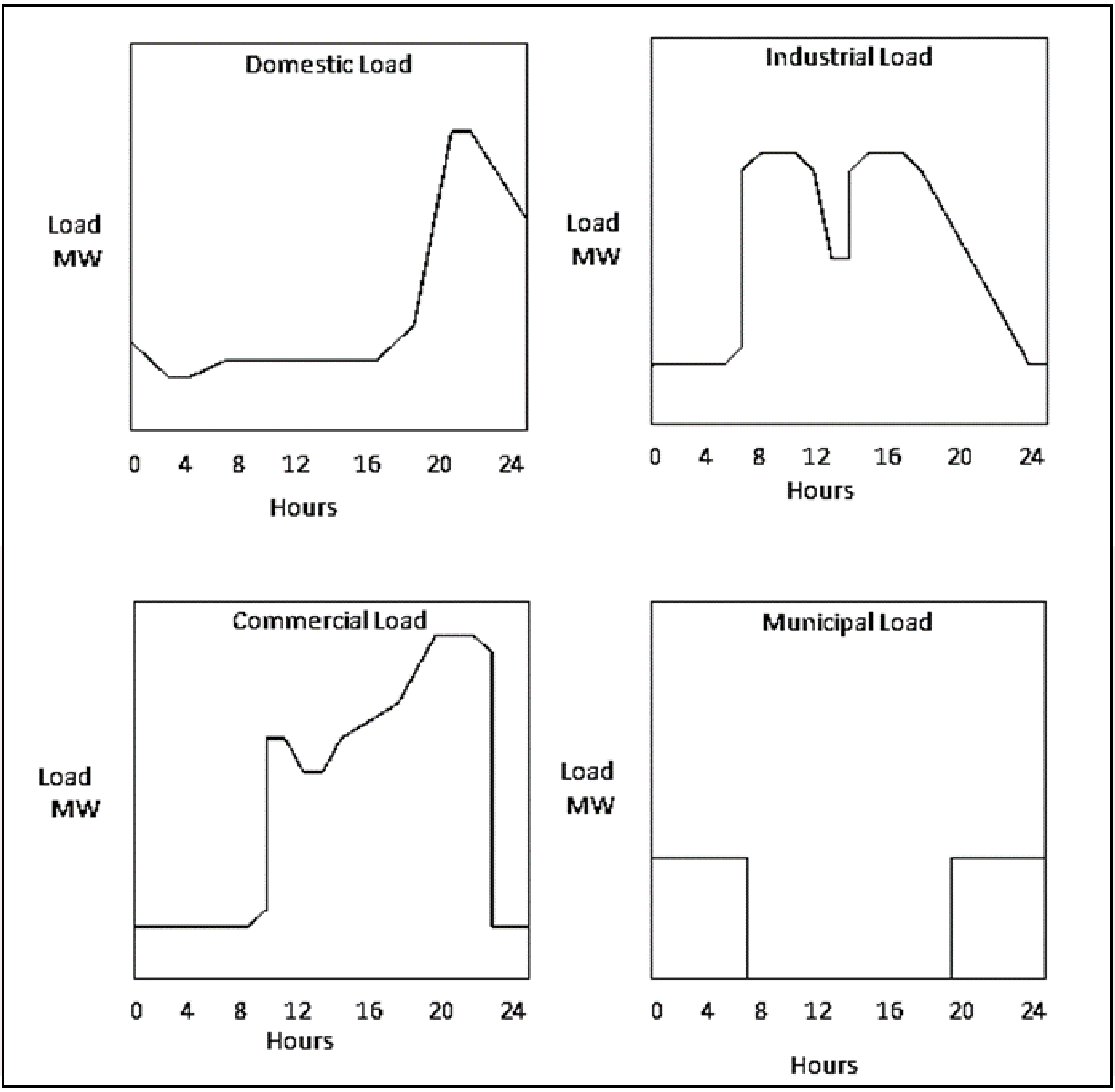


Figure 3.4: Demand Curve for Variable Loads

DAILY INDUSTRIAL LOAD CURVE

- The curve displays the daily load demand of an industrial load for 24 hours.
- The load demand starts to increase after 5 a.m when some of the machinery starts running.
- By 8 a.m., the entire industrial load comes into action and remains constant up to shortly before noon, when it begins to decrease due to lunch hour.
- From roughly 2 p.m., the morning shape of the curve is resumed and remains such until around 6 p.m.
- The majority of the machines begin to shutdown at night. By 9 p.m., the load demand has dropped to a minimum level and has remained stable until 5 a.m. the next day.
- Over the following 24 hours, the identical process was repeated.

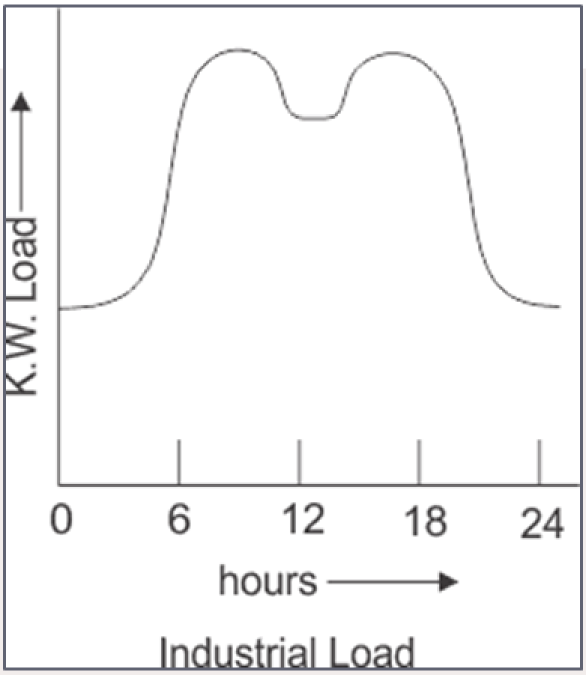


Figure 3.5: Demand Curve for Industrial Load

DAILY RESIDENTIAL LOAD CURVE

- The figure shows the minimum load is reached in between 2 a.m. and 3 a.m. when most people are asleep and during 12 p.m. when most people are out at work.
- The peak load demand starts at around 5 p.m. and lasts up to 9 p.m. to 10 p.m. at night.
- After that, the load drops rapidly, as most people retire to bed.
- The load demand in summer is a bit higher (shown in bold line) compared to a similar pattern of lower values during the winter season (shown in dotted line).

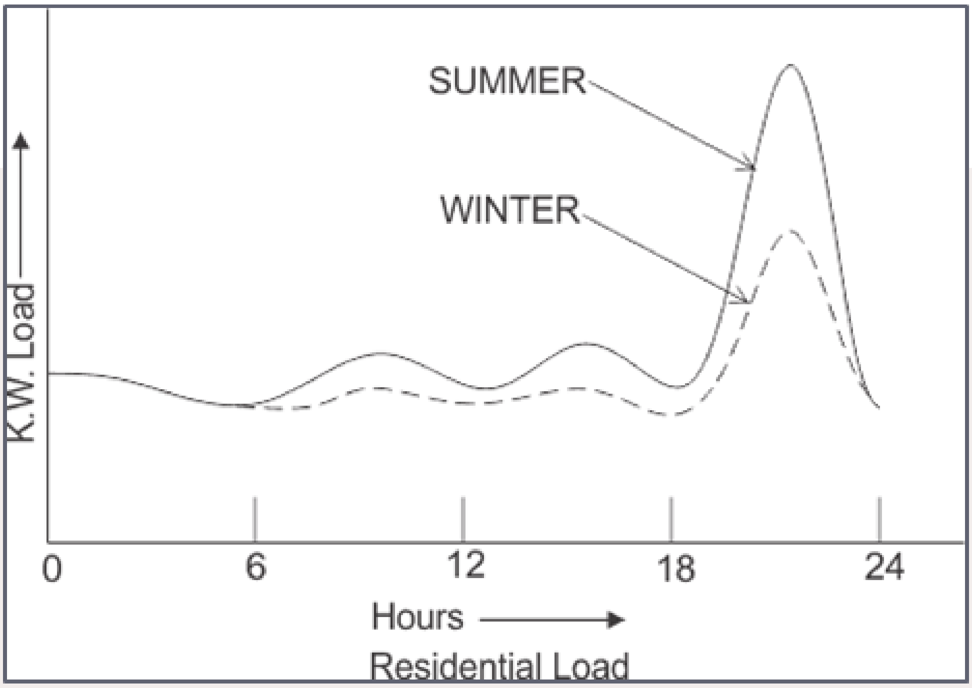


Figure 3.6: Demand Curve for Residential Load

VARIABLE LOADS

Table 3.3: Types of Variable Load

Types of Loads	Loads
Domestic load	lights, fans, refrigerators, heaters, television, etc.
Commercial load	lighting for shops, fans and electric appliances used in restaurant etc.
Industrial load	load demand by industries
Municipal load	street lighting, power required for water supply and drainage purposes.
Irrigation load	the electric power needed for pumps driven by motors to supply water fields
Traction load	tram cars, trolley buses, railways etc.

IMPORTANT TERMS

- **Maximum Demand** – The greatest demand of load on the power station during a given period.

- **Sum of Generated Power Per Day** – Area (in kWh) under the demand curve.

- **Average Load** – The average of loads occurring on the power station in a given period (day/month/year).

$$Daily\ Average\ Load = \frac{No.of\ units\ (kWh) generated\ in\ a\ day}{24\ hours}$$

- **Load Factor** – The ratio of average load to the maximum demand during a given period.

$$Load\ Factor = \frac{Average\ Load}{Maximum\ Demand}$$

- **Diversity Factor** – The ratio of the sum of individual maximum demands to the maximum demand on power station.

$$Diversity\ Factor = \frac{Sum\ of\ Individual\ Maximum\ Demands}{Maximum\ Demand\ on\ Power\ Station}$$

6 8

EXAMPLE

Q

A power plant has a daily load demand as shown in the table below. Sketch the demand curve and calculate,

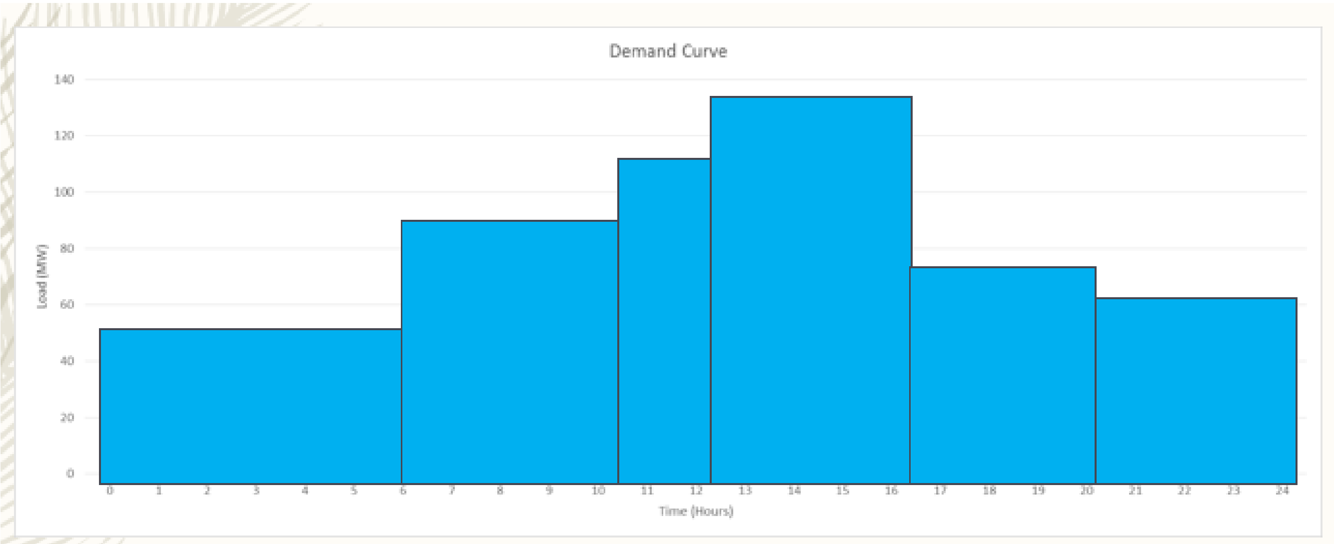
a) Maximum demand

b) Sum of generated power per day

c) Average load

d) Load factor

Time (Hours)	0-6	6-10	10-12	12-16	16-20	20-24
Load (MW)	50	80	100	120	70	60



a) Maximum demand = 120MW

b) Sum of generated power per day

$$= [(6 \times 50) + (4 \times 80) + (2 \times 100) + (4 \times 120) + (4 \times 70) + (4 \times 60)]$$
$$= 1820MWh$$

c) Average load

$$= \frac{[(6 \times 50) + (4 \times 80) + (2 \times 100) + (4 \times 120) + (4 \times 70) + (4 \times 60)]MWh}{24h}$$

$$= \frac{1820MW}{24} = 75.83MW$$

d) Load factor

$$= \frac{75.83MW}{120MW} = 0.657$$

EXERCISE

QUESTION 1

A power station supplies the load as tabulated below. Sketch the demand curve and calculate:

a)Maximum demand

b)Sum of generated power per day

c)Average load

d)Load factor

Time (Hours)	6am-9am	9am-12pm	12pm-2pm	2pm-6pm
Load (MW)	1.3	3.0	1.5	2.5

QUESTION 2

A power station supplies the load as tabulated below. Calculate:

a) Maximum demand

b) Average load

c) Load factor

Load	Tesco	Mydin	Polytechnic	Jusco	Giant
Demand (kWh)	16 000	19 000	7 500	13 000	10 000

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