ANNAMACHARYA INSTITUTE OF TECHNOLOGY AND SCIENCES:: RAJAMPET
(An Autonomous Institution)

DEPARTMENT OF MECHANICAL ENGINEERING

LECTURE NOTES

POWER PLANT ENGINEERING
[23A036FT]

Prepared by
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ANNAMACHARYA INSTITUTE OF TECHNOLOGY AND SCIENCES RAJAMPET
(An Autonomous Institution)
Department of Mechanical Engineering

Title of the Course: Power Plant Engineering
Category: Professional Elective-III
Couse Code: 23A036FT
Branch/es: Mechanical Engineering
Year & Semester: III Year II Semester

Lecture Hours	Tutorial Hours	Practice Hours	Credits
3	0	0	3

Course Objectives:
1. To familiarize the sources of energy, power plant economics and environmental aspects.
2. To outline the working components of different power plant.
3. To gain knowledge of working mechanism of diesel and gas turbine power plants.
4. To impart types of nuclear power plants, and outline working principle and advantages and hazards.
5. To provide insight of renewable energy sources; characteristics, working principle, classify types, layouts, and plant operations.

Course Outcomes:
At the end of the course, the student will be able to
1. Summarize sources of energy, power plant economics, and environmental aspects.
2. Comprehend working components of a steam power plant.
3. Comprehend the working mechanism of diesel and gas turbine power plants.
4. Summarize types of renewable energy sources and their working principle.
5. Comprehend the working principle of nuclear power plants.

Unit 1 Introduction to the Sources of Energy 08
Resources and Development of Power in India. Convectional and non- conventional energy sources, Power Plant Economics and Environmental Considerations: Capital Cost, Investment of Fixed Charges, Operating Costs, General Arrangement of Power Distribution, Load Curves, Load Duration Curve. Definitions of Connected Load, Maximum Demand, Demand Factor, Average Load, Load Factor, Diversity Factor - Tariff - Related Exercises. Effluents from Power Plants and Impact on Environment - Pollutants and Pollution Standards - Methods of Pollution Control. Inspection And Safety Regulations

Unit 2 Steam Power Plant 10
Introduction to Boilers- Modern High Pressure and Supercritical Boilers - Analysis of Power Plant Cycles - Modern Trends in Cycle Improvement - Waste Heat Recovery, Fluidized Bed Boilers., Fuel and Handling Equipments, Types of Coals, Coal Handling, Choice of Handling Equipment, Coal Storage, Ash Handling Systems.
Steam Power Plant: Combustion Process: Properties of Coal - Overfeed and Under Feed Fuel Beds, Travelling Grate Stokers, Spreader Stokers, Retort Stokers, Pulverized Fuel Burning System and Its Components, Combustion Needs and Draught System, Cyclone Furnace, Design and Construction, Dust Collectors, Cooling Towers and Heat Rejection. Analysis of Pollution from Thermal Power Plants - Pollution Controls.CO_2 Recorders

Unit 3 Diesel Power Plant 08
Diesel Power Plant, Construction, Plant lay out with auxiliaries, fuel storage. GAS TURBINE PLANT: Introduction - Classification - Construction - Layout with Auxiliaries - Principles of Working Closed and Open Cycle Gas Turbines. Advantages And Disadvantages Combined Cycle Power Plants.

Unit 4 Hydro Electric Power Plant **09**

Water Power - Hydrological Cycle / Flow Measurement - Drainage Area Characteristics - Hydrographs - Storage and Pondage - Classification of Dams and Spill Ways. Hydro Projects Plant: Types - Typical Layouts - Plant Auxiliaries - Plant Operation Pumped Storage Plants.

Unit 5 Power from Non-Conventional Sources **08**

Power from Non-Conventional Sources: Utilization of Solar Collectors- Working Principle, Wind Energy - Types of Turbines - HAWT & VAWT-Tidal Energy. MHD power Generation.

Nuclear Power Station: Nuclear Fuel - Nuclear Fission, Chain Reaction, Breeding and Fertile Materials - Nuclear Reactor -Reactor Operation. Types of Reactors: Pressurized Water Reactor, Boiling Water Reactor, Sodium-Graphite Reactor, Fast breeder Reactor, Homogeneous Reactor, Gas Cooled Reactor, Radiation Hazards and Shielding - Radioactive Waste Disposal.

Textbooks:

1. Power Plant Engineering, P.K. Nag, —3rd edition, TMH, 2013, ISBN, 0070435995, ...
2. Power plant technology, Wakil, M.M.El TMH Publications. ISBN: 978-93-329-0125-4

Reference Books:

1. A Text Book of Power Plant Engineering, Rajput, 4th edition, Laxmi Publications, 2012, ISBN-10: 8170086523.
2. Power plant Engineering, Ramalingam, Sci tech Publishers, 2013, ISBN of 978-81-87328-77-3,
3. Power Plant Engineering, P.C. Sharma, S.K. Kataria Publications, 2012, ISBN, 978-93-5014-384-1.
4. A course in Power Plant Engineering, Arora and S.Domakundwar, Dhanpat Rai & Co (p) Ltd, 2014, ISBN: 9788177001075

Online Learning Resources:

- https://nptel.ac.in/courses/112107291
- https://youtube.com/playlist?list=PLLy_2iUCG87BT8H9uMufjrcPF5e6Qd2bz&si=RQhZwEibgqXK2dRL
- https://youtube.com/playlist?list=PLLy_2iUCG87BT8H9uMufjrcPF5e6Qd2bz&si=LjgzdabT7tIsCwJC
- https://youtu.be/IdPTuwKEfmA?si=PyF04z9beiVGkXAS

CO-PO Mapping:

Course Outcomes	Engineering Knowledge	Problem Analysis	Design/Development of solutions	Conduct investigations of complex problems	Modern tool usage	The engineer and society	Ethics	Individual and team work	Communication	Project management and finance	Life-long learning	**PSO1**	**PSO2**
23A036FT.1	3	3	1	-	-	-	1	-	1	1	2	2	2
23A036FT.2	3	3	2	-	-	-	1	-	1	1	2	2	2
23A036FT.3	3	3	2	-	-	-	1	-	1	1	2	2	2
23A036FT.4	3	2	2	-	-	-	1	-	1	1	2	2	2
23A036FT.5	3	2	2	-	-	2	1	-	1	1	2	2	2

CONVENTIONAL AND NON CONVENTIONAL ENERGY SOURCES

INTRODUCTION OF CONVENTIONAL ENERGY SOURCES

Definition: These are energy sources used extensively for a long time, primarily non-renewable resources that exist in limited quantities.

Main Characteristic: They are "stock" resources—once consumed, they cannot be easily replaced within a human time frame.

Examples: Fossil fuels (Coal, Petroleum, Natural Gas), Nuclear energy, and Hydro-electric power.

Classification of Conventional Sources:

Traded in the market for a price. Examples: Coal, Petroleum, and Electricity.

Non-Commercial Sources: Generally found in nature for free. Examples: Firewood, animal dung, and agricultural waste (straw), Solar Energy, Wind Energy, Tidal Energy, Geothermal Energy, Ocean Thermal Energy.

Sources of energy

Conventional sources

Commercial

- Coal
- Oil & natural gas
- Thermal power

Non-commercial

- Firewood (Fuel wood)
- Hydro power
- Nuclear power

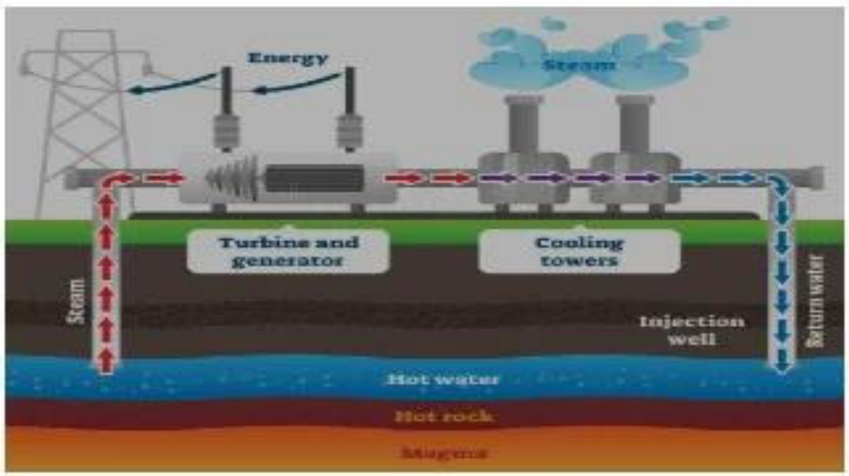
Non-conventional sources

- Solar energy
- Wind energy
- Tidal energy
- Geothermal energy
- Biomass - based energy

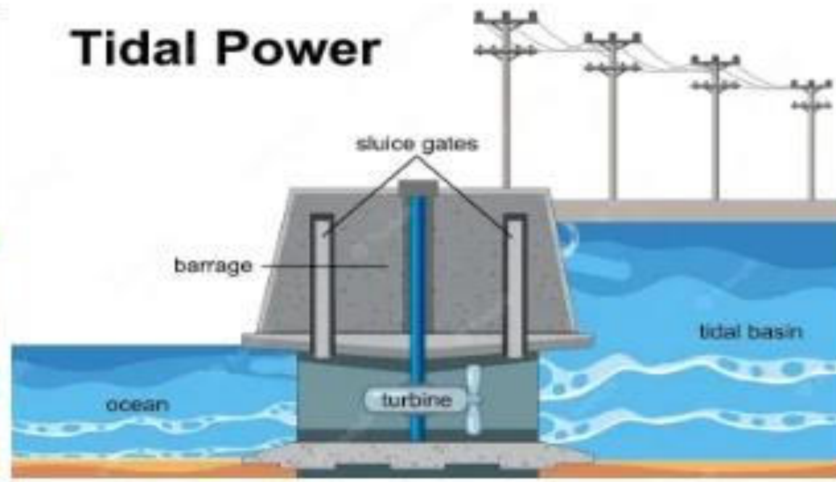
Nuclear Energy

Wind Energy

Solar Energy



Geothermal Energy



Tidal Energy

Figure: Non-Conventional Energy Sources

Fossil Fuel – Coal Formation: Formed from decayed plant matter over millions of years under high pressure and heat.

Usage: Primary fuel for thermal power plants to generate electricity, produce steel and Cement.

Global Status: Remains the most abundant fossil fuel.

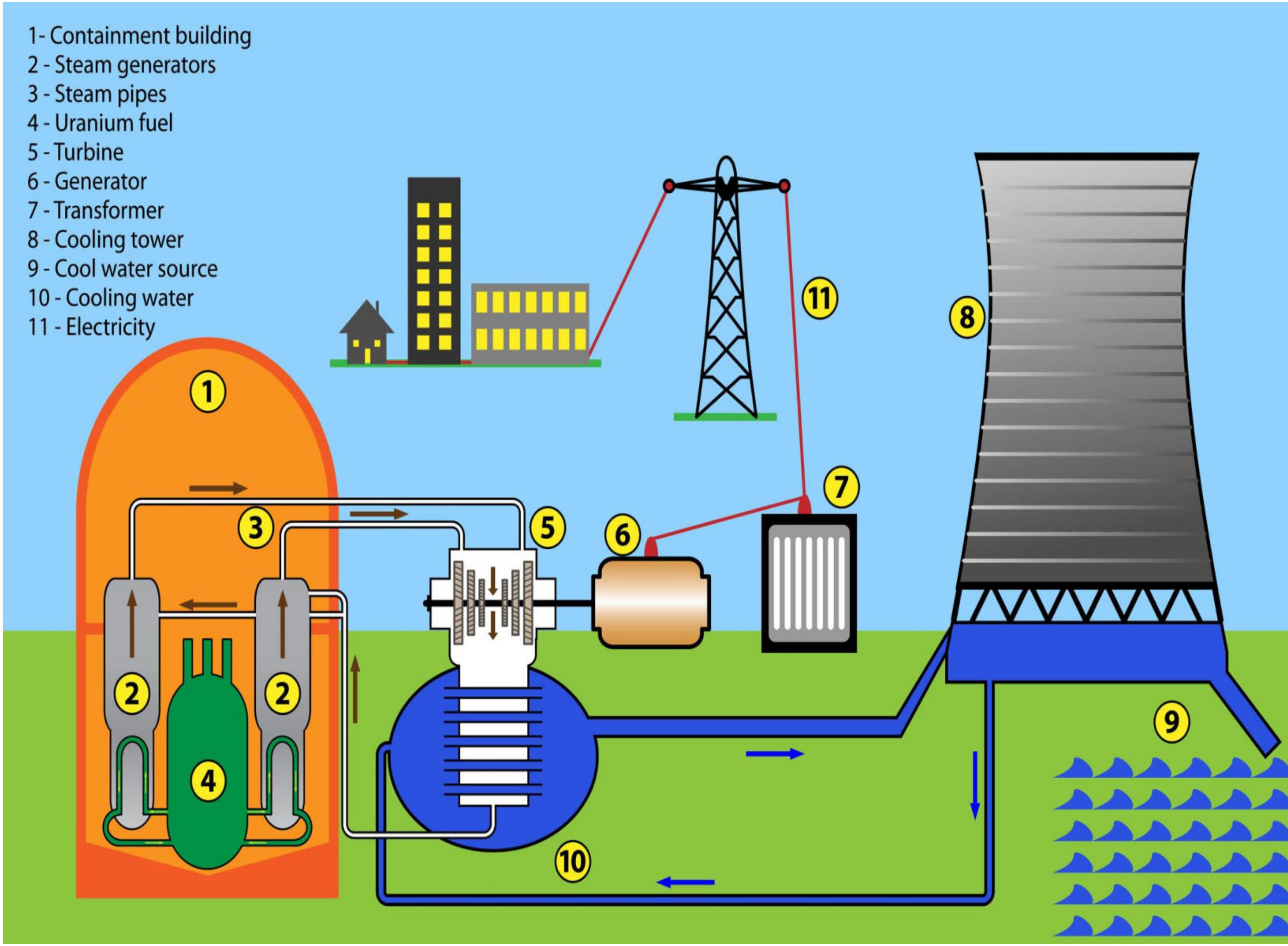
Fossil Fuel – Petroleum & Natural Gas:

Petroleum: Known as "liquid gold," it is refined into gasoline, diesel, and aviation fuel for transportation.

Natural Gas: Primarily composed of methane; used for industrial heating, cooking (LPG/CNG), and power generation.

Nuclear Energy Mechanism: Produced through nuclear fission—splitting the nuclei of heavy elements like Uranium or Thorium.

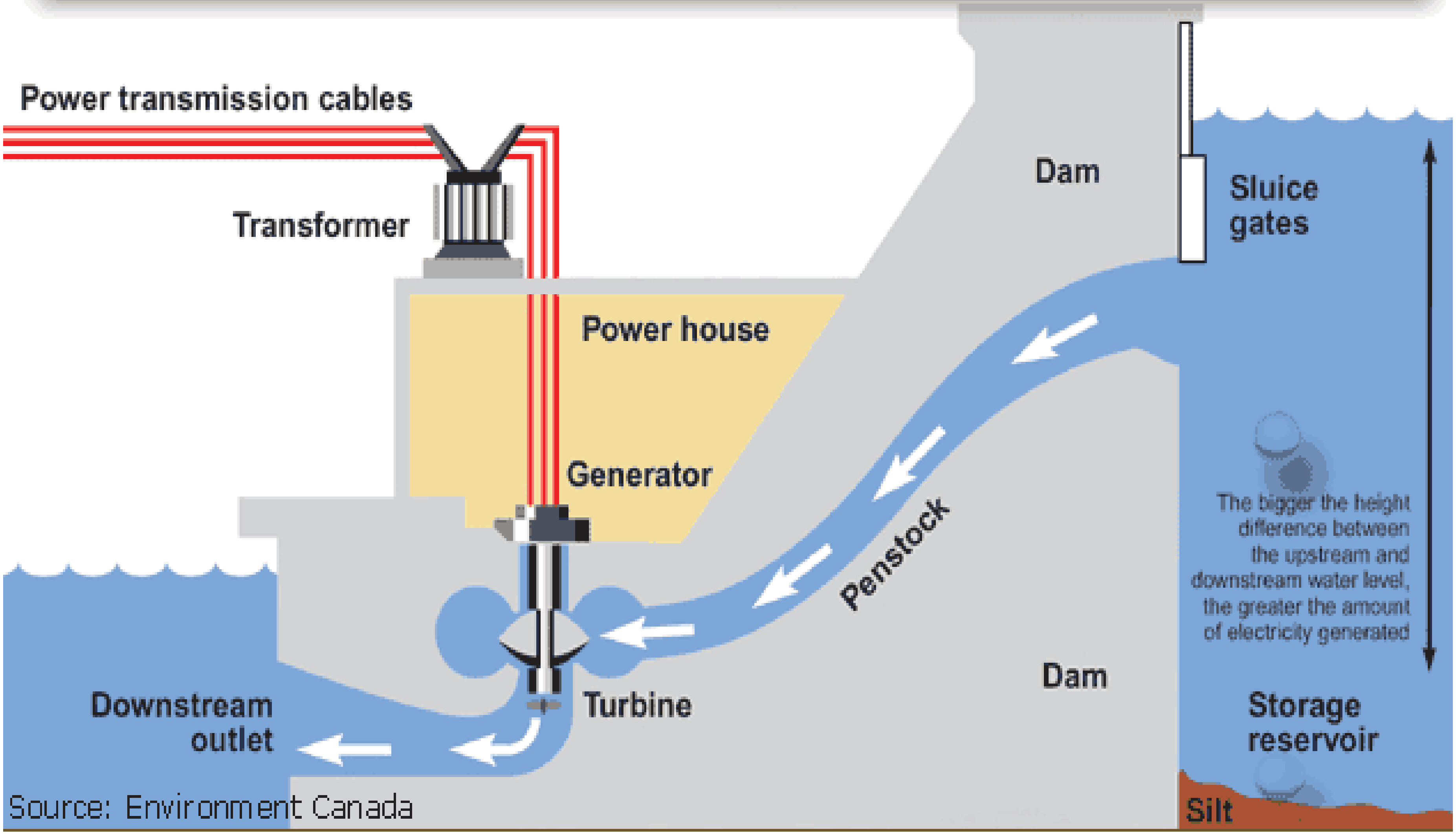
Impact: Highly efficient with zero carbon emissions during generation, but requires complex waste management.


1- Containment building
2 - Steam generators
3 - Steam pipes
4 - Uranium fuel
5 - Turbine
6 - Generator
7 - Transformer
8 - Cooling tower
9 - Cool water source
10 - Cooling water
11 - Electricity
1
2
3
4
5
6
7
8
9
10
11

Hydro-electric Power Concept: Uses the kinetic energy of flowing water to rotate turbines. Pressure energy water stored in Dams used to run turbines.

Distinction: Unlike fossil fuels, it is a **renewable** conventional source because the water cycle is continuous.

Hydroelectric power generation



Source: Environment Canada

Advantages : Established infrastructure, high energy output, reliable/stable supply, and cost-effective.

Disadvantages : Environmental pollution (GHG emissions), non-renewable nature, and health hazards from extraction/burning.

Conclusion and Future Outlook Transition: While conventional sources provide over 80% of global energy today, the shift toward renewable "non-conventional" sources (Solar, Wind) is accelerating to meet climate goals by 2050.

What are Non-Conventional Energy Sources?

- **Definition**: Energy derived from natural, renewable processes that are continuously replenished.
- **Key Characteristics**: Inexhaustible, eco-friendly, and typically produce little to no greenhouse gas emissions.
- **Modern Context (2025)**: As of late 2025, non-conventional sources (including large hydro) contribute nearly **49%** of India's total installed capacity.

Why the Shift? (Need for Change)Depletion: Conventional fossil fuel reserves are finite and rapidly exhausting.

Climate Goals: Urgent need to meet "Net Zero" targets (e.g., India's 2070 goal) and limit global warming.

Energy Security: Reducing reliance on imported fuels.

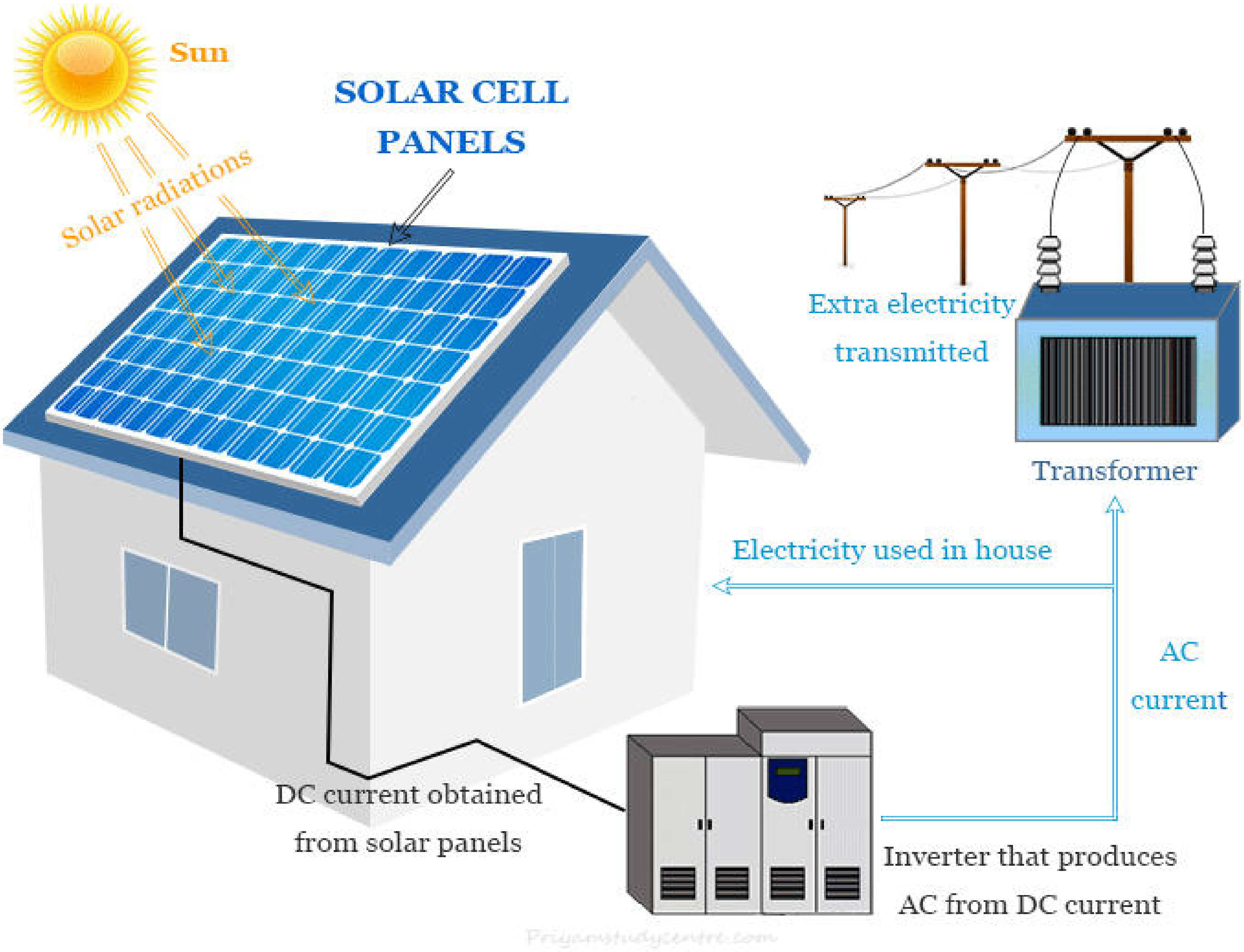
Major Types of Non-Conventional Energy Solar Energy: Harnessing sunlight via Photovoltaic (PV) cells or solar thermal systems.

Wind Energy: Using turbines to convert wind's kinetic energy into electricity.

Biomass & Biogas: Energy from organic waste like agricultural residues and animal dung.

Geothermal Energy: Utilizing heat from the Earth's interior.

Tidal & Wave Energy: Capturing energy from ocean movements.


Sun
SOLAR CELL
PANELS
Solar radiations
Extra electricity
transmitted
Transformer
Electricity used in house
AC
current
DC current obtained
from solar panels
Inverter that produces
AC from DC current

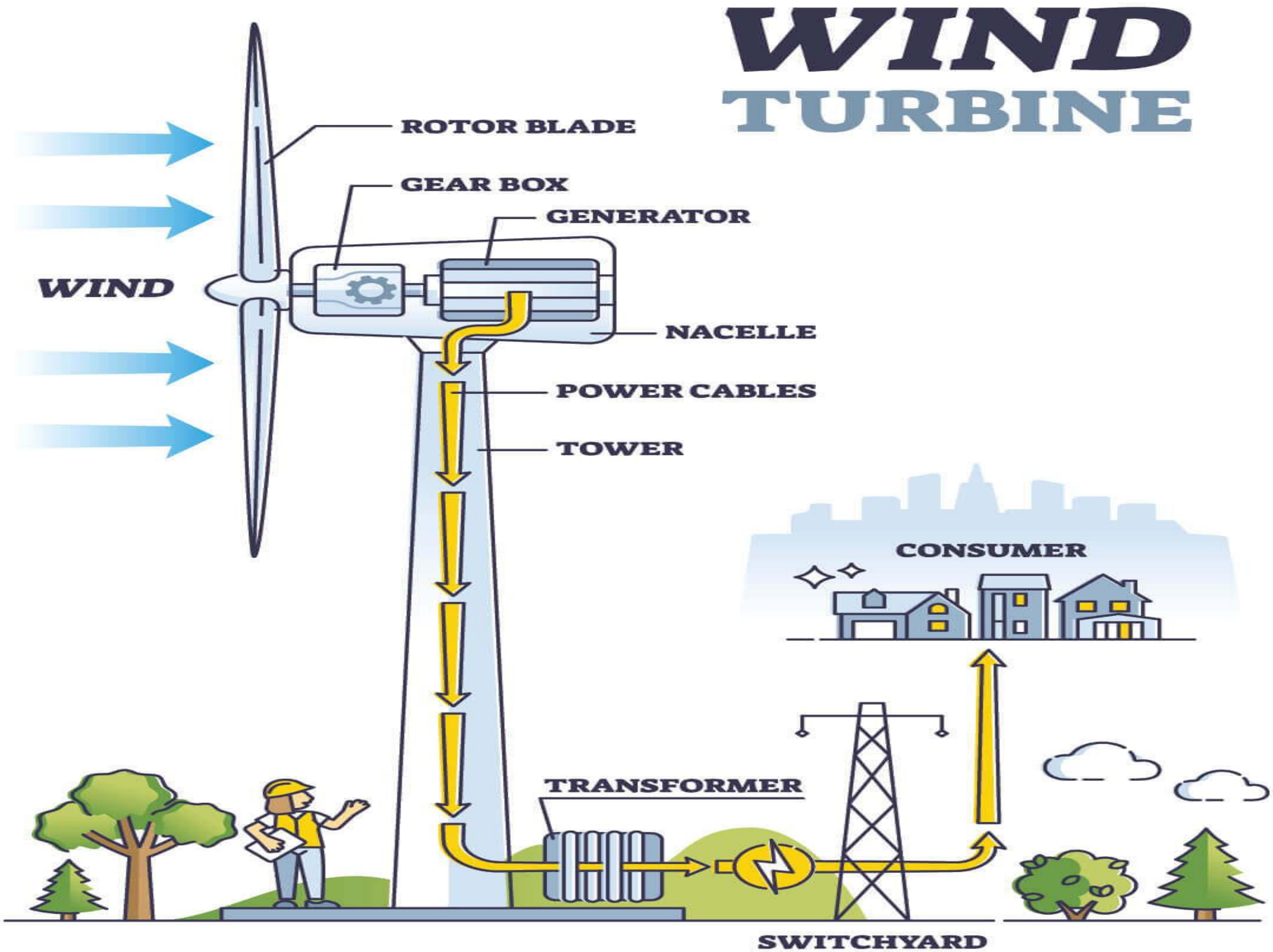
Solar Energy (2025 Focus)Status: Solar is the leading renewable source, with India surpassing **110 GW** capacity by 2025.

New Initiatives: Schemes like **PM Surya Ghar** aim to install rooftop solar on 10 million houses.

Tech Trend: Transitioning from mere capacity to "capability" with integrated battery storage.

Wind and Bio Energy Wind: Global leader status; India ranks 4th with over **51 GW** installed. Offshore wind is emerging as a major growth area for 2026.

Bio Energy: Shifting from simple burning to system-level solutions like Compressed Biogas (CBG) for transportation.


WIND
TURBINE
ROTOR BLADE
GEAR BOX
GENERATOR
WIND
NACELLE
POWER CABLES
TOWER
CONSUMER
TRANSFORMER
SWITCHYARD

Emerging Trends in 2025 Green Hydrogen: Using renewable power to create clean fuel for heavy industries.

AI & Smart Grids: Using Artificial Intelligence to predict demand and manage fluctuating renewable supply.

Decentralized Systems: Rise of microgrids and community-based power in remote areas.


H2
GREEN
HYDROGEN

Advantages and Challenges Advantages: Pollution-free, reduces electricity bills, and creates millions of "green jobs".

Challenges: High initial setup costs, intermittency (no sun at night), and land acquisition issues.

Conclusion and Future Outlook Vision

2030: Target of **500 GW** of non-fossil fuel capacity.

Final Word: Renewable energy is no longer just an "alternative"—it is becoming the backbone of the global energy grid.

THANK YOU

STEAM POWER PLANT - UNIT 2

INTRODUCTION TO BOILERS:

A **boiler** is a closed pressure vessel designed to transfer heat from fuel combustion into water to produce steam. In power plant engineering, they are classified by their operating pressure, with **high-pressure** and **supercritical** designs being the standard for modern electricity generation.

Classification of Boilers:

Boilers are primarily distinguished by the relative passage of water and hot gases:

Fire-Tube Boilers: Hot gases pass through tubes surrounded by water (e.g., Cochran, Lanchashire).

Water-Tube Boilers: Water flows inside tubes surrounded by hot combustion gases (e.g., Babcock & Wilcox). This design is preferred for power plants because it handles much higher pressures.

High-Pressure Boilers

High-pressure boilers typically operate at pressures above **80 bar**. They utilize **forced circulation** via centrifugal pumps to ensure rapid heat transfer and prevent scale formation.

La-Mont Boiler: The first forced-circulation boiler, using a pump to drive water through evaporator tubes.

Loeffler Boiler: Uses superheated steam to evaporate water in a drum, effectively handling poor water quality.

Velox Boiler: Uses pressurized combustion and high-velocity gas to achieve very high heat transfer rates.

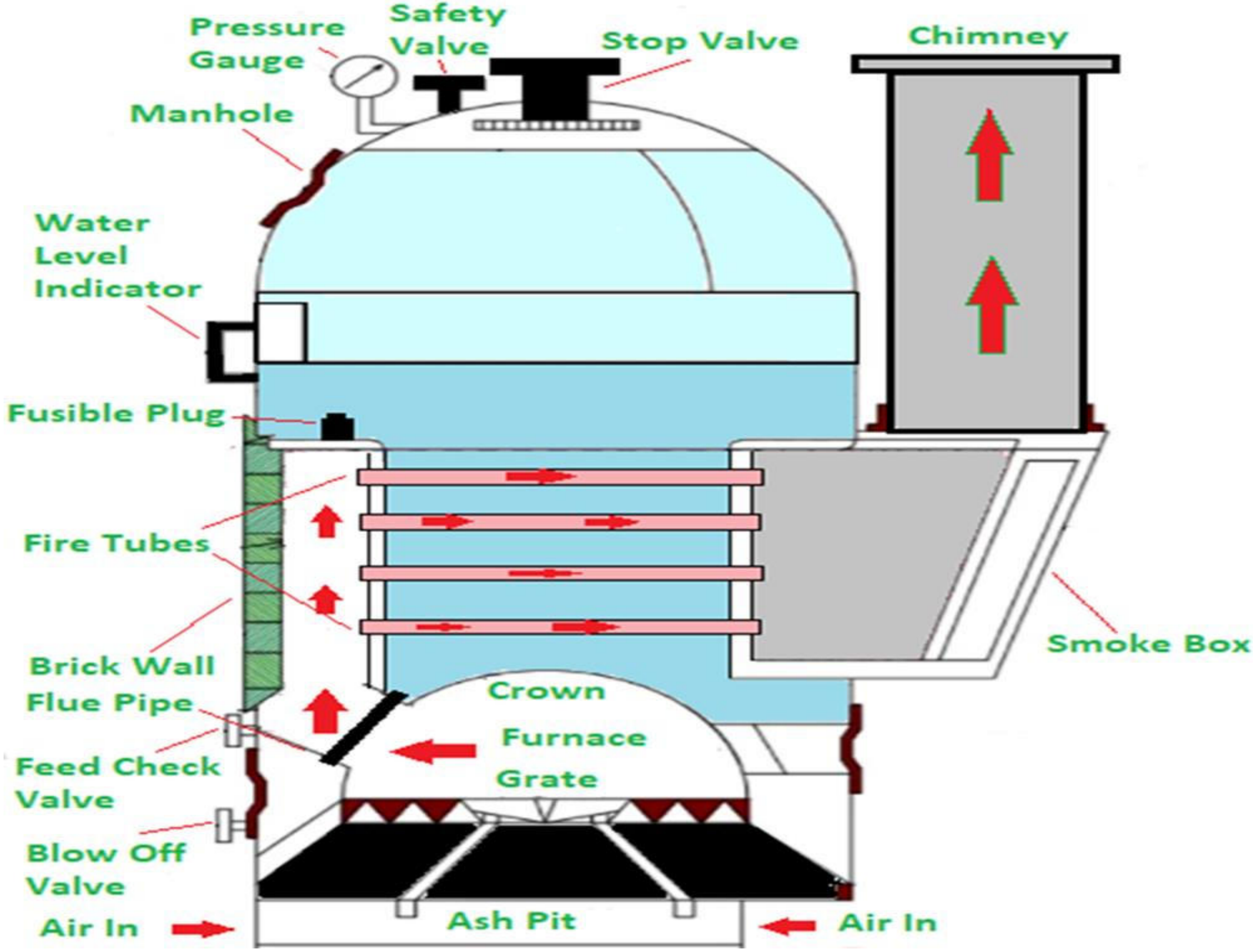
Supercritical Boilers:

Supercritical boilers operate above the critical point of water (221.2 bar and 374.15°C).

Once-Through Principle: These are drum less boilers. Water is pumped at supercritical pressure and flashes instantly into steam without a liquid-vapor phase transition.

Benson Boiler: A prominent super critical design that eliminates the need for a steam drum, reducing weight and allowing for faster start-up and load response.

Efficiency: They achieve up to **45–50%** thermal efficiency, significantly higher than subcritical units.



Cochran Boiler

The **Cochran boiler** is a vertical, multi-tubular fire tube boiler used primarily for small-scale steam generation. It is considered a modification of the simple vertical boiler, designed with multiple horizontal fire tubes to significantly increase the heating surface area and improve efficiency.

Core Characteristics

Type: Vertical, internally fired, multi-tubular, and natural circulation.

Operating Range: Typically generates **150 to 3000 kg/hr** of steam with a working pressure up to **15–20 bar**.

Efficiency: Generally ranges between **70% and 75%**.

Main Components:

Hemispherical Shell & Firebox: The top of the shell and the firebox are hemispherical. This shape provides maximum strength to withstand internal pressure and a higher volume-to-surface area ratio.

Grate & Fire Hole: Fuel (coal or wood) is fed through the fire hole onto the grate for combustion.

Combustion Chamber: A brick-lined chamber where fuel continues to burn. It is connected to the firebox by a short flue pipe.

Fire Tubes: Horizontal tubes that carry hot flue gases from the combustion chamber to the smokebox, transferring heat to the surrounding water.

Smokebox & Chimney: Collects the exhaust gases after they pass through the fire tubes and releases them into the atmosphere.

Mountings: Essential safety and control tools including a **Water Level Indicator**, **Pressure Gauge**, **Safety Valve**, and **Fusible Plug** (to extinguish fire if water levels drop too low).

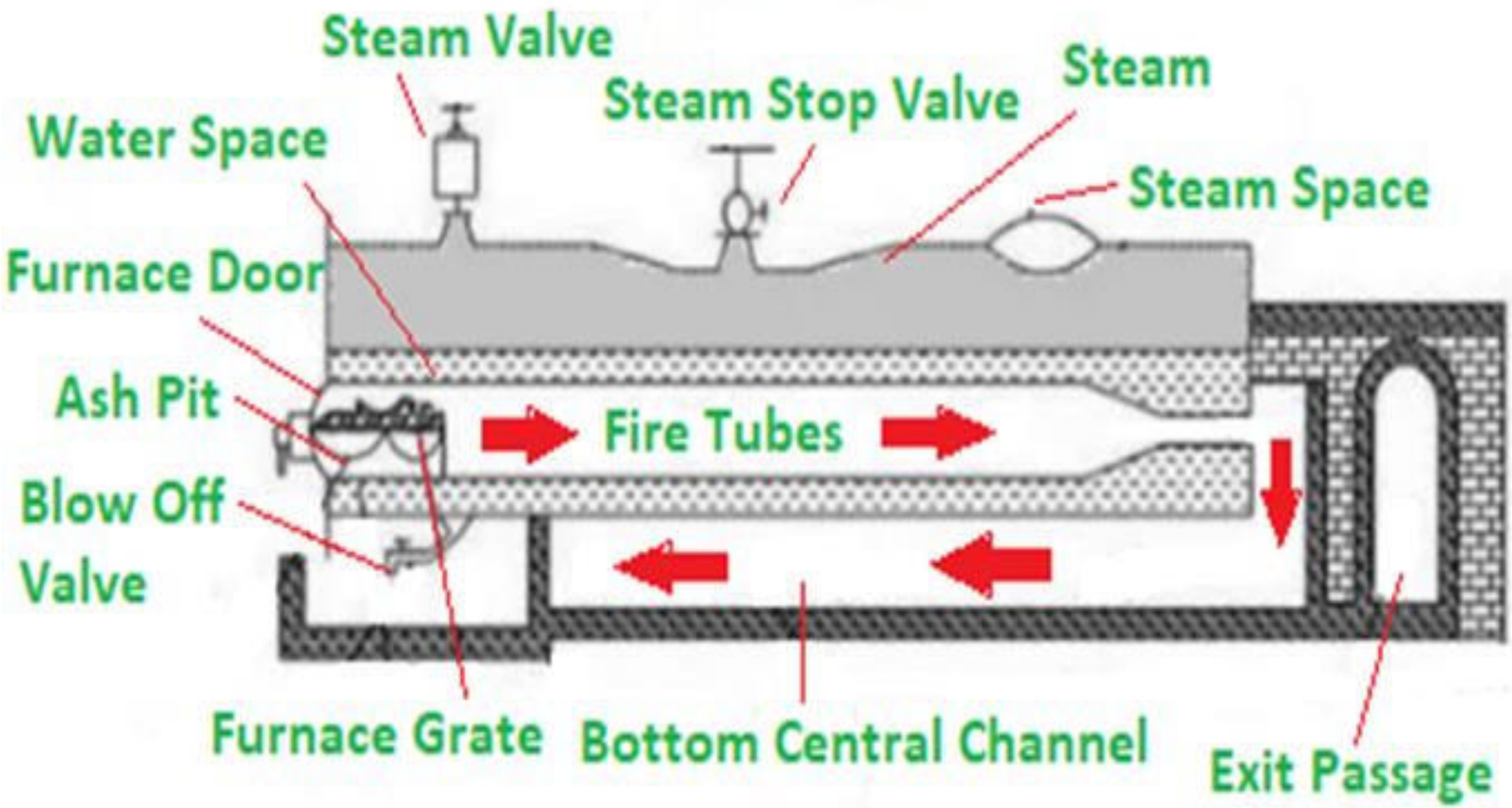
Working Principle

Combustion: Fuel is ignited on the grate, producing hot flue gases.

Heat Transfer: These gases travel through the flue pipe into the combustion chamber and then through the horizontal **fire tubes**. As they pass through, they transfer heat to the water surrounding the tubes via convection.

Steam Generation: The heated water turns into steam, which rises and collects in the hemispherical dome at the top of the shell.

Exhaust: The cooled flue gases enter the smokebox and are discharged through the chimney.



Lanchashire Boiler

The **Lancashire Boiler** is a horizontal, internally fired, natural circulation fire-tube boiler invented by **Sir William Fairbairn** in 1844. It is widely valued for its large water reserve, which allows it to handle sudden load fluctuations effectively, making it a staple in industries like sugar mills, textiles, and chemical plants.

Working Principle:

The boiler operates as a heat exchanger where hot flue gases flow through internal tubes while water surrounds them in the shell. It utilizes a **three-pass** heating system to maximize thermal efficiency (typically 80–90%):

First Pass: Hot gases from the furnace pass through two internal fire tubes from front to back, transferring roughly 80–90% of the total heat.

Second Pass: The gases travel back to the front via a central **bottom flue** beneath the shell, transferring about 8–10% more heat.

Third Pass: The gases divide into two **side flues** and travel once more to the rear before escaping through the chimney, contributing the final 6–8% of heat transfer.

Main Components:

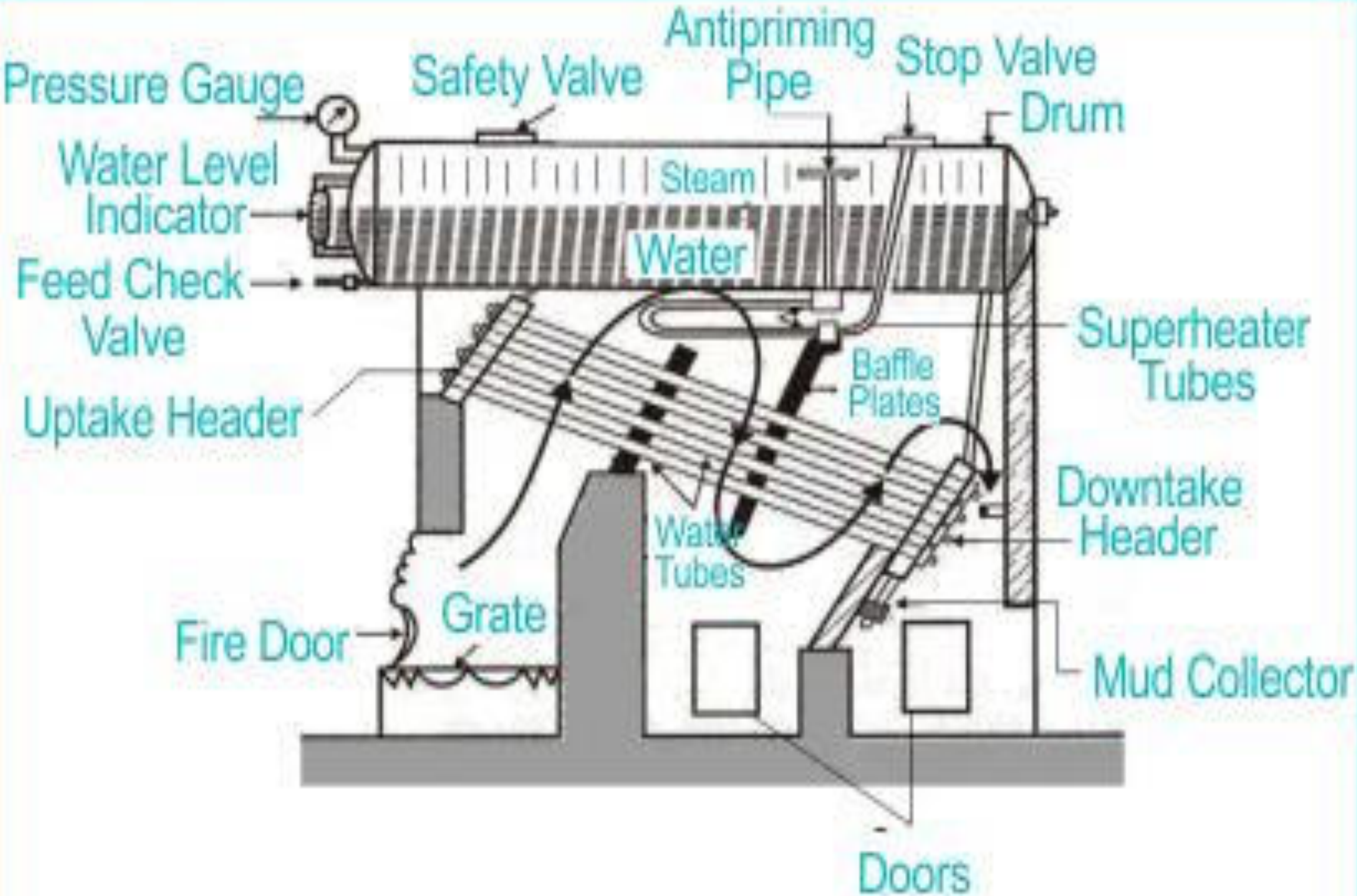
Shell: A large cylindrical drum (usually 7–9m long and 2–3m in diameter) that holds water and steam.

Fire Tubes: Two parallel tubes running the length of the shell where combustion occurs.

Safety Mountings: Includes water level indicators to monitor levels, Safety Valves to prevent overpressure, and a **Fusible Plug** to extinguish the fire if water levels drop dangerously low.

Efficiency Accessories: Uses an Economizer to preheat feed water and a Superheater to increase steam temperature without raising pressure.

testbook



Babcock and Wilcox Boiler

The **Babcock and Wilcox (B&W) boiler** is a high-pressure, water-tube boiler designed for large-scale steam generation in power plants and industrial processes. Patented in 1867, it is defined by its horizontal drum and a series of inclined water tubes that maximize heat transfer through natural circulation.

Main Components:

The design of the B&W boiler integrates several critical parts to ensure efficient steam production:

Steam and Water Drum: A horizontal cylindrical vessel that stores both water (in the bottom half) and steam (in the top half).

Water Tubes: Steel tubes inclined at an angle of **10° to 15°** to promote the natural circulation of water.

Headers: The **Uptake Header** (at the front) and **Downtake Header** (at the rear) connect the water tubes to the drum.

Baffles: Fire-brick plates arranged to force hot flue gases into a **zig-zag path**, ensuring they pass over the water tubes multiple times for maximum heat absorption.

Super heater: A set of tubes located above the water tubes that further heats the saturated steam to produce dry, high-pressure superheated steam.

Mud Box: Located at the bottom of the downtake header to collect and periodically remove sediment via a blow-off cock.

Working Principle:

The boiler operates on the principle of **natural circulation** (thermo syphon effect) caused by density differences:

Heating: Fuel burns on the grate in the furnace. The resulting hot flue gases are guided by baffles over the inclined water tubes.

Circulation: As water in the inclined tubes heats up, its density decreases, causing it to rise through the **uptake header** into the drum. Simultaneously, cooler, denser water from the drum descends through the **down take header** to replace it.

Steam Separation: In the drum, steam separates from the water and collects in the upper space.

Superheating: Saturated steam passes through an **anti-priming pipe** (to remove moisture) into the superheater, where it is heated further by flue gases before being discharged via the main stop valve.

Performance & Applications:

Capacity: It can generate between **20,000 to 40,000 kg** of steam per hour.

Pressure: Operates at high pressures, typically up to **140 bar**.

Efficiency: Generally ranges from **60% to 80%**.

Use Cases: Primarily used in **thermal power stations** to drive turbines for electricity and in heavy industries like textiles, chemicals, and sugar refineries.

Modern high-pressure and supercritical boilers are advanced steam-generating systems used primarily in large-scale thermal power plants. They differ from conventional boilers in their operating pressures, water circulation methods, and the thermodynamic state of the steam they produce.

1. High-Pressure Boilers

Generally defined as boilers operating at pressures above **80 bar**, these systems are designed to maximize thermal efficiency and handle massive steam capacities, often ranging from 30 to 650 tons per hour.

Forced Circulation: Most modern high-pressure units use pumps rather than natural convection to move water through the tubes. This ensures uniform heating and prevents tube overheating.

Small Diameter Tubes: They utilize a network of small, parallel water tubes to increase the heating surface area, making the unit more compact and efficient.

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Key Designs:

- **La-Mont Boiler:** A pioneer in forced circulation, using a centrifugal pump to deliver water to the evaporator tubes.
- **Loeffler Boiler:** Designed to prevent salt deposition by using superheated steam to evaporate feedwater in a separate drum.
- **Velox Boiler:** Achieves extreme heat transfer rates by using pressurized combustion and high-speed flue gases.

2. Supercritical Boilers

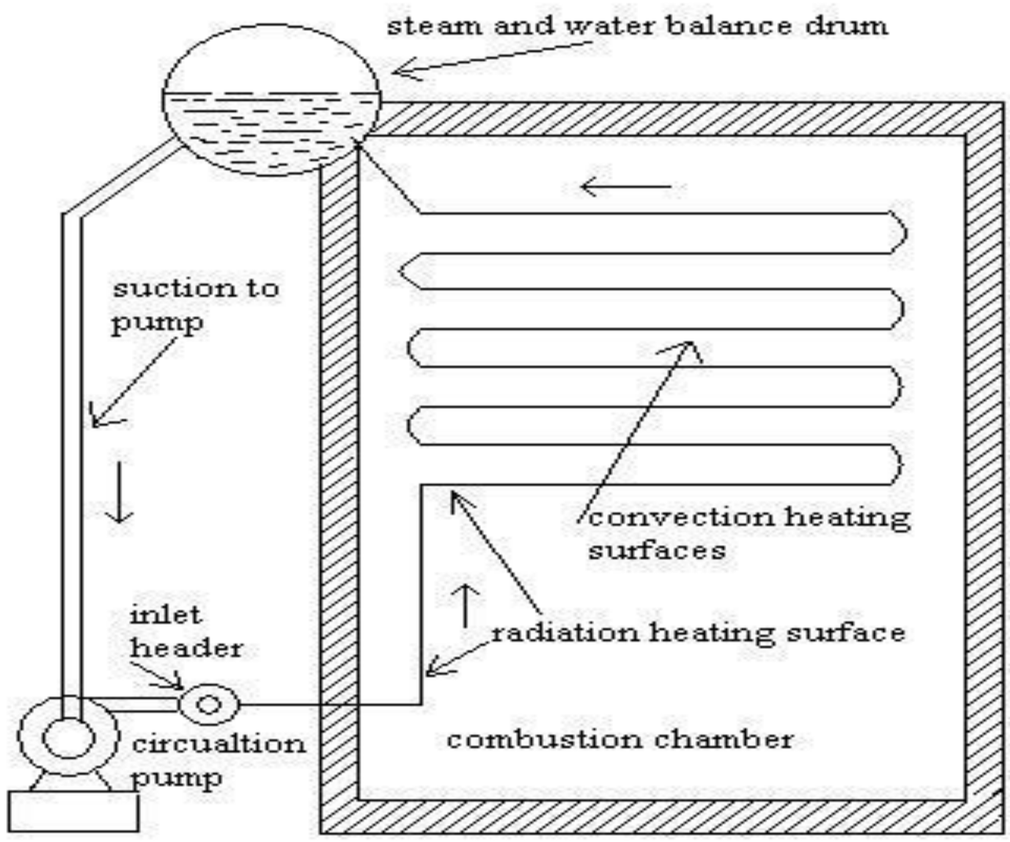
Supercritical boilers operate above the "critical point" of water—**221 bar (3,200 psi)** and **374°C (705°F)**. At this stage, the distinction between liquid and gas disappears, and water converts directly into steam without boiling.

"Once-Through" Design: Because there is no phase change (and thus no steam bubbles), these boilers do not require a **steam drum** for separation. Water enters at one end and exits as dry steam at the other.

Efficiency: Supercritical plants can reach thermal efficiencies of **45–50%**, compared to the 32–38% seen in subcritical plants.

Environmental Impact: Higher efficiency means they burn less fuel per megawatt of power produced, leading to significantly lower CO_2 and NO_x emissions.

Example: The **Benson Boiler** is a classic once-through supercritical design that eliminates the heavy weight and cost of a steam drum.



Schematic diagram of La Mont Boiler

La-Mont Boiler

The **La-Mont boiler** is a type of high-pressure, forced-circulation water-tube boiler that uses an external pump to rapidly circulate water through small-diameter tubes, ensuring efficient and high-capacity steam generation.

Working Principle

The primary distinguishing feature is the use of a **centrifugal pump** to force water circulation, rather than relying solely on natural convection.

Feed Water Preheating: Feed water is first pumped through an **economizer** where it absorbs heat from the outgoing flue gases, increasing the overall thermal efficiency.

Forced Circulation: The preheated water enters a steam-separating drum. An external centrifugal pump draws water from this drum and circulates it at a high velocity (8 to 10 times the evaporation rate) through the evaporator tubes. This high flow rate prevents the formation of scale and reduces the risk of the tubes overheating.

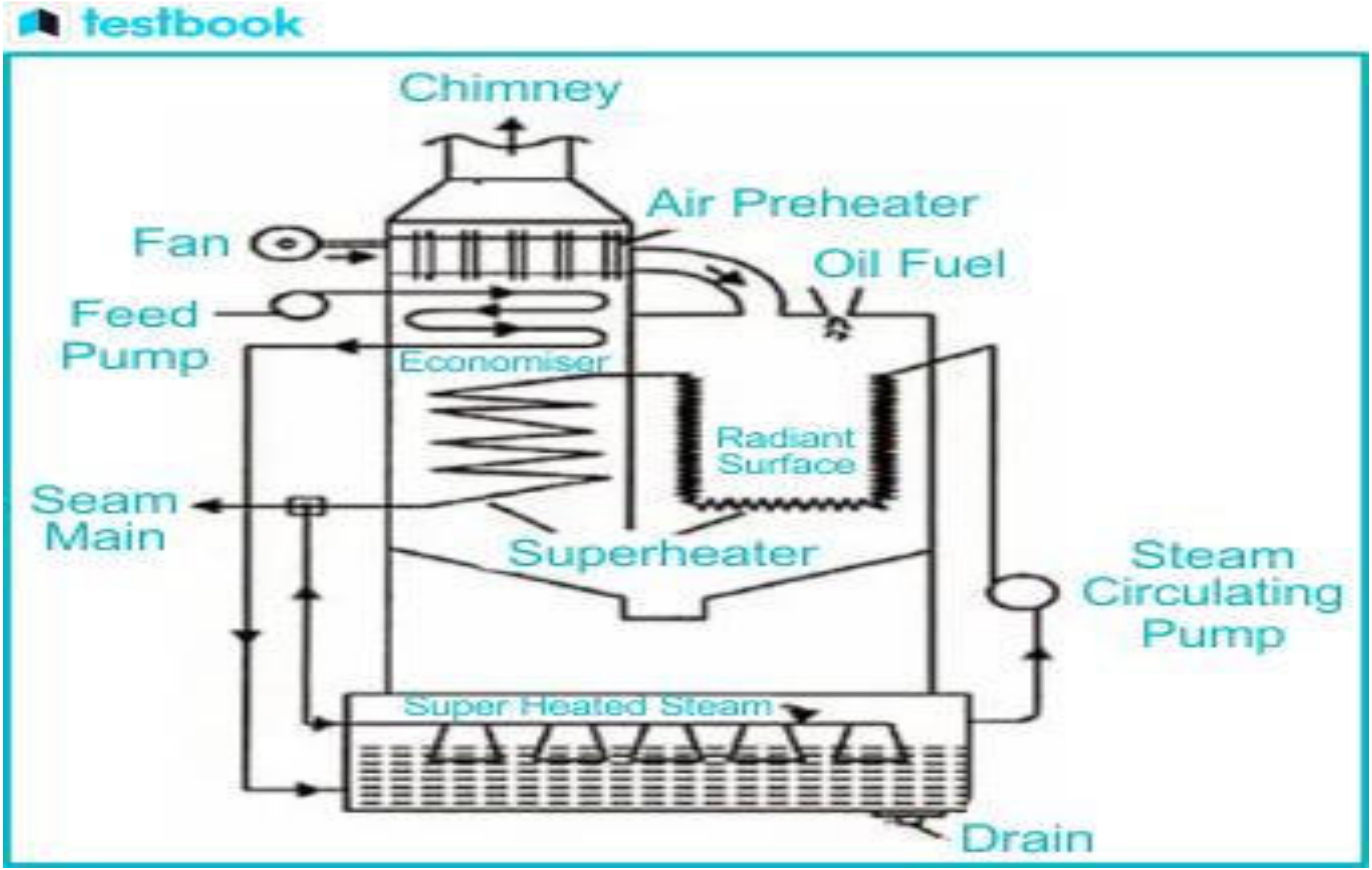
Evaporation: The water in the evaporator tubes is heated by hot combustion gases from the furnace, producing a mixture of water and saturated steam.

Separation and Superheating: This mixture returns to the separating drum, where the steam is separated from the water. The separated steam then passes through a **super heater**, which further increases its temperature using more heat from the flue gases to produce superheated steam, which is ideal for driving turbines.

Re-circulation and Exhaust: The remaining water in the drum is recirculated by the pump, and the waste flue gases are finally passed through an air preheater before exiting to the atmosphere.

Applications:

Due to its high efficiency and capacity, the La-Mont boiler is primarily used in **power plants** for electricity generation and in **industrial settings** that require high-pressure and high-temperature steam. It is also suitable for marine applications due to its compact design.



Loeffler boiler

The **Loeffler Boiler** is a specialized high-pressure, forced-circulation water-tube boiler designed to eliminate the common issue of salt and sediment deposition within boiler tubes.

Working Principle:

The defining feature of the Loeffler boiler is that it generates steam **indirectly**. Instead of evaporating water directly in the tubes exposed to the furnace, it uses **superheated steam** to evaporate feed water inside an external drum. This ensures that only pure steam flows through the furnace tubes, while impurities like salt settle in the evaporating drum where they can be easily drained

Main Components:

Evaporating Drum: An external vessel where preheated water is converted into saturated steam by mixing with superheated steam.

Steam Circulating Pump: A centrifugal pump that forces saturated steam from the drum through the superheaters.

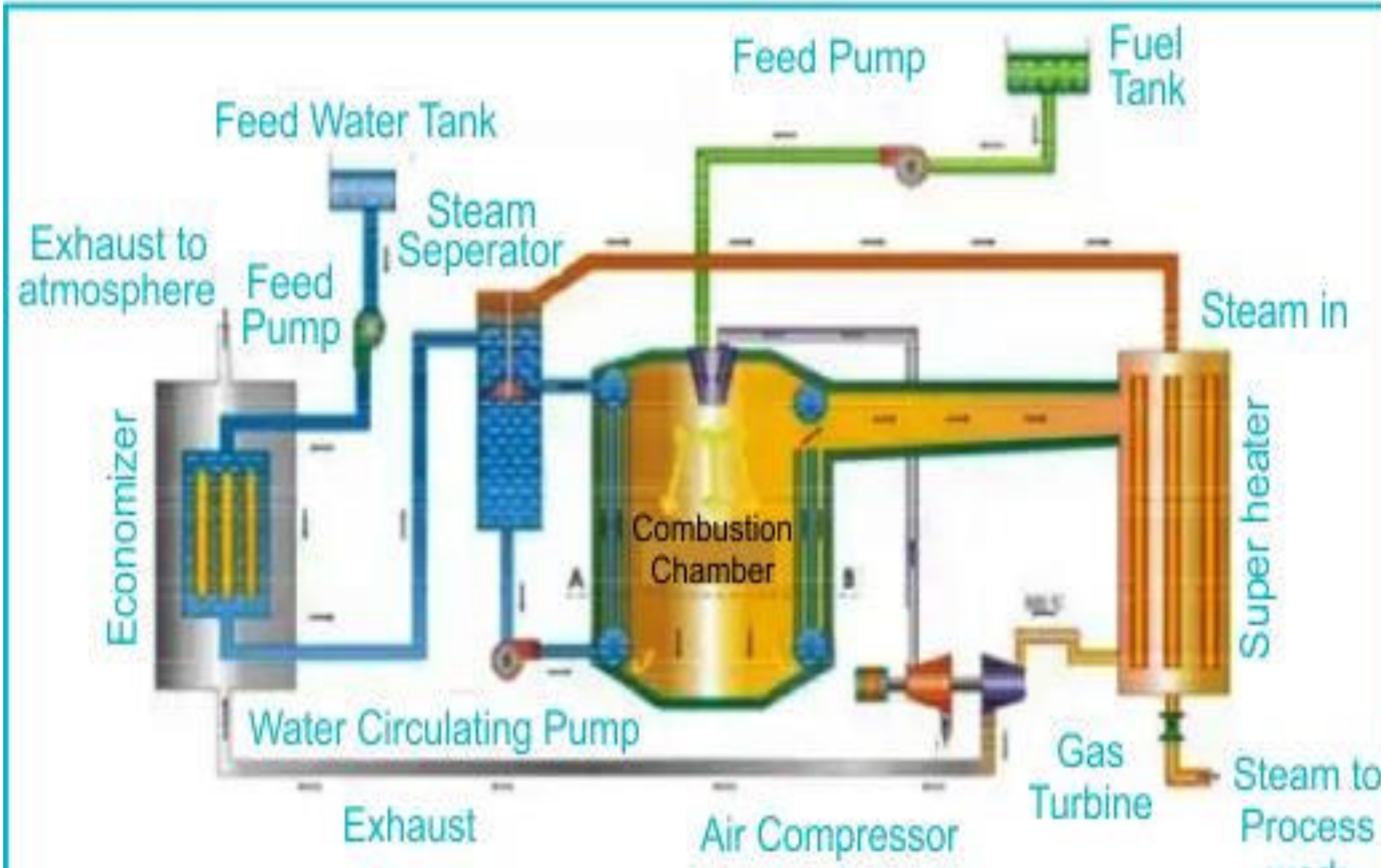
Radiant & Convective Superheaters: These heat the steam to approximately **500°C** using furnace radiation and hot flue gases.

Mixing Nozzles: Located inside the evaporating drum to efficiently distribute superheated steam into the water for rapid evaporation.

Economizer & Air Preheater: Standard accessories that recover waste heat from flue gases to preheat feedwater and combustion air, increasing overall efficiency.

Operational Flow:

Feed water is pumped through the **economizer** into the **evaporating drum**. **Superheated steam** (approx. 65-75% of the total output) is injected into the drum through nozzles to evaporate the water. The resulting **saturated steam** is drawn out by the **steam circulating pump**. This steam passes through the **radiant** and then **convective super heaters** to reach high temperatures. Finally, **25-35%** of the superheated steam is sent to the **turbine** for power generation, while the rest returns to the evaporating drum to repeat the cycle.



Velox Boiler

A **Velox Boiler** is a high-pressure, forced-circulation water-tube boiler that is uniquely distinguished by its use of **supersonic gas velocities** to achieve exceptionally high heat transfer rates. Developed in 1931 by the Brown Boveri Company, it was the first steam generator to incorporate an axial compressor and a gas turbine as integral parts of its cycle.

Working Principle

The Velox Boiler operates on the thermodynamic principle that heat transfer from gas to water increases dramatically when gas flows at speeds exceeding the **velocity of sound**.

Pressurized Combustion: An axial compressor, powered by a gas turbine, forces air into the combustion chamber at pressures around 2 to 2.5 bar.

Supersonic Flow: This high-pressure combustion accelerates flue gases to supersonic speeds as they pass through small-diameter fire tubes surrounded by water tubes.

High Efficiency: This rapid movement allows for massive heat exchange without needing a larger boiler surface, resulting in thermal efficiencies of **90% to 95%**.

Key Components & Operation

Feed Pump & Economizer: Water is pumped into an economizer where it is preheated by exhaust gases before entering the main system.

Water Circulating Pump: This pump forces water through the evaporator tubes at 15–20 times the rate of steam generation to prevent overheating of the metal walls.

Combustion Chamber: Fuel and compressed air mix here, creating high-velocity flue gases.

Steam Separator: A centrifugal separator uses rotational force to throw heavier water particles against the walls, effectively separating dry steam from the water-steam mixture.

Gas Turbine-Compressor Set: The flue gases drive a gas turbine, which in turn runs the axial compressor. An electric motor is often used during startup until the turbine can sustain the compressor's load.

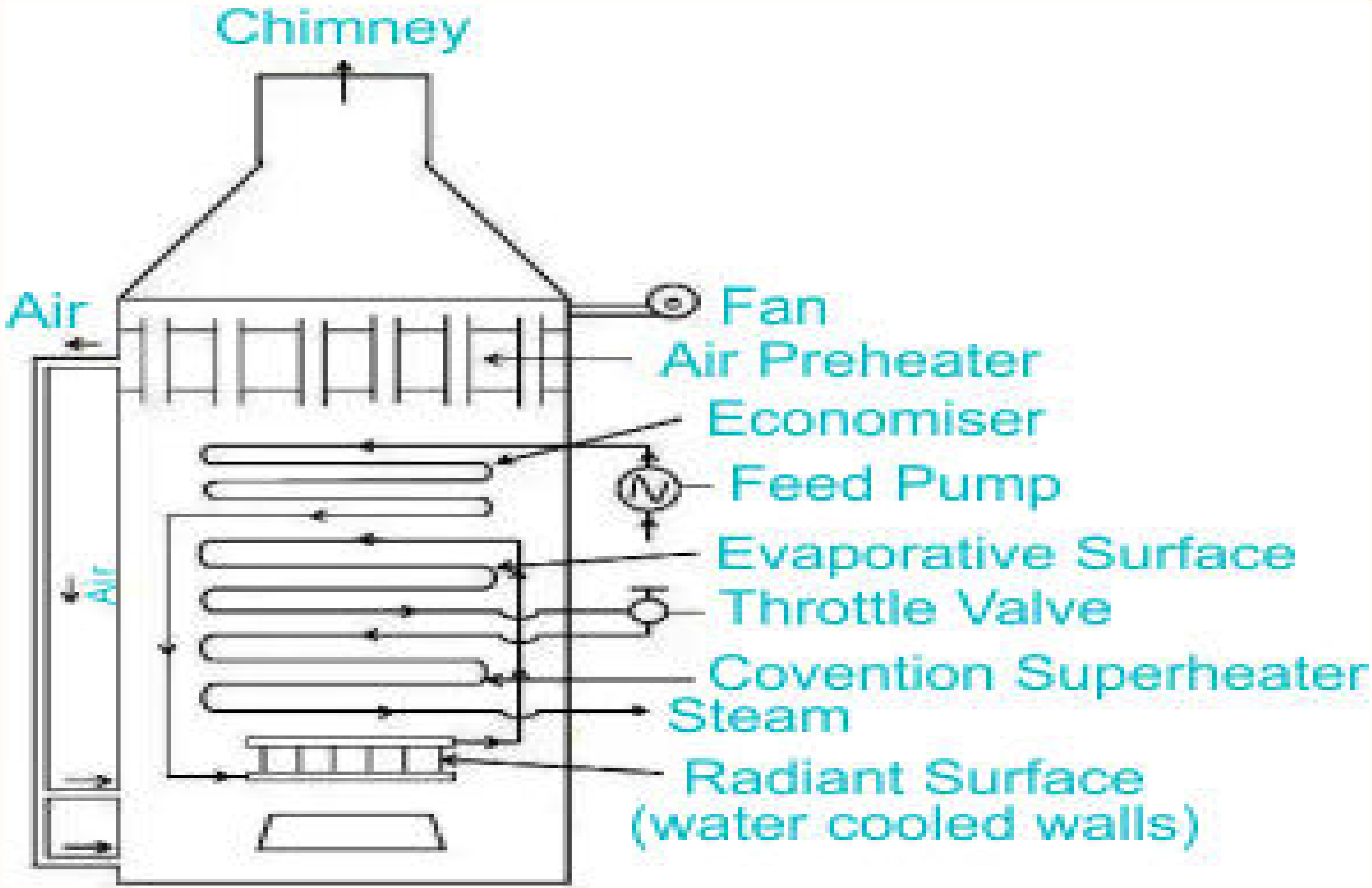
Technical Specifications & Applications

Capacity: Typically limited to **100 tonnes/hour** because of the massive power (approx. 4,500 kW) required to run the compressor at larger scales.

Pressure Range: Operates at high pressures, commonly between **50 to 100 bar**.

Fuels: Primarily designed for **liquid (oil) or gaseous fuels**.

Uses: Used extensively in gas turbine power plants, marine propulsion, and standby power plants due to its ability to start quickly (within minutes) and its compact, space-saving design.



Benson Boiler

A **Benson Boiler** is a high-pressure, water-tube steam boiler developed by Mark Benson in 1922. It is distinguished as a **"once-through"** supercritical boiler, meaning water is pumped in at one end and emerges as superheated steam at the other in a single continuous path.

Core Principle: The boiler operates at **supercritical pressure** (above 225 bar). At this pressure: Water and steam have the same density. The **latent heat of evaporation is zero**, so water transforms into steam instantly without boiling or forming bubbles.

This lack of bubble formation allows for higher heat transfer rates and prevents tube damage caused by "steam films".

Key Components & Operation: Feed Pump: Forces water into the system at supercritical pressure.

Economizer: Preheats the feed water using waste heat from flue gases.

Radiant Evaporator: Water enters this section near the furnace, absorbing heat through radiation to reach near-critical temperatures.

Convective Evaporator: Flue gases transfer heat by convection to complete the conversion into steam.

Superheater: The final stage where steam is further heated (often up to 650°C) for use in turbines.

Main Features

Drumless Design: Unlike other high-pressure boilers (like the Lamont Boiler), it lacks a steam-separating drum, making it roughly **20% lighter** and more compact.

Fast Startup: It can reach full capacity in just **10–15 minutes**.

Safety: Its small-diameter tubes and lack of a large water storage drum significantly reduce explosion hazards.

Efficiency: It typically achieves thermal efficiencies of around **90%**.

Limitations

Water Purity: Because all water evaporates, any impurities quickly form **salt deposits** in the tubes, requiring regular flushing (roughly every 4,000 hours).

Complex Control: Precise coordination of feed water, fuel, and steam output is required due to the low storage capacity.

Analysis of power plant cycles:

Power plant cycles are thermodynamic processes that convert heat energy into mechanical work and eventually electricity. They are primarily categorized based on the phase of the working fluid—**Vapor Power Cycles** (where the fluid changes phase) and **Gas Power Cycles** (where it remains a gas).

1. Vapor Power Cycles (Steam Plants)

These cycles use water as the primary working fluid and are the foundation of most thermal, coal, and nuclear plants.

Rankine Cycle: The practical standard for steam power plants. It consists of four main stages: isentropic compression in a **pump**, constant-pressure heat addition in a **boiler**, isentropic expansion in a **turbine**, and constant-pressure heat rejection in a **condenser**.

Reheat Cycle: Used to prevent moisture damage in turbine blades. Steam is extracted after partial expansion, reheated in the boiler, and then expanded again in a lower-pressure turbine.

Regenerative Cycle: Increases efficiency by preheating the "feed water" before it enters the boiler. This is done by "bleeding" some steam from the turbine to heat the incoming water in **feedwater heaters**.

Binary Vapor Cycle: Uses two different working fluids (e.g., mercury and water) to take advantage of high-temperature stability in one and low-temperature efficiency in the other.

2. Gas Power Cycles (Gas Turbines)

These cycles are commonly used in aviation and "peaker" natural gas plants.

Brayton Cycle: The fundamental cycle for gas turbines. It involves air being compressed, mixed with fuel for combustion, and then expanded through a turbine to generate power.

Otto and Diesel Cycles: Internal combustion cycles used in smaller-scale power generation (e.g., backup generators).

Advanced and Combined Cycles

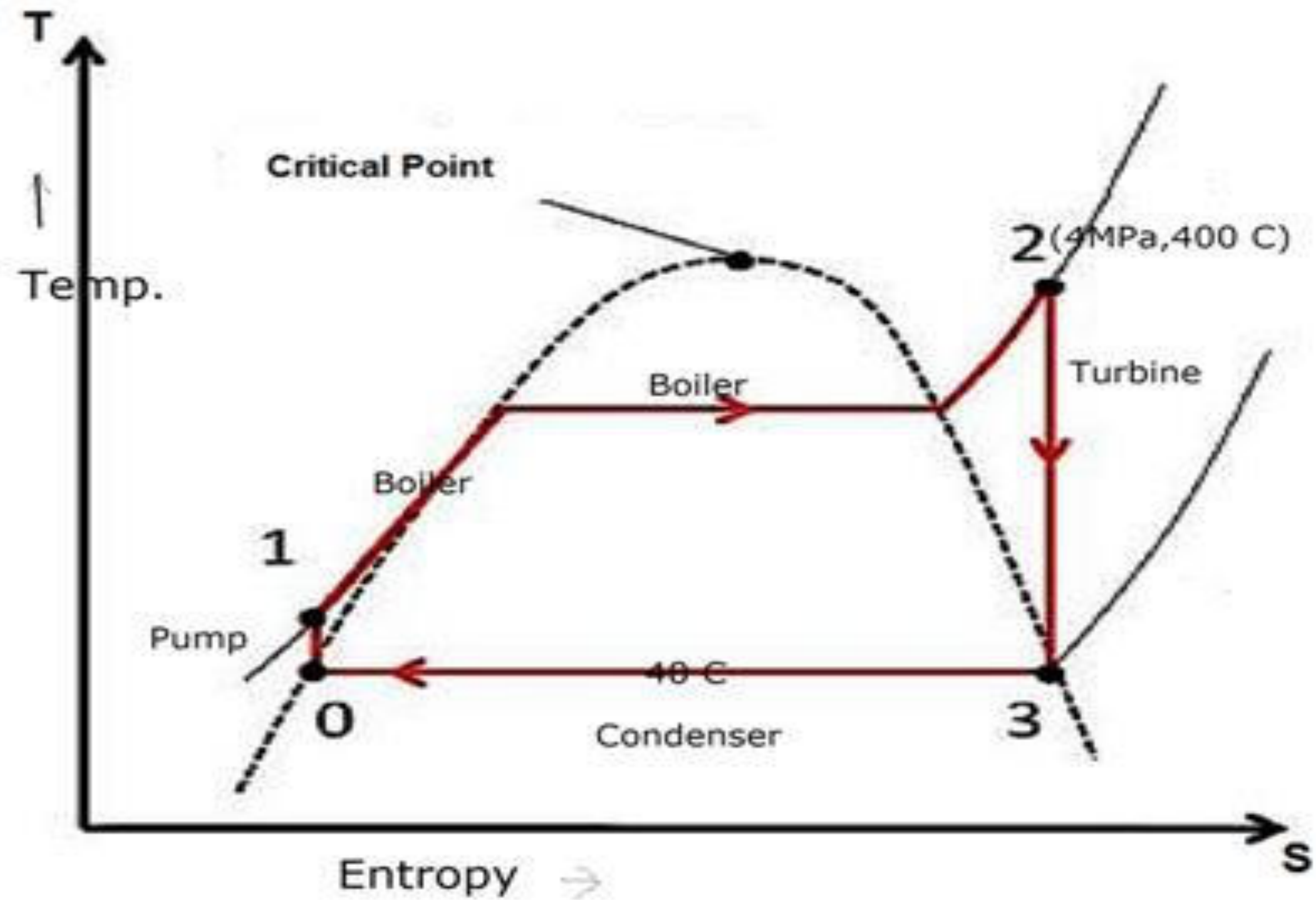
Combined Cycle (CCGT): Pairs a gas turbine (Brayton) with a steam turbine (Rankine). The high-temperature exhaust from the gas turbine is used to generate steam for the Rankine cycle via a **Heat Recovery Steam Generator (HRSG)**. This can push efficiencies above 60%.

4. Key Performance Metrics

Thermal Efficiency (η): The ratio of net work produced to the total heat input.

Heat Rate: The amount of fuel energy required to produce one unit of electricity (inverse of efficiency).

Back Work Ratio: The percentage of turbine work required to run the compressor or pump. It is much lower in Rankine cycles ($\approx$1-3%) than in Brayton cycles.



Rankine Cycle

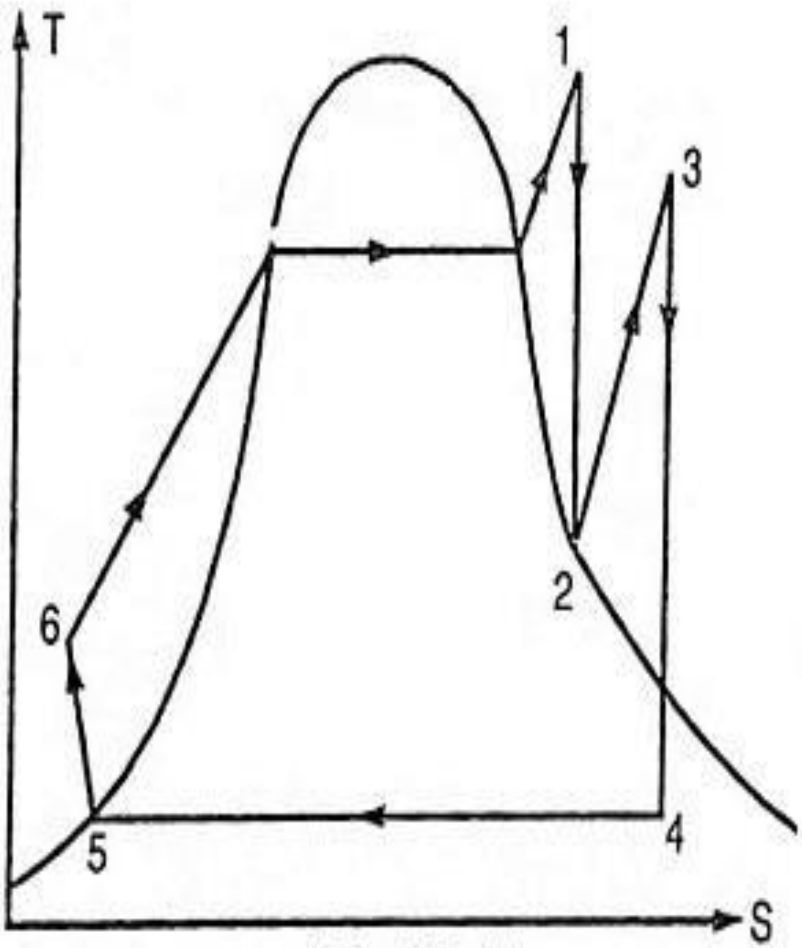


Fig:1.8 (a)

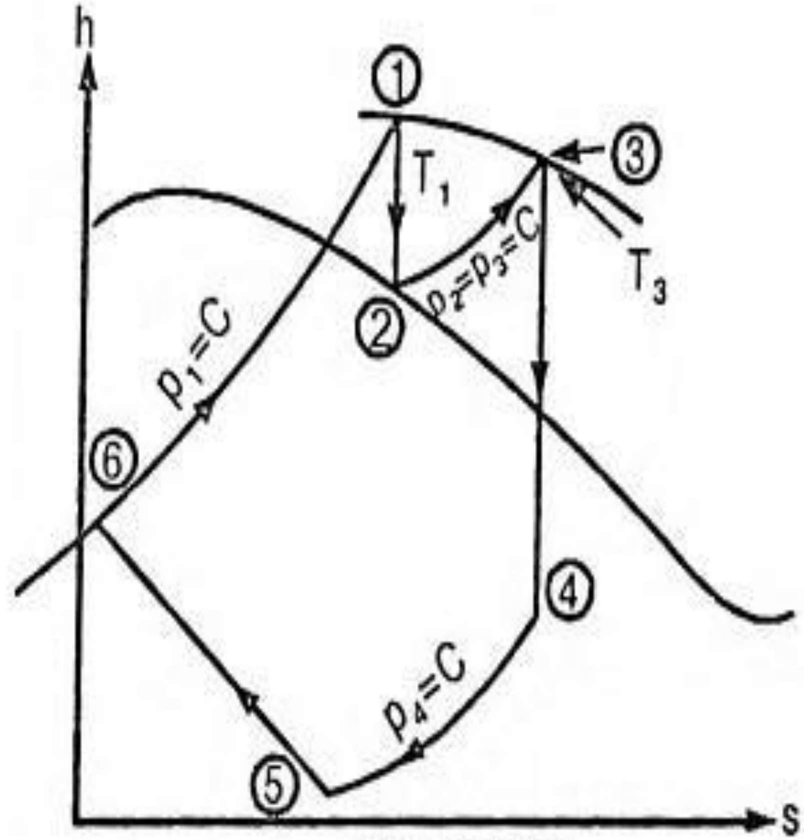
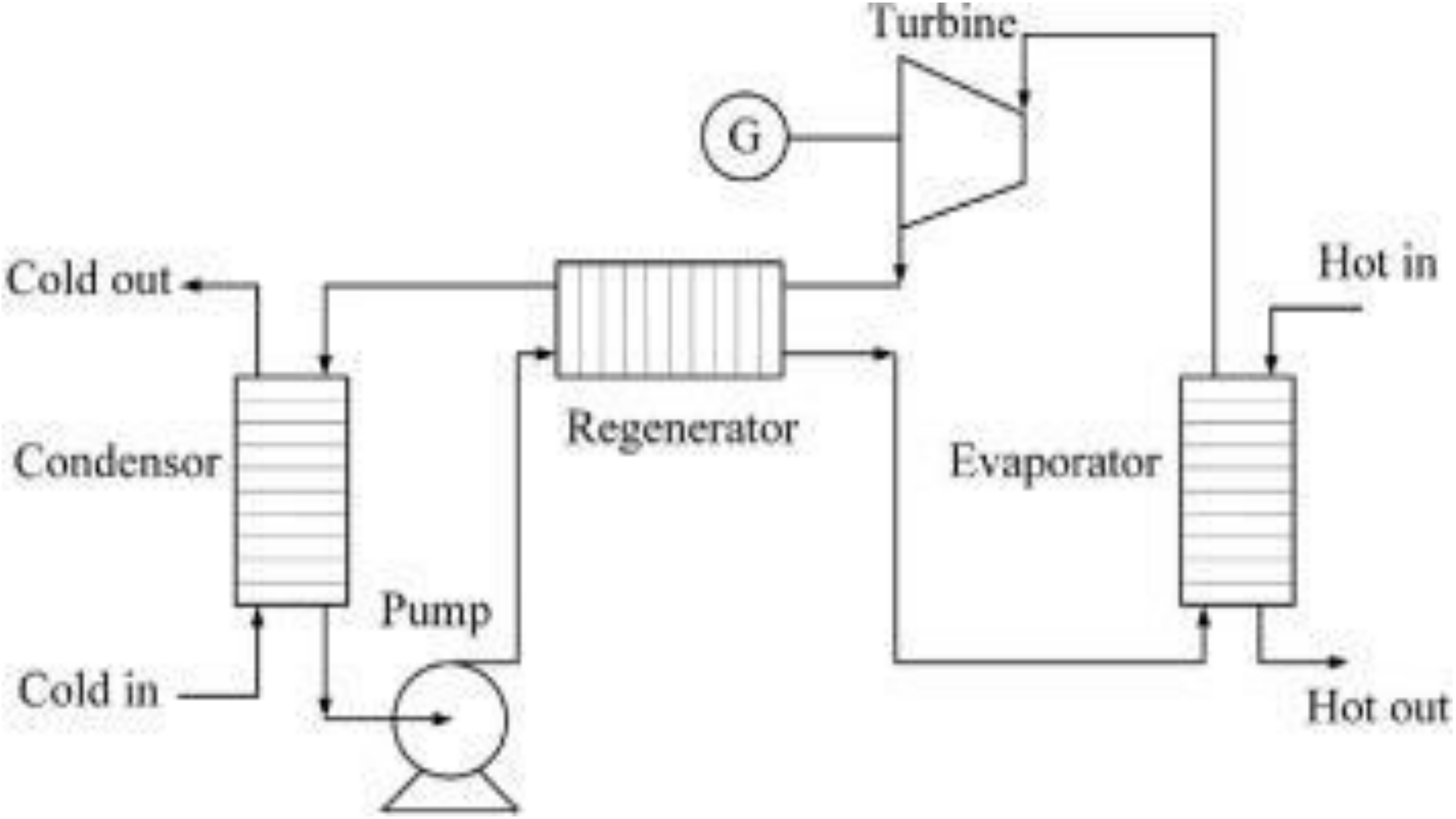


Fig:1.8 (b)

Reheat cycle



Regenerative cycle

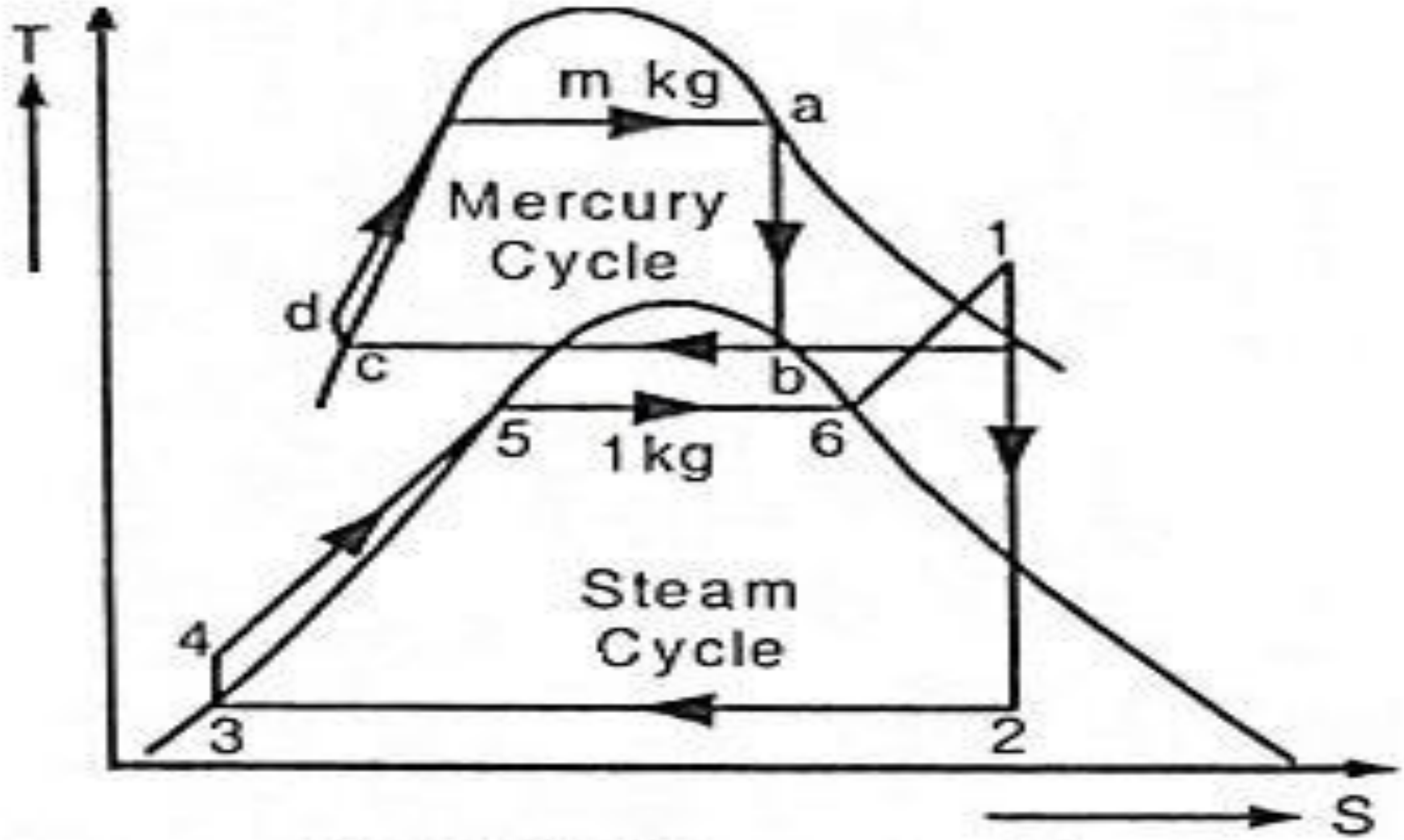
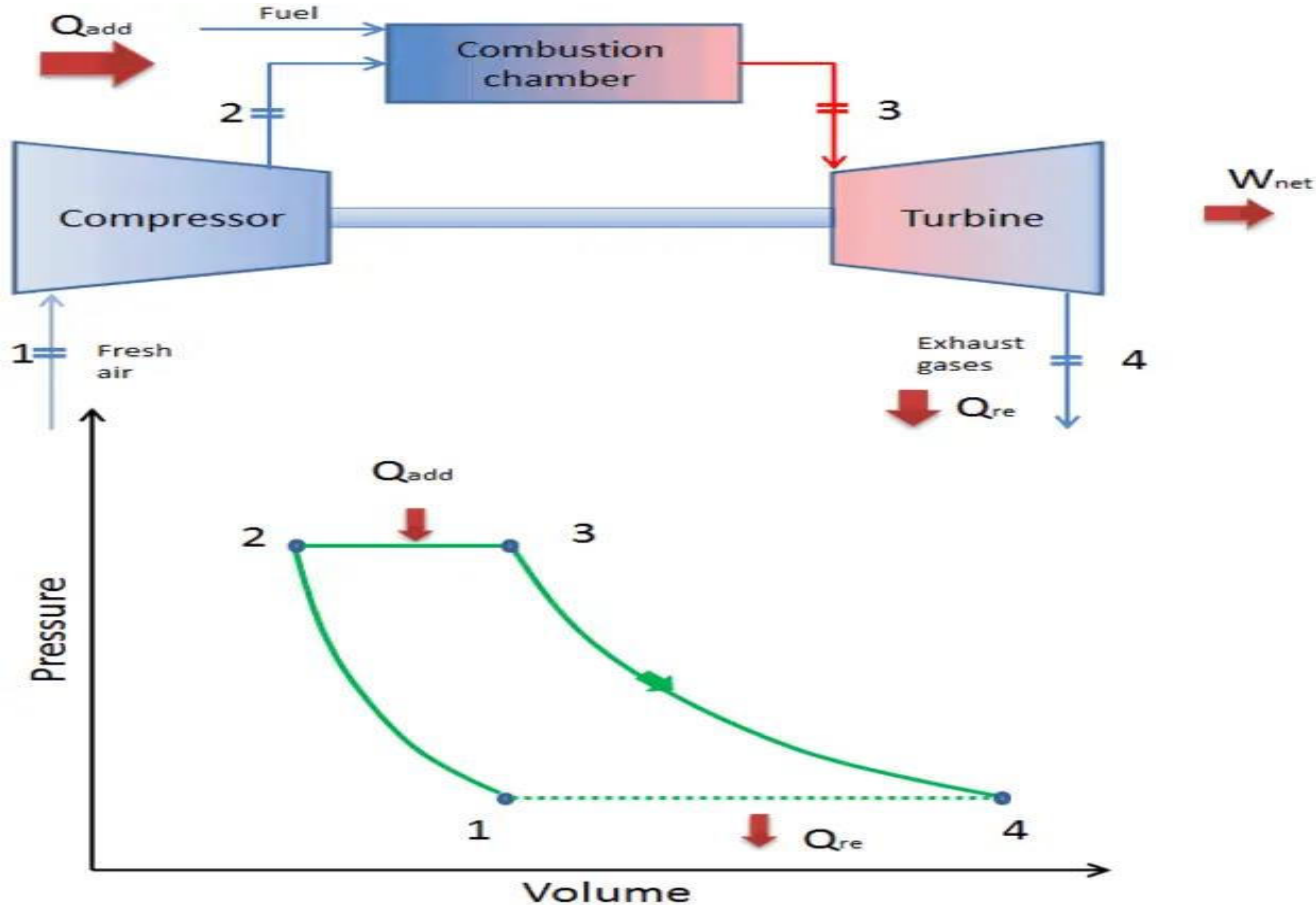


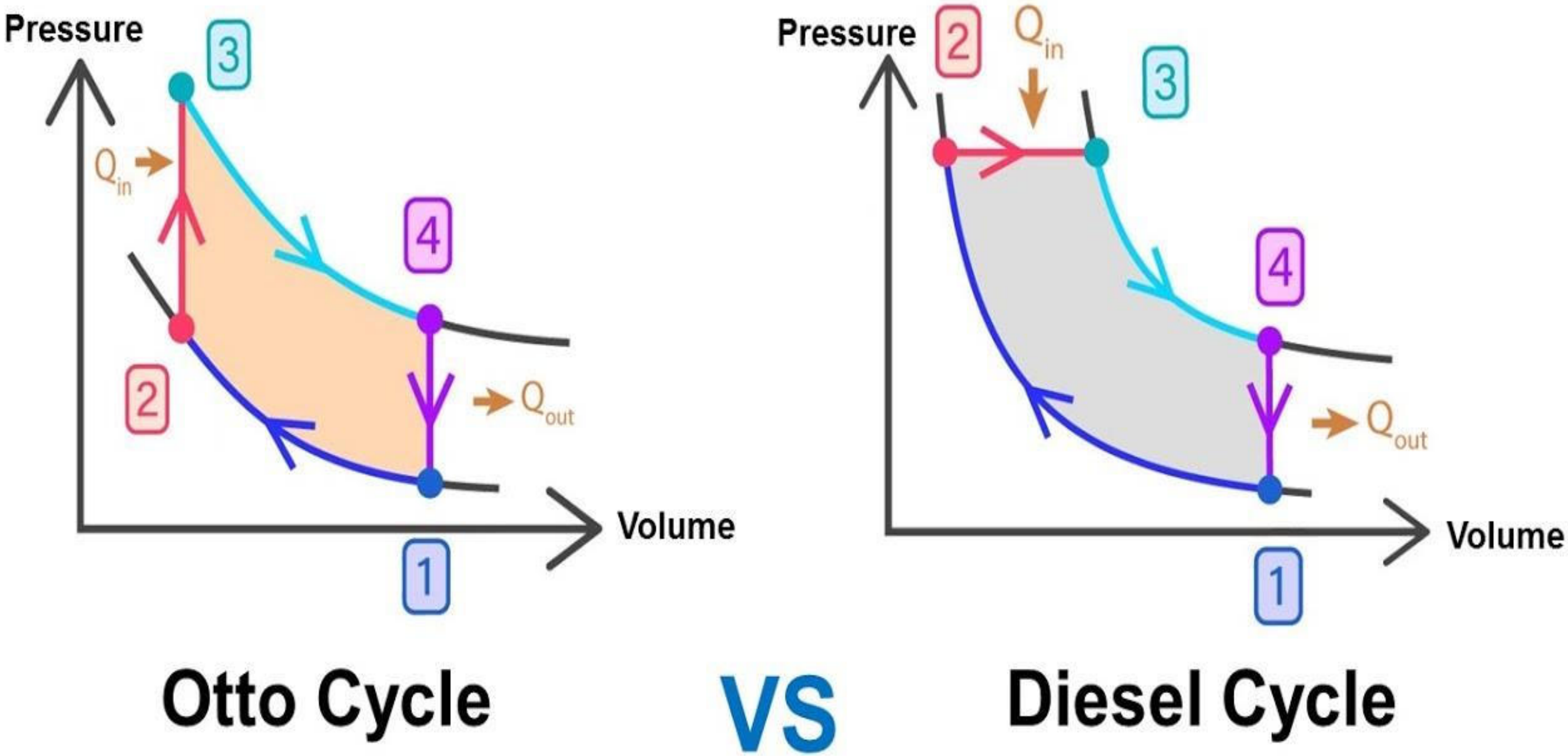
Fig:1.92 Mercury - Steam Binary Cycle

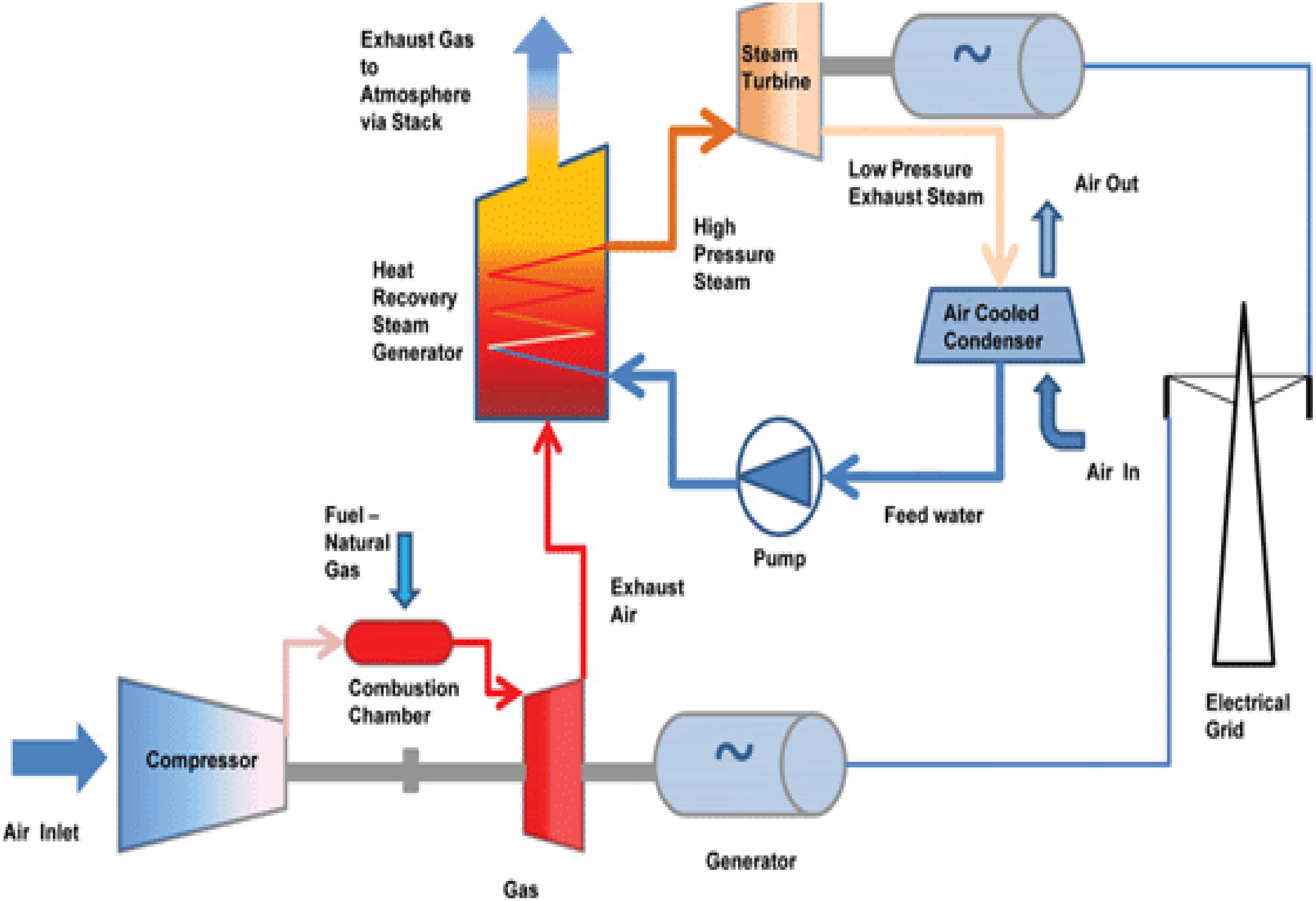
Binary vapour cycle



Brayton cycle

DIFFERENCE BETWEEN OTTO CYCLE & DIESEL CYCLE





Combined cycle Gas turbine and steam turbine power plant

A **Combined Cycle Gas Turbine (CCGT)** power plant is a highly efficient energy generation system that integrates two thermodynamic cycles—the **Brayton cycle** (gas turbine) and the **Rankine cycle** (steam turbine)—to produce significantly more electricity from the same amount of fuel.

Working Principle

The process occurs in two primary stages:

Topping Cycle (Gas Turbine): Natural gas or other fuels are burned to drive a gas turbine, which produces the first batch of electricity via a generator.

Heat Recovery: Instead of venting the hot exhaust gases (often exceeding 500°C), they are captured by a **Heat Recovery Steam Generator (HRSG)**.

Bottoming Cycle (Steam Turbine): The HRSG uses this waste heat to boil water into high-pressure steam, which drives a secondary steam turbine to generate additional power.

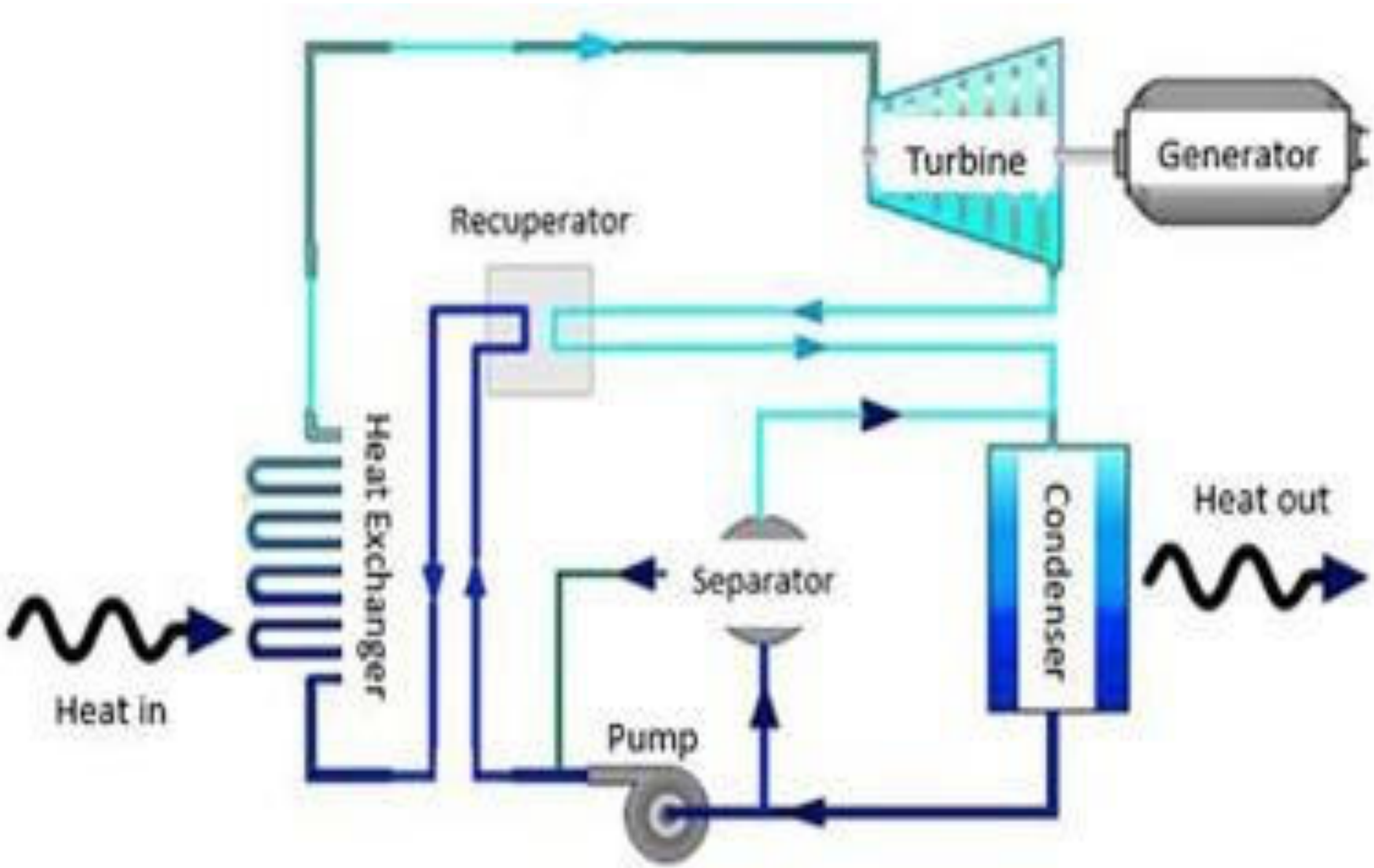
Key Advantages

Superior Efficiency: CCGT plants achieve thermal efficiencies of **50% to 64%**, far outperforming single-cycle gas turbines (33–43%) and coal-fired plants (33–40%).

Operational Flexibility: They can start up quickly and ramp power output up or down to balance the intermittency of renewable energy like wind and solar.

Lower Emissions: Because they use fuel more efficiently, they emit roughly **50% less CO_2** than traditional coal plants.

Hydrogen Readiness: Modern plants are increasingly designed to blend hydrogen with natural gas, moving toward zero-emission goals.



Waste heat recovery

In power plant engineering, **Waste Heat Recovery (WHR)** is the process of capturing thermal energy that would otherwise be rejected into the environment—typically through exhaust gases, cooling water, or steam—and repurposing it for beneficial use. This practice significantly boosts the overall thermal efficiency of a facility, often reaching levels of **75–85%**.

1. Classification of Waste Heat

Engineers categorize waste heat by its "grade" or temperature, which determines its potential for recovery:

High-Grade (>400–650°C): Found in direct combustion exhausts, such as from gas turbines or industrial furnaces. These sources have high potential for secondary power generation.

Medium-Grade (100–400°C): Typical of steam boiler exhausts and chemical reactors. Suitable for preheating or low-pressure steam generation.

Low-Grade (<100°C): Often found in cooling water or HVAC systems. While harder to recover cost-effectively, it can be used for space heating or via advanced cycles like the Organic Rankine Cycle.

Recovery Technologies

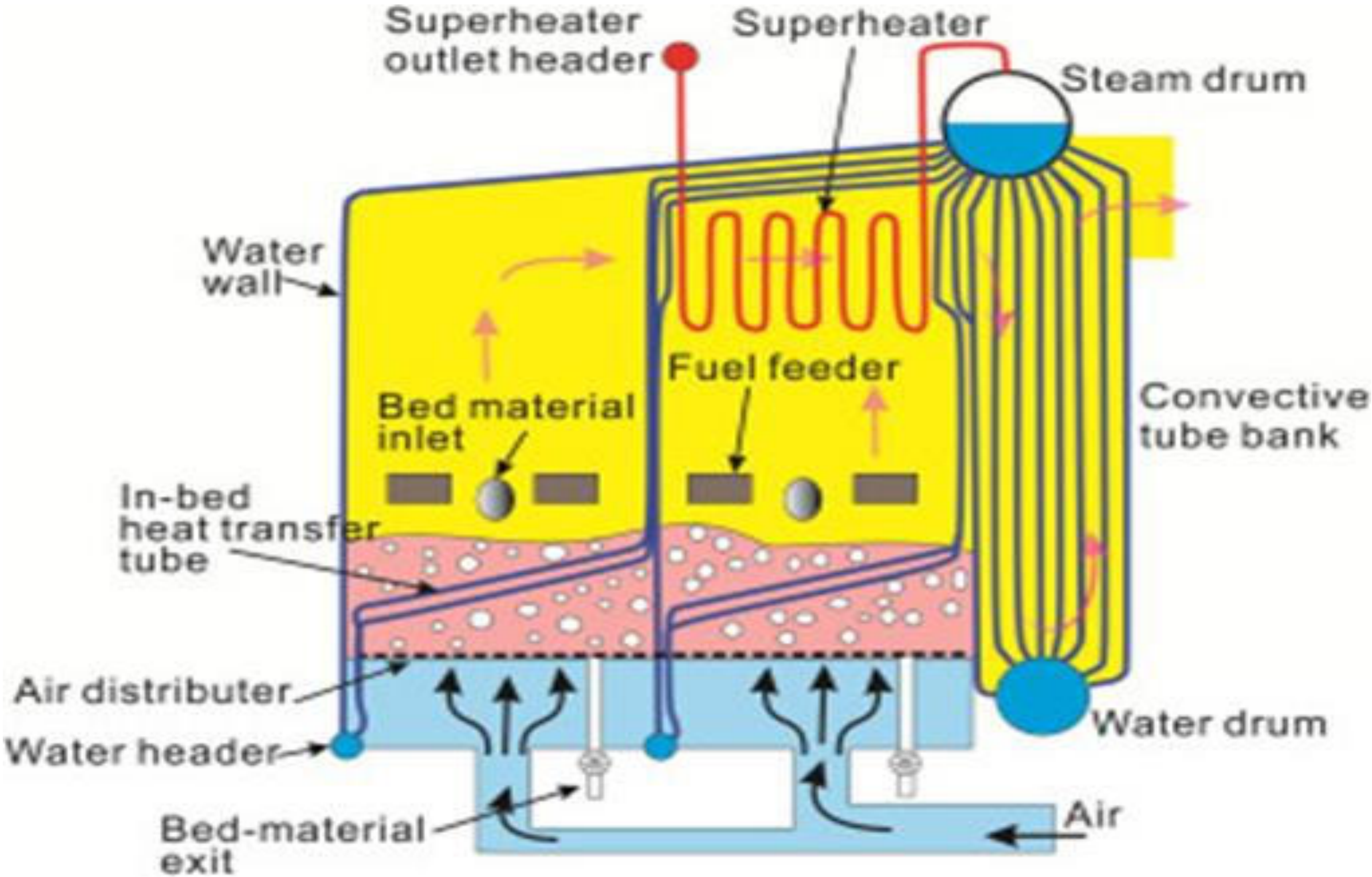
Various specialized devices act as heat exchangers to transfer energy from the waste stream to a working fluid:

Economizers: Common in boilers, these recover heat from flue gases to preheat incoming feed water, reducing the fuel required to reach boiling point.

Recuperators: Metallic or ceramic heat exchangers that use exhaust gas to preheat incoming combustion air.

Regenerators: Use a storage medium (like a rotating "heat wheel") to temporarily store heat from a hot gas stream before transferring it to a cold one.

Heat Recovery Steam Generators (HRSG): Large, complex units essential in **Combined Cycle Power Plants**. They capture gas turbine exhaust to create steam, which then drives a secondary steam turbine.



Fluidized bed water tube Boiler

Fluidized Bed Combustion (FBC) is a power plant engineering technology that suspends solid fuel in an upward-flowing stream of air, causing the fuel and bed material to behave like a boiling liquid. This state, known as **fluidization**, ensures high heat transfer rates and exceptional fuel-to-air mixing.

Working Principle

Fluidization: Pressurized air is passed through a bed of inert material (sand, ash, or limestone) supported by a distributor plate.

Suspension: As air velocity increases, particles become suspended. At higher velocities, bubbles form, creating a "bubbling" or "circulating" state where fuel burns rapidly at uniform temperatures.

Heat Transfer: Heat is extracted through waterwalls or tubes immersed directly in the hot bed, resulting in a compact boiler design compared to conventional pulverized coal (PC) units.

Primary Types of FBC Boilers

Bubbling Fluidized Bed (BFB): Operates at lower velocities (1.2–3.7 m/s) where particles remain mostly in the lower furnace. It is commonly used for smaller-scale industrial applications and biomass.

Circulating Fluidized Bed (CFB): Uses higher velocities (4–9 m/s) to entrain solids, which are then captured by a **cyclone separator** and recirculated back to the furnace. This type is standard for large-scale utility power plants due to its higher efficiency and capacity.

Pressurized Fluidized Bed (PFBC): Operates under high pressure (up to 16 kg/cm^2), allowing the hot exhaust to drive a **gas turbine** while steam drives a **steam turbine**. This combined cycle can reach significantly higher efficiencies.

Advantages in Power Generation

Fuel Flexibility: Capable of burning low-grade fuels like high-ash coal, biomass, washery rejects, and municipal waste without needing expensive pulverization.

Emission Control:

- **Low NOx:** Operating temperatures are kept between **800–900°C**, which is below the threshold for significant thermal NOx production.
- **In-situ Desulfurization:** Adding limestone to the bed captures up to 95% of SO_2 during combustion, eliminating the need for separate flue gas scrubbers.

Operational Efficiency: CFB boilers offer high combustion efficiency (up to 99.5%) and a wider turn-down ratio, allowing stable operation at 25–40% load.

Fuel and handling equipment in power plant engineering manages the entire lifecycle of fuel—from its arrival at the facility to its final combustion and disposal of by-products. Systems are primarily categorized by the type of fuel used: solid (coal), liquid (oil), or gas.

1. Solid Fuel (Coal) Handling Systems

Coal handling involves out-plant and in-plant operations to prepare raw coal for combustion.

Unloading Equipment: Used to receive coal from rail, road, or sea.

- **Wagon Tipplers & Track Hoppers:** Rapidly empty railway wagons.
- **Grab Buckets & Cranes:** Used for unloading ships or barges.

Preparation Equipment: Raw coal must be processed before use.

- **Crushers & Sizers:** Break large lumps into small, uniform pieces (e.g., <20mm).
- **Magnetic Separators:** Remove ferrous metal scrap to prevent damage to conveyors and burners.
- **Driers:** Use hot flue gases to remove moisture for better combustion.

Transfer & Conveying Equipment:

- **Belt Conveyors:** The most common method for long-distance transport within the plant.
- **Bucket Elevators:** Ideal for vertical lifting of coal to overhead bunkers.
- **Screw Conveyors:** Used for short-distance transfers in confined spaces.

Storage Equipment: Includes **Dead Storage** (long-term outdoor piles) and **Live Storage** (indoor bunkers or silos ready for feeding the boiler).

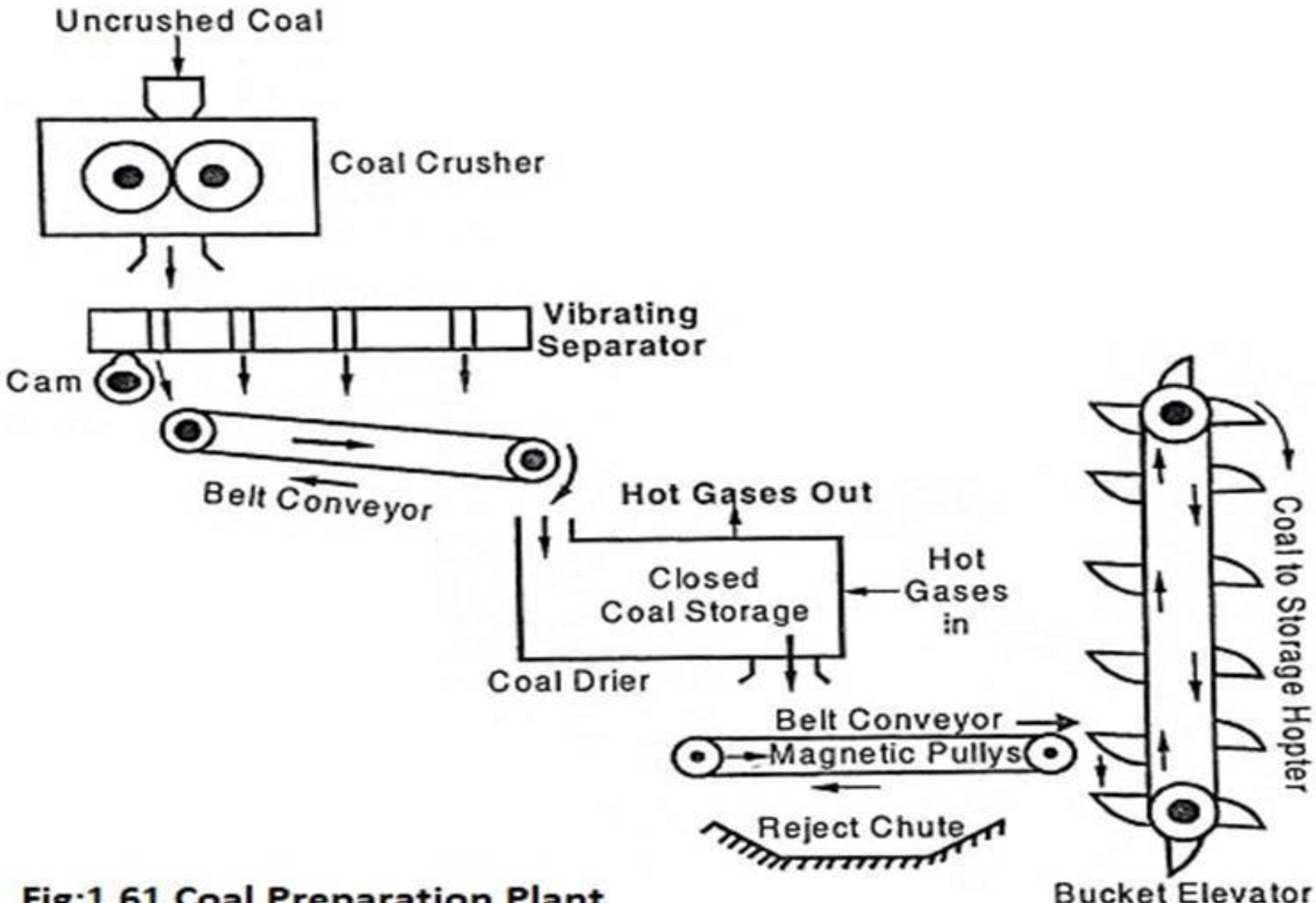


Fig:1.61 Coal Preparation Plant

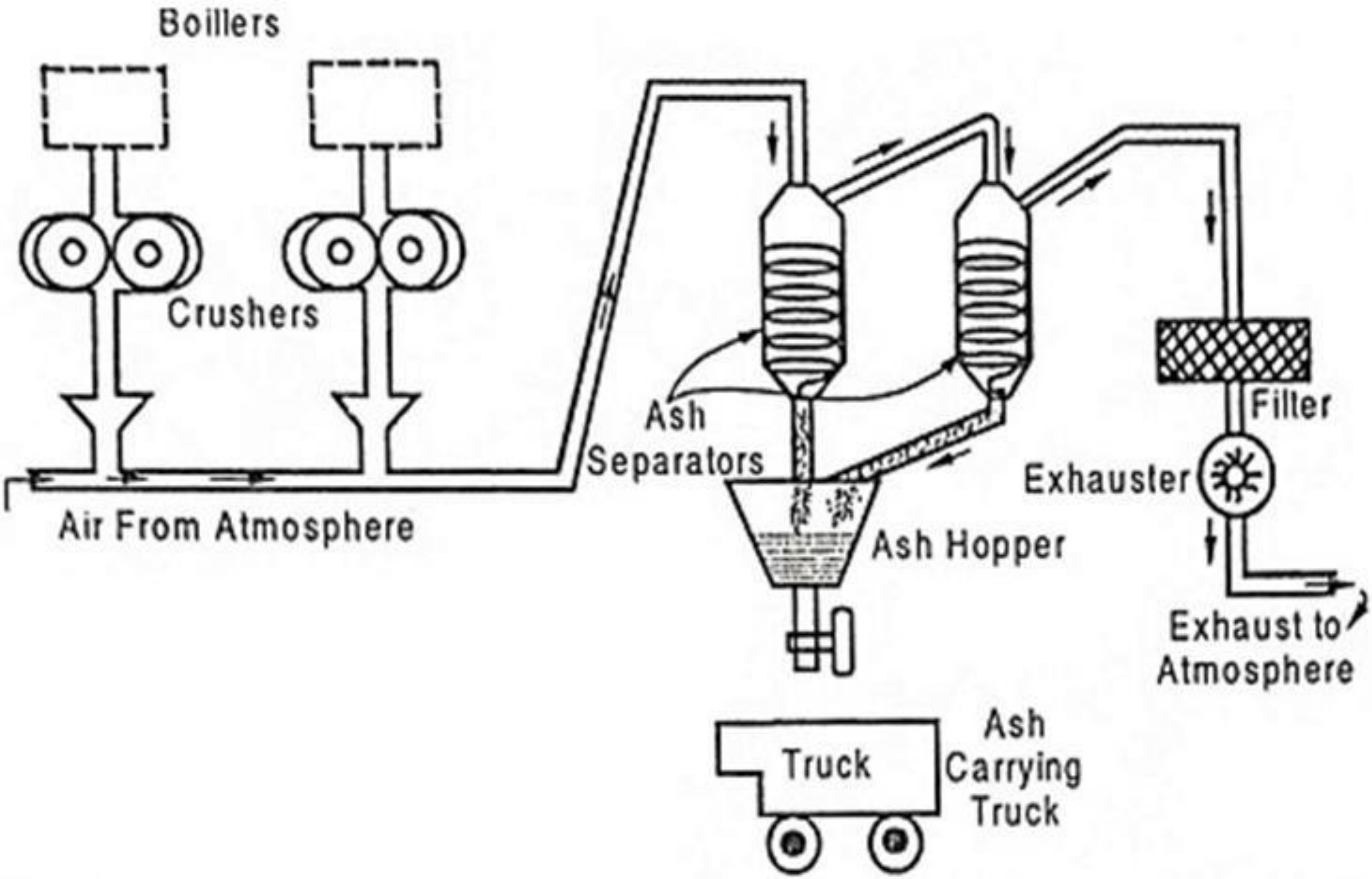
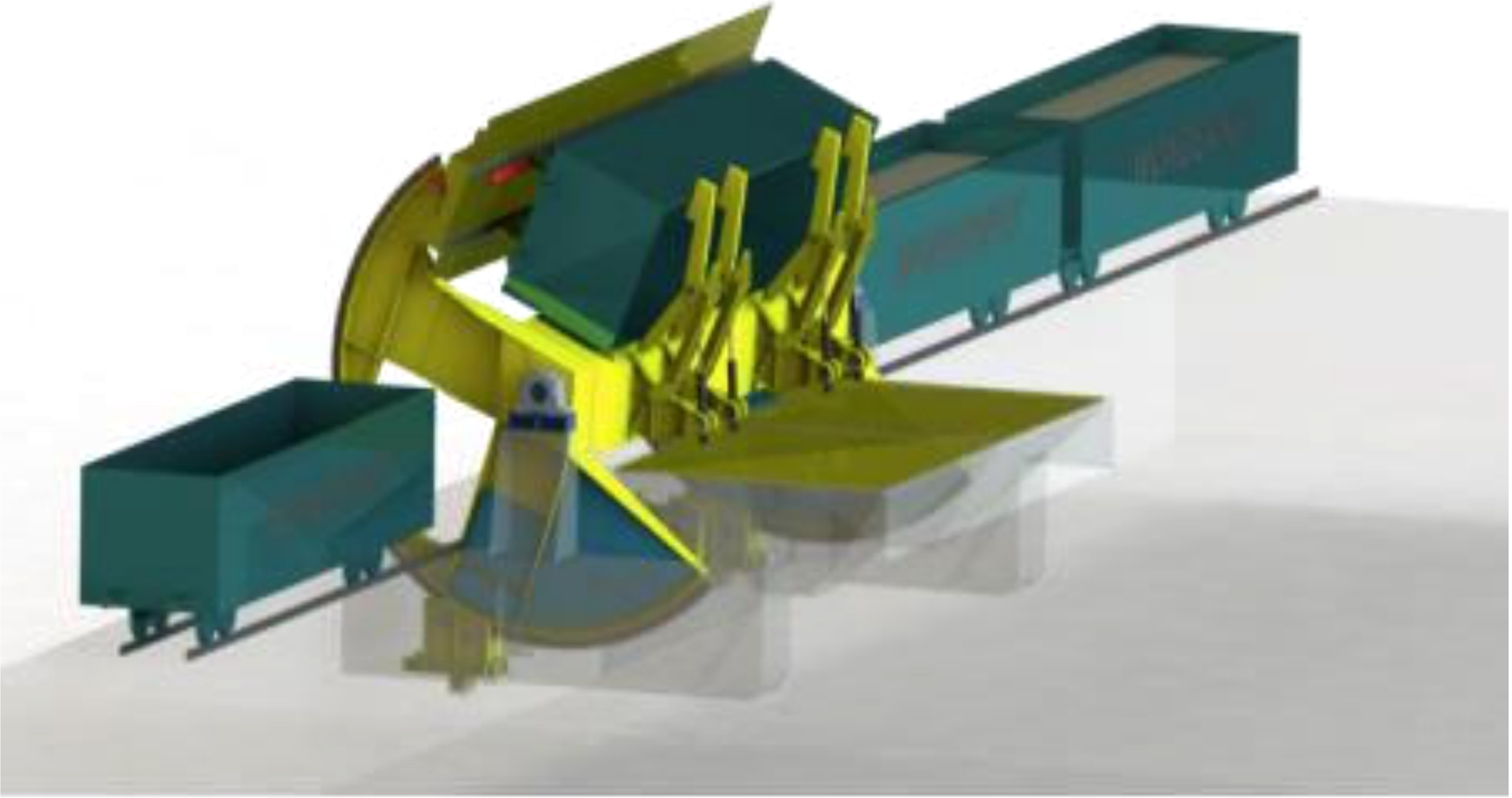
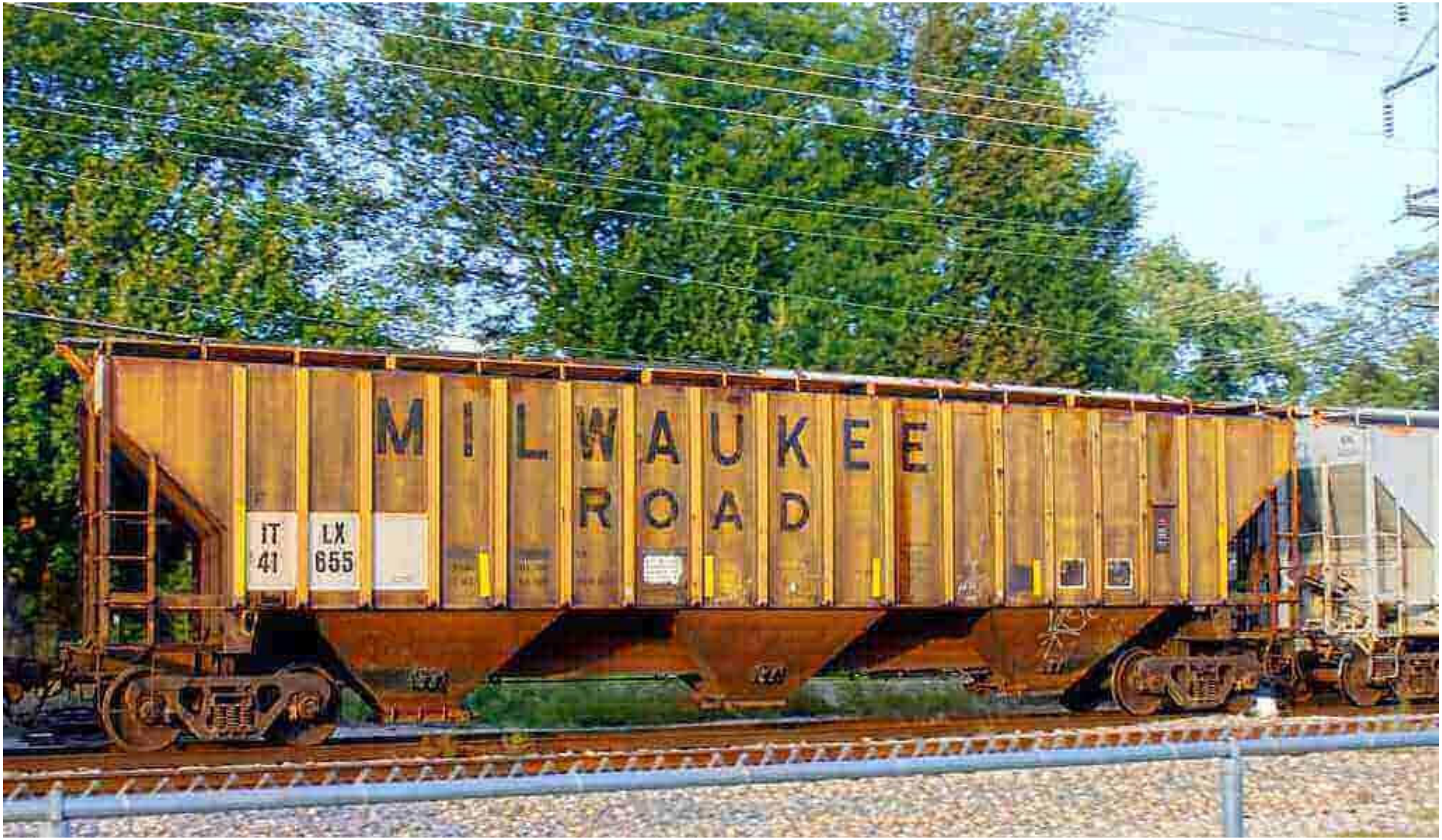


Fig:1.70 Pneumatic or Vacuum Extraction Ash Handling System.

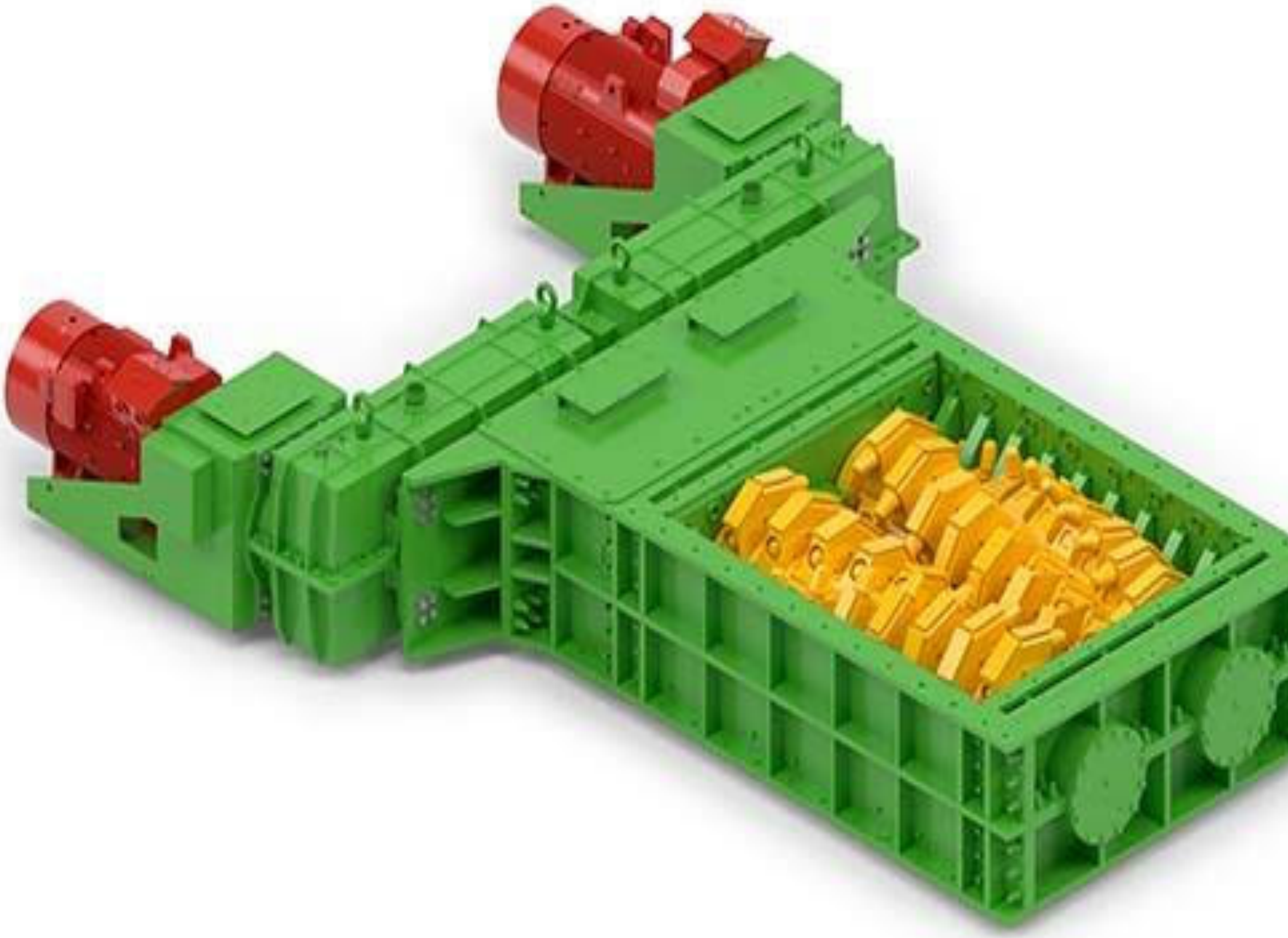


Wagon Tippler And Track Hoppers

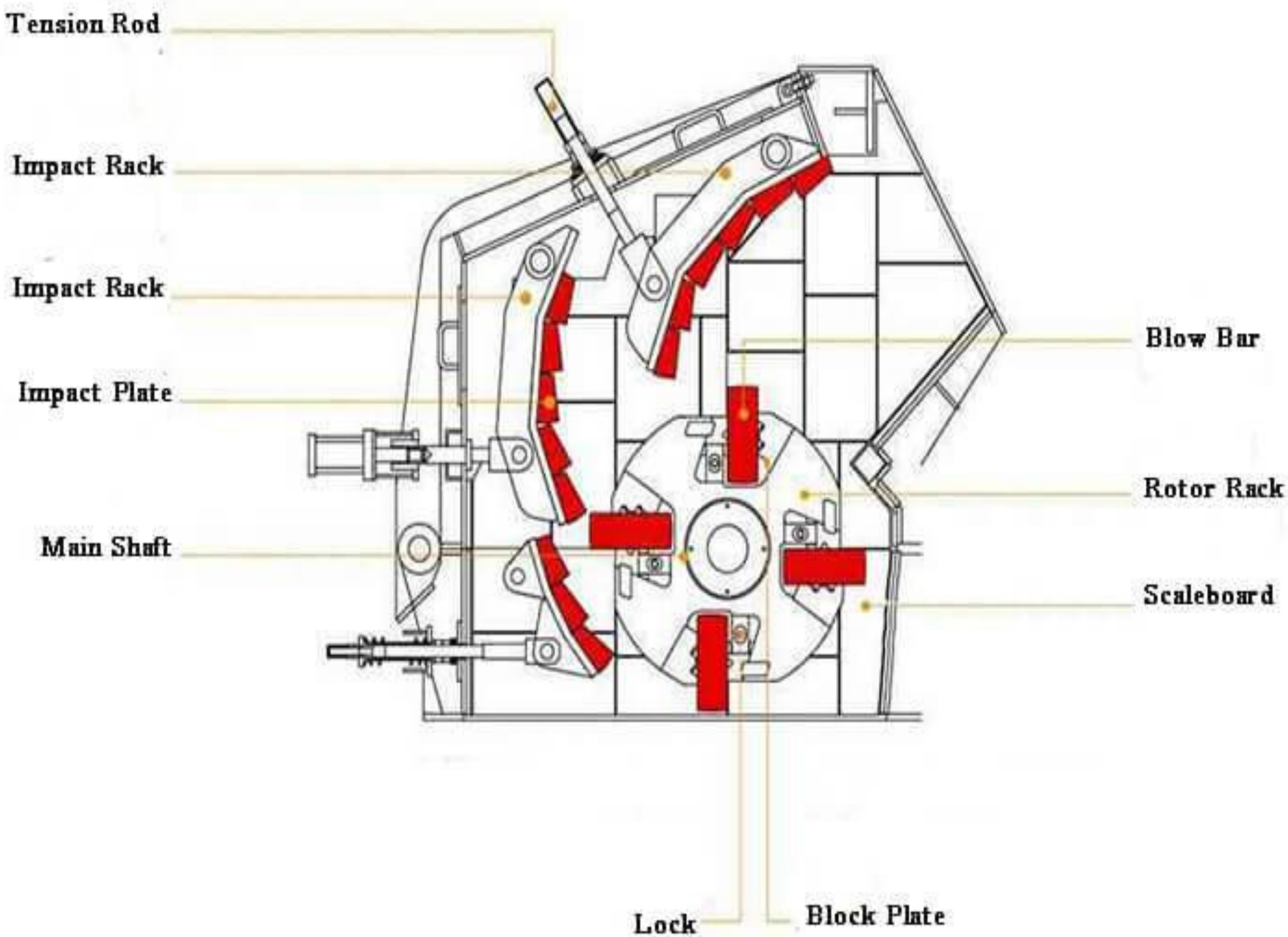


Hopper Car

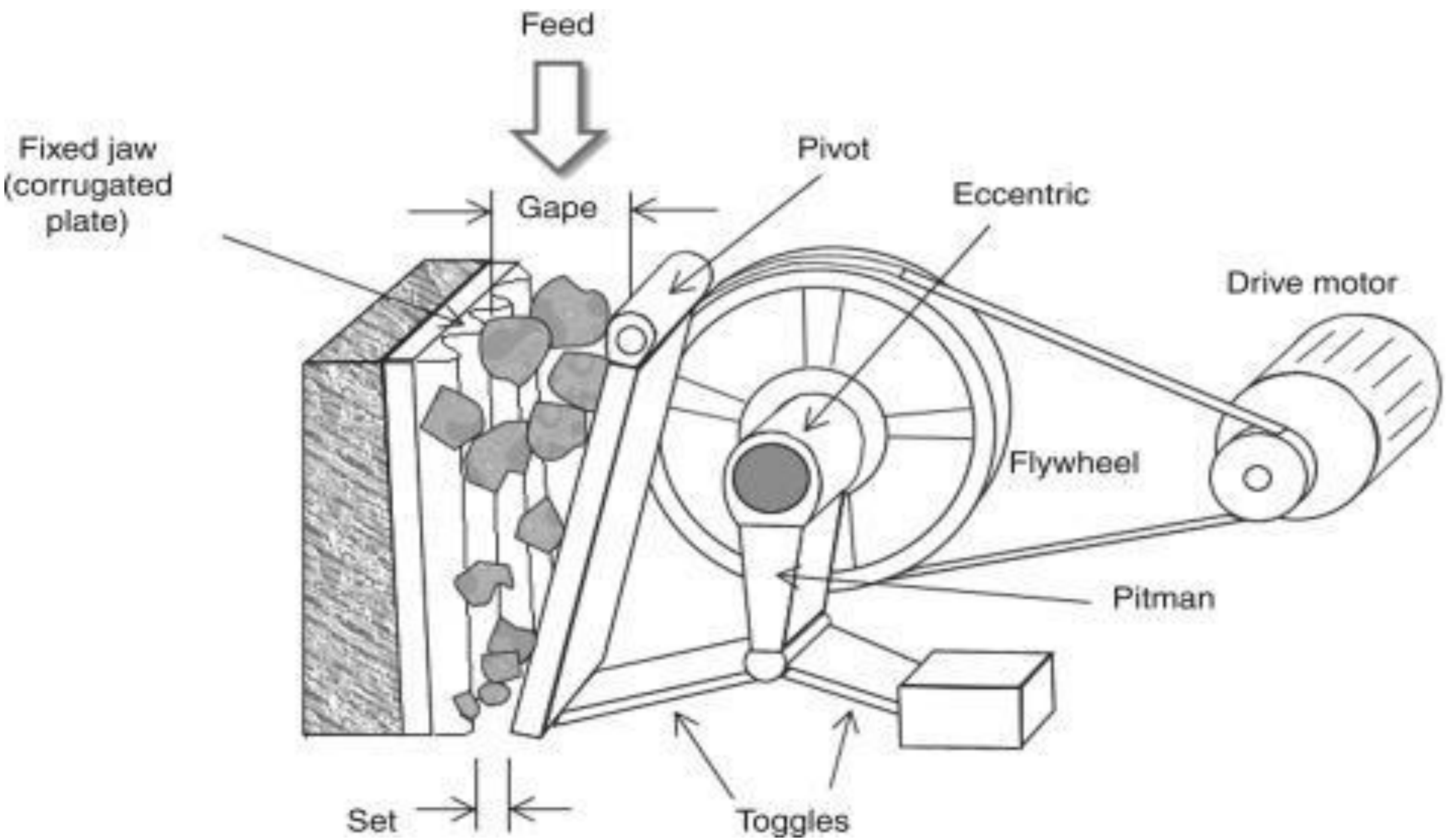
Grab Buckets & Cranes



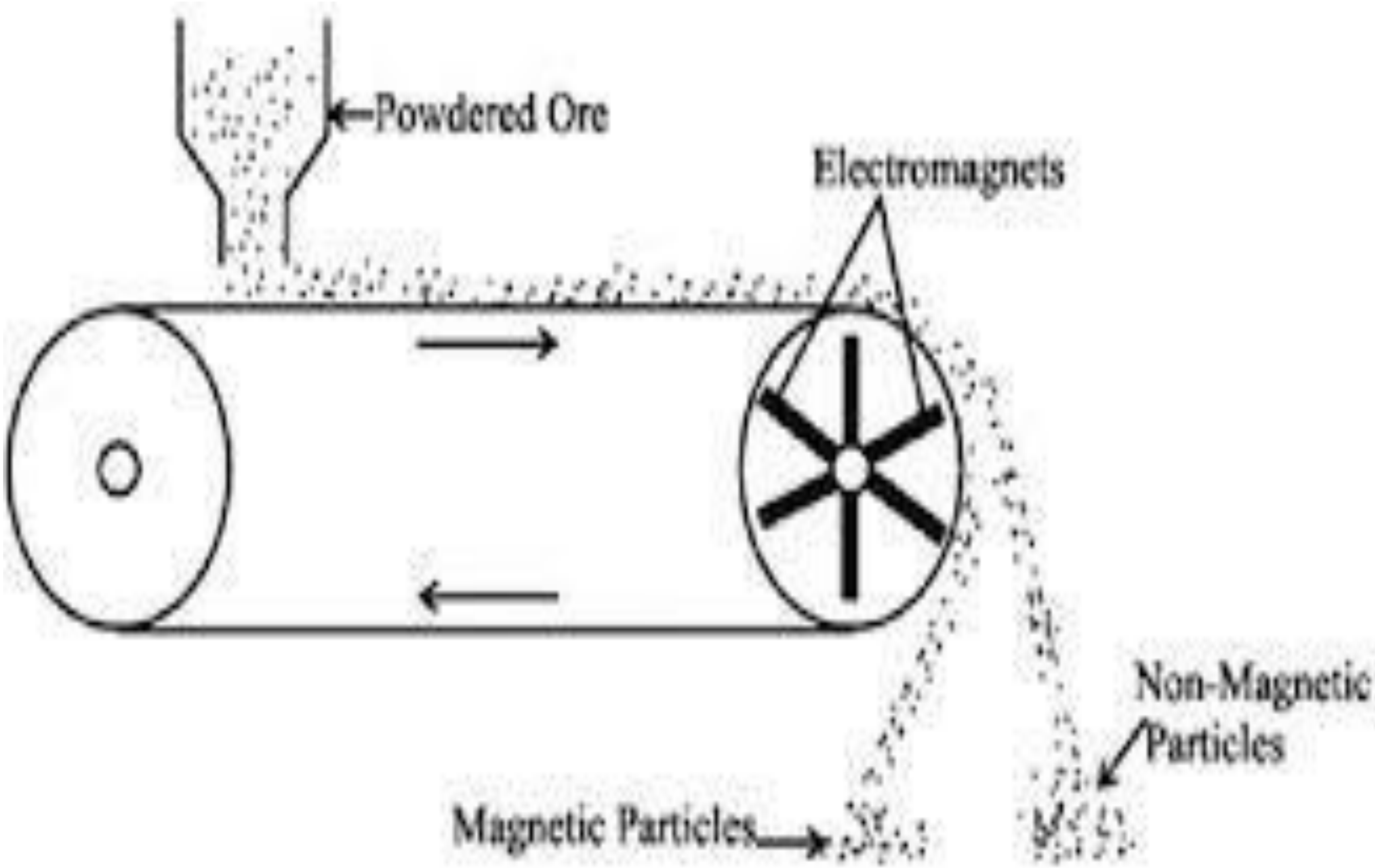
MINERAL SIZERS



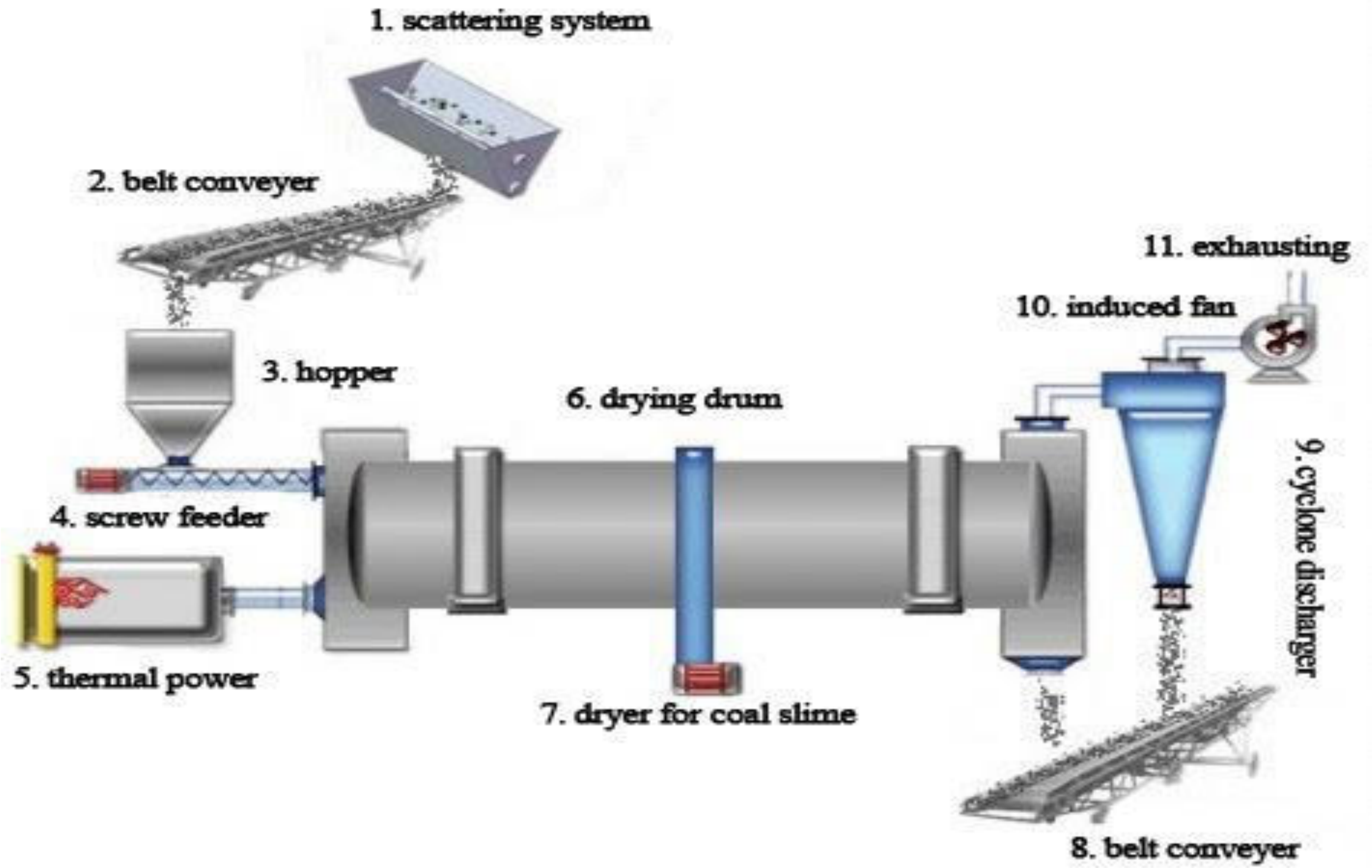
IMPACT CRUSHER


Feed
Fixed jaw
(corrugated
plate)
Gape
Pivot
Eccentric
Drive motor
Flywheel
Pitman
Set
Toggles

JAW CRUSHER



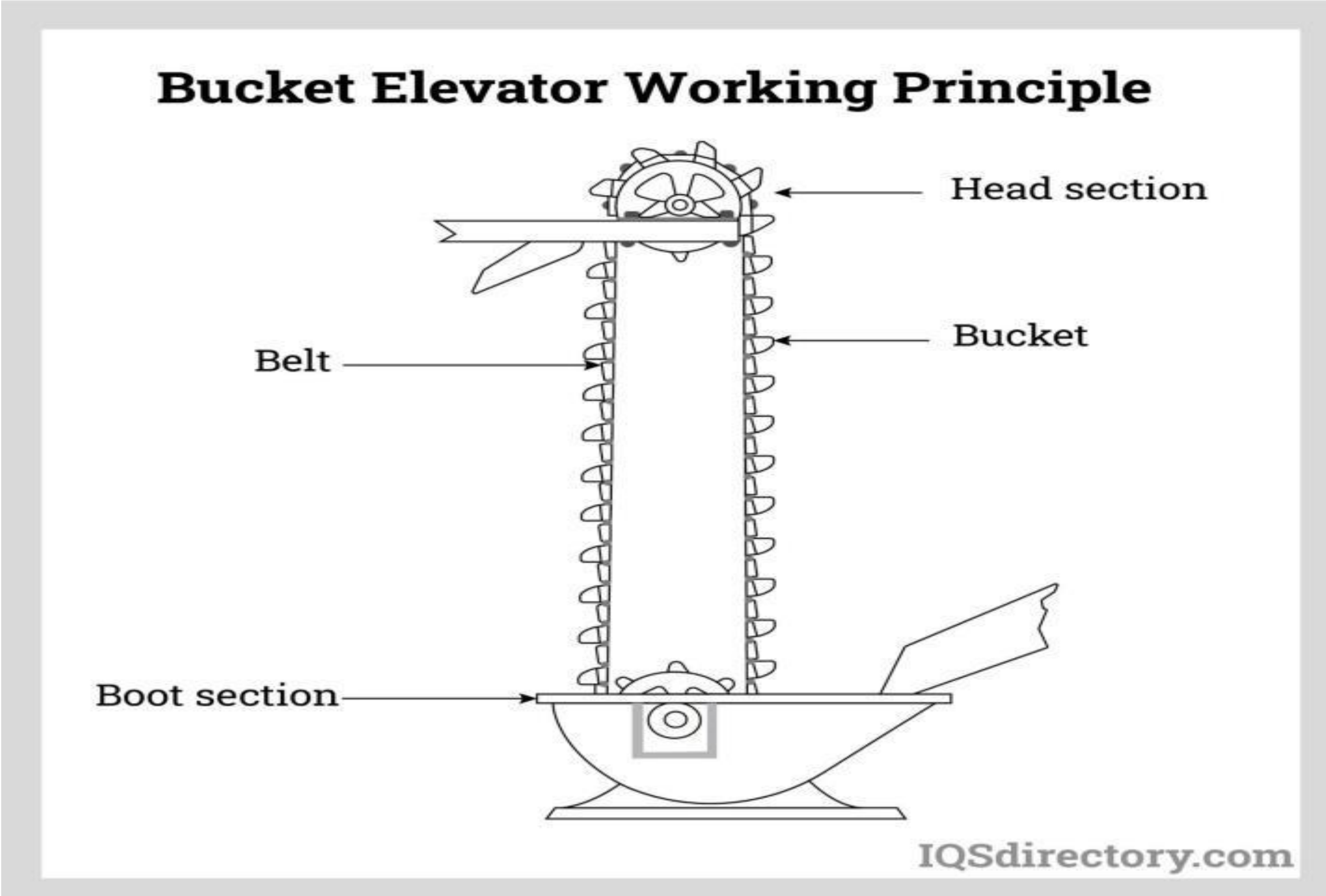
MAGNETIC SEPARATORS



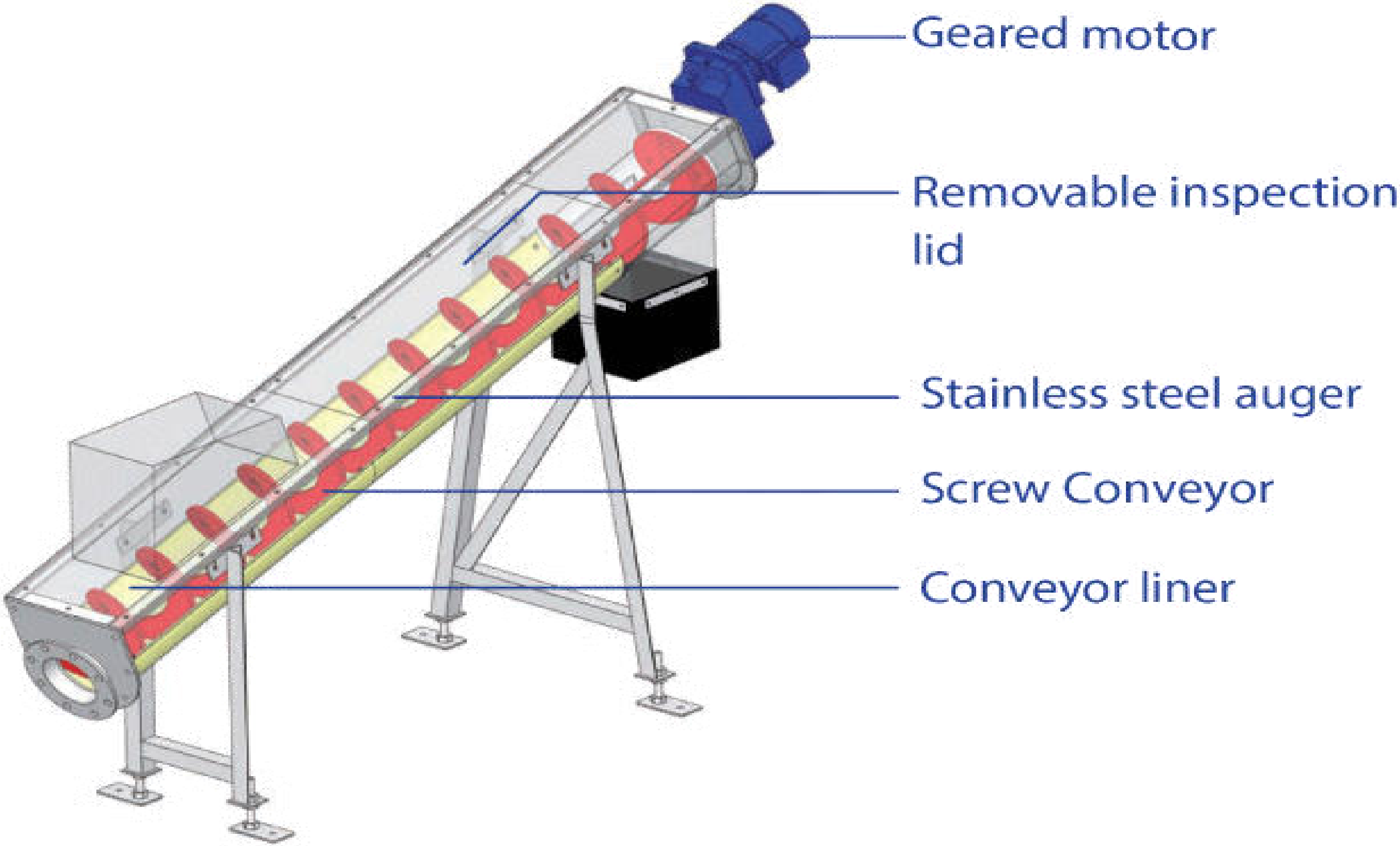
Best coal slime dryer machine

DIFFERENT TYPES OF BELT COVEYORS

DIFFERENT TYPES OF BELT COVEYORS



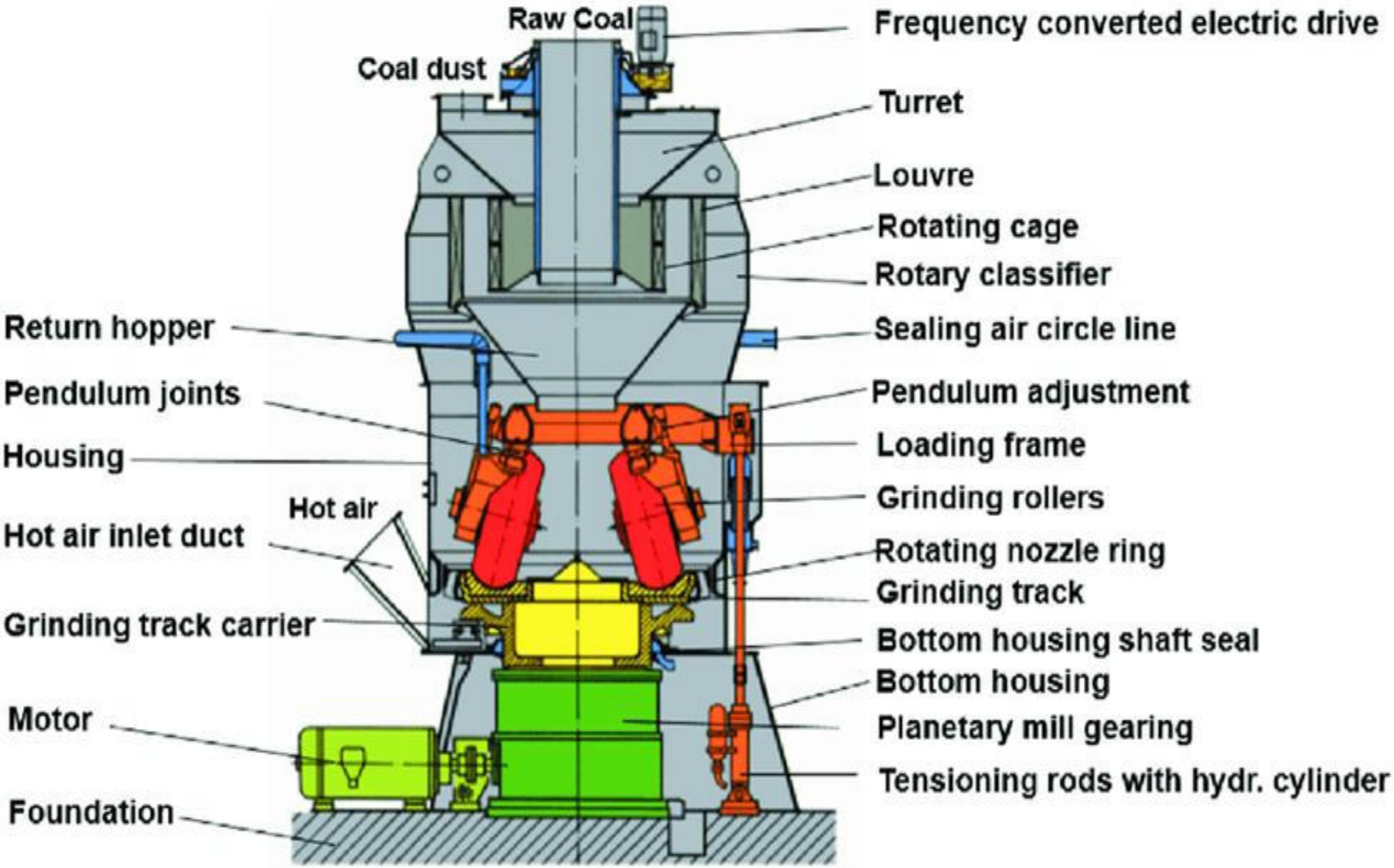
BUCKET ELEVATORS AND CONVEYORS



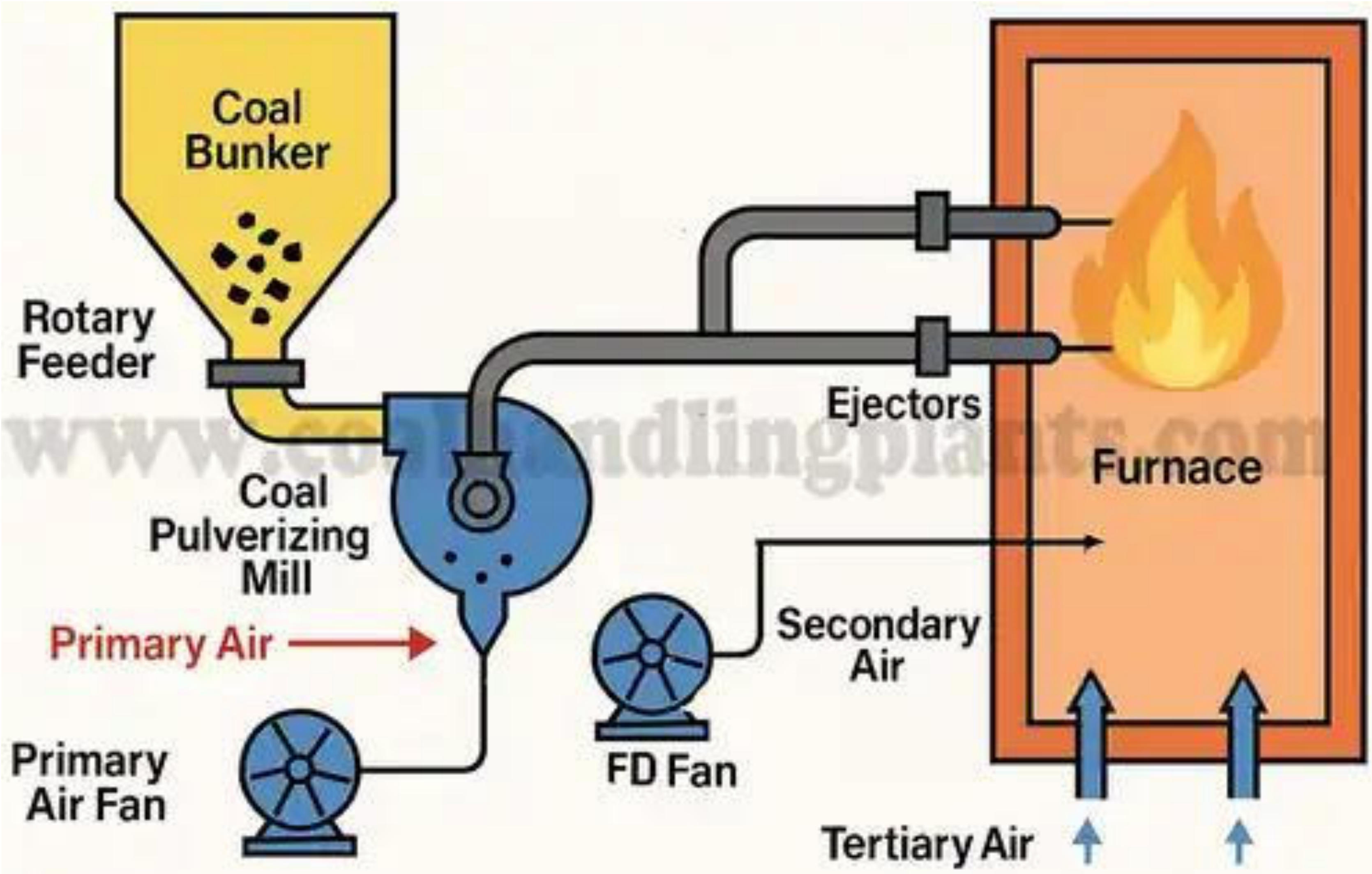
Sludge Screw Conveyor

Different Structure of Coal Storage Sheds in Power Plant

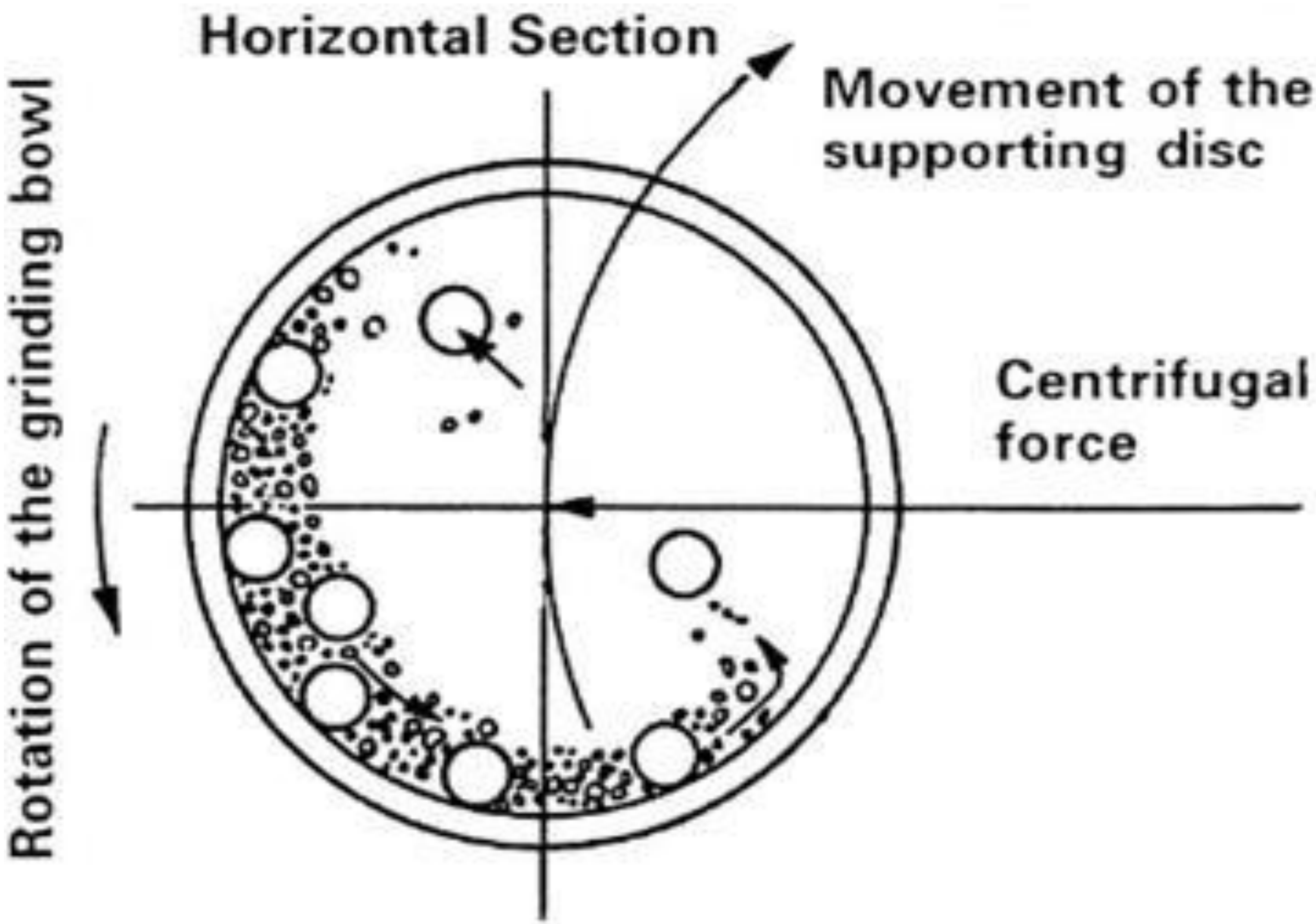
Bunker Storage Silos



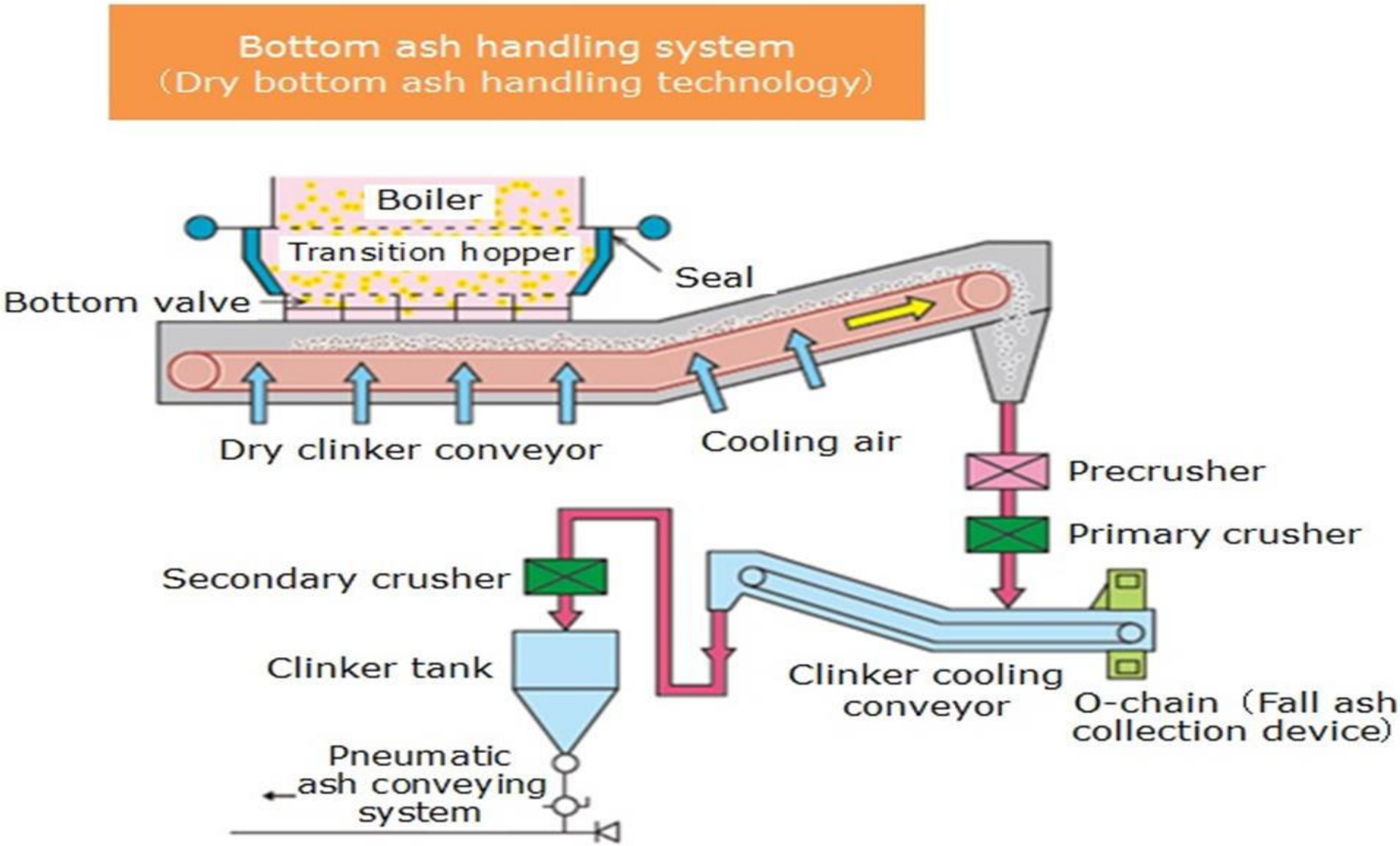
The layout of the coal mill with a rotary classifier



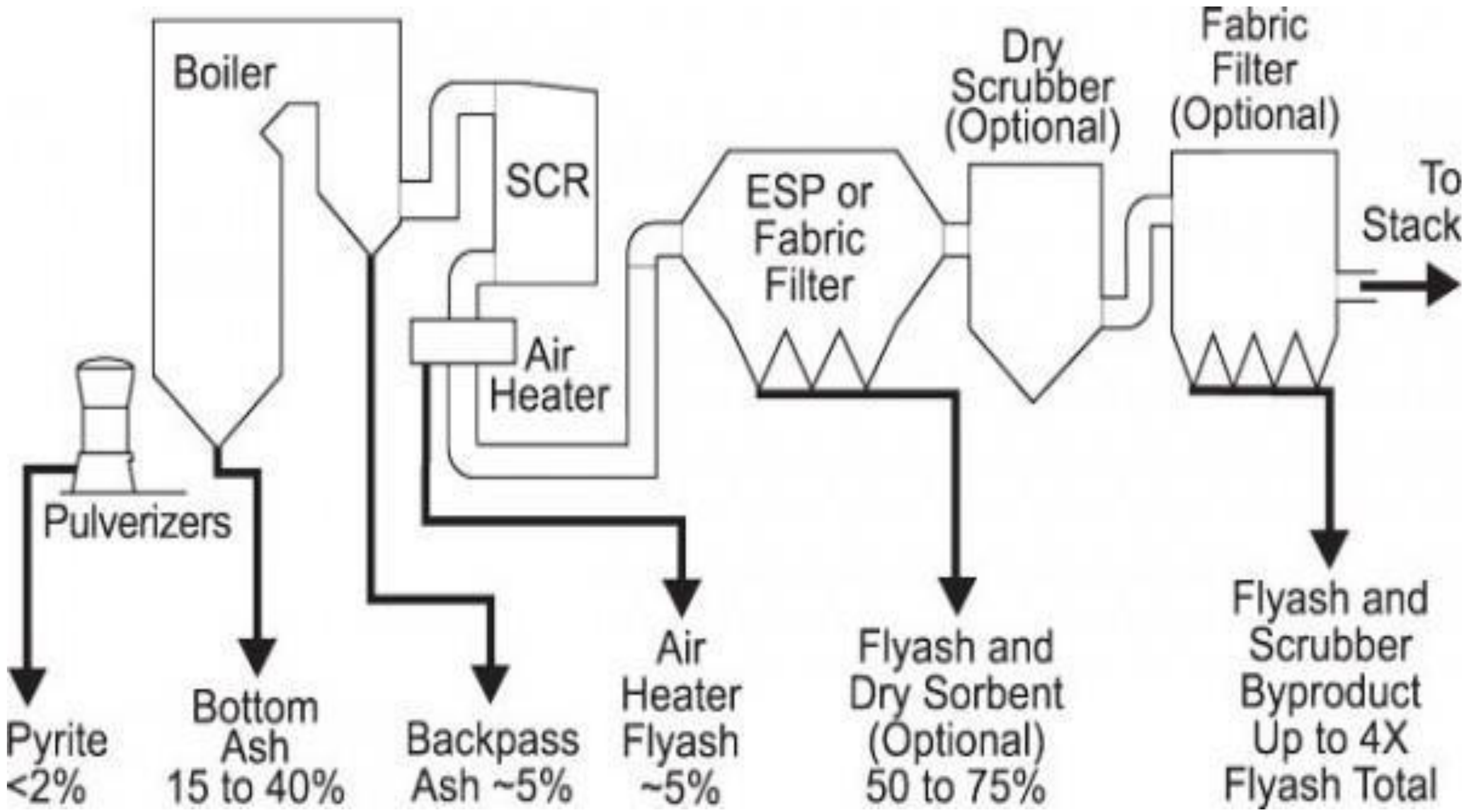
Pulverized Coal Firing System in Boiler



Principle of ball milling process



BOTTOM ASH HANDLING SYSTEM (Dry bottom ash handling Technology)


Boiler
SCR
Air Heater
ESP or Fabric Filter
Dry Scrubber (Optional)
Fabric Filter (Optional)
To Stack
Pulverizers
Pyrite <2%
Bottom Ash 15 to 40%
Backpass Ash ~5%
Air Heater Flyash ~5%
Flyash and Dry Sorbent (Optional) 50 to 75%
Flyash and Scrubber Byproduct Up to 4X Flyash Total

In a coal-fired boiler, the general categories of ash are:

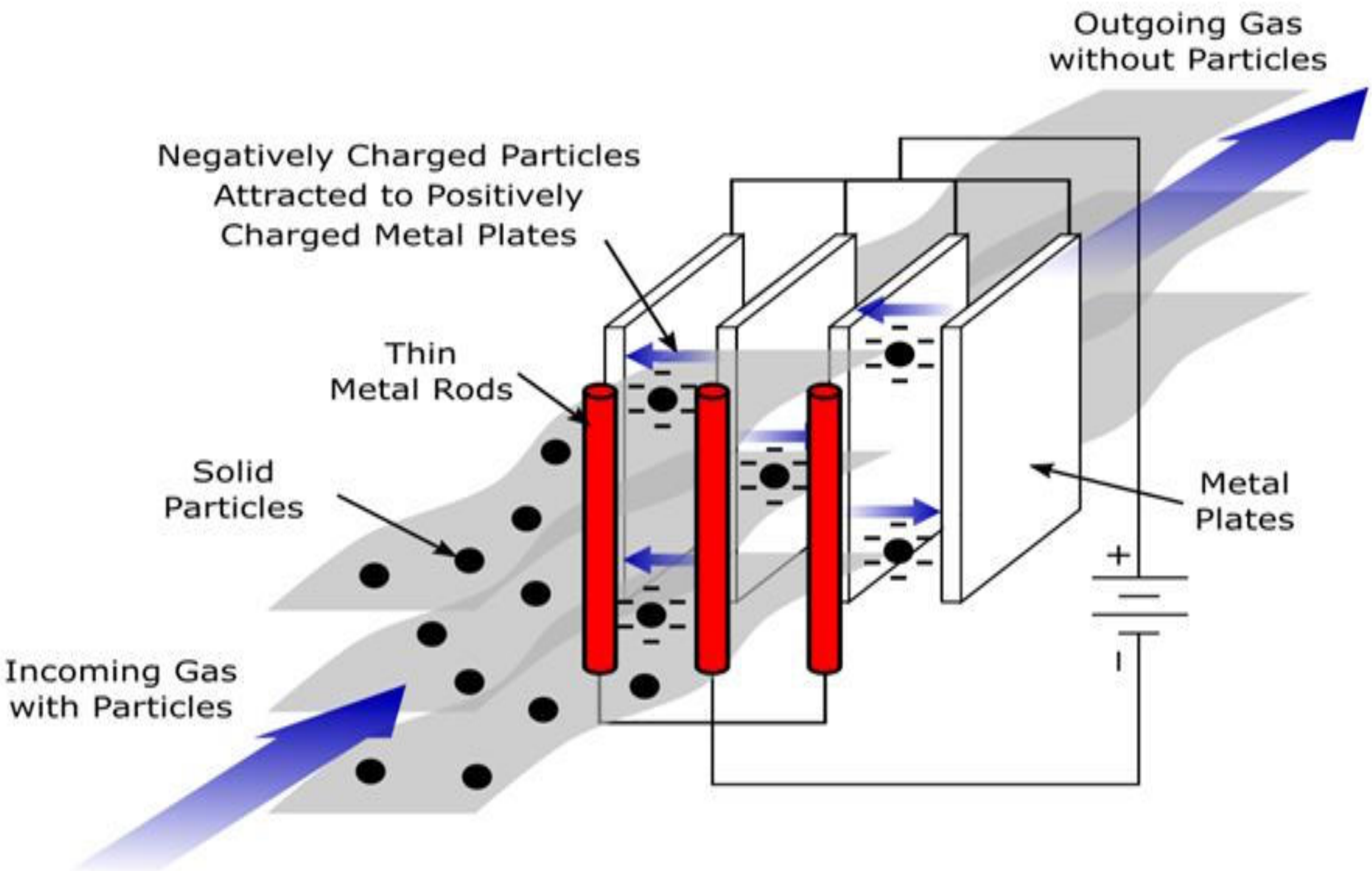
Bottom ash – the material that collects at the bottom of the furnace, possibly a heavy slag.

Mill rejects – the heavy pieces of stone, slate and iron pyrite that are discharged from the coal pulverizer.

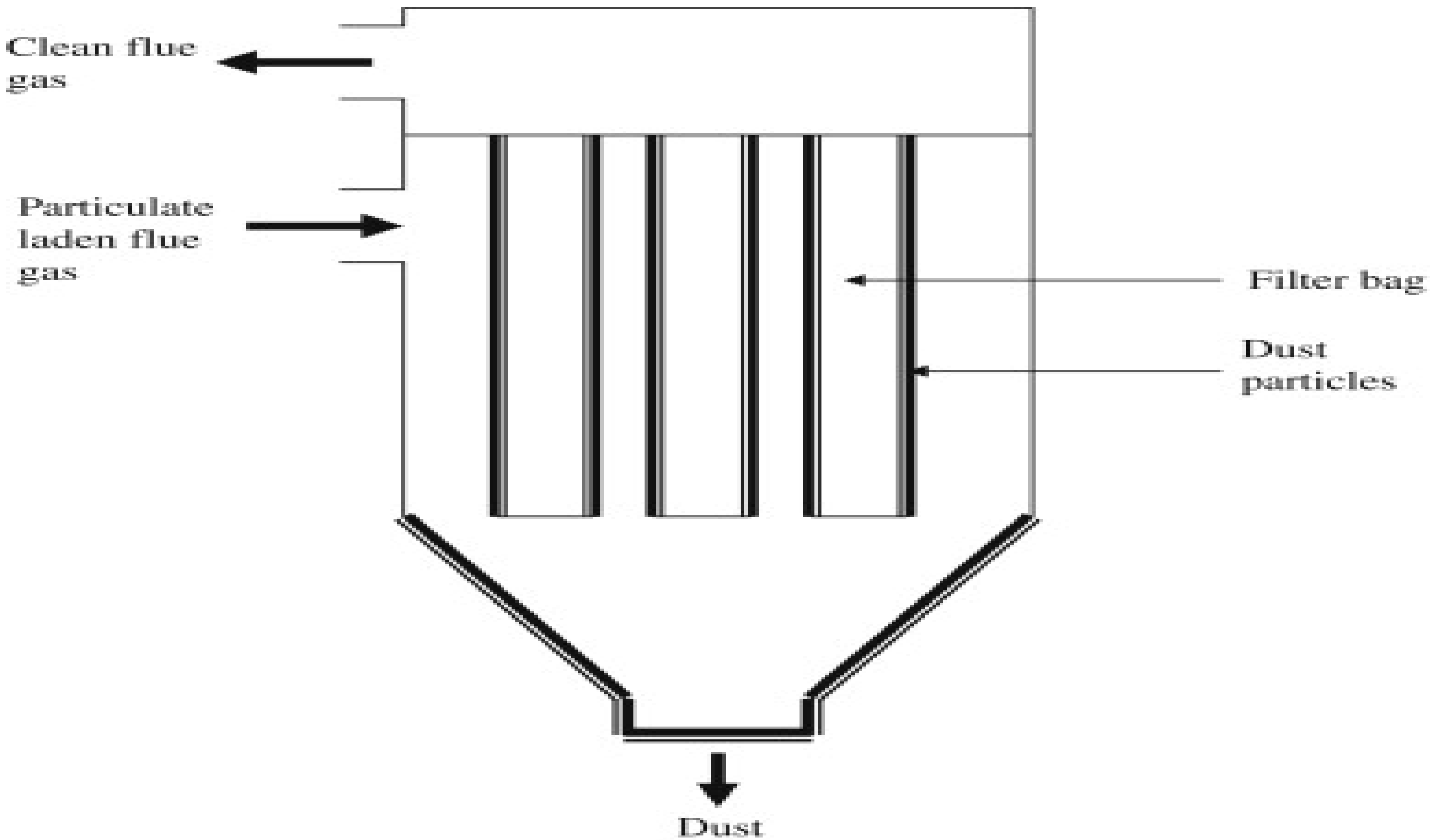
Economizer ash or popcorn ash – the coarse and comparatively dense particles that drop out of the flue gas when the gas changes direction abruptly, such as in the back pass and air heater ducts.

Fly ash – the fine ash particles that are collected in the particulate control equipment.

Scrubber byproduct – reacted lime discharged from desulfurization devices.



Electrostatic Precipitator (ESP)


Clean flue gas
Particulate laden flue gas
Filter bag
Dust particles
Dust

Bag Filter

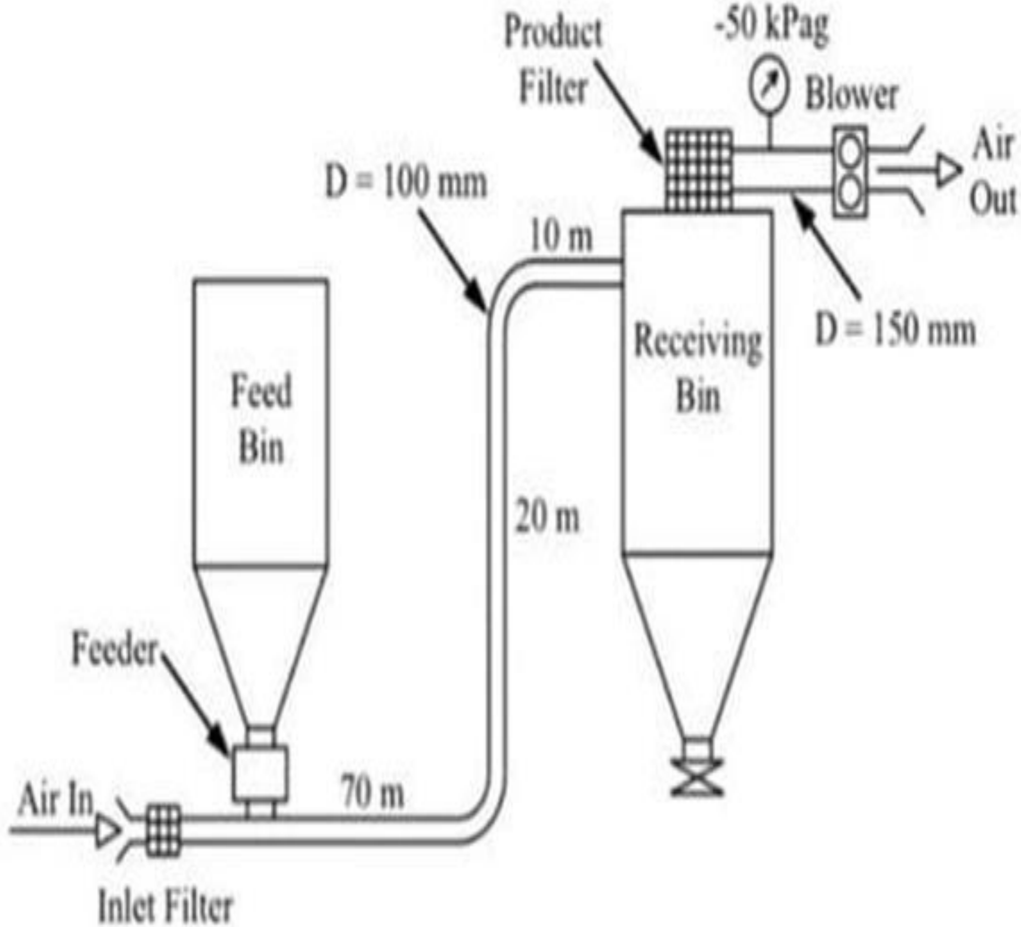
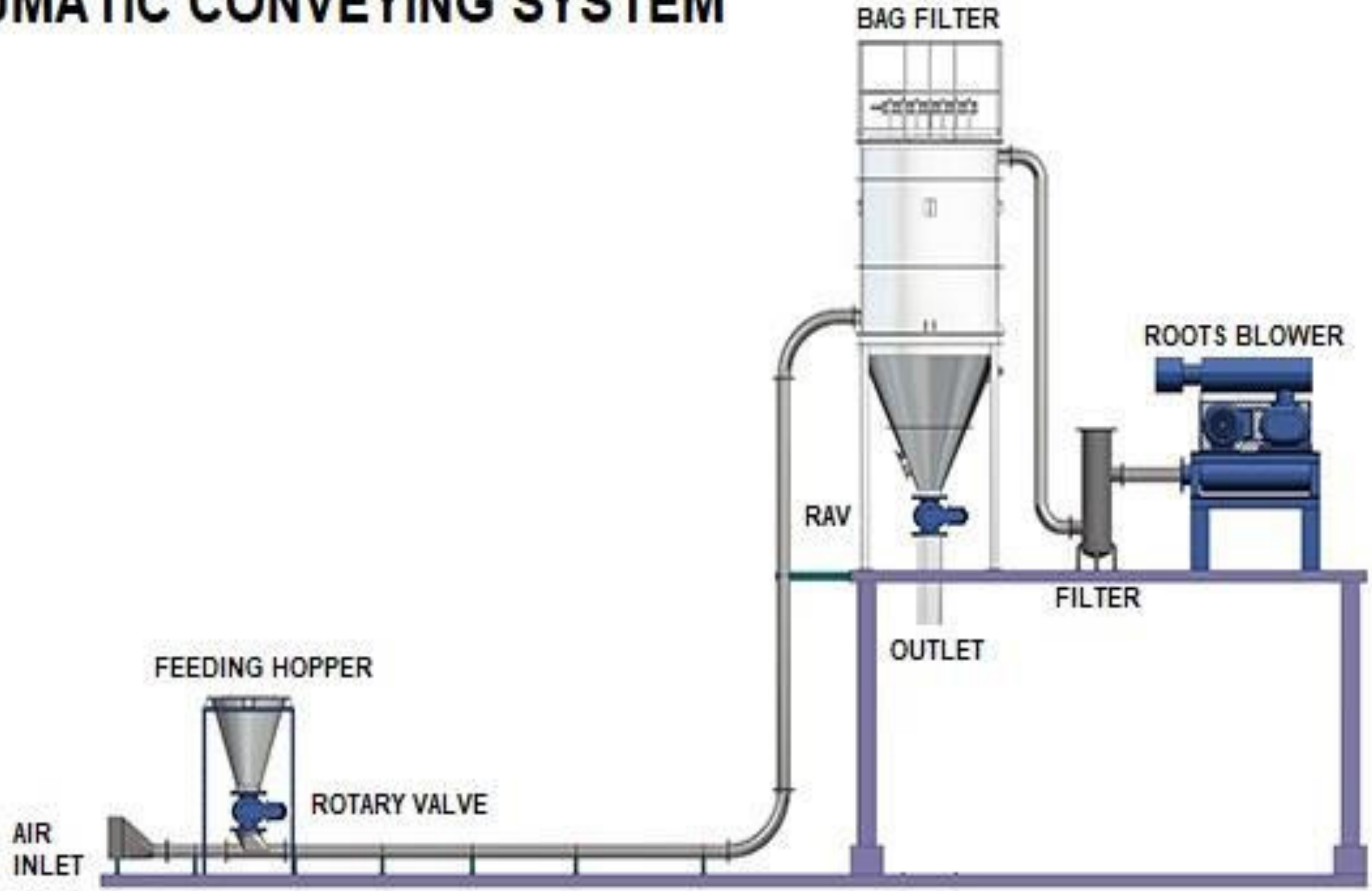


Figure 1: Vacuum Pneumatic Conveying System (not to scale)

PNEUMATIC CONVEYING SYSTEM



Thermal power plants primarily use **thermal coal** (also known as steam coal), which is specifically chosen for its ability to generate steam to drive turbines.

The specific types used are categorized by their **geological rank**, which determines their carbon content and energy density:

1. Bituminous Coal

Most Common: This is the most widely used coal for electricity generation globally.

Properties: It is a dense, black rock with 45% to 86% carbon.

Efficiency: It has a high heating value, making it highly cost-effective for large-scale power production.

Bituminous Coal

2. Sub-bituminous Coal

Cleaner Burning: Often preferred because it typically has lower sulfur content than other types, leading to fewer emissions.

Properties: It contains 35% to 45% carbon and has a lower heating value than bituminous coal.

3. Lignite (Brown Coal)

Lowest Grade: This is the youngest form of coal with the lowest carbon content (25%–35%) and high moisture.

Usage: Due to its low energy density and high transport costs, it is almost exclusively used in power plants located very close to the mines.

4. Anthracite

Highest Quality: Contains over 86% carbon and has the highest energy density.

Limited Power Use: While it burns the cleanest, it is rarely used in power plants because it is more expensive and valuable for high-heat industrial processes like steel manufacturing.