17BEEEOE04 RENEWABLE ENERGY RESOURCES
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OBJECTIVES:

- To gain the knowledge about environmental aspects of energy utilization.
- To understand the basic principles of wind energy conversion, solar cells, photovoltaic conversion.
- To understand the basic principles fuel cell, Geo thermal power plants.
- To gain the knowledge about hydro energy.

INTENDED OUTCOME:

- At the end of the course student understands about all types of energy sources and utilization.

UNIT I INTRODUCTION 9

Energy scenario - Different types of Renewable Energy Sources - Environmental aspects of energy utilization - Energy Conservation and Energy Efficiency - Needs and Advantages, Energy Conservation Act 2003.

UNIT II SOLAR ENERGY 9

Introduction to solar energy: solar radiation, availability, measurement and estimation– Solar thermal conversion devices and storage – solar cells and photovoltaic conversion – PV systems – MPPT. Applications of PV Systems – solar energy collectors and storage.

UNIT III WIND ENERGY 9

Introduction – Basic principles of wind energy conversion- components of wind energy conversion system - site selection consideration – basic–Types of wind machines. Schemes for electric generation – generator control, load control, energy storage – applications of wind energy – Inter connected systems.

UNIT IV HYDRO ENERGY 9

Hydropower, classification of hydro power, Turbine selection, Ocean energy resources, ocean energy routes. Principles of ocean thermal energy conversion systems, ocean thermal power plants. Principles of ocean wave energy conversion and tidal energy conversion.

UNIT V OTHER SOURCES 9

Bio energy and types –Fuel cell, Geo-thermal power plants; Magneto-hydro-dynamic (MHD) energy conversion.

Total Hours: 45

TEXTBOOKS:

S. NO.	Author(s) Name	Title of the Book	Publisher	Year of Publication
1	Rai.G.D	Non-conventional sources of energy	Khanna publishers	2011
2	Khan.B.H	Non-Conventional Energy Resources Second edition	The McGraw Hills,	2009

REFERENCES:

S. NO.	Author(s) Name	Title of the Book	Publisher	Year of Publication
1	Rao.S. & Parulekar.	Energy Technology.	Khanna publishers, Eleventh Reprint.	2013
2	Godfrey Boyl.	Renewable Energy: Power sustainable future Third edition.	Oxford University Press.	2012
3	John W Twidell and Anthony D Weir.	Renewable Energy Resources – 3rd edition.	Taylor and Francis.	2015

WEBSITES:

1. www.energycentral.com
2. www.catelelectricpowerinfo.com

Syllabus

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Syllabus continued….

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Reference Books

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4. Godfrey Boyl Renewable Energy: Power sustainable future Oxford University Press, Third edition 2012.
5. John W Twidell and Anthony D Weir Renewable Energy Resources Taylor and Francis – 3rd edition 2015.

Additional Books

1. **D P Kothari, K C Singh & Rakesh Ranjan, "*Renewable Energy Sources and Emerging Technologies*", Prentice Hall of India Private ltd, new Delhi, 2008.**

2. **Tasneem Abbasi and S A Abbasi, " Renewable Energy Sources"' PHI Learning Private Limited, New Delhi, 2011.**

3. **S.P. Sukhatme, *Solar Energy*, Tata McGraw Hill Publishing Company Ltd., New Delhi, 1997.**

4. **G.N. Tiwari, *Solar Energy* – Fundamentals Design, Modelling and applications, Narosa Publishing House, New Delhi, 2002.**

UNIT 1

INTRODUCTION

Energy scenario - Different types of Renewable Energy Sources - Environmental aspects of energy utilization - Energy Conservation and Energy Efficiency - Needs and Advantages, Energy Conservation Act 2003.

Energy

- Any physical activity in this world is caused due to flow of *energy* in one form or other.

- Energy is required to do any kind of work.

- The capability to do work depends on the amount of energy one can control and utilize.

- Energy is the most basic infrastructure input for economic growth and development of any country.

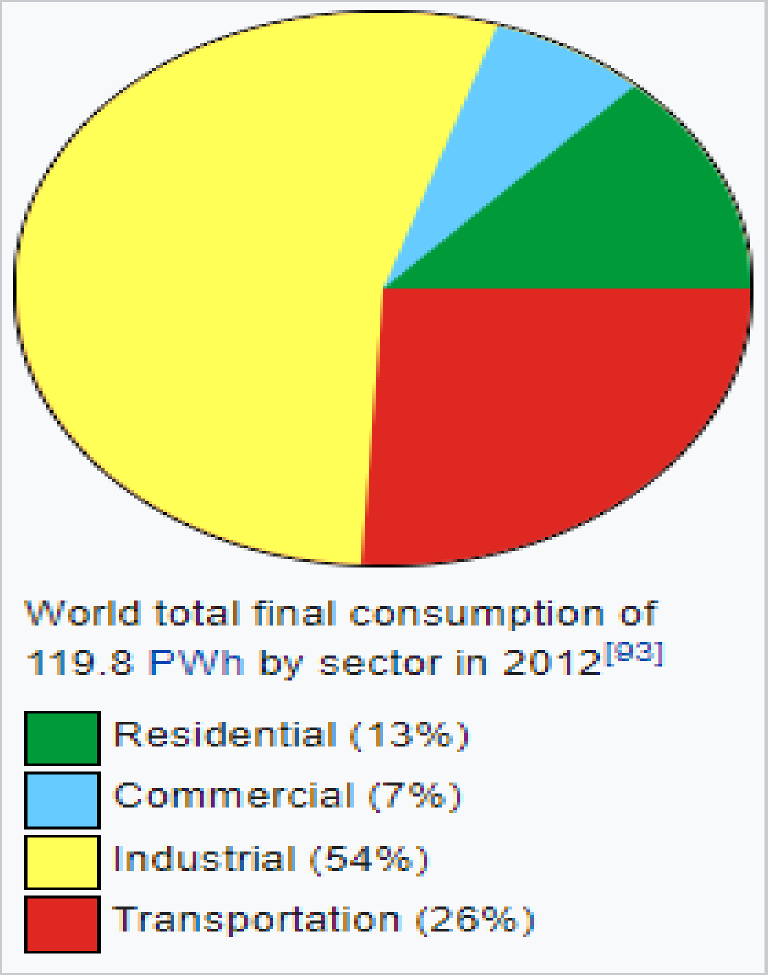
Common Forms of Energy

1. Mechanical Energy
2. Electrical Energy
3. Thermal energy
4. Chemical Energy
5. Nuclear Energy
6. Hydro Energy

Energy consumption and standard of living

Energy consumption of a nation can be broadly divided into the following area or sectors:

- **Domestic sector**
- **Agricultural sector**
- **Transportation sector**
- **Industrial sector**



World total final consumption of 119.8 PWh by sector in 2012[93]

Energy consumption and standard of living continued…..

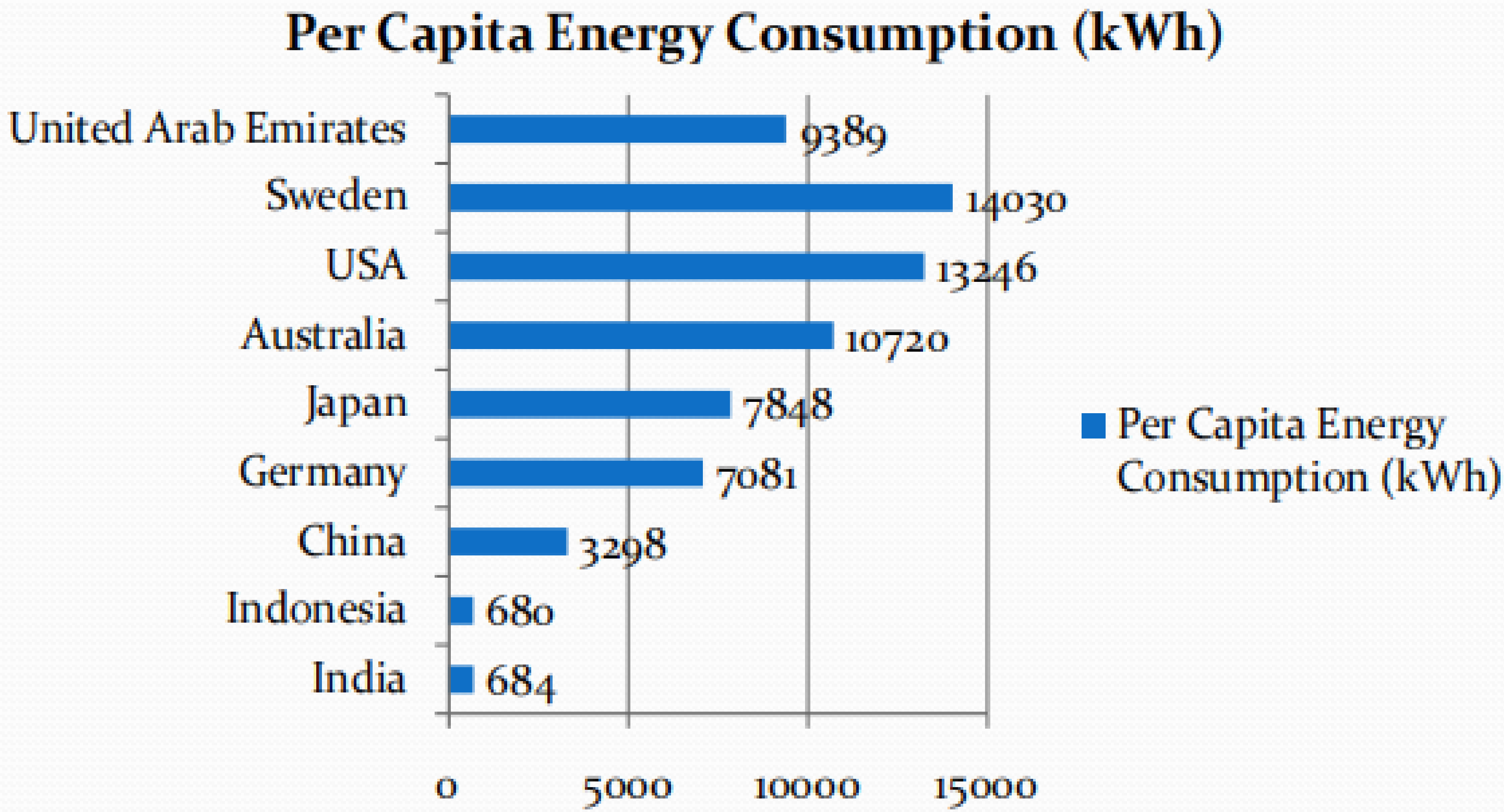
- Consumption of a large amount of energy in a country indicates increased activities in these sectors.

- This may imply better comforts at home due to use of various appliances, better transport facilities and more agricultural and industrial production. All these amount to a better quality of life.

- Therefore, the *per capita energy consumption* of a country is an index of the standard of living or prosperity of the country.

- USA, having around 5 % of world population, consumes around 25% of the total world energy.

- India, which houses around 18 % of the world's population, consumes around 4 % of the total world energy.For instance, an average American consumes more than 15 times the energy consumed by an average Indian



Source: http://data.worldbank.org/indicator/EG.USE.ELEC.KH.PC

World Energy Supply & Energy Consumption

Year	Primary energy supply (TPES)[1]	Final energy consumption[1]	Electricity generation
1973	71,013 (Mtoe 6,106)	54,335 (Mtoe 4,672)	6,129
1990	102,569	—	11,821
2000	117,687	—	15,395
2010	147,899 (Mtoe 12,717)	100,914 (Mtoe 8,677)	21,431
2011	152,504 (Mtoe 13,113)	103,716 (Mtoe 8,918)	22,126
2012	155,505 (Mtoe 13,371)	104,426 (Mtoe 8,979)	22,668
2013	157,482 (Mtoe 13,541)	108,171 (Mtoe 9,301)	23,322
2014	155,481 (Mtoe 13,369)	109,613 (Mtoe 9,425)	23,816
2015	158,715 (Mtoe 13,647)	109,136 (Mtoe 9,384)	
2017	162,494 (Mtoe 13,972)	113,009 (Mtoe 9,717)	25,606

[1] converted from Mtoe into TWh (1 Mtoe = 11.63 TWh) and from Quad BTU into TWh (1 Quad BTU = 293.07 TWh)

- From 2000–2012 coal was the source of energy with the total largest growth. The use of oil and natural gas also had considerable growth, followed by hydropower and renewable energy. Renewable energy grew at a rate faster than any other time in history during this period.

- More recently, consumption of coal has declined relative to renewable energy. Coal dropped from about 29% of the global total primary energy consumption in 2015 to 27% in 2017, and non-hydro renewables were up to about 4% from 2%.

Major Classification of Energy Resources

1. Based on usability of energy:

(a) Primary resources

ex: Coal, crude oil, uranium, solar, wind etc

(b) Secondary resources

ex: Electricity, steam etc

2. Based on traditional use:

(a) Conventional resources

ex: Fossil fuels, nuclear, hydro resources etc

(a) Non-conventional resources

ex: Solar, wind, biomass, ocean etc

Major Classification of Energy Sources continued….

3. Based on long term availability:

(a) Renewable resources

Resources, which are renewed by nature again and again and their supply is not affected by the rate of their consumption, are called renewable resources. Examples are solar, wind, biomass, ocean (thermal, tidal and wave), geothermal, hydro etc

(b) Non-renewable resources

Resources, which are finite and do not get renewed after their consumption, are called non-renewable resources. Examples are fossil fuels (coal, oil, and natural gas), uranium etc

Major Classification of Energy Sources continued….

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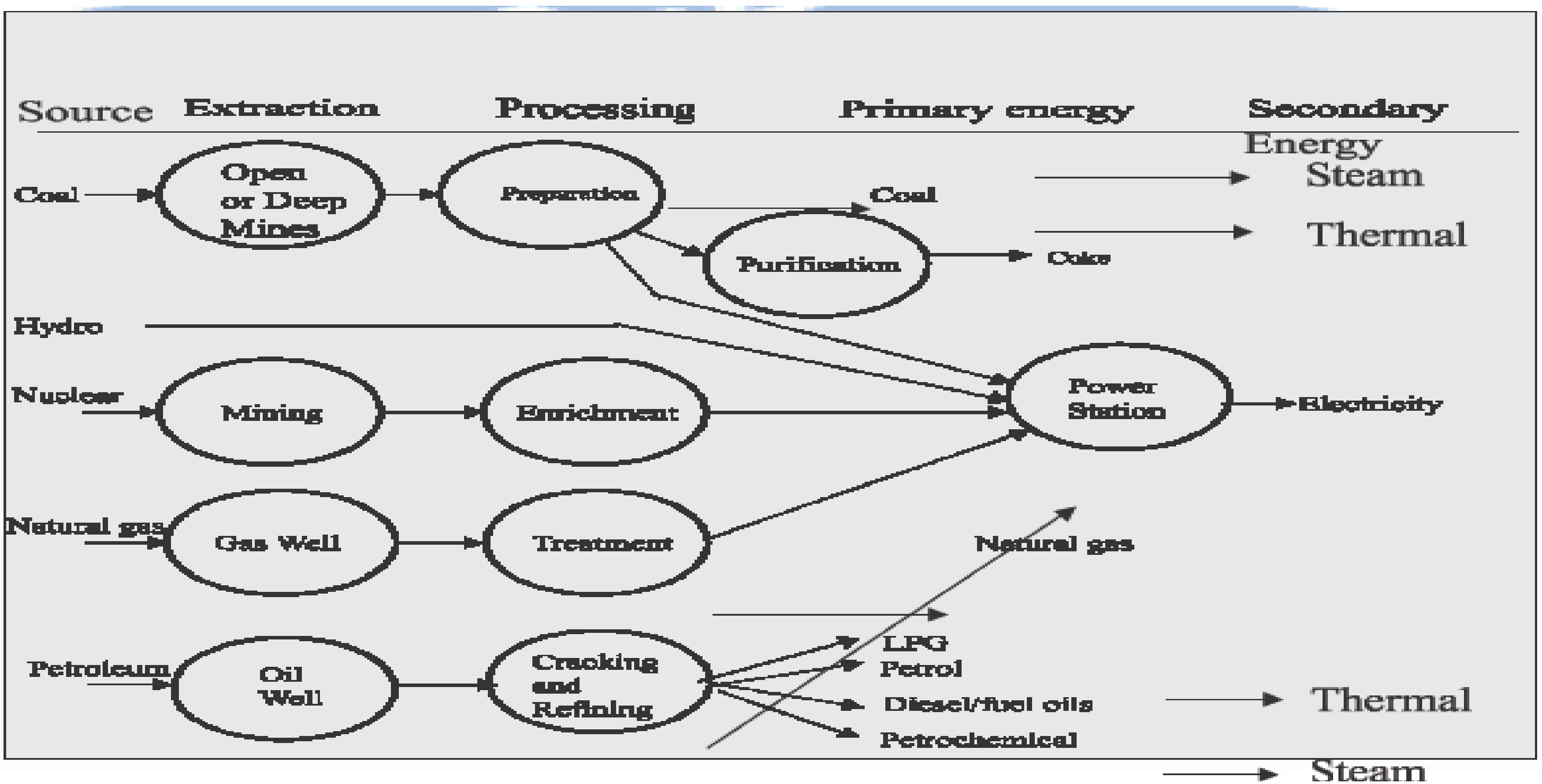
Different types of Renewable Energy Sources

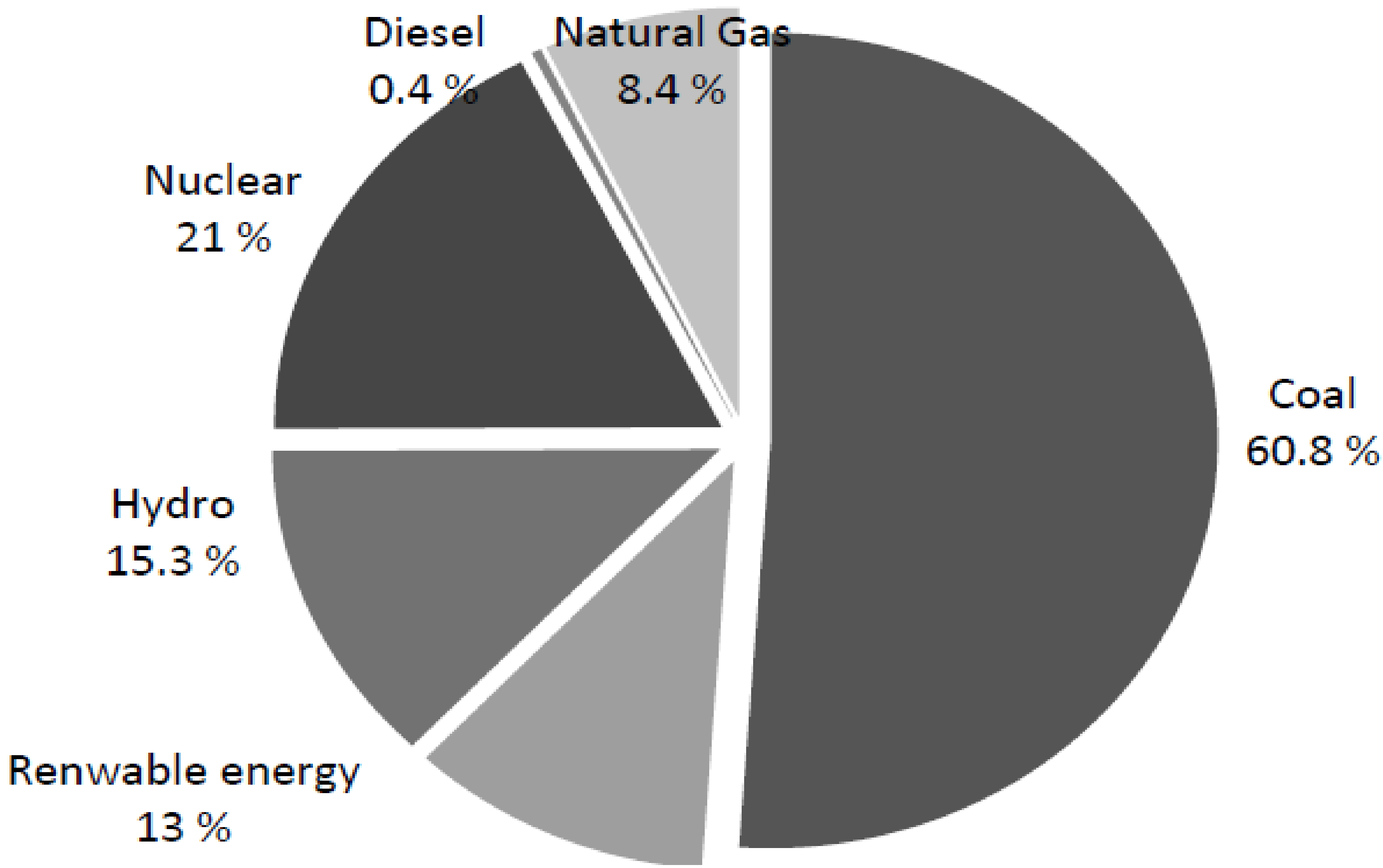
1. Solar
2. Wind
3. Biomass
4. Geothermal
5. Ocean (tidal, wave and thermal)
6. Small hydro
7. Fuel cell
8. Hydrogen
9. Magneto hydrodynamic (MHD)

Introduction Of Renewable Energy Sources

Major primary and secondary sources



Global Energy use by Source



Commercial Energy and Non-Commercial *Energy*

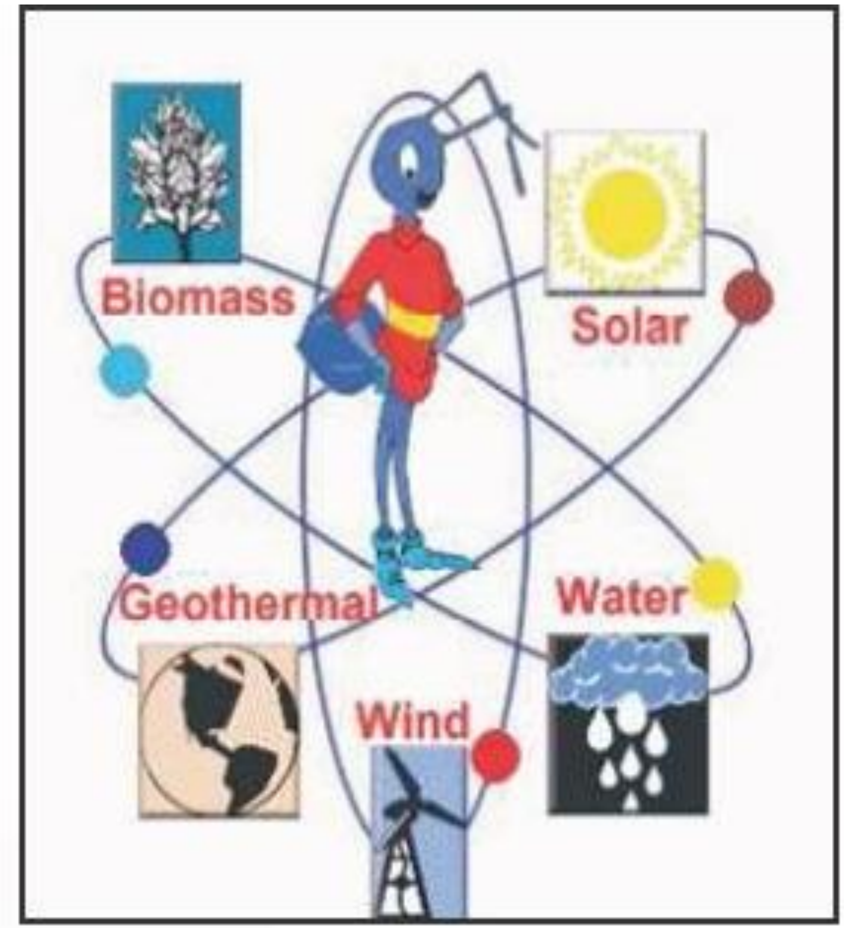
- Commercial Energy:
- The energy sources that are available in the market for a definite price are know as commercial energy.
- By far the most important forms of commercial energy are electricity, coal
- and refined petroleum products.
- Examples: Electricity, lignite, coal, oil , natural gas, etc..

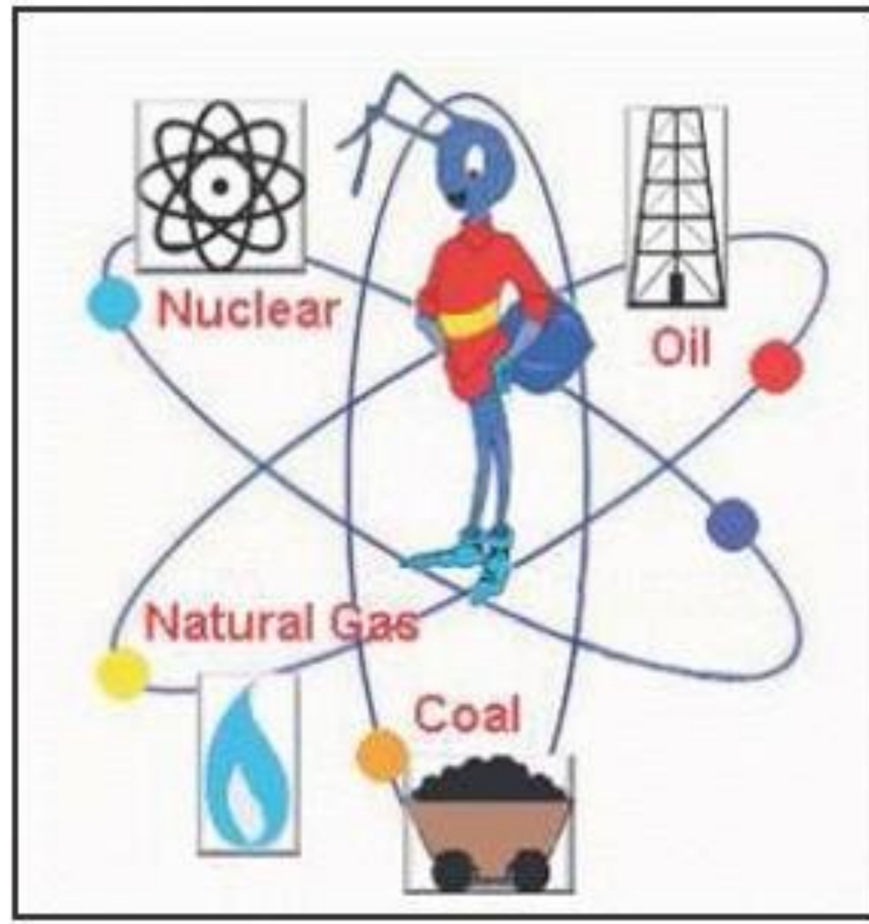
- Non-Commercial Energy:

Renewable energy and Non-renewable energy

- Renewable energy is energy obtained from sources that are essentially inexhaustible. Examples of renewable resources include wind power, solar power, geothermal energy, tidal power and hydroelectric power. The most important features of renewable energy is that it can be harnessed without the release of harmful pollutants.
- Non-renewable energy is the conventional fossil fuels such as coal, oil and gas, which are likely to deplete with time.

Renewable and Non-renewable energy





Sector wise Energy Consumption Pattern

Sectors	International Level	National Level	State Level
Industry	51.7%	29%	25%
Transport	26.6%	30%	0.6%
Domestic	13.9%	27%	49%
Commercial	7.8%	9%	17%
Others	0	5%	8.4%

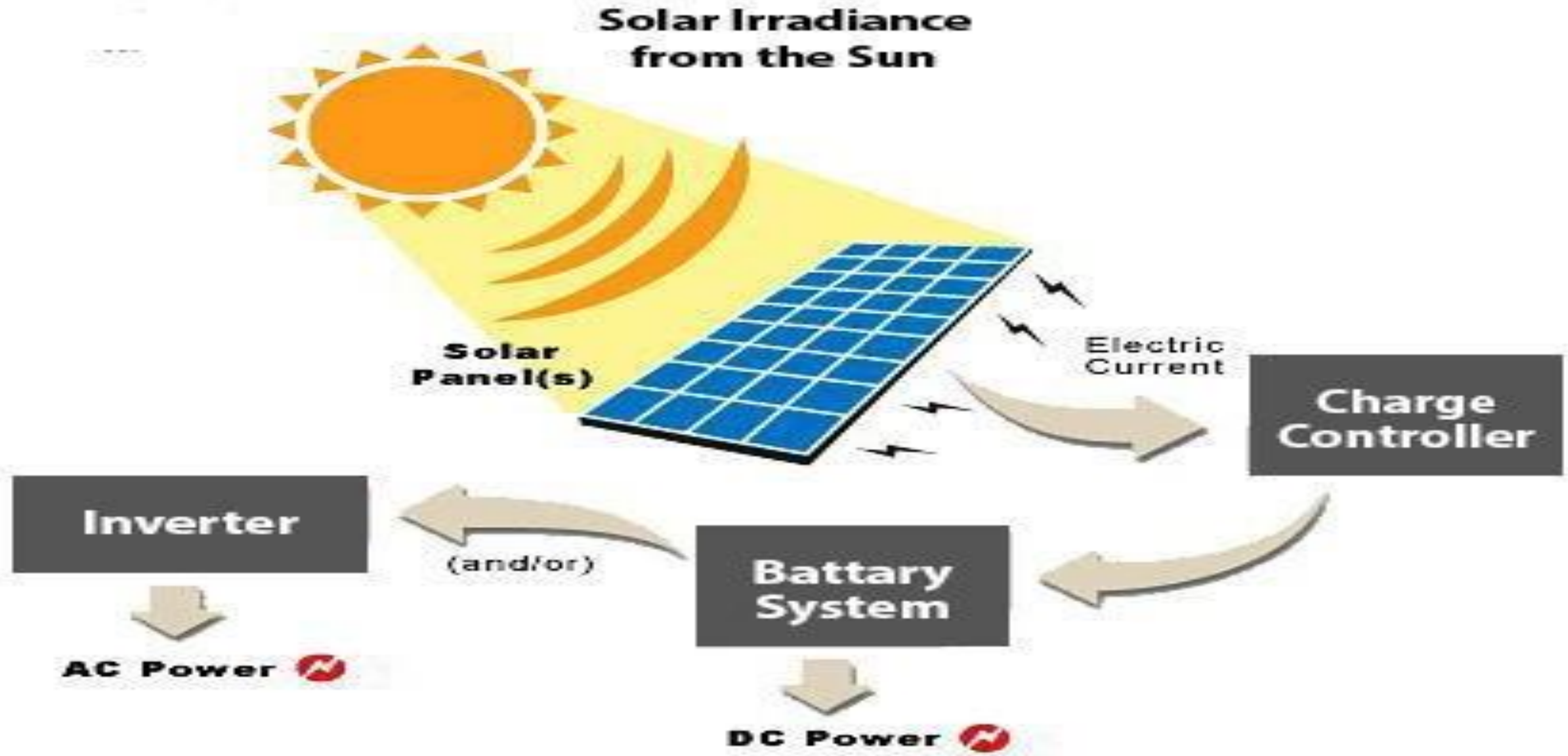
Advantages And Disadvantages Of Energy *Sources*

Energy resource	Advantages	Disadvantages
Fossil fuels	Provide a large amount of thermal energy per unit of mass Easy to get and easy to transport Can be used to generate electrical energy and make products, such as plastic	Nonrenewable Burning produces smog Burning coal releases substances that can cause acid precipitation Risk of oil spills
Nuclear	Very concentrated form of energy Power plants do not produce smog	Produces radioactive waste Radioactive elements are nonrenewable
Solar	Almost limitless source of energy Does not produce air pollution	Expensive to use for large-scale energy production Only practical in sunny areas

Solar Energy Source

- Modern residential solar power systems use photovoltaic (PV) to collect the sun’s energy. “Photo” means “produced by light,” and “voltaic” is “electricity produced by a chemical reaction.”
- Commercial residential PV modules range in power output from 10 watts to 300 watts, in a direct current. A PV module must have an inverter to change the DC electricity into alternating current energy in order to be usable by electrical devices and compatible with the electric grid.

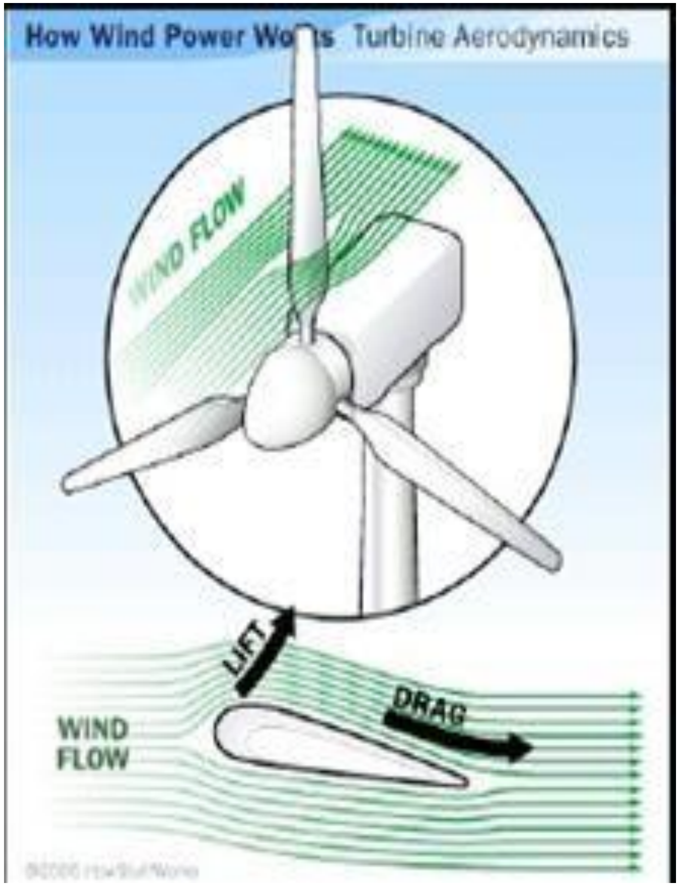
Solar Energy Source



Solar energy Applications

1. Heating and cooling of residential building.
2. Solar water heating.
3. Solar drying of agricultural and animal products.
4. Salt production by evaporation of seawater.
5. Solar cookers.
6. Solar engines for water pumping.
7. Solar Refrigeration.
8. Solar electric power generation.
9. Solar photo voltaic cells, which can be used for electricity.
10. Solar furnaces.

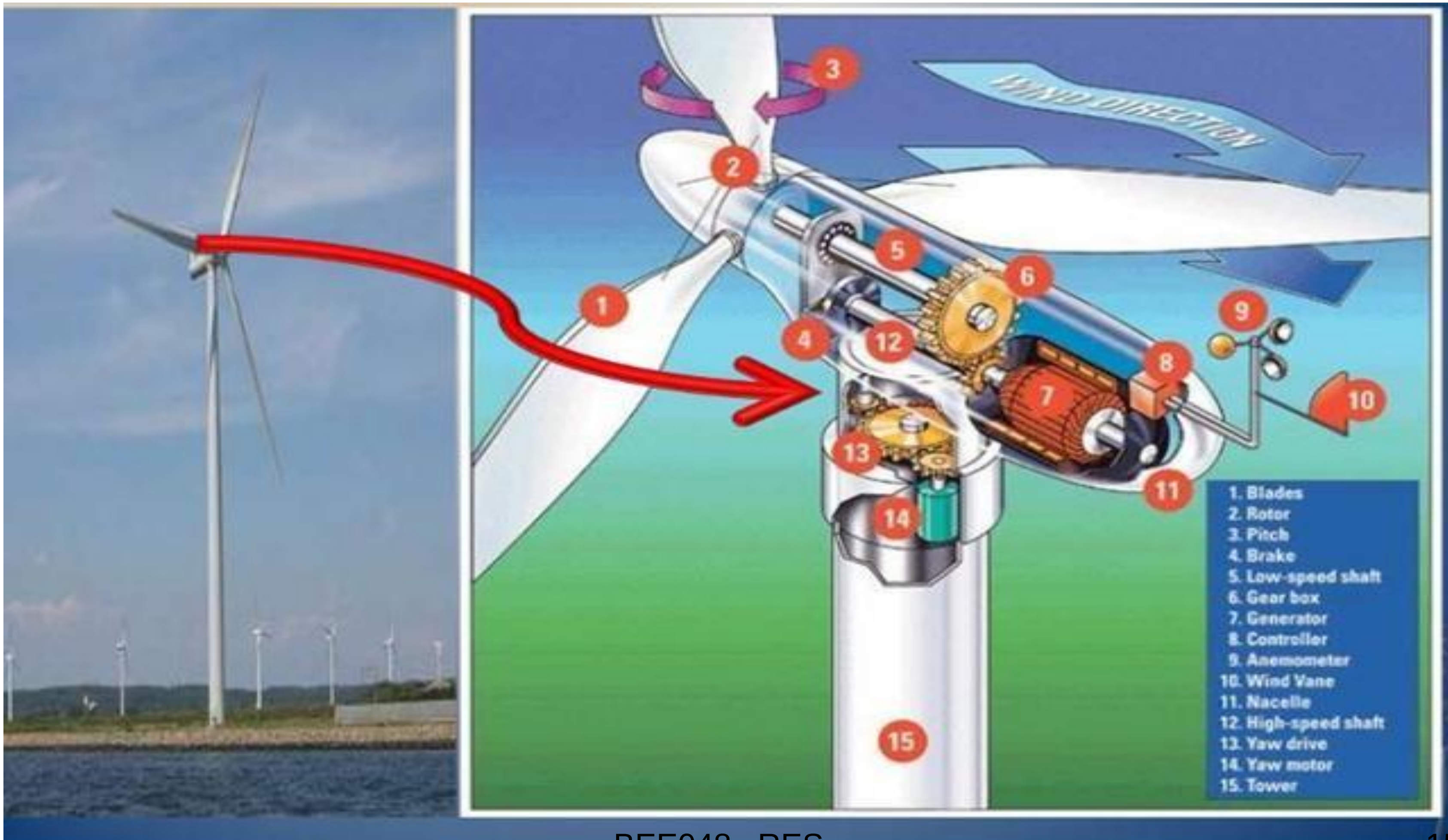
Wind energy source



Wind energy source

- Wind energy is a free, renewable resource, so no matter how much is used today, there will still be the same supply in the future. Wind energy is also a source of clean, non-polluting, electricity. Unlike conventional power plants, wind plants emit no air pollutants or green house.
- It's a clean fuel source. Wind energy doesn't pollute the air like power plants that rely on combustion of fossil fuels, such as coal or natural gas, which emit particulate matter, nitrogen oxides, and sulfur dioxide—causing human health problems and economic damages' gases.

Wind Energy Electricity Generation

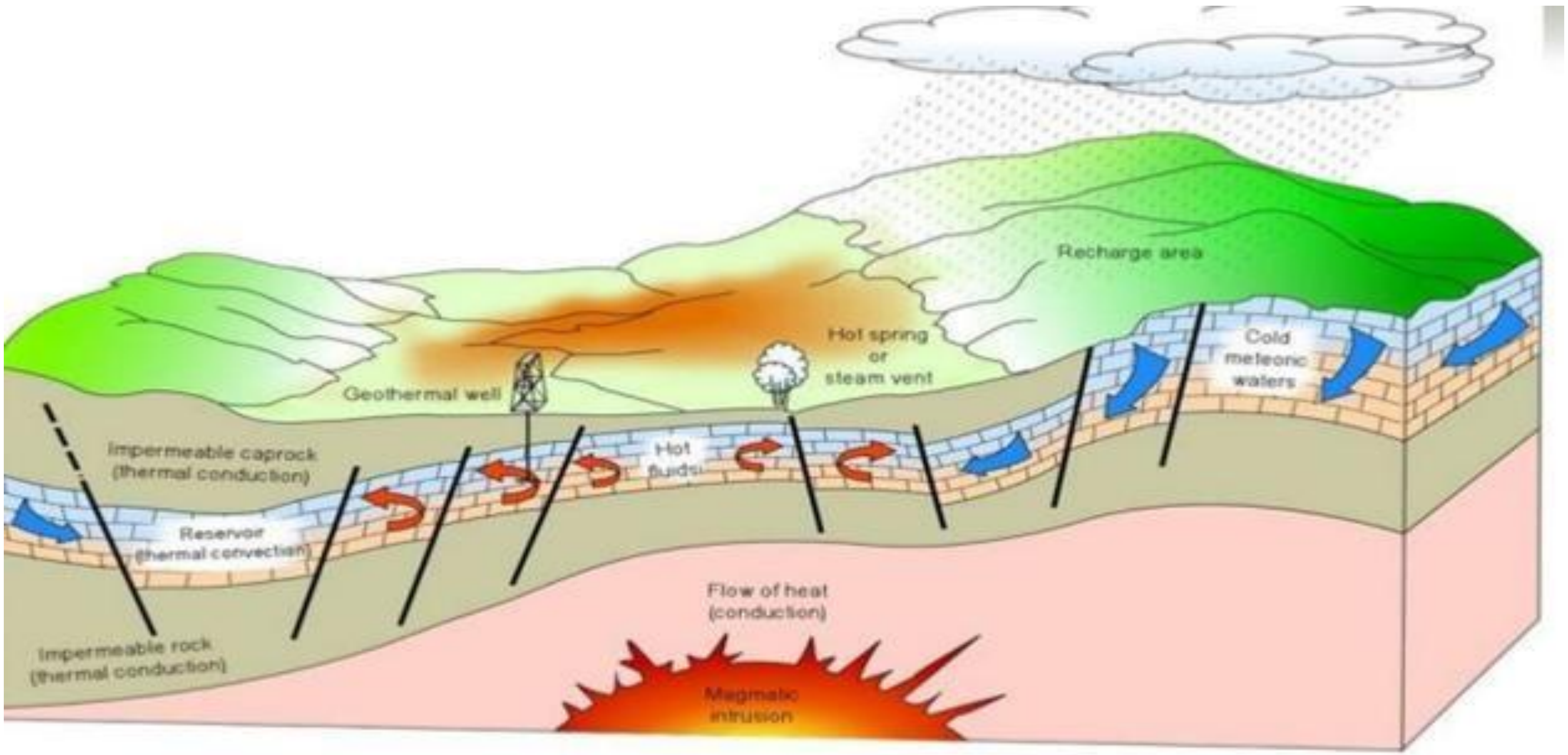


Geothermal energy Source

- Geothermal energy is heat from within the Earth.
- We can recover this heat as steam or hot water and use it to heat buildings or generate electricity.
- It is a natural part of the energy flow within the Earth's depths.
- Most of the commercial-grade production geothermal energy is harvested along localized "geothermal systems", where the heat flow is near enough to the surface that hot water or steam is able to rise either to the surface, or to depths that we can reach by drilling.

Hot Water Springs Form Due To Geothermal *Energy Of The Earth*

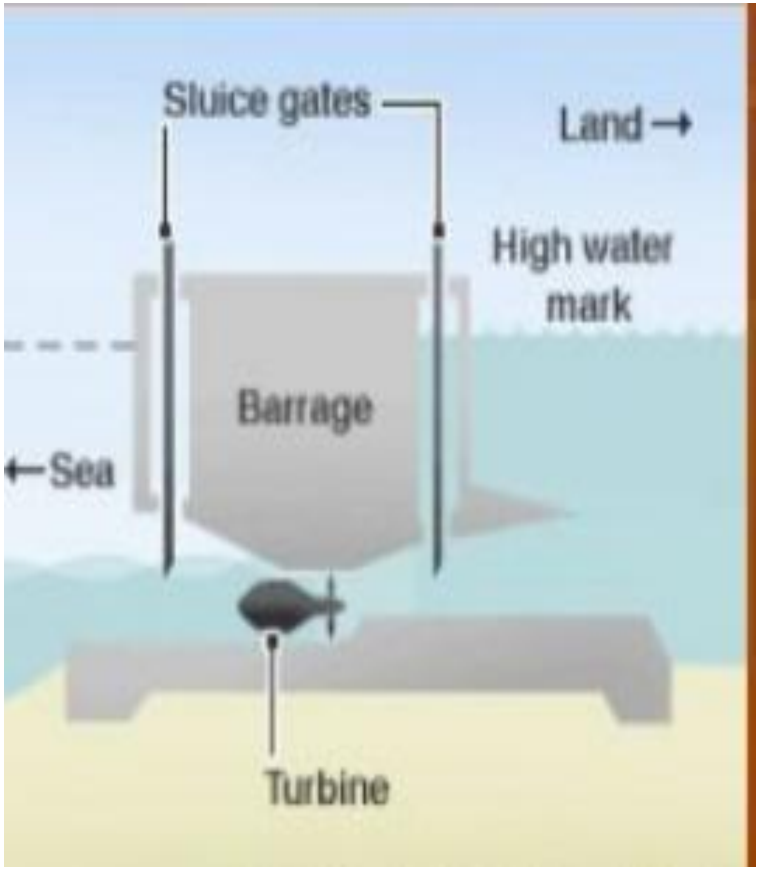
Schematic Representation Of An Ideal *Geothermal System*



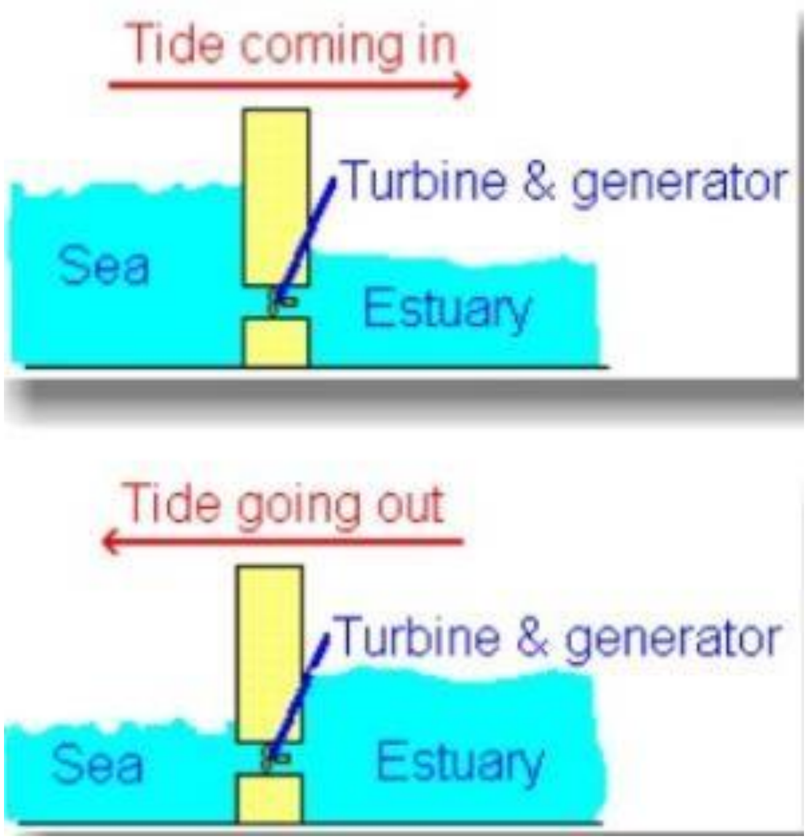
Tidal power

- Tidal power or tidal energy is a form of hydropower that converts the energy obtained from tides into useful forms of power, mainly electricity.
- Tides are more predictable than the wind and the sun.
- Among sources of renewable energy, tidal energy has traditionally suffered from relatively high cost and limited availability of sites with sufficiently high tidal ranges or flow velocities, thus constricting its total availability.

Tidal power



Sluice gates
Land →
High water mark
Barrage
← Sea
Turbine



Tide coming in
Turbine & generator
Sea
Estuary
Tide going out
Turbine & generator
Sea
Estuary

Biomass Energy

- Biomass is organic material that comes from plants and animals, and it is a renewable source of energy.
- Biomass contains stored energy from the sun. Plants absorb the sun's energy in a process called photosynthesis. When biomass is burned, the chemical energy in biomass is released as heat

Types of biomass

Schematic Diagram For Biomass Energy

Merits and demerits of renewable energy sources

Merits:

1. They are available in nature free of cost.
2. They produce no or very little pollution and, by and large, environment friendly.
3. They are inexhaustible.
4. They have a low gestation period.

Demerits:

1. In general, the energy is available in dilute form.
2. Though available freely In nature, the cost of harnessing energy is generally high.
3. Availability is uncertain.
4. It is difficult to transport such forms of energy.

Environmental aspects of energy utilization

- Environment literally means surroundings. Air, soil and water are the main constituents of environment. Nature has originally provided them to human beings in clean form.
- However, with passage of time, their quality is continuously being degraded due to various manmade reasons. The chief among them are a number of activities involving energy generation and its utilization.
- During every energy conversion process some energy is expelled by the energy conversion system into the surroundings in the form of heat. Also, some pollutants are produced as a by-product of this process. Both of these cause degradation of environment.

Environmental aspects of energy utilization continued……

- Every step must be taken to conserve the environment.
- Therefore, while supplying the increased energy demand, efforts should be made to adopt measures to minimize the degradation of environment.
- The present trend is to have a trade-off between the two. The future seems to be in favour of developing renewable and environment-friendly energy resources.
- To create public awareness about environment, 5th June is observed as World Environment Day.

Environmental aspects of energy utilization continued……

Energy generation and utilization have the following effects on the environment:

- **Disturbance to ecological balance**
- **Generation of greenhouse gases**
- **Global warming**
- **Pollution**

Energy Conservation

- Energy is one of the basic and essential requirements of human life. It is the backbone of present day civilization. It is the indispensable component of industrial product, employment, economic growth, environment and comfort.
- Higher per capita energy consumption means a higher per capita Gross Domestic Product (GDP).
- Consumption of energy is increasing with improvement in per capita income. One way to cope up with increased energy demand is to increase energy production. But, the problem can be solved to a great extent by conservation (saving) of energy.
- Increasing energy production is an expensive and long term option whereas energy conservation offers a cost effective and immediate solution.

Energy Conservation continued…..

- Conventional energy sources are fast depleting and cost of energy is increasing.
- Therefore, it is important to conserve energy which also in turn helps in reducing the environmental pollution.
- **Energy conservation means reduction in energy consumption but without making any sacrifice in the quality or quantity of production.**
- It means increasing the output for a given input by reducing the losses and thereby maximizing the efficiency.

Energy Conservation continued…..

Three major incentives (or advantages) of energy conservation:

1. **It decreases the energy requirement.**
2. **It conserves the limited conventional energy sources.**
3. **It reduces the environmental pollution.**

- To create awareness about energy conservation, 14th December is observed as " National Energy Conservation Day". This day is also observed as "World Energy day" internationally.
- Experts have indicated a saving potential ranging from 10 to 25% in the total spectrum of Indian industries without any major investment.

Energy Conservation continued…..

- Developed countries have been able to reduce their consumption of energy through self-discipline and strict energy-conservation measures.
- Japanese primary energy consumption per unit GDP is the lowest in the world, owing to various energy conservation measures taken for the respective sectors.
- Energy consumption levels in the industrial sector of Japan are still at 1973 levels.
- In Denmark, energy consumption has increased by only 2% since 1980, while GDP growth is 56% in the same period.

Energy Conservation continued…..

- Saving of usable energy, which is otherwise wasted, has direct impact on economy, environment and long-term availability of non-renewable energy sources.
- Energy conservation implies reduction in energy consumption by reducing losses and wastage by employing energy efficient means of generation and utilization of energy.
- There are three important aspects of energy conservation:

  1. Economic aspect

  2. Environmental aspect

  3. Energy sources aspect

Energy Conservation continued…..

1. Economic Aspect:

- **Reduction in cost of product:**

  Energy conservation ultimately leads to economic benefits as the cost of production is reduced

- **New job Opportunities:**

  Energy conservation usually requires new investments in more efficient equipment to replace old inefficient ones, monitoring of energy consumption, training of manpower, etc. Thus, energy conservation can result in new job opportunities.

Energy Conservation continued…..

2. Environmental Aspect:

Energy is generated and utilized at the expanse of adverse environmental impacts. Adoption of energy-conservation means can minimize this damage.

3. Energy sources Aspect:

The vast bulk of energy used in the world today comes from fossil fuels, which are non-renewable. This finite, non-renewable asset is being used up very fast. Therefore, its prices are bound to go up. Energy conservation practices will reduce the consumption of these fossil fuels so that they can be saved for future generations.

General principles of energy conservation

- **Recycling of waste**
- **Modernization of technology**
- **Waste heat utilization**
- **Judicial Use of proper types of energy**
- **Judicial use of proper type of fuel**
- **Cogeneration**
- **Training of manpower**
- **Adopting daylight saving time**
- **Proper operation and maintenance**

General Electrical ECOs
(Energy Conservation Opportunities)

Class A: Simple Electrical ECOs

- Switching off the loads when not in use
- Changing from electrical heating to solar heating or gas-burner heating wherever possible
- Reducing peak demand by staggering the use of large loads
- Providing automatic thermostatic (or any other) control to water heaters, refrigerators, air conditioners etc.
- Changing operating cycle of electrical equipment to conserve energy. For example, electrical furnaces may be used continuously in three shifts (instead of two shifts) for better economy
- Replacing inefficient lamps by energy-efficient lamps

General Electrical ECOs continued….

Class B: Intermediate Electrical ECOs

- Installation of static VAR sources at substations
- Employing automatic controlled load switches
- Heat recovery from cooling oil/water associated with transformers
- Automatic voltage control by means of on-load tap changer
- Installation of shunt capacitors near inductive load for power-factor improvement and reducing kVA demand
- Improvement in operation and maintenance, reducing down time

General Electrical ECOs continued….

Class C: Comprehensive Electrical ECOs

- Modern, more efficient and easy to maintain plant equipments may replace old and less efficient ones.
- The simple manual / semi manual controlled equipments in electrical plants may be retrofitted with energy efficient, computer controlled equipments.

Energy Efficiency

- Efficient use of energy, sometimes simply called energy efficiency, is the goal of efforts to reduce the amount of energy required to provide products and services.
- For example, insulating home allows a building to use less heating and cooling energy to achieve and maintain a comfortable temperature.
- Installing fluorescent tubes reduces the amount of energy required to attain the same level of illumination compared to using traditional incandescent bulbs. Compact fluorescent tubes use two-thirds less energy and may last 6 to 10 times longer than incandescent bulbs. LED lights consume only one third of the power the sodium vapour and other street lights consume (Coimbatore corporation has gone in for LED bulbs in street lights- Hindu dt 10-12-2011).

Energy Efficiency continued…

- Improvements in energy efficiency are most often achieved by adopting a more efficient technology or production process. There are various motivations to improve energy efficiency.
- Reducing energy use reduces energy costs and may result in a financial cost saving to consumers if the energy savings offset any additional costs of implementing an energy efficient technology.
- Reducing energy use is also seen as a key solution to the problem of reducing greenhouse gas emissions.
- According to the International Energy Agency, improved energy efficiency in buildings, industrial processes and transportation could reduce the world's energy needs in 2050 by one third, and help control global emissions of greenhouse gases.

Energy Efficiency continued…

- Energy efficiency and renewable energy are said to be the *twin pillars* of sustainable energy policy.
- In many countries energy efficiency is also seen to have a national security benefit because it can be used to reduce the level of energy imports from foreign countries and may slow down the rate at which domestic energy resources are depleted.
- Making homes, vehicles, and businesses more energy efficient is seen as a largely untapped solution to addressing the problems of pollution, global warming, energy security and fossil fuel depletion.

Energy Efficiency continued…

- Many of these ideas have been discussed for years, since the 1973 oil crisis brought energy issues to the forefront. In the late 1970s, physicist Amory Lovins popularized the notion of a "soft energy path", with a strong focus on energy efficiency. Among other things, Lovins popularized the notion of negawatts—the idea of meeting energy needs by increasing efficiency instead of increasing energy production.
- The state of California in USA began implementing energy efficiency measures in the mid-1970s, including building code and appliance standards with strict efficiency requirements. During the following years, California's energy consumption has remained approximately flat on a per capita basis while national USA consumption doubled.

Energy Efficiency continued…

Lovins Rocky Mountain Institute points out that in industrial settings, there are abundant opportunities to save

(i) 70% to 90% of the energy for lighting, fan, and pump systems,

(ii) 50% for electric motors and

(iii) 60% in areas such as heating, cooling, office equipment, and appliances.

- In general, up to 75% of the electrical energy used in USA today could be saved with efficiency measures.
- The USA Department of Energy has stated that there is potential for energy saving in the magnitude of 90 Billion kWh by increasing home energy efficiency.

Salient features of "Energy Conservation Act, 2001"

- Energy conservation involves all the sectors of the economy. Efforts for energy conservation were not adequate previously and there was lack of adequate focus on the institutional arrangements, which would devise suitable incentives and disincentives appropriate to each sector.
- Considering the vast potential of energy saving and the benefits of energy efficiency , the Government of India, on 29th of September 2001, enacted the **Energy Conservation Act, 2001**.
- The Act provides the legal framework, institutional arrangement and a regulatory mechanism at the central and state levels to embark upon an energy efficient drive in the country.

Energy Conservation Act continued…..

This act requires the following:

- Large energy consumers to adhere to energy consumption norms
- New buildings to follow the energy conservation building code
- Appliances to meet energy performance consumption labels

The act provides a long range consequences, which are appended below:

- Establishment of Bureau of Energy Efficiency (BEE) in place of Energy Management Centre (EMC) to implement the provisions of the act
- Declaration of a user or class of users of energy as a designated consumer

Energy Conservation Act continued…..

- To lay down minimum energy consumption standards and labeling for identified appliances / equipments and norms for industrial processes for energy intensive industries
- Formation of energy consumption codes
- Dissemination of information and best practices
- Establishment of an energy conservation fund, both at the central and state levels
- Provision of penalties that would be effective during the first five years as the focus during this period would be on promotional activities and creating the infrastructure for implementing the Act

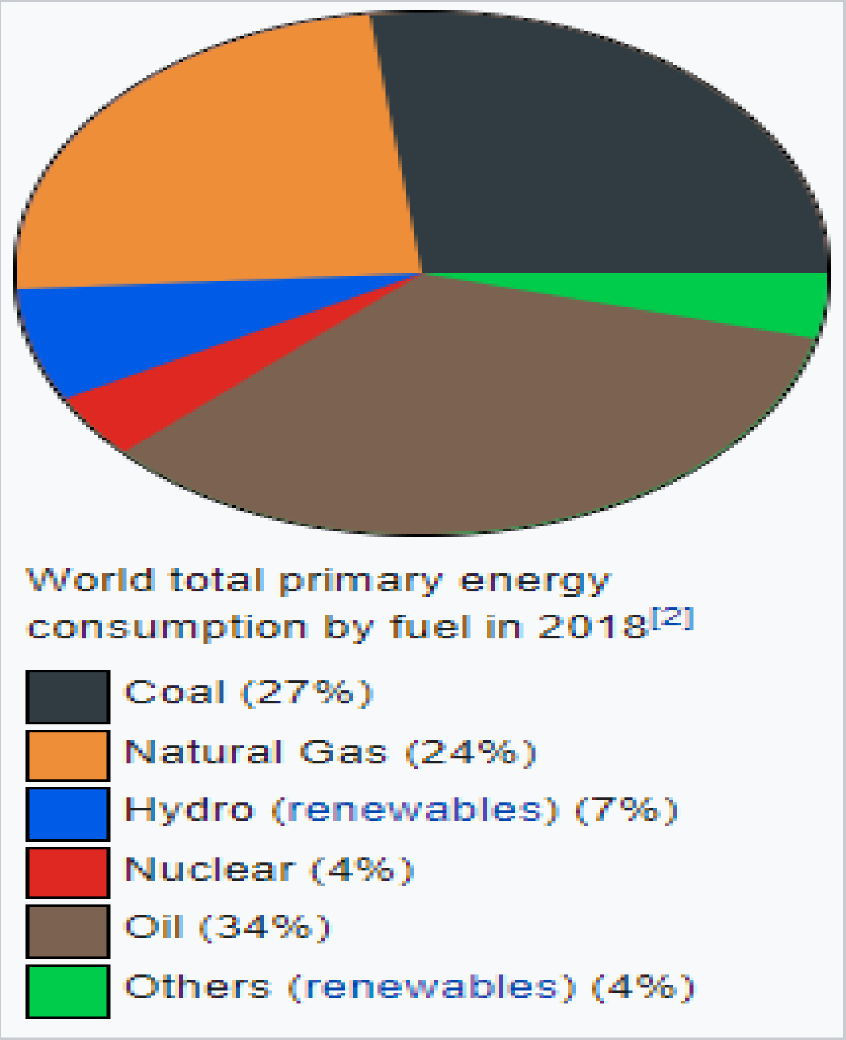
Energy Conservation Act continued…..

- BEE to act as a facilitator for the evolution of a self-regulatory system and organizations to regulate on their own with a view to save energy and thereby bring the commercial concept in the organization.
- The central government has established the BEE with effect from 1 March 2002.
- In the year 2007, the potential of power saving though energy conservation measures was assessed as 20,000 MW.
- The potential harnessed during the 10th plan period (2002-2007) is 877 MW.
- The target set for 11th plan period (2007-2012) is 10,000 MW.

Energy resources availability in the world

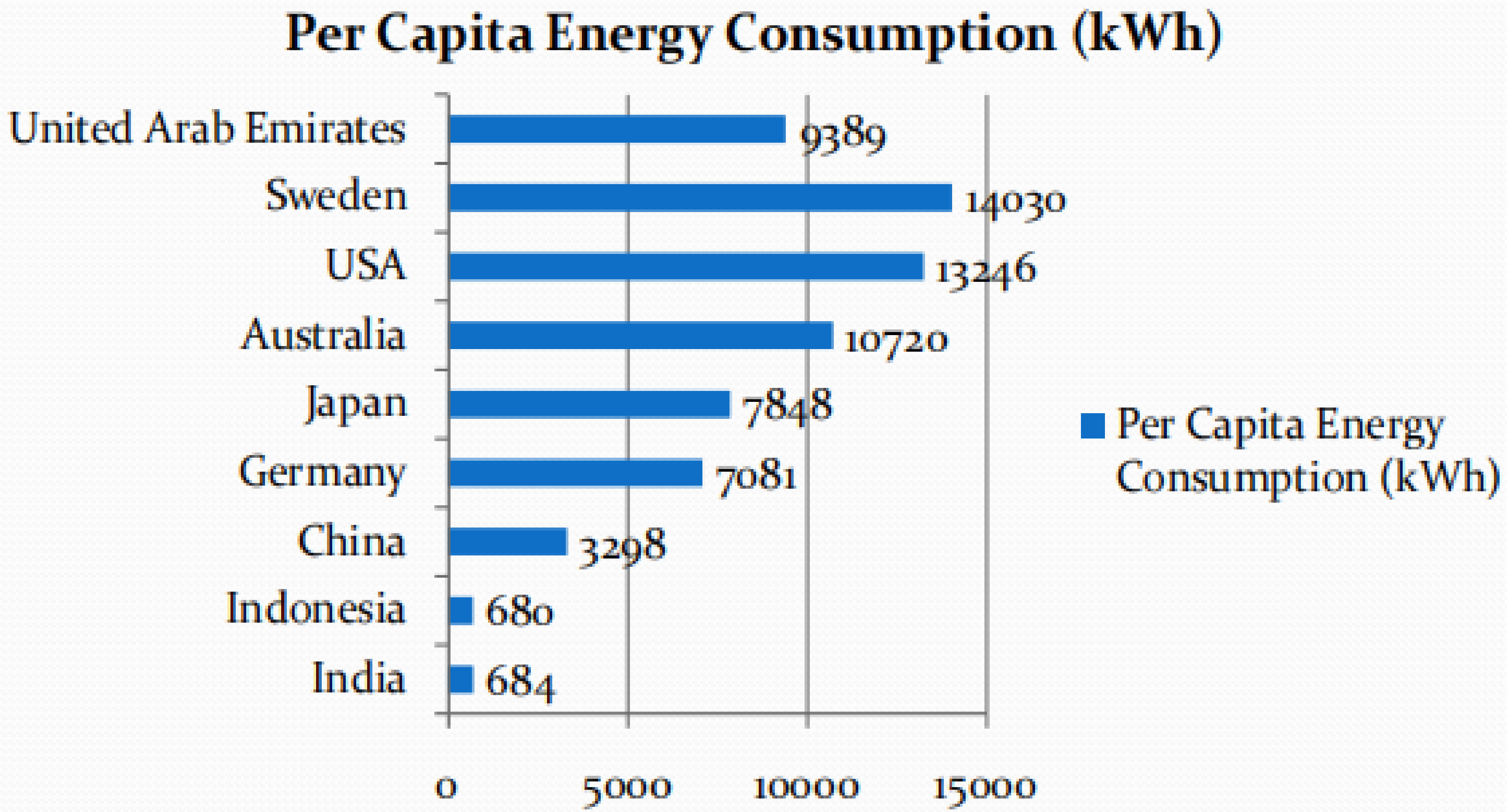
World Energy: present Situation (Year 2017)

- At present the annual primary energy consumption of the world is 113,003 TWh (equivalent to 9,717Mtoe).
- Fossil fuels roughly provide about 65% of this energy .



Energy resources availability in the world continued…..

- Approximately 25% of this energy is consumed in transportation sector and remaining 75% by industries, domestic, agriculture and social consumers.
- This growth is expected to continue at an annual average rate of 2.2% during 2004 – 2030.
- Over 70% of this growth will come from developing countries.



Source: http://data.worldbank.org/indicator/EG.USE.ELEC.KH.PC

World Energy Supply & Energy Consumption

Year	Primary energy supply (TPES)[1]	Final energy consumption[1]	Electricity generation
1973	71,013 (Mtoe 6,106)	54,335 (Mtoe 4,672)	6,129
1990	102,569	—	11,821
2000	117,687	—	15,395
2010	147,899 (Mtoe 12,717)	100,914 (Mtoe 8,677)	21,431
2011	152,504 (Mtoe 13,113)	103,716 (Mtoe 8,918)	22,126
2012	155,505 (Mtoe 13,371)	104,426 (Mtoe 8,979)	22,668
2013	157,482 (Mtoe 13,541)	108,171 (Mtoe 9,301)	23,322
2014	155,481 (Mtoe 13,369)	109,613 (Mtoe 9,425)	23,816
2015	158,715 (Mtoe 13,647)	109,136 (Mtoe 9,384)	
2017	162,494 (Mtoe 13,972)	113,009 (Mtoe 9,717)	25,606

[1] converted from Mtoe into TWh (1 Mtoe = 11.63 TWh) and from Quad BTU into TWh (1 Quad BTU = 293.07 TWh)

- From 2000–2012 coal was the source of energy with the total largest growth. The use of oil and natural gas also had considerable growth, followed by hydropower and renewable energy. Renewable energy grew at a rate faster than any other time in history during this period.

- More recently, consumption of coal has declined relative to renewable energy. Coal dropped from about 29% of the global total primary energy consumption in 2015 to 27% in 2017, and non-hydro renewables were up to about 4% from 2%.

Conventional Resources

(i) Fossil fuel resources:

- Fossil fuels are so called because these are in fact the fossils of old biological life that once existed on the surface of the earth. It is formed in several parts of the earth at varying depths, during several million years by slow decomposition and chemical actions of buried organic matter under favorable pressure, heat and bacterial marine environment. The fossil fuels include coal, oil and gas.
- Fossil fuels have been a major source of energy since about 1850, the start of the industrial era.
- As per one estimate, if the world continues to consume fossil fuels at year 2006 rates, the reserves of coal, oil and gas will last for 200, 40 and 70 years respectively.
- The locations and estimates of the world's main fossil fuel reserves are indicated in the next slide.

World's main fossil-fuel reserves, as in 2006

Region	Fossil fuel reserves (Percentage)			
	Oil	Coal	Gas	Sum
North America	0.86	18.20	0.75	19.81
South America	1.61	1.39	0.64	3.64
Europe	0.21	4.28	0.54	5.03
Africa	1.71	3.64	1.39	6.75
Russia	1.93	16.27	5.57	23.77
Middle East	10.81	0.00	7.07	17.88
India	0.11	6.64	0.11	6.85
China	0.21	8.14	0.21	8.57
Australia &East Asia	0.21	6.42	1.07	7.71
Total	17.67	64.99	17.34	100.00

Conventional Resources continued…..

(ii) **Hydro Resources**:

- Among all renewables, hydro power is the most advanced and flexible source of power. It is a well developed and established source of electric power.
- The early generation of electricity from about 1880, was often derived from hydro schemes.
- A number of large and medium–sized hydro schemes have been developed.
- Due to requirement of huge capital investment and strong environmental concerns about large plants, only about one- third of the realistic potential has been tapped so far.
- Hydro installations and plants are long lasting (turbine life is about 50 years). Therefore, it often produces electricity at low cost with consequent economic benefits.

Conventional Resources continued…..

- The global installed generating capacity of hydro power is about 7,78,038 MW, which accounts for about 20% of the world's total installed electric power-generation capacity.
- Industrialized countries account broadly for two-thirds and developing countries for one-third of the present hydro power production.
- Five countries make up more than half of the world's hydropower production: China (100,000 MW), USA (77,350 MW), Canada (71,978 MW), Brazil (71,060 MW,) and Russia (45,000 MW).
- Norway derives 90% of its required electric power from Hydro resources.
- The world's biggest hydroelectric power station is located in Brazil. Its capacity is 12,000 MW.

Top 10 countries in Hydro Power (March 2010)

1. China: 179,056 MW
2. Brazil: 81,955 MW
3. USA: 78,054 MW
4. Canada: 75,287 MW
5. Russia: 46,756 MW
6. India: 39,546 MW
7. Norway: 29,317 MW
8. Japan: 22,089 MW
9. France: 20,850 MW
10. Sweden: 16,266 MW

Conventional Resources continued…..

(iii) Nuclear Resources

- U^{235}, U^{233} (isotopes of uranium) and Pu^{239} (plutonium) are used as nuclear fuels in nuclear reactors (Thermal reactors) and are known as fissile (or fissionable) materials.
- Out of these, only U^{235} occurs in nature. U^{233} and Pu^{239} are produced from Th^{232} (thorium) and U^{238} respectively in Fast Breeder Reactors (FBRs).
- Natural uranium contains 0.71% of U^{235} and 99.29% of U^{238}
- Uranium reserves in the world are small (expected to last hardly for 59 years at the 2008 rate of consumption) and its recovery is expensive.
- Concentrated deposits of uranium are not available. The content of natural uranium in uranium ore is about 0.1 - 0.5%.

Conventional Resources continued…..

- Major available sources of uranium are in Australia, Canada, and Kazakhstan and to a lesser extent in USA. Thorium reserves are expected to be more than those of uranium.
- Nuclear power is a low cost and low emission technology that can provide base-load power.
- As on 2011, there are around 441 nuclear power plants in the world, operating in 29 countries and generating about 375 GW, which is about 16% of the world's electrical power. 60 more units , with a total target capacity of 58.6 GW, are under construction.
- France produces 74% of its total electrical power by nuclear means. The share for USA is around 20%, for Japan 30 %, Russia 17 %, Canada 15 %, UK 16 %, and for India it is only 3 %. Refer to the next slide.

SHARE OF NUCLEAR POWER IN TOTAL (2011)

Country (ranking in the order of total nuclear power)	Total nuclear power capacity (MW)	Percentage of nuclear power in total electrical power generated
United States (1)	101,433	19.59
France (2)	63,130	74.12
Japan (3)	47,348	29.21
Russia (4)	23,084	17.09
Republic of Korea (5)	18,785	32.18
Ukraine (6)	13,168	48.11
Canada (7)	12,044	15.07
United Kingdom (8)	10,745	15.66
India (15)	4,385	2.85

Conventional Resources continued…..

- In the European Union as a whole, nuclear energy provides 30% of the electricity.
- Presently, most commercial reactors are thermal reactors.
- Fast Breeder Reactors (FBRs) utilize fast neutrons and generate more fissile material than they consume. They generate energy as well as convert fertile material (U^{238}, Th^{232}) into fissile material (Pu^{239} and U^{233} respectively).
- The breeder technology is not yet commercially developed, the main problem being their slow breeding rate and, therefore, long doubling time (the time required by an FBR to produce sufficient fissile material, to fuel a second identical reactor) of around 25 years.

Conventional Resources continued…..

- It is hoped that by 2050, Fast Breeder Reactors will be the main source of power.
- Nuclear fusion reaction has a lot more potential and vast resources are available. However, controlled fusion reaction has not yet been achieved . It is predicted that by year 2050 some breakthrough will take place in fusion technology and once this happens, nuclear fusion reaction will be the main source of energy on earth.
- The amount of energy that can be produced by 10,000 tonnes of coal (a typical type-0 fuel) can be generated by a mere 500 kg of uranium (type-1 fuel) and a much less 62.5 kg of thorium, which is considered to be the nuclear fuel of the future.

Non conventional (Renewable) resources

(i) Solar energy:

- Solar energy can be a major source of power and can be utilized by using thermal and photovoltaic conversion systems. The solar radiation received on the surface of the earth on a bright sunny day at noon is approximately $1 kW/m^2$
- The earth continuously intercepts solar power of 178 billion MW, which is about 10,000 times the world's demand. But so far, it could not be developed on a large scale.
- According to one estimate, if all the buildings of the world are covered with solar PV panels, it can fulfill electrical power requirements of the world.
- Solar PV power is considered to be an expensive source of power. At present, the capital of a solar PV system is ` 200/ per watt (20 crore/MW as against 4 crore/MW for coal-fired thermal plant).

Top 10 countries in Solar PV Power (March 2010)

1. Germany: 6526.00 MW
2. Spain: 5504.76 MW
3. Japan: 2347.00 MW
4. USA: 1487.71 MW
5. Italy: 908.59 MW
6. Korea: 557.60 MW
7. France: 253.42 MW
8. China: 223.00 MW
9. India: 223.00 MW
10. Australia: 114.39 MW

Renewable resources continued…..

(ii) Wind Energy:

- The power available in the winds flowing over the earth surface is estimated to be 1.6×10^7 MW, Which is more than the present energy requirement in the world.
- Wind power has emerged as the most economical and fastest growing of all renewable energy sources.
- The installation cost of wind power is 4 crore/MW, which is comparable to that of conventional thermal power plants.

Renewable resources continued…..

- There has been remarkable growth of wind-power installation in the world.
- Wind-power installations worldwide have crossed 94,100 MW (at the end of 2007), which is about 1% of the world's electrical power generation capacity.
- It accounts for approximately 19% of electricity production in Denmark, 9% in Spain and Portugal, and 6% in Germany and the Republic of Ireland.
- China, USA and Germany are the world leaders in wind power.

WIND POWER INSTALLED CAPACITY ACROSS THE WORLD (As on 01.04.2009)

Sl.No	Country	Installed Capacity in MW
1	USA	25,388
2	Germany	23,903
3	Spain	16,740
4	China	12,200
5	India	10,242
6	Italy	3,736
7	France	3,387
8	UK	3,334
9	Denmark	3,180
10	Portugal	2,833

Wind power installed capacity across the world (as on January 2011)

Sl.No	Country	Installed Capacity in MW
1	China	42,287
2	US	40,180
3	Germany	27,214
4	Spain	20,676
5	India	13,065

Grand Total: 1,94,400 MW

Renewable resources continued…..

(iii) Biomass Energy:

Energy resources available from animal and vegetation are called biomass energy resources. This is an important resource for developing countries, especially in rural areas.

The Principal biomass resources:

- Trees (wood. leaves and forest industry waste)
- Plants grown for energy, Algae and other vegetation from oceans and lakes
- Urban waste (municipal and industrial waste)
- Rural waste (agricultural and animal waste, crop residue, etc.)

Renewable resources continued…..

- Solar energy absorbed by plants (through the photosynthesis process) is estimated to be 2 $\times 10^{21}$ J/year.
- Biomass material may be transformed by chemical or biological processes to produce intermediate bio-fuels such as biogas (methane), producer gas, ethanol and charcoal.
- At present, there are millions of biogas plants in the world, and most of them are in China.

Top 10 Countries in Biomass Power (March 2010)

1. United States:	9,391 MW
2. Germany:	5,890 MW
3. Sweden:	4,522 MW
4. Brazil:	3,970 MW
5. Japan:	2,834 MW
6. Netherlands:	2,531 MW
7. China:	2,381 MW
8. Finland:	2,352 MW
9. India:	2,117 MW
10. Canada:	1,885 MW

Renewable resources continued…..

(iv) Geothermal Energy:

- Geothermal Energy is derived from huge amounts of stored thermal energy in the interior of the earth.
- Its economic recovery on the surface of the earth is not feasible everywhere.
- Its overall contribution in total energy requirement is negligible. However, it is a very important resource locally.
- At the end of 2005, the world's total installed electrical power-generating capacities from geothermal resources was about 8,932 MW and direct thermal-use installed capacity was 28,267 MW.

Renewable resources continued…..

- Globally, the use of geothermal power is growing annually at a rate of about 3% electrical and 7.5% thermal.
- The island of Hawaii generates 25% of its electrical power from geothermal resources.
- Likewise, geothermal electrical energy production in El Salvador is 23% of the country's total installed electricity-generation capacity.
- The oldest geothermal power generator is located at Italy. It was commissioned in 1904 and presently producing 460 MW of power.

Top 10 Countries in Geothermal Power(March 2010)

1. United States:	3153.0 MW
2. Philippines:	2195.3 MW
3. Indonesia:	1132.0 MW
4. Mexico:	965.0 MW
5. Italy:	810.0 MW
6. New Zealand:	577.0 MW
7. Japan:	535.0 MW
8. Kenya:	169.0 MW
9. Turkey:	83.0 MW
10. Russia:	81.0 MW

Renewable resources continued…..

(v) Ocean Tidal Energy

- Tidal energy is a form of hydro power that converts energy of ocean tides into electricity or other useful forms of power. It is in the developing stage and although not yet widely used, tidal power has potential for future electricity generation. There are at present only a few operational tidal power plants.
- The first and biggest, a 240 MW tidal power plant was built in 1966 in France. A 20 MW tidal plant is located at Canada, and a 400 kW capacity plant is located at Kislaya Guba.
- Many sites have been identified in USA, Argentina, Europe, India and China for development of tidal power.

Renewable resources continued…..

(vi) Ocean Wave Energy:

- Wave power refers to the energy of ocean surface waves and the capture of that energy to do useful work. Good wave power locations have a flux of about 50 kW per metre of shoreline.
- As per one estimate, the potential for shoreline-based wave power generation is about 50,000 MW.
- Deep water wave power resources are truly enormous, but perhaps impractical to capture.
- The world's first 2250 MW commercial waveform is in Portugal. Other plans for wave forms include a 3 MW plant in Scotland and a 20 MW plant in England.

Renewable resources continued…..

(vi) Ocean thermal energy:

- Ocean Thermal Energy Conversion (OTEC) is a new technology which converts the thermal energy , available due to temperature difference between the warm surface water and the cold deep water, into electricity. This technology is still in its infant stage.
- Concept designs of small OTEC plants have been finalized. However, their commercial prospects are quite uncertain.
- The potential is likely to be more than that of tidal or wave energy . But, it is a very low grade solar thermal energy and the efficiency of energy recovery is quite low.

Statistical report on energy scenario in India

- India currently ranks as the world's eleventh largest energy producer, accounting for about 2.4% of the world's total annual energy production, and as the world's sixth largest energy consumer, accounting for 3.3% of the world's total annual energy consumption.
- Thus India is a net energy importer, mostly due to the large imbalance between oil production and consumption.
- The per capita primary energy consumption is 520 KGOE for India, where as the world average is 2366 KGOE (2007 data).
- Similarly, the per capita annual electrical energy consumption in India is 702 kWh whereas the world average is 2600 kWh (2007 data).

Electrical Power Generations as on November, 2010

Resource	Production (MW)	Percentage share
Thermal: Coal Gas Oil	89,778.38 17,384.85 1,199.75 Total: 1,08,362.98	53.3 10.5 0.9 Total: 64.7
Hydro	37,367.40	24.7
Renewable Energy Sources (excluding hydro)	16,786.98	7.7
Nuclear	4560.00	2.9
Total	1,67,077.36	100

Conventional energy scenario in India

(i) Fossil fuels:

- India has vast reserves of coal, the fourth largest in the world after USA, Russia and China.
- According to a rough estimate, the total recoverable coal in India is 90 billion tonnes. With the present rate of consumption, India will have enough coal for about 300 years.
- Oil and Gas represent over 40 per cent of the total energy consumption in India.
- Crude oil Reserves are estimated as 600 million tonnes, enough to last for about 22 years.
- Natural gas reserves are estimated as 1000 billion m^3, enough to last for about 30 years.

(ii) Hydro Resources:

- India stands seventh in the list of nations with hydro resources with a total potential of 100,000 MW of which approximately 37,367 MW has been developed.

Conventional energy scenario in India continued…

- Huge installation cost, environmental and social problems are the major difficulties in its development.

(iii) Nuclear Resources:

- India has modest reserves of uranium, mostly located at Jharkand. Huge deposits of natural uranium , which promise to be one of the top 20 of the world reserves, have been found in Tummalapalle belt in the southern part of the Kadapa basin in AP (Hindu, 20th March 2011 report).
- Nuclear-power generation is planned to reach 10,280 MW by the year 2012 and 20,000 MW by 2020.
- Thorium is available in abundance in India in the form of monazite (ore) in the sand beaches of Kerala.
- The economically viable reserve of thorium in India is estimated at 3,00, 000 tonnes, which is 25% of the world's thorium reserves.

Renewable energy scenario in India

(i) Wind energy:

- The highly successful wind power programme in India was initiated in 1983-84.
- This sector has been growing at over 35% in the last three years.
- India currently (2011) stands 5th in the world in wind power generation after China, USA, Germany, Spain.
- The current installed capacity for wind power stands at 15,567 MW (November 2011), and is mostly located in Tamil Nadu, Maharashtra, Gujarat, Karnataka and Rajasthan.
- The government aims to add 10,000 MW from wind during 11th plan period (2007-2012).

WIND POWER INSTALLED CAPACITY IN INDIA

(As on 31 March 2010)

Sl.No	State	Installed Capacity in MW
1	Tamilnadu	5073.1
2	Maharashtra	2108.1
3	Gujarat	1934.6
4	Karnataka	1517.2
5	Rajasthan	1095.6
6	Madhya Pradesh	230.8
7	Andhra Pradesh	138.4
8	Kerala	28.0
9	West Bengal	1.1
TOTAL		12,126.9

WIND POWER INSTALLED CAPACITY IN INDIA

(As on 31 March 2011)

Sl.No	State	Installed Capacity in MW
1	Tamilnadu	5904
2	Maharashtra	2317
3	Gujarat	2176
4	Karnataka	1727
5	Rajasthan	1525
6	Madhya Pradesh	276
7	Andhra Pradesh	192
8	Kerala	35
9	Others	4
	TOTAL	14,156

WIND POWER INDIA 2012

- The Indian Wind Turbine Manufacturers Association (IWTMA), the World Institute of Sustainable Energy (WISE), and the Global Wind Energy Council (GWEC) announce **WIND POWER INDIA 2012**, India's premier conference and exhibition on wind power development.
- To be held from **28–30 November 2012 at the Chennai Trade Centre, Chennai,** 'Wind Power India 2012' is the second event being organized by IWTMA, GWEC, and WISE.
- The first event 'Wind Power India 2011' was organized from 7–9 April 2011 in Chennai and marked the beginning of a new chapter in the history of wind power events organized in India, receiving a massive response from the global wind fraternity.

WIND POWER INDIA 2012 continued…..

- WIND POWER INDIA 2012 aims to take the event several notches higher.
- Wind power has shown remarkable growth over the past decade, with the global cumulative installed capacity reaching 215 GW by June 2011.
- By 2015, installations are predicted to grow at an annual average rate of 15.5%, with the annual installed capacity growing to 81.4 GW from the current 39.5 GW (2010), including offshore development.
- India has maintained its position as one of the leading wind power nations, remaining at fifth position worldwide in terms of cumulative installations in 2011.

WIND POWER INDIA 2012 continued…..

- The Indian wind industry has successfully weathered the economic slowdown encountered by many other nations and is moving towards achieving maturity.
- Presently, the country has a cumulative installed capacity of 15,567 MW.
- The capacity addition for FY 2011-12 is expected to be around 3,000 MW, out of which 1,411 MW has already been achieved.
- According to WISE estimates, the annual capacity increase for the Indian wind market is expected to reach 5000 MW by 2015.

WIND POWER INDIA 2012 continued…..

- As witnessed in last year's event, WIND POWER INDIA 2012 will continue to focus on India's pre-eminent position in the global wind market, bringing together the entire international wind fraternity into its realm.
- But this time on, the event will be organized on a grander scale comprising a state-of-the-art, business-oriented, and technically-innovative conference, and a high-tech international exhibition.
- With huge opportunities for networking, knowledge-sharing, and B2B meets, you will also find yourself in the elite company of some of the biggest names in the global wind industry.

Renewable energy scenario in India continued…..

(ii) Solar energy:

- India receives a solar energy equivalent of more than 5,000 trillion kWh per year, which is far more than its total annual consumption.
- The daily global radiation is around 5 kWh per sq. m per day with sunshine ranging between 2300 and 3200 hours per year in most parts of India.
- Though the energy density is low and the availability is not continuous, it has now become possible to harness this abundantly available energy very reliably for many purposes by converting it to useful heat or through direct generation of electricity.
- The Conversion systems are modular in nature and can be appropriately used for decentralized applications.

Renewable energy scenario in India continued…..

- In an ambitious plan to meet energy demands, Government of India approved in November 2009 the **Jawaharlal Nehru National Solar Mission** 'Solar India' at an estimated cost of Rs 4,337 crores.
- This solar mission aims to generate 20,000 MW by 2022.
- The mission proposes to scale-up off-grid solar applications by installing another 2,000 MW capacity by 2022 including 20 million square metres solar power collective area and 20 million solar lines

Renewable energy scenario in India continued…..

- There will be an aggressive research and development department to reduce the cost and improve the overall performance of this field. A sum of Rs 385 crores will be spent on research and development.
- The R&D department will carry out field-testing of emerging applications in solar energy and the first phase of the mission was started carefully with proven applications.
- For facilitating the early launch of the mission, the public sector Vidyut Vitraran Nigam, a subsidiary of NTPC, was designated as a nodal agency for entering into power purchase agreement with the solar power developers.

Renewable energy scenario in India continued…..

(a) Solar thermal energy:

- Use of solar thermal energy is being promoted for water heating, cooking, drying and space heating through various schemes.
- The government is proposing to make solar-assisted water heating mandatory in certain categories of buildings through amendments in the building bylaws.
- Banglore has been declared a solar thermal city with special attention to popularize solar water heaters, and Thane in Mumbai is to follow soon.

Renewable energy scenario in India continued…..

- Several Large projects are under consideration at the Ministry of New and Renewable Energy.
- India is planning to develope 60 ‘Solar Cities’ based on a model already practiced in New York, Tokyo and London.
- The target is to reduce the use of conventional energy resources by at least 10% over the next five years.
- Recently, the idea of an integrated solar city with ambitious 5 GW solar projects has been mooted by The Clinton Foundation for Gujarat.

Renewable energy scenario in India continued…..

(b) Solar photovoltaic energy:

- Solar PV energy is being used for solar lanterns, home-lighting systems, street lighting systems, solar water pumps and power plants.
- A number of 100 kW grid interactive plants are already in operation at various places in the country.
- A 200 kW plant is installed recently at the native village of Sardar Bhagat Singh in Punjab.
- Aditya Solar Shops: The ministry is promoting the establishment of special sales outlets under the name Aditya solar shops in major cities (104 cities so far).Different models of solar-system devices from various manufactures are sold through these shops.

Renewable energy scenario in India continued…..

(iii) Biomass energy:

- A large quantity of biomass is available in our country in the form of dry waste like agro residues, fuel wood, twigs, etc., and wet wastes like cattle dung, organic effluents, sugarcane bagasse, banana stems, etc.
- The potential for generation of electric power/cogeneration is 16,881 MW from agro residues and 5000 MW from bagasse through cogeneration.
- The potential from urban waste is 2700 MW. Also, there is a vast scope for production of bio-diesel from some plants.

Renewable energy scenario in India

continued…..

(iv) Small hydro energy:

- Hydro resources of capacity less than 25 MW are called small, less than 1 MW are called mini and less than 100 kW are called micro hydro resources.
- The total potential is 15,000 MW out of which 2.015 MW has been realized by approximately 611 plants.

(V) Geothermal energy:

- The potential in geothermal resources in the country in 10,00 MW.
- As a result of various resource assessment studies/surveys, nearly 340 potential hot springs have been identified throughout the country.
- Most of them are low temperature hot water resources and can best be utilized for direct thermal applications.

Renewable energy scenario in India

continued…..

- Only some of them can be considered suitable for electrical power generation.
- The geothermal reservoirs suitable for power generation have been located at Tattapani in Chhattisgarh and Puga valley of Ladakh, Jammu and Kashmir.
- A 300 kW demonstration electric-power-production plant is being installed at Tattapani.
- Hot water resources are located at Badrinath, Kedarnath and a few other locations in the Himalayan ranges and elsewhere.
- They are being used mostly for heating purposes and very little has been developed.

Renewable energy scenario in India

continued…..

(vi) Ocean tidal energy:

- There is no functional tidal plant at present. The total potential has been estimated as 9,000 MW.
- Three sites have been identified for development of tidal energy:

(1) Gulf of Kutch: Potential=900MW, Tidal range=5m

(2) Gulf of Cambay: Potential=7,000 MW,

Tidal range=6m

(3) Sundarbans: Potential=1,000 MW, Tidal range=3.9m

- The Ministry of New and Renewable Energy has sponsored the preparation of a feasibility report by the West Bengal Renewable Energy Development Agency (WBREDA) to setup a 3.6 MW capacity demonstration tidal power plant at the Sundarbans area of West Bengal.

Renewable energy scenario in India

continued…..

(vii) Ocean wave and OTEC resources:

- A 150 kW pilot plant has been installed at Vizhingum harbour near Thiruvanadapuram, Kerala.
- The average Potential (annual basis) for Indian coasts has been estimated at around 0.02 MW/m of wavefront. There is a proposal for an OTEC plant at the Minicoy island of Lakhsdweep.

(viii) Fuel Cell and Hydrogen energy:

- Emerging technologies like ‘fuel cell’ and ‘hydrogen energy’ are suited for stationary and portable power generation, which suits transportation purposes.
- The newly established National Hydrogen Energy Board will provide guidance for the preparation and implementation of the National Hydrogen Energy Road Map, covering all aspects of Hydrogen energy.

Grid interactive renewable power in India (In MW as on 30.06.2010)

1.	Wind:	12,009.48
2.	Small hydro:	2,767.05
3.	Cogeneration:	1,411.53
4.	Biomass:	973.56
5.	Solar:	12.28

Total: 17,173.09 MW

Syllabus

UNIT II SOLAR ENERGY

Introduction to solar energy: solar radiation, availability, measurement and estimation– Solar thermal conversion devices and storage – solar cells and photovoltaic conversion – PV systems – MPPT. Applications of PV Systems – solar energy collectors and storage.

THE SUN

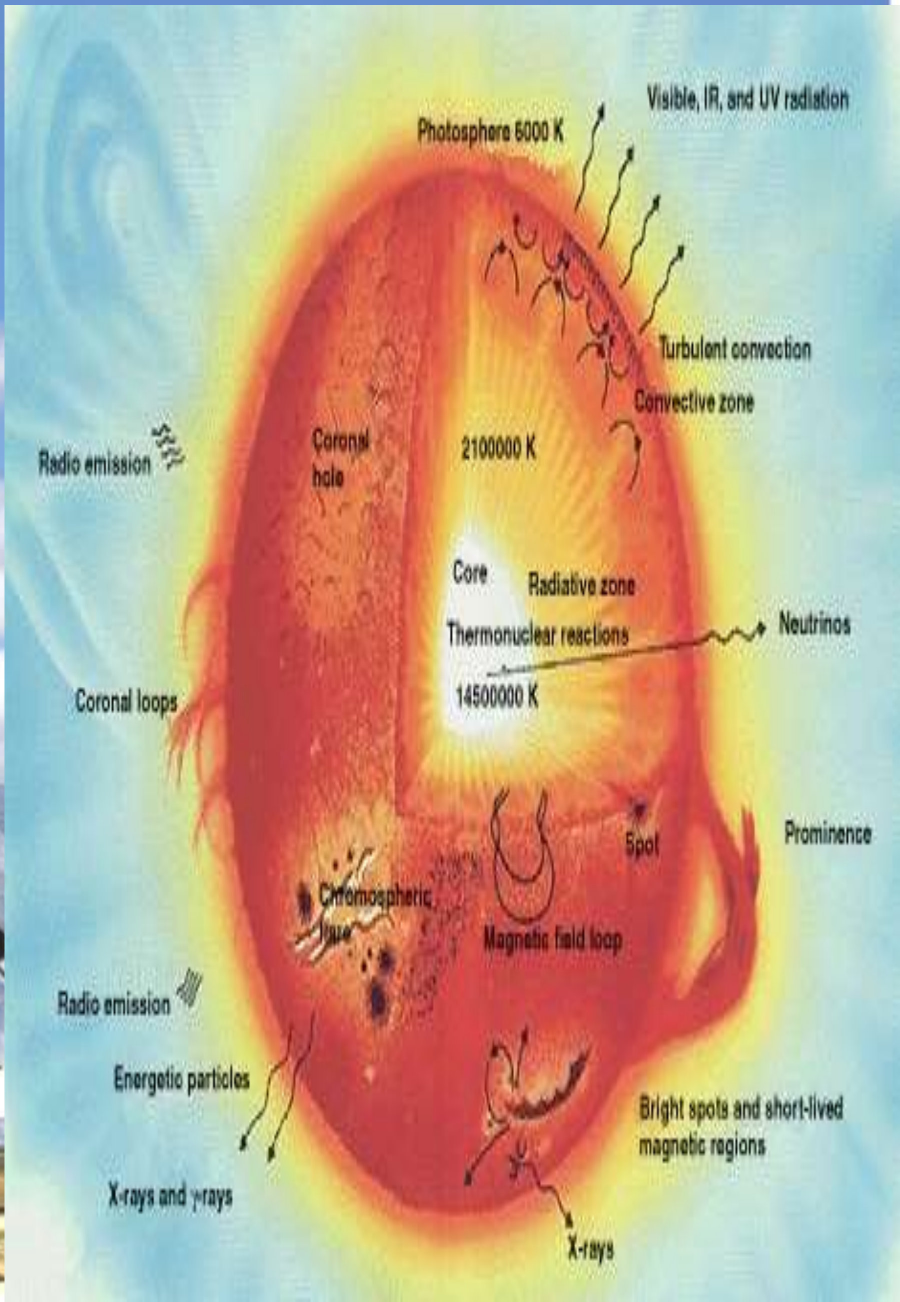
- The sun is a hydrodynamic spherical boby of extremely hot ionized gases (plasma), generating energy by the process of thermonuclear fusion with a diameter of 1.39*10^9 m, at a distance of 1.5 * 10^11 from the earth. The temperature of the interior of the sum is estimated at 8*10^6 K to 40*10^6 K, Where energy is released by fusion of hydrogen to helium.
- It is estimated that solar energy equivalent to over 15,000 times the world annual commercial energy consumption reaches the earth every year and 1000 times more power than we need..
- With an effective black body temperature Ts of 5777K, the sun is,effectively, a continuous fusion reactor.
- Several fusion reactions have been suggested to supply the energy radiated by the sun, the most important being in which hydrogen(i.e four protons) combines to form helium (i.e.helium nucleus); the mass of the helium nucleus is less than that of four protons, mass having been lost in the reaction and converted to energy.

- **The reaction is : 4(1H^1) 2He^4 +26.7 MeV**
- **The produced energy must be transferred out to the surface and then be radiated into space .Every body with a temperature different than T=0 K emits radiation as a function of its temperature according to the Stefan-Boltzmann law R= ἐT4**

- **The phenomena of the sun is determined by solar magnetic field it was done by the astronomical methods. • It intersects with many disciplines of pure physics, astrophysics, and computer science, including fluid dynamics, plasma physics including magneto-hydrodynamics(MHD), seismology, particle physics, atomic physics, nuclear physics, stellar evolution, space physics, spectroscopy, radiative transfer, applied optics, signal processing, computer vision, computational physics, stellar physics and solar astronomy.**

PHYSICS OF THE SUN

- The sun is a hydrodynamic spherical boby of extremely hot ionized gases (plasma), generating energy by the process of thermonuclear fusion. The temperature of the interior of the sum is estimated at 8*10^6 K to 40*10^6 K, Where energy is released by fusion of hydrogen to helium
- It is estimated that solar energy equivalent to over 15,000 times the world annual commercial energy consumption reaches the earth every year and 1000 times more power than we need

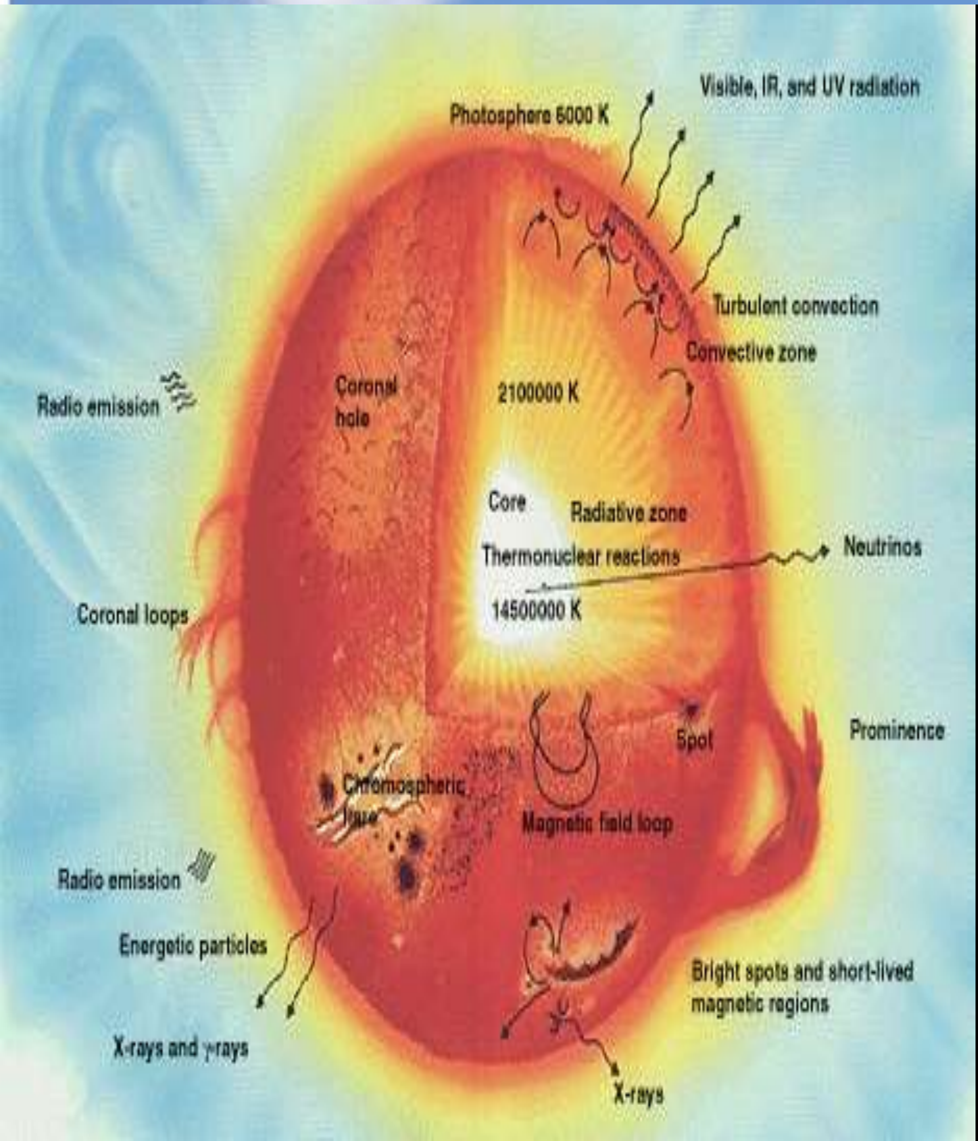


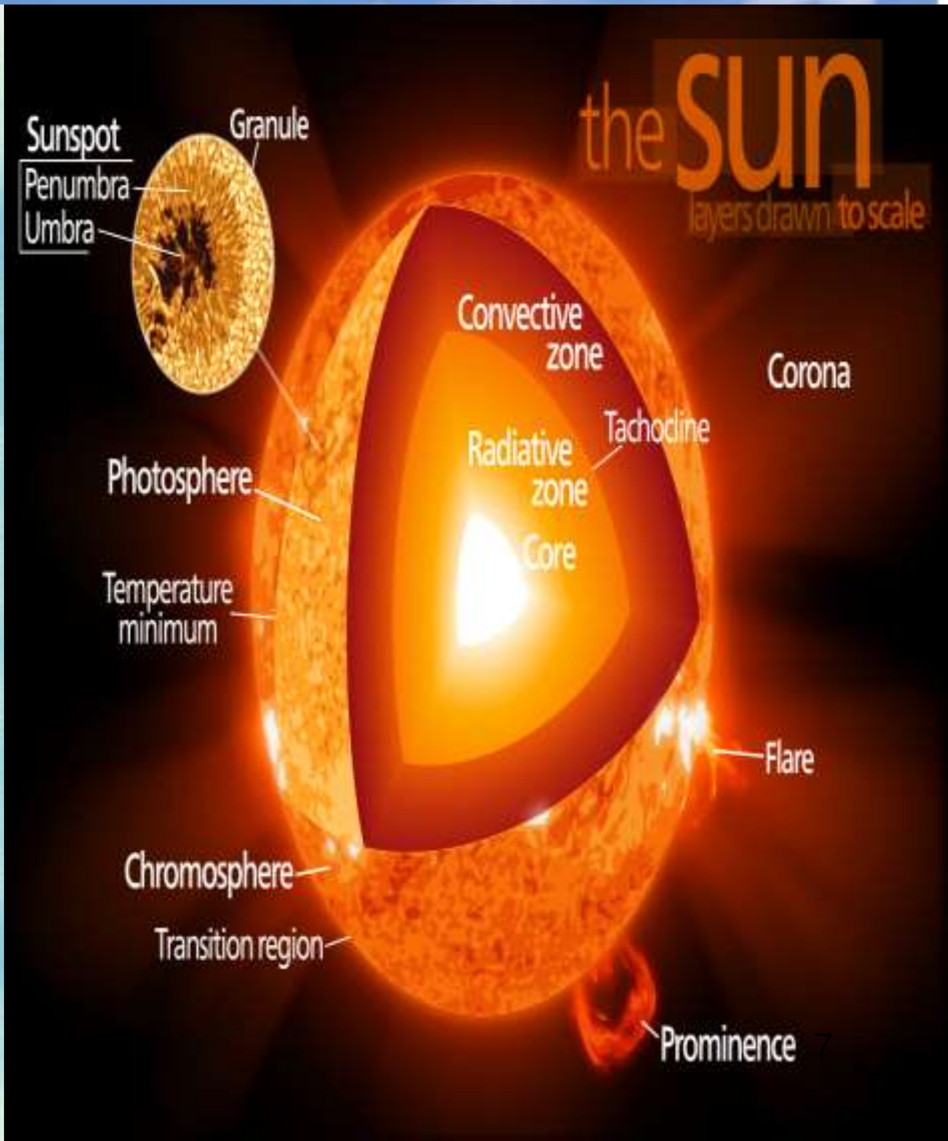
PHYSICS OF THE SUN

- **With an effective black body temperature Ts of 5777K, the sun is,effectively, a continuous fusion reactor. The produced energy must be transferred out to the surface and then be radiated into space .Every body with a temperature different than T=0 K emits radiation as a function of its temperature according to the Stefan-Boltzmann law .**

$$\underbrace{\boxed{R}}_{\text{Radiation emitted}} = \underbrace{\boxed{\epsilon}}_{\text{emissivity}}\underbrace{\boxed{\sigma}}_{\text{Stefan-Boltzmann constant}}\underbrace{\boxed{T}^4}_{\text{absolute temperature}}$$

PHYSICS OF THE SUN





SOLAR ENERGY

•The sun provides the energy needed to sustain life in our solar system. It is a clean, inexhaustible, abundantly and universally available source of renewable energy.

•Solar energy is radiant light and heat from the Sun that is harnessed using a range of ever-evolving technologies(electro magnetic radiation).

Energy is released by the sun as electromagnetic waves. This energy reaching the earth's atmosphere consists of about three spectral regions; (i) Ultraviolet 6.4 % ($\lambda \leq 0.38$ µm), (ii) Visible 48.0 % (0.38 µm < λ < 0.78 µm), and (iii) Infrared 45.6 % ($\lambda \geq$ 0.78 µm) of total energy. Due to the large distance between the sun and the earth (1.495 × 108 km) the beam radiation received from the sun on the earth is almost parallel.

- The solar power where sun hits atmosphere is 10^27 watts, on earth’s is 10^16 watts. The total world-wide power demand of all needs of civilization is 10^13 watts. India has an average annual temperature that ranges from 25C- 27.5 C. The energy radiated by the sun on a bright sunny day is approximately 1 kW/m2.
- It is an important source of renewable energy and its technologies are broadly characterized as either passive solar or active solar depending on how they capture and distribute solar energy or convert it into solar power.
- Energy used for cooling/heating/drying/distillation/power generation ,etc.,
- The Earth receives 174,000 terawatts (TW) of incoming solar radiation (insolation) at the upper atmosphere. • Most of the world's population live in areas with insolation levels of 150-300 watts/m², or 3.5-7.0 kWh/m² per day.

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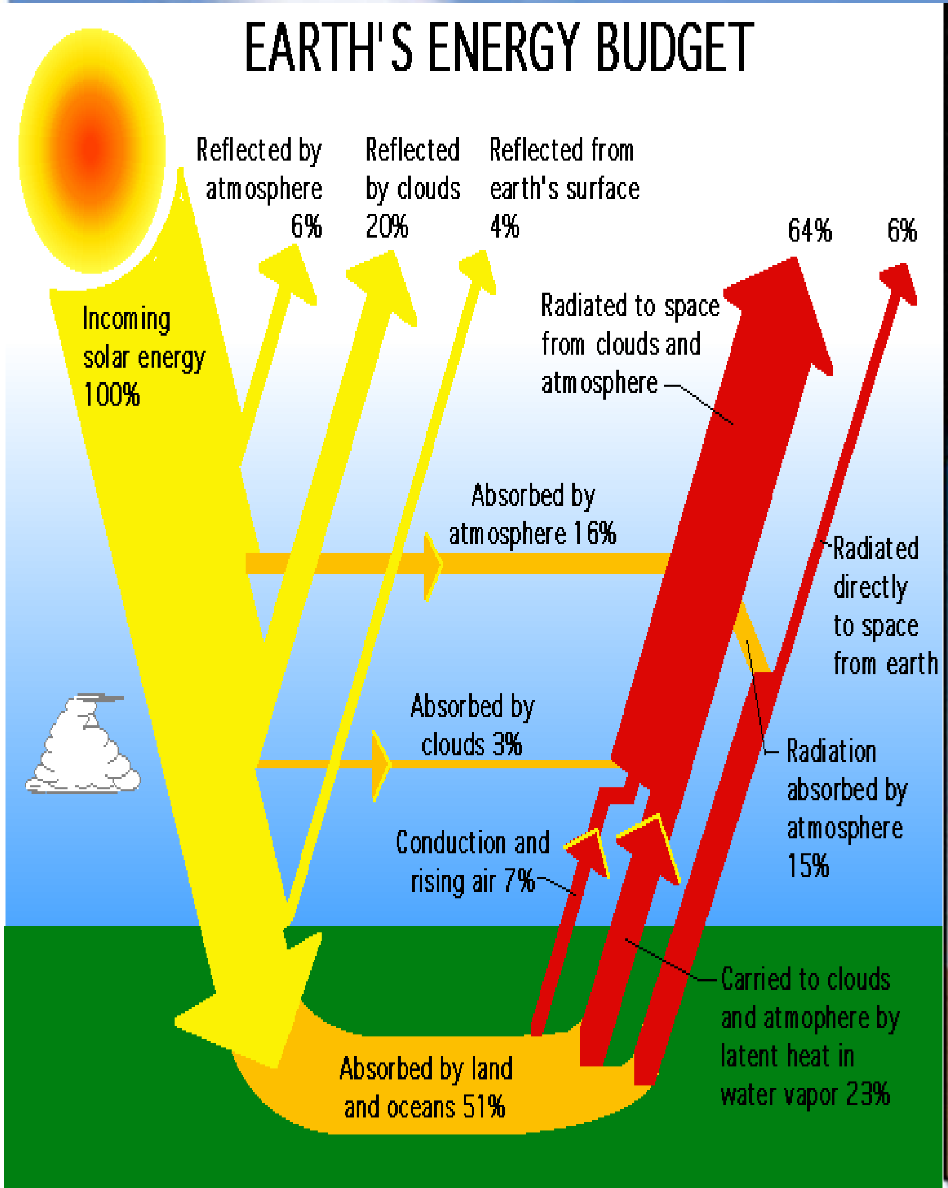
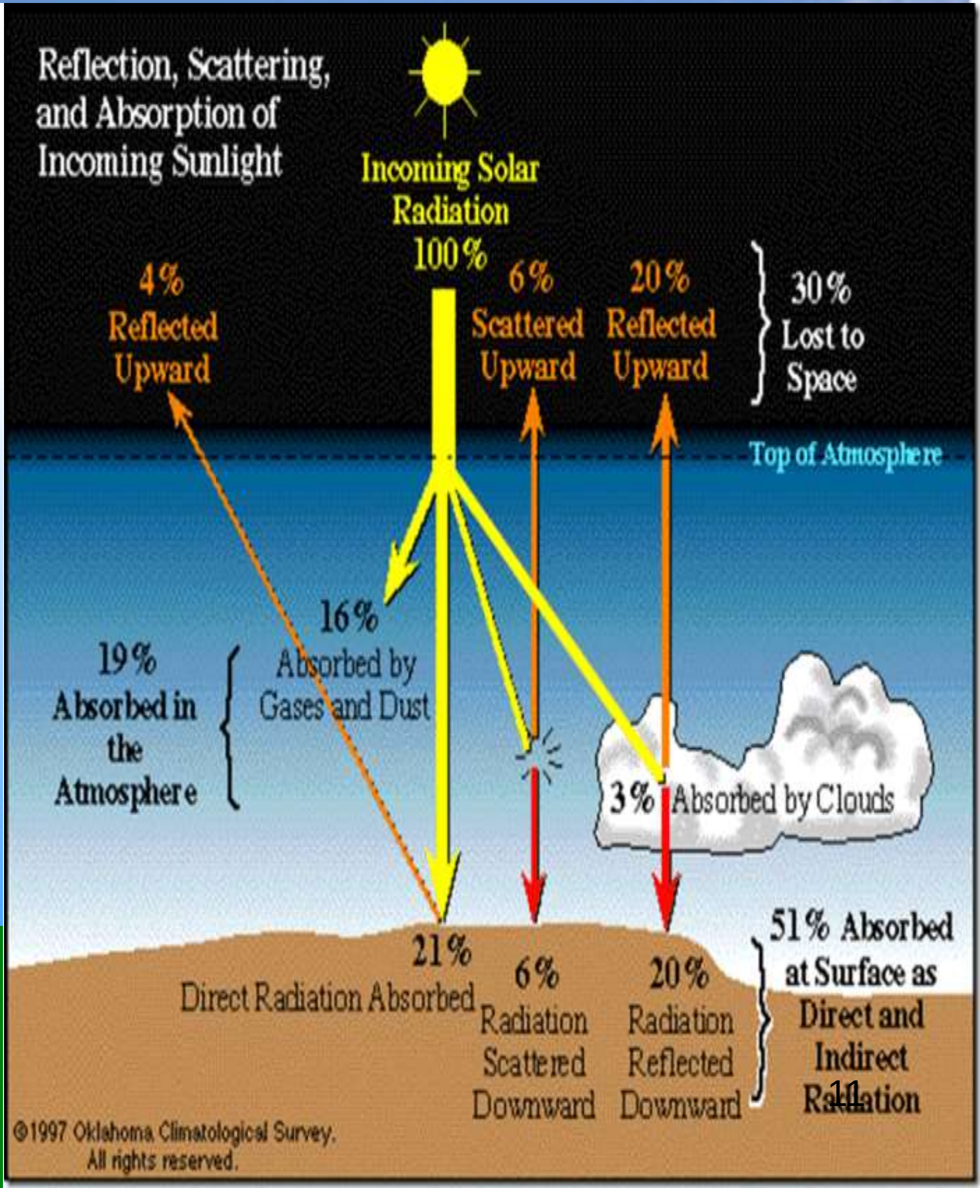
SOLAR ENERGY



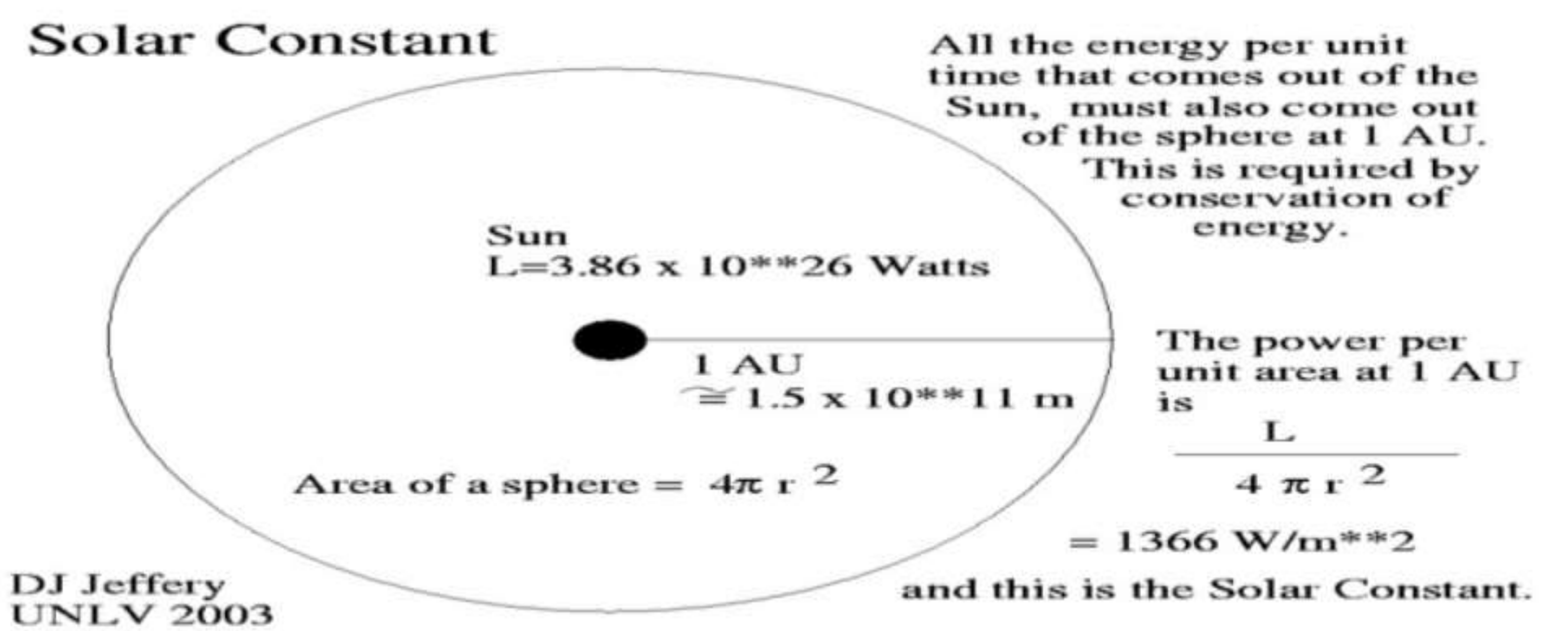


SOLAR CONSTANT

- The rate at which energy reaches the earth's surface from the sun, usually taken to be 1,388 watts per square metre.
- The formula for calculating the solar constant is written as

  So = E(Sun) x (R(Sun) / r)2,

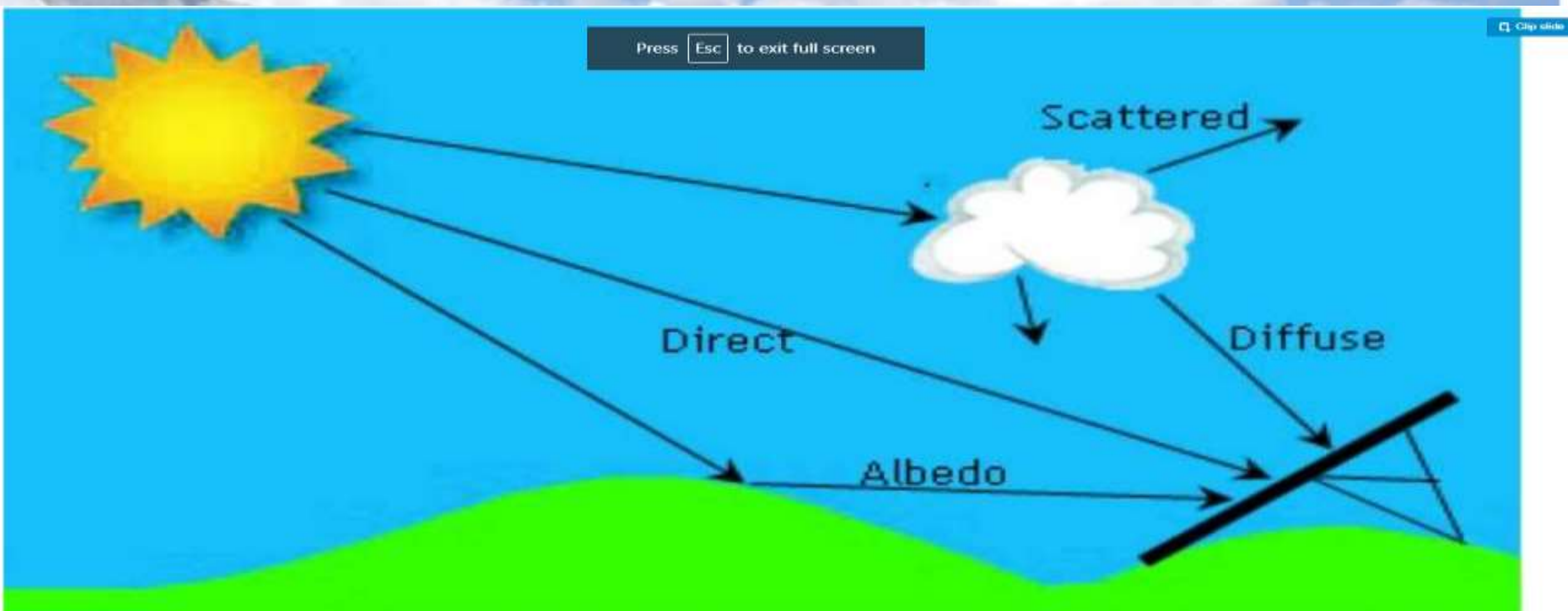
- So-solar constant, E- irradiance of the sun R-Radius of the sun r-distance between the Earth and the sun



ASTRONOMICAL UNIT-A unit of length used for distances within the solar system; equal to the mean distance between the Earth and the Sun (approximately 93 million miles or 150

SOLAR RADIATION

Solar radiations while passing through the earths atmosphere are subjected to the mechanisms of atmospheric absorption and scattering. A fraction of the radiation reaching the earth's surface is reflected back into the atmosphere and is subjected to these atmospheric phenomenon again; the remainder is absorbed by the earth's surface



SOLAR RADIATION

- **Direct Radiation: Solar radiation that reaches to the surface of earth without being diffused is called direct beam radiation.**
- **Diffused Radiation: As sunlight passes through the atmosphere, some of it is absorbed, scattered and reflected by air molecules, water vapour, cloud, dust, and pollutants from power plants, forest fires, and volcanoes. This is called diffused radiation.**
- **Global Solar Radiation: The sum of diffuse and direct solar radiation is called global solar radiation.**
- **Albedo: The earth reflects back nearly 30% of the total solar radiant energy to the space by reflection from clouds, by scattering and by reflection at the earth's surface. This is called the albedo of the earth's atmosphere system**

THE SUN continued…..

- The produced energy must be transferred out to the surface and then be radiated into space .
- The sun provides the energy needed to sustain life in our solar system. It is a clean, inexhaustible, abundantly and universally available source of renewable energy.

Solar energy can be utilized in two ways:

(i) By collecting the radiant heat and using it in a thermal system – called as Solar thermal system.

(ii) By collecting and converting it directly to electrical energy using a photovoltaic system – called as solar photovoltaic system.

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Solar thermal systems

Solar thermal energy collectors

- A solar thermal energy collector is an equipment in which solar energy is collected by absorbing radiation in an absorber and then transferring to a fluid. In general, there two types of collectors:

Flat-plate solar collector:

It has no optical concentrator. Here, the collector area and the absorber area are numerically the same, the efficiency is low, and temperatures of the working fluid can be raised only up to 100 °C.

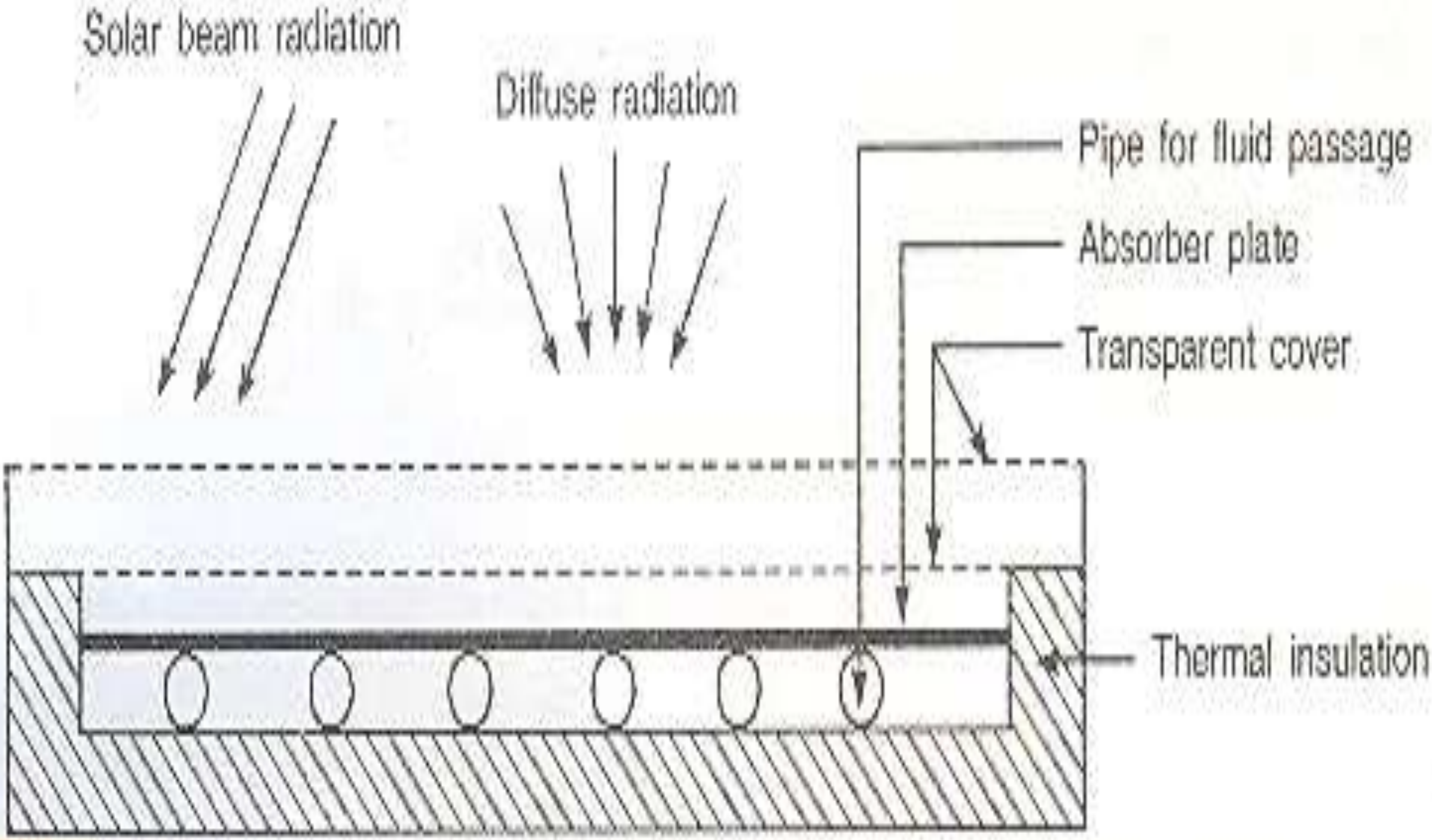
Concentrating-type solar collector:

Here, the area receiving the solar radiation is several times greater than the absorber area and the efficiency is high. Mirrors and lenses are used to concentrate sun rays on the absorber, and the fluid temperature can be raised up to 500° C. For better performance, the collector is mounted on a tracking equipment to always face the sun with its changing position.

Solar flat plate collector

A schematic cross-section of a flat-plate collector is shown in the next slide. It consists of five major parts as mentioned below:

1. A metallic flat absorber plate of high thermal conductivity, made of copper, steel, or aluminium, and having black surface – The thickness of the metal sheet ranges from 0.5 to 1 mm.
2. Tubes or channels soldered to the absorber plate- Water flowing through these tubes takes away the heat from the absorber plate. The diameter of tubes is around 1.25 cm, while that of the header pipe which leads water in and out of the collector and distributes it to the absorber tubes, is 2.5 cm.



Schematic cross section of a flat-plate collector.

Solar flat plate collector
continued……

3. A transparent toughened glass sheet of 5 mm thickness provided as the cover plate - It reduces convection losses through a stagnant air layer between the absorber plate and the glass. Radiation losses are also reduced as the glass is such that it is transparent to short wave radiation and nearly opaque to long wave thermal radiation emitted by interior collector walls and absorbing plate
4. Fibre glass insulation of thickness 2.5 to 8 cm provided at the bottom and on the sides in order to minimize heat loss
5. A container enclosing the whole assembly in a box made of metallic sheet or fibre glass

Solar flat plate collector
continued….

- Since the heat transfer fluid is liquid, this type of flat-plate collector is also known as liquid flat-plate collector.
- The commercially available collectors have a face area of 2 sq.m.
- The whole assembly is fixed on a supporting structure that is installed in a tilted position at a suitable angle facing south in northern hemisphere.
- For the whole year, the optimum tilt angle of collectors is equal to the latitude of its location.
- During winter, the tilt angle is kept 10-15° more than the latitude of the location while in summer it is 10-15° less than the latitude.

Solar concentrating collectors

- While dealing with flat-plate collectors with heat transport medium as water or air, the area of glass cover and that of absorber plate are practically the same.
- Thus, solar radiation intensity is uniformly distributed over the glass cover and the absorber, keeping the temperature rise of the solar device up to 100°C.
- If the solar radiation falling over a large surface is concentrated to a smaller area of the absorber plate or receiver, the temperature can be increased up to 500°C.
- Concentration is achieved by an optical system either from the reflecting mirrors or from the refracting lenses.
- These concentrators are used in medium temperature or high temperature energy conversion cycles.

Solar concentrating collectors

continued….

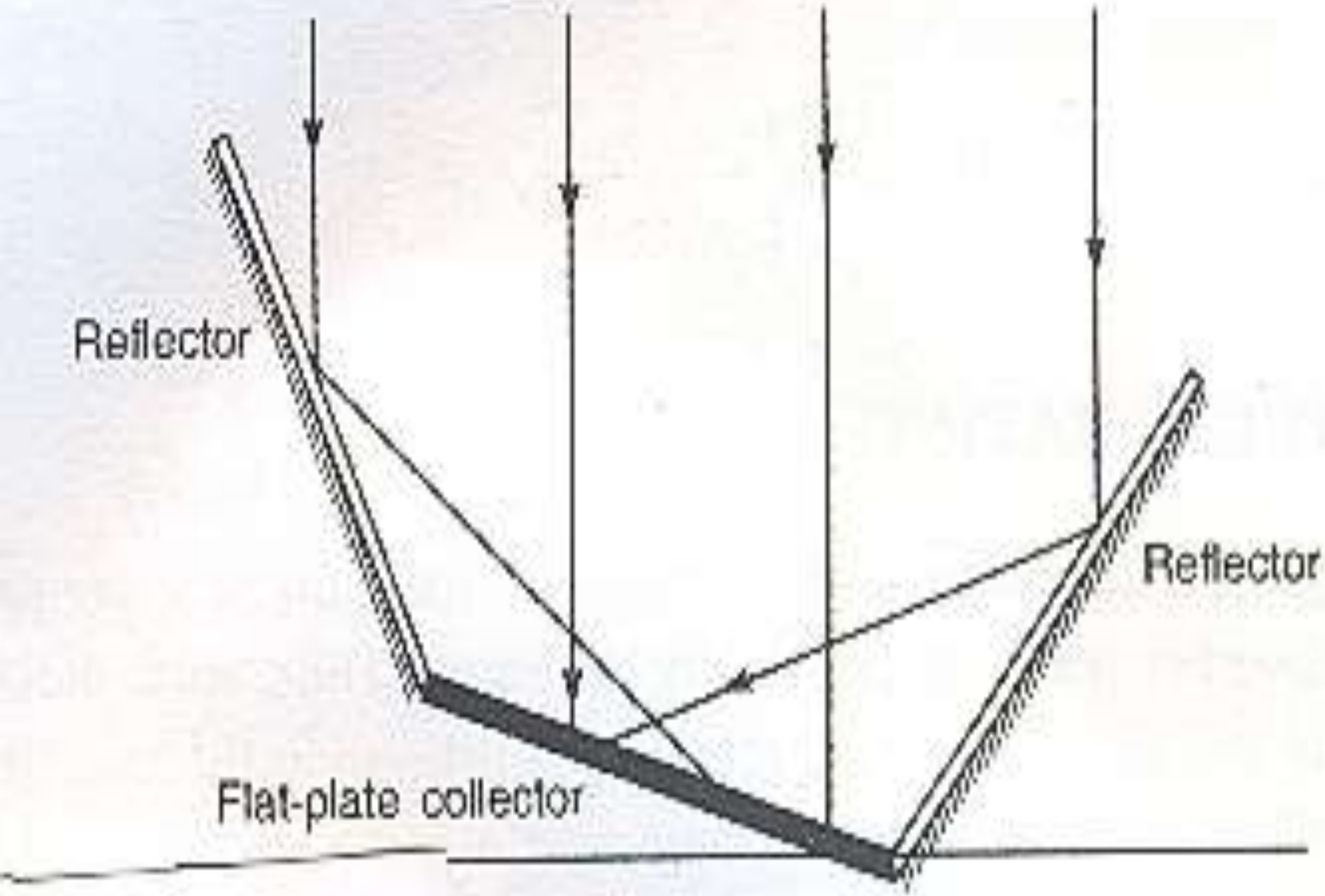
- An optical system of mirrors or lenses projects the radiation on to an absorber of smaller area.
- This process compensates the reflection or absorption losses in mirrors or lenses and losses on account of geometrical imperfections in the optical system.
- For higher collection efficiency, concentrating collectors are supported by a tracking arrangement that tracks the sun all the time, so that beam radiation is on to the absorber surface.
- As collectors provide a high degree of concentration, a continuous adjustment of collector orientation is required.

Solar concentrating collectors

continued….

Plane Receiver with Plane Collector:

- It is a simple concentrating collector (next slide), having up to four adjustable reflectors all around, with a single collector.
- The concentration ratio varies from 1 to 4 and the non-imaging operating temperature can go up to 140°C.
- The concentration ratio (CR) is the ratio of the effective area of the aperture to the surface area of the absorber.
- The value of CR may change from unity (for flat-plate collectors) to a thousand (for parabolic dish collectors).
- The CR is used to classify collectors by their operating temperature range.



Plane receiver with plane reflectors.

Solar concentrating collectors

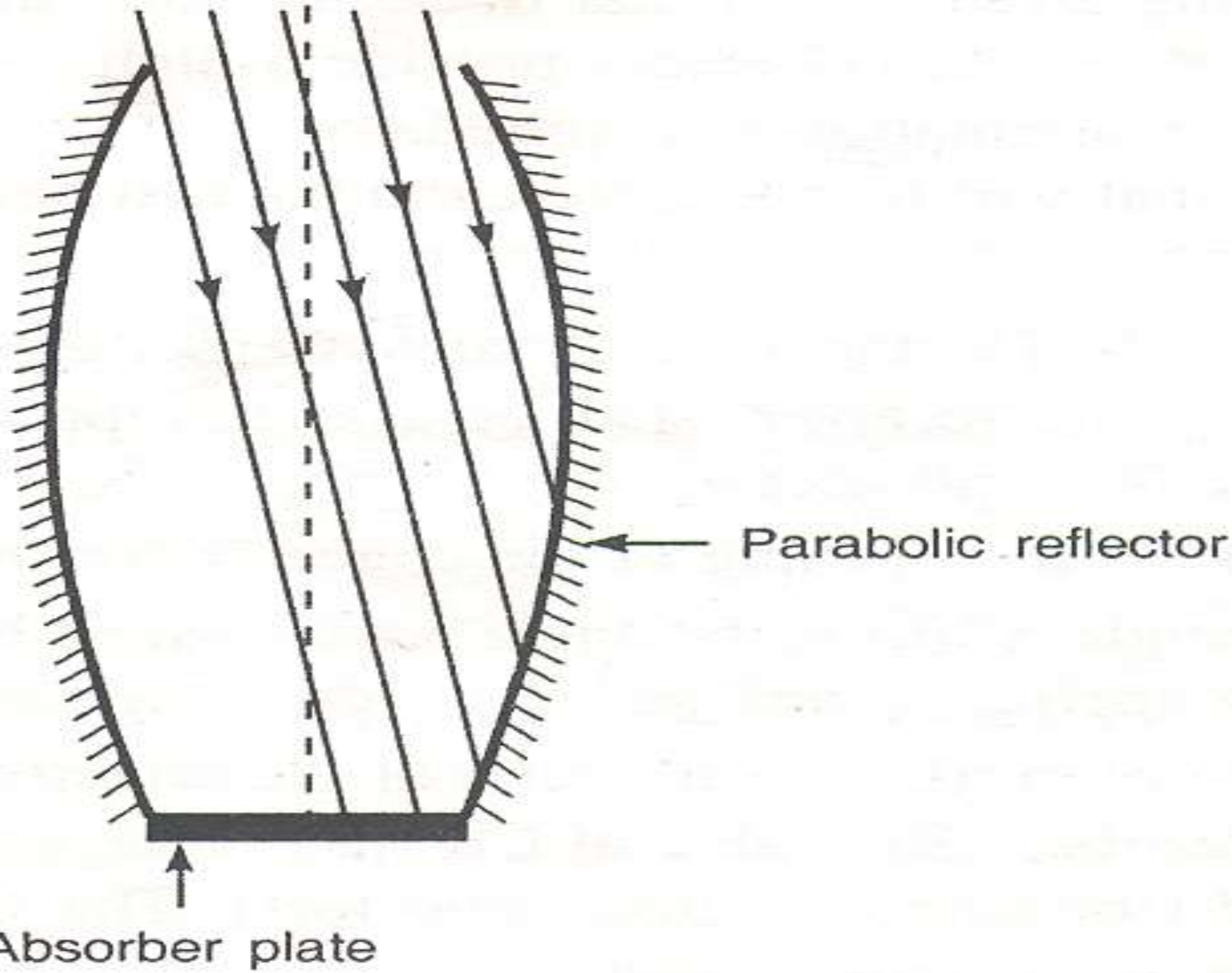
continued….

- **Compound parabolic collector with plane receiver**

  This collector is shown in the next slide. Reflectors are curved segments that are parts of two parabolas. The CR varies from 3 to 10.

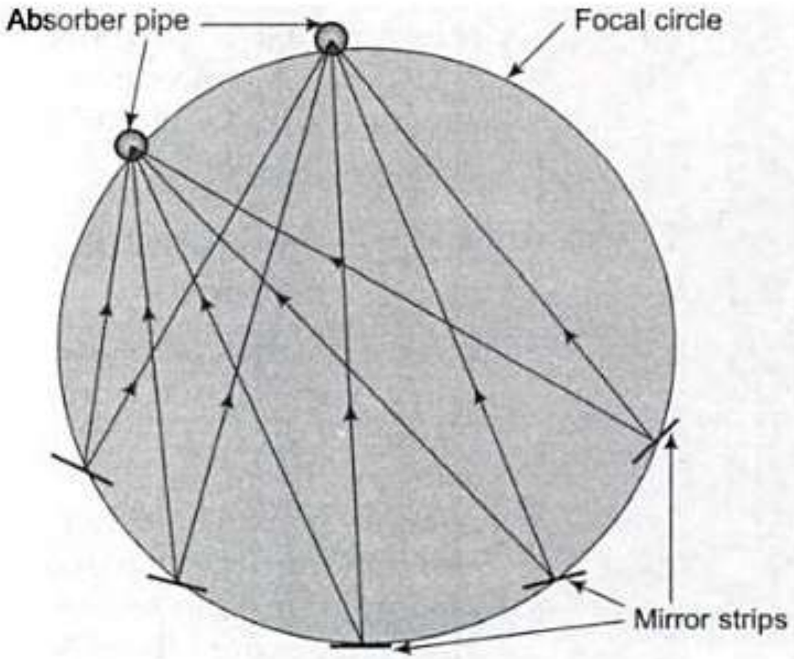
- **Fresnel lens collector**

  This is a refraction type focusing collector made up of an acrylic plastic sheet, flat on one side, with fine longitudinal grooves on the other. The angles of grooves are designed to bring radiation to a line focus. The CR ranges between 10 and 80 with temperature varying between 150°C and 400°C.

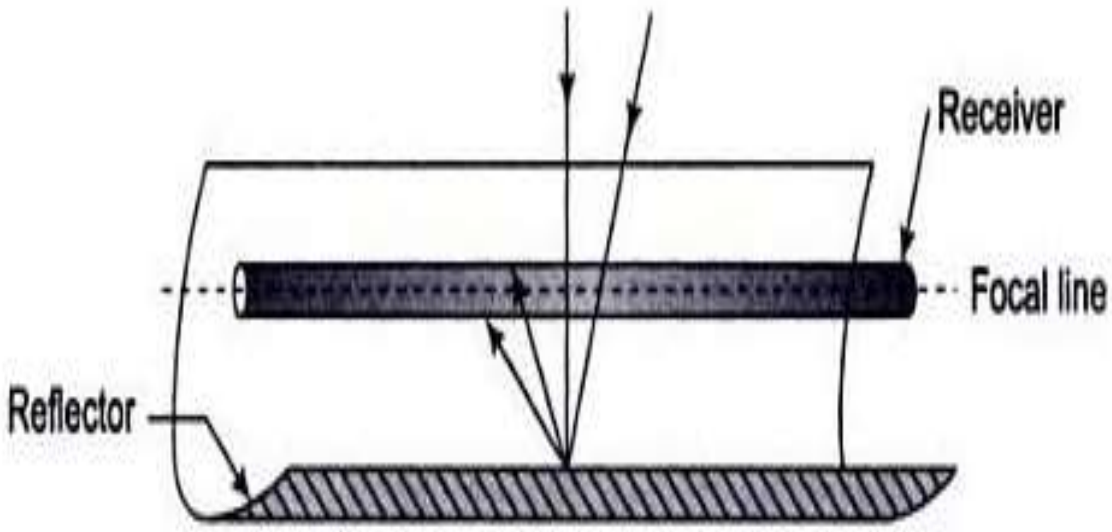


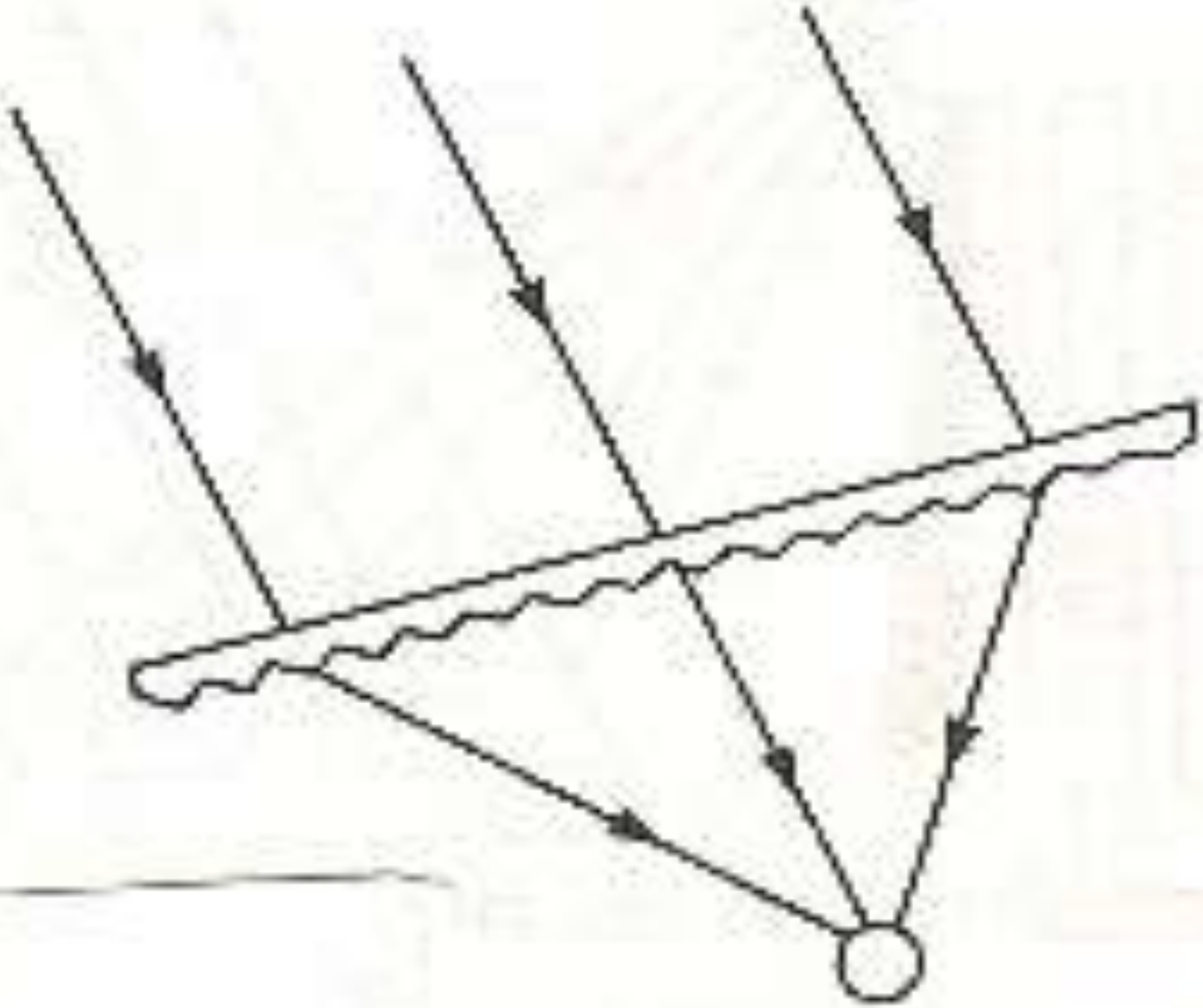
Compound parabolic collector with a plane receiver.

Fixed mirror solar concentrator



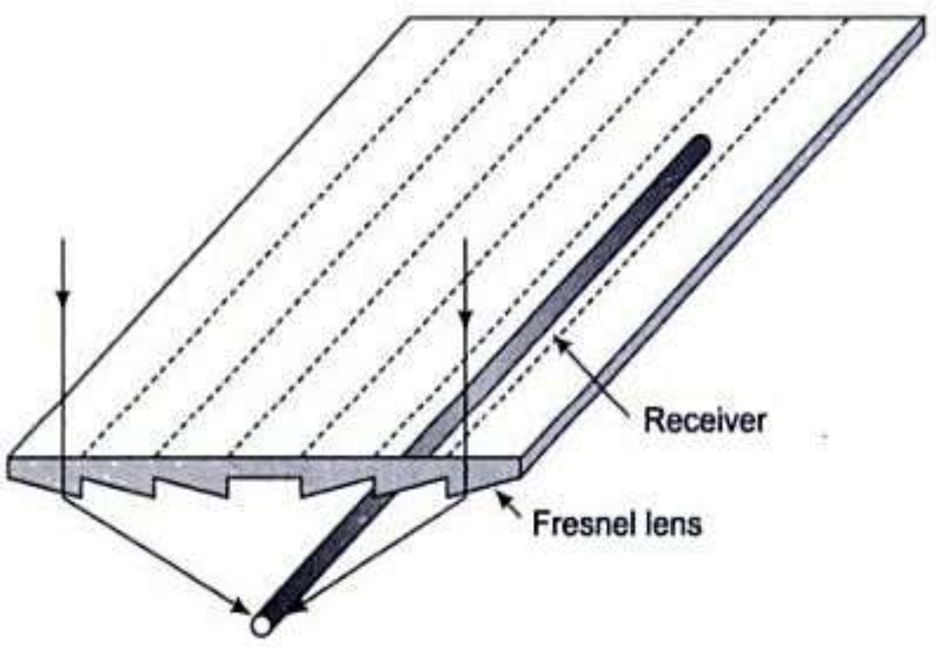
Cylindrical Parabolic Concentrator





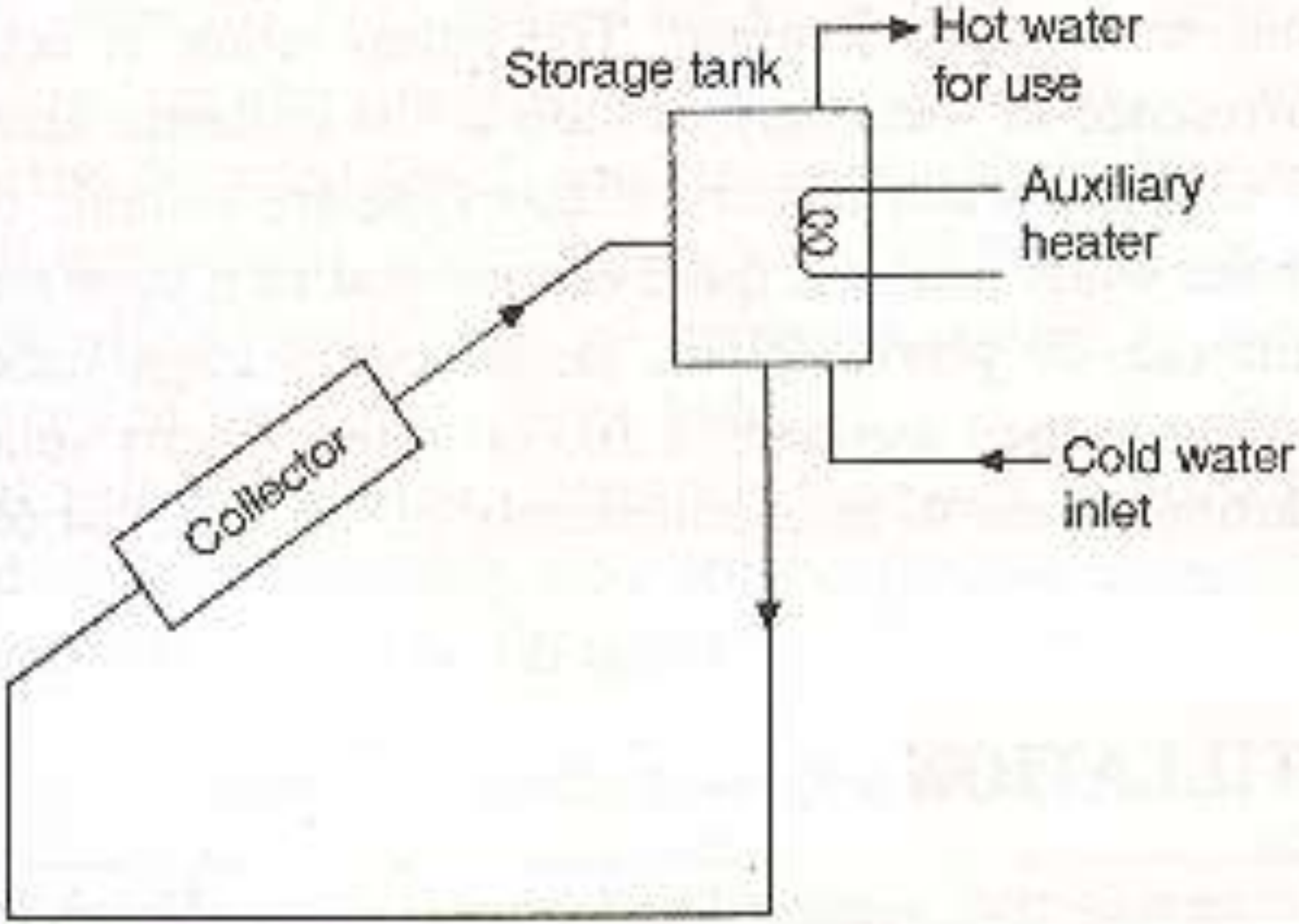
Fresnel lens collector.

Linear Fresnel Lens Collector



Solar water heating

- Solar water heating is one of the most common applications of solar energy.
- A simple solar water heater with natural circulation is shown in the next slide.
- The system consists of a flat-plate solar collector, normally single glazed, and a storage tank kept at a height.
- It is installed on a roof with the collector facing the sun and connected to a continuous water supply.
- The collector comprises copper tubes welded to a copper sheet (both coated with a highly absorbing black coating) with a toughened glass sheet on top and insulating material on the rear.



Natural circulation solar water heater.

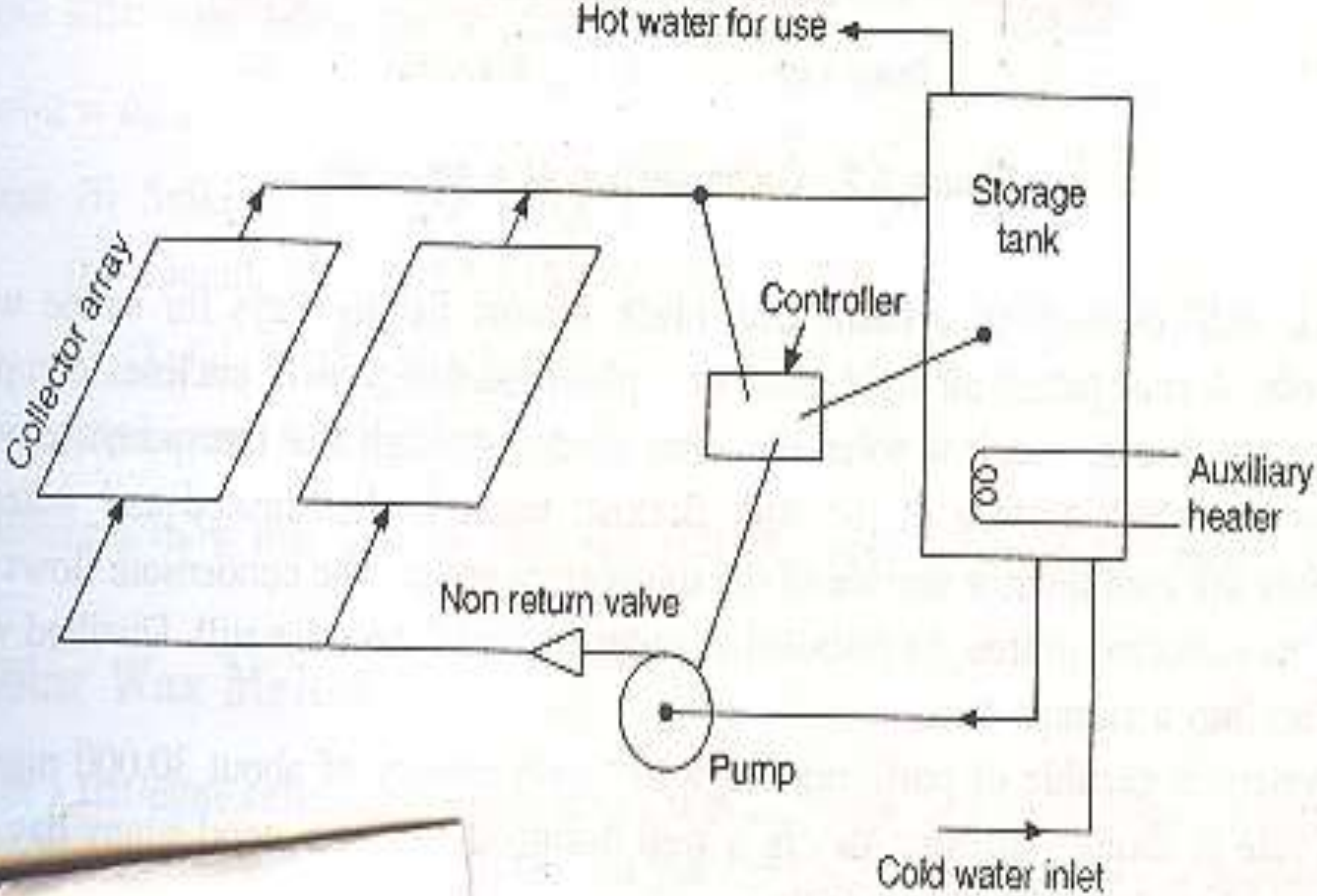
Solar water heating
continued…..

- Water flows through the tubes, absorbs solar heat and is stored in a tank.
- Water circulation is entirely based on the density difference between the solar-heated water in the collector and the cold water in the storage tank.
- Hot water for use is taken out from the top of the tank.
- An auxiliary heating system is provided for use on cloudy and rainy days.

Solar water heating

continued……

- When a large quantity of hot water is required, natural circulation is not feasible and hence forced circulation with a water pump is used as shown in the next slide.
- Water is pumped through a collector array where it is heated and flows back into the storage tank.
- Whenever hot water is withdrawn for use, cold water takes its place.
- The pump motor is actuated by a differential thermostat when the difference in water temperature at the collector array outlet and that at the storage tank exceeds 7°C.



Forced-circulation solar water heater.

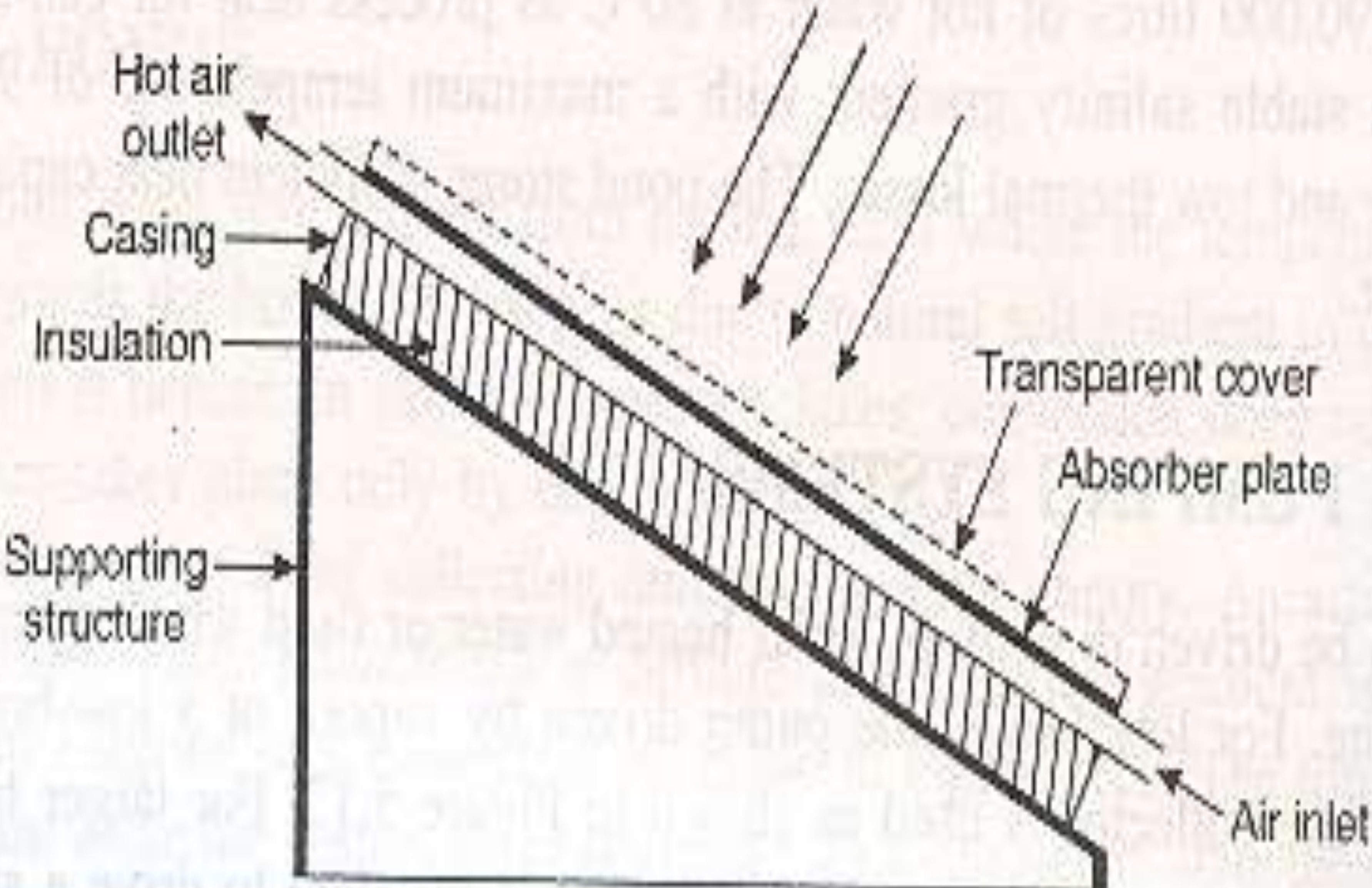
Solar water heating

continued……

- Solar water heaters of this type are suitable for industries, hospitals, hostels and offices.
- A solar water heater is quite economical as it pays back its cost in 3-4 years and lasts for a long time (15-20 years).
- BHEL manufactures large-sized industrial solar water heating systems. According to their estimate, a 10,000-litre capacity solar water heating system utilized for 300 days during a year to maintain supply of hot water at 60°C saves 30,000 liters of diesel per annum.

Solar air heaters

- A solar air heater constitutes a flat-plate collector with an absorber plate, a transparent cover at the top, a passage through which the air flows and insulation at the bottom and sides as shown in the next slide.
- Air to be heated flows between the cover and the absorber plate which is fabricated from a metal sheet of 1 mm thickness.
- Cover is either made up of glass or plastic of 4 to 5 mm thickness.
- Glass wool of thickness 5 to 8 cm is used for bottom and side insulation.
- Full assembly is encased in a sheet metal box and kept inclined at a suitable angle. The face area of a solar heater is about 2 m^2, matching the heat requirement.

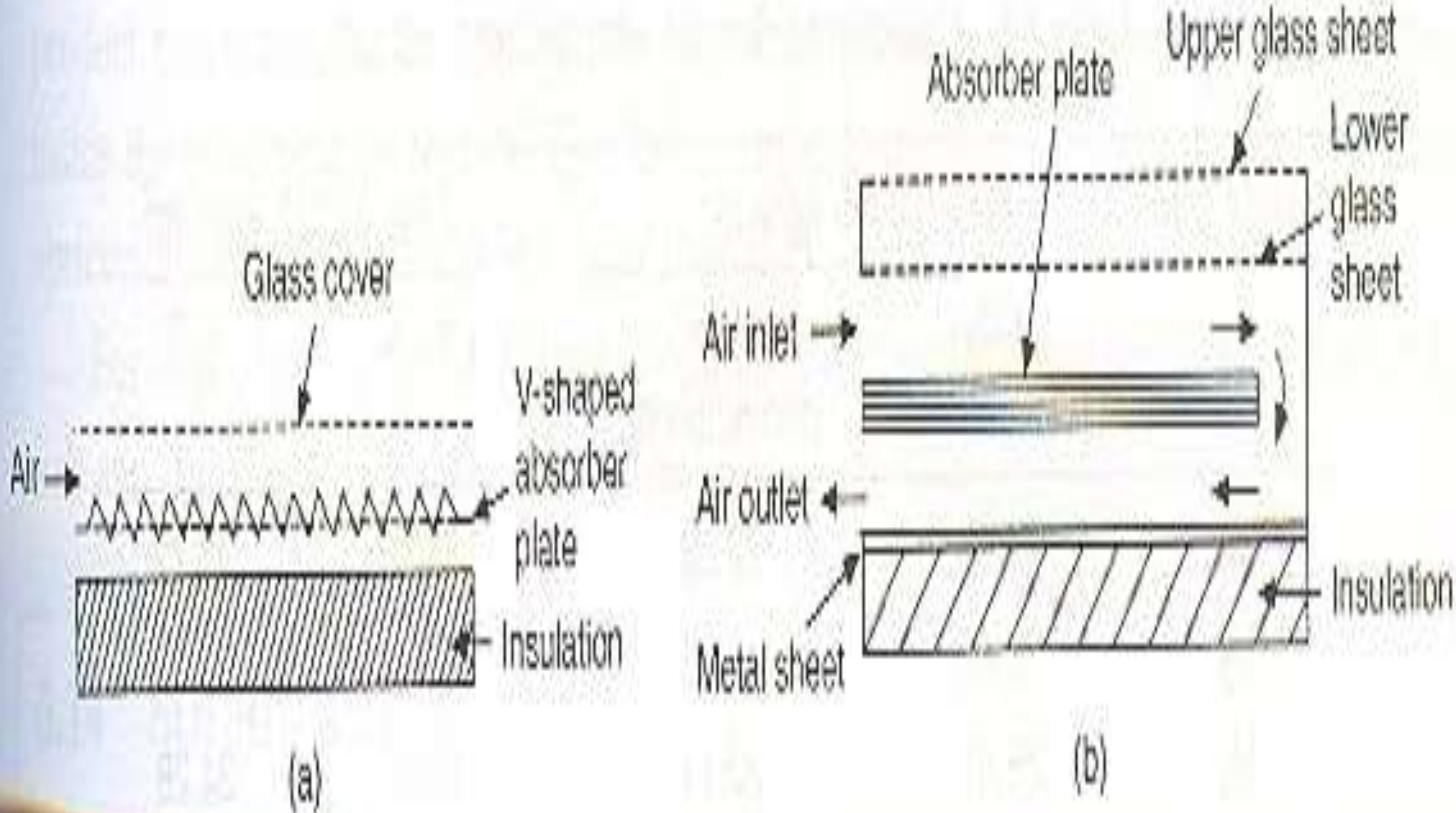


Solar air heater.

Solar air heaters

continued….

- The value of heat transfer coefficient between the absorber plate and the air is low and hence the operating efficiency of a simple air heater is also low.
- To boost heat transfer, the contact area of air with the absorber plate is increased either by adopting a V-shaped absorber plate or by designing two-pass air heaters as shown in the next slide (a) and (b) respectively.
- The two-pass solar air heater carries two glass cover sheets, separated by an air gap which reduces heat losses.
- Solar air heaters have major applications like drying of agricultural products, seasoning of timber, space heating etc.



(a) V-shaped absorber plate, and (b) two-pass solar air heater.

Solar cooling

- One of the thermal applications of solar energy is for cooling buildings (Known as air-conditioning) or refrigeration needed for preserving food.
- Solar cooling is advantageous in tropical countries where the cooling demand is the highest when the sunshine is the strongest.

There are three modes of solar energy cooling:

- Evaporative cooling
- Absorption cooling system
- Passive desiccant cooling

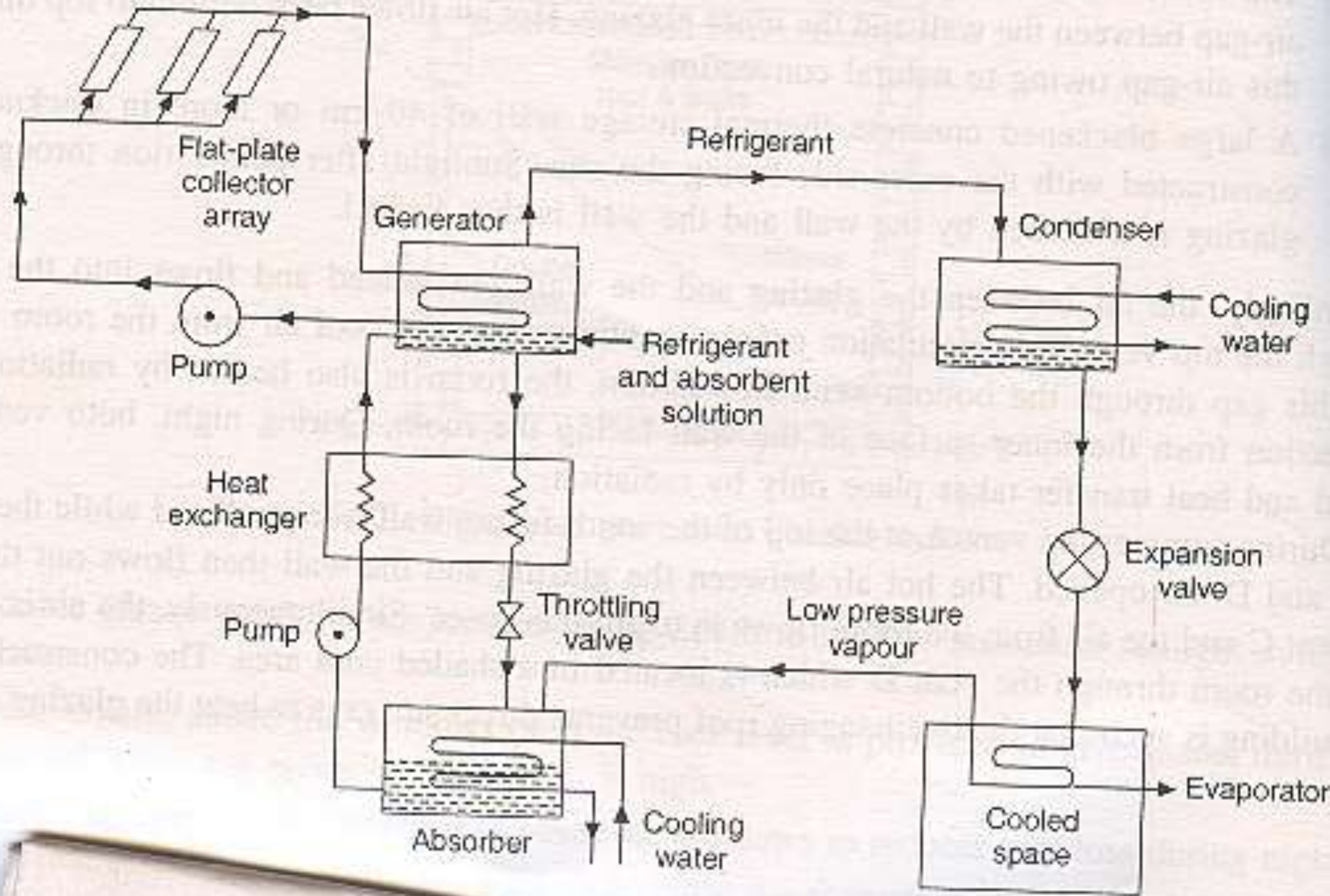
Solar cooling continued….

Evaporative cooling:

- Evaporative cooling is a passive cooling technique, generally used in hot and dry climates.
- It works on the principle that when warm air is used to evaporate water, the air itself becomes cool, and then it cools the living space of a building.
- Common techniques used for cooling are vapour absorption and vapour compression. Among these two, the absorption cooling system is considered to be more practical, since there is a seasonal matching between the energy needs for refrigeration system and the availability of solar radiation. The vapour absorption cooling system is discussed here.

Absorption cooling system

- A simple solar-operated cooling system is shown in the next slide.
- Water is heated in a flat-plate collector array and is passed through a heat exchanger called the generator.
- Suitable chemical solutions for absorptions cooling are: (i) NH_3-H_2O where NH_3 is used as the working fluid, and (ii) LiBr-H_2O solution, where H_2O operates as the working fluid.
- The whole system consists of four units: generator, condenser, evaporator, and absorber
- The generator contains a solution mixture of absorbent and refrigerant, and this mixture gets heated with solar energy.



Solar absorption cooling system.

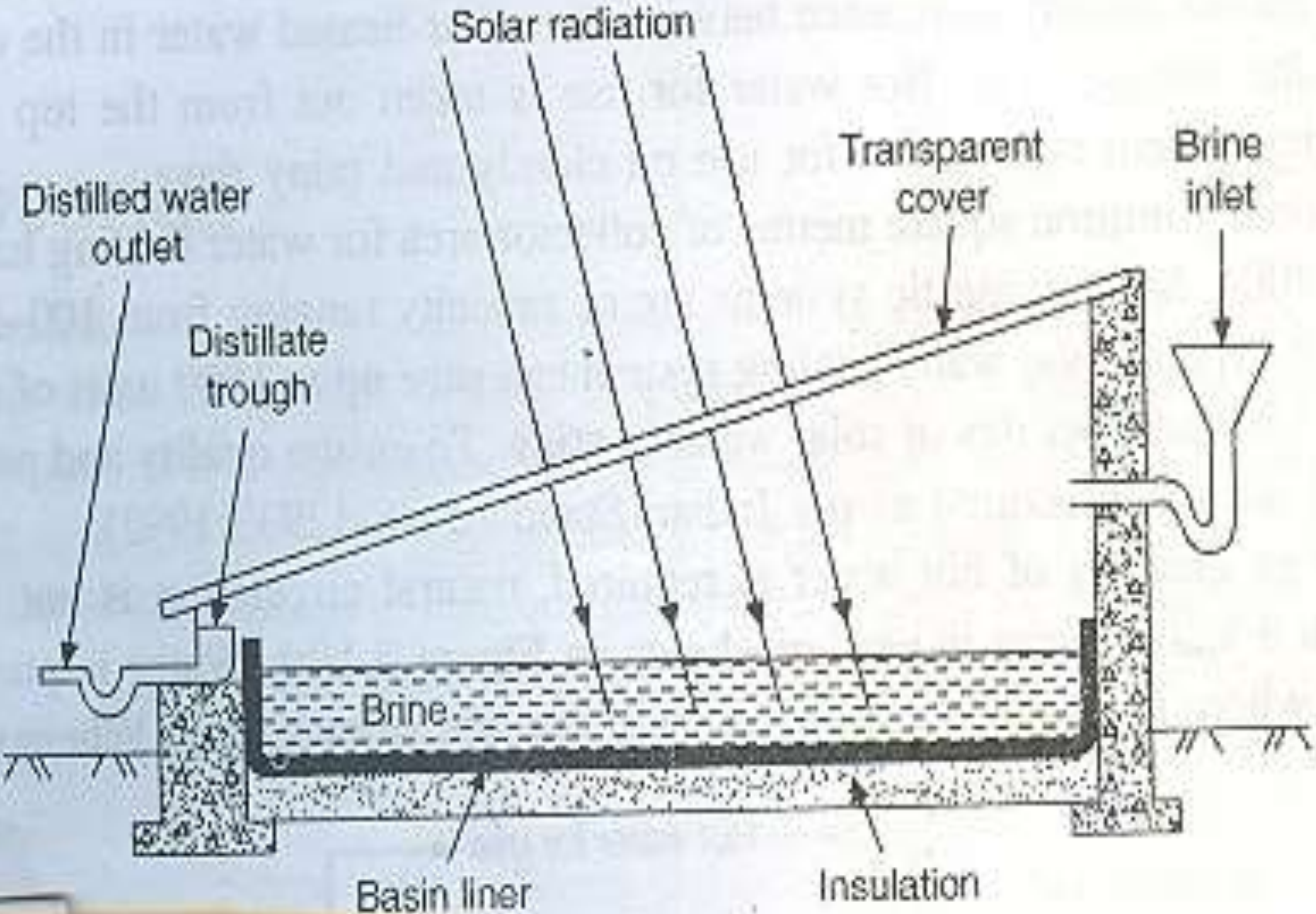
Absorption cooling system

continued….

- Refrigerant vapour is boiled off at a high pressure and flows into condenser, where it gets condensed rejecting heat and becomes liquid at high pressure.
- Refrigerant then passes through the expansion valve and evaporates in the evaporator.
- The refrigerant vapour is then absorbed into a solution mixture taken from the generator in which the refrigerant concentration is quite low.
- The rich solution thus prepared is pumped back to the generator at a high pressure to complete the cycle.
- A heat exchanger is provided to transfer heat between solutions flowing between the absorber and the generator.

Solar desalination

- Safe drinking water is scarce in arid, semiarid and coastal areas.
- At such places, saline water is available underground or in the ocean. This water can be distilled utilizing abundant solar insolation available in the area.
- A device which produces potable water by utilizing solar heat energy is called 'solar water still' and it is shown in the next slide.
- A 'solar still' consists of a basin with black bottom having trays for saline water with shallow depth.
- A transparent air-tight glass or a plastic slanting cover encloses completely the space above the basin.



Cross section of a solar still.

Solar desalination continued…..

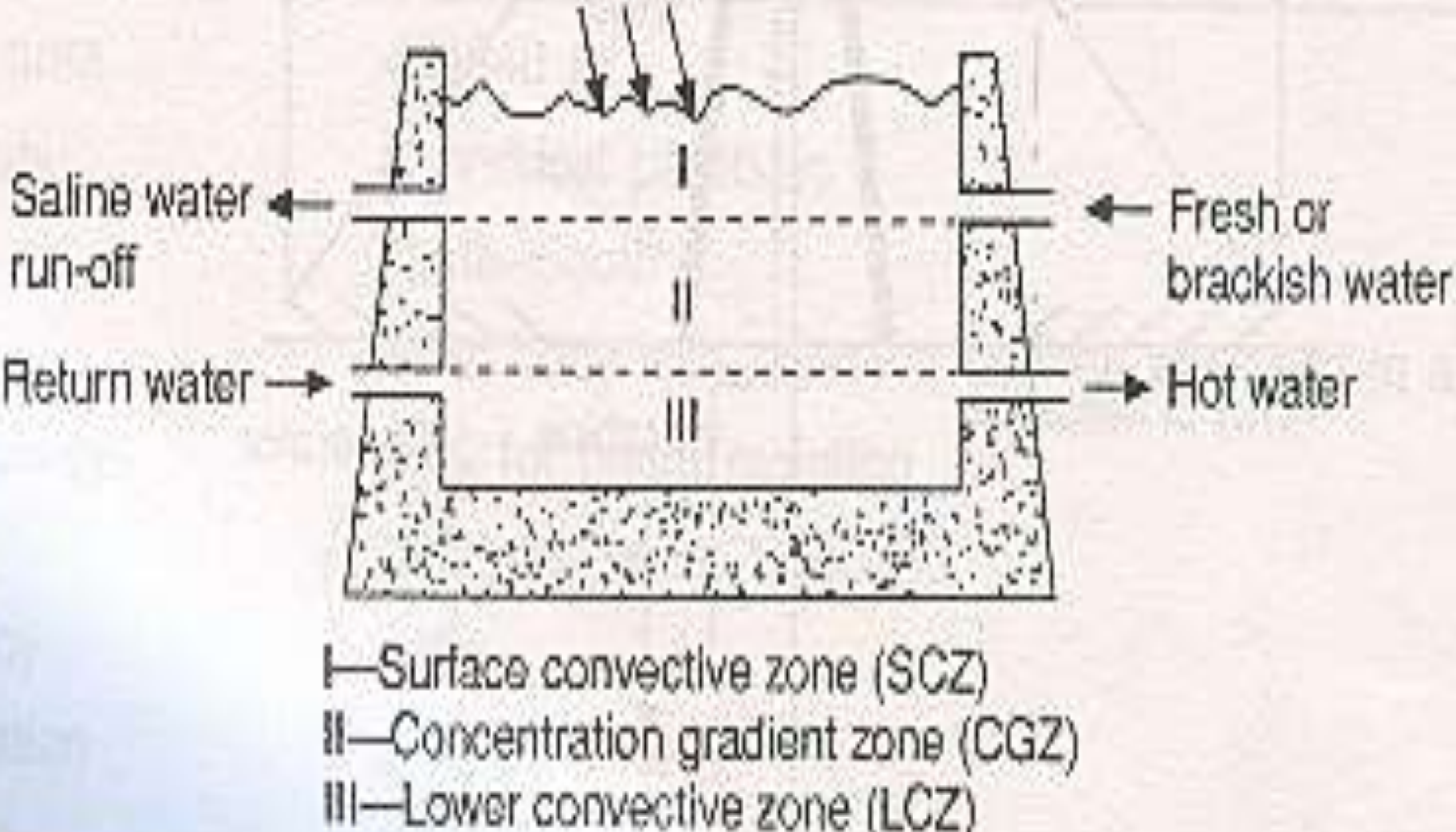
- Incident solar radiation passes through the transparent cover and is absorbed by the black surface of the still.
- Brakish water is then heated and water vapours condense over the cool interior surface of the transparent cover.
- The condensate flows down the glass and gets collected in troughs installed as outer frame of the solar still.
- Distilled water then is transferred into a storage tank.
- This system is capable of purifying sea water with salinity of about 30,000 mg/litre. The production rate is about 3 litres /m^2/day in a well designed still on a good sunny day.
- The cost of water comes to about 50 paise per litre.

Solar desalination continued…..

- The performance of solar still is expressed as the quantity of water produced by each unit of basin area per day.
- However, the production rate depends on the intensity of solar radiation, the ambient air temperature, the wind speed, and the sky condition.
- Desalination output increases with the rise in ambient temperature and is independent of the salt content in raw feed water.
- Design parameters that affect production of drinking water include orientation of still, inclination of glass cover and insulation of the base.

Solar pond

- The concept of solar pond was derived from natural lakes where the temperature rises (of the order of 45°C) towards the bottom.
- It happens due to natural salt gradient in these lakes where water at the bottom is denser.
- In salt concentrated lakes, convection does not occur and heat loss from hot water takes place only by conduction.
- This technique is utilized for collecting and storing solar energy. An artificially designed pond filled with salty water maintaining a definite concentration gradient is called a solar pond. A schematic diagram of a solar pond is shown in the next slide.
- The top layers remain at ambient temperature while the bottom layer attains a maximum steady-state temperature of about 60-85°C.



Schematic diagram of a solar pond.

Solar pond continued….

- For extracting heat energy from the pond, hot water is taken out continuously from the bottom and returned after passing through a heat exchanger.
- As a result of continuous movement and mixing of salty water at the top and bottom, the solar pond can have three zones:
- Surface convective Zone (SCZ) having a thickness of about 10-20 cm with a low uniform concentration at nearly the ambient air temperature
- Non-Convective Zone (NCZ) occupying more than half the depth of the pond. It serves as an insulating layer from heat losses in upward direction
- Lower Convective Zone (LCZ) having thickness nearly equal to NCZ. This Zone is characterized by constant temperature and concentration. It operates as the major heat-collector and also as thermal storage medium

Solar pond continued….

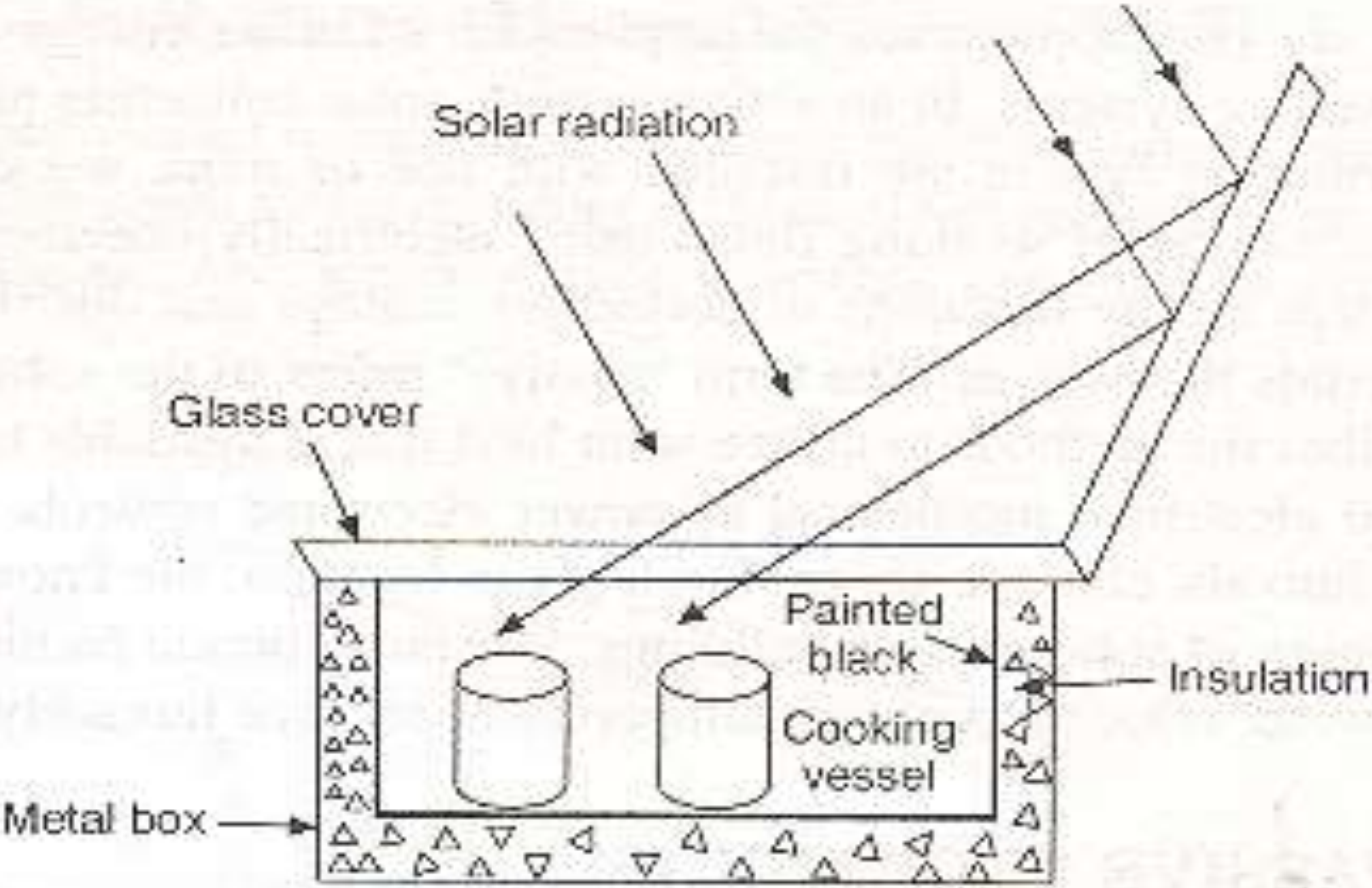
- The largest solar pond so far built is the 250,000 m^2 pond at Bet Arava in Israel.
- In India, the first solar pond with an area of 1200 m^2 was built at the Central Salt Research Institute, Bhavnager in 1973. Since then several solar ponds have been built and are in operation.
- The latest pond with an area of 6000 m^2, built at Bhuj (Gujarat) is the second largest in world. It provides daily 90,000 litres of hot water at 80°C as process heat for can-sterilization.
- This pond maintains a stable salinity gradient with a maximum temperature of 99° C due to high radiation intensity and low thermal losses. The pond stores sufficient heat capable of generating 150 kW of power.

Solar cooker

- Cooking is a common application of solar energy in India. Several varieties of solar cookers are available to suit different requirements.

Box solar cooker:

- It consists of an outer box made of either fibre glass or aluminium sheet, a blackened aluminium tray, a double glass lid, a reflector, insulation and cooking pots as detailed in the figure shown in the next slide.
- A blackened aluminium tray is fixed inside the box, and sides are covered with an insulating material to prevent heat loss. A reflecting mirror provided on the box cover increases the solar energy input.
- Metallic cooking pots are painted black on the outer side. Food to be cooked is placed in cooking pots and the cooker is kept facing the sun to cook the food.



9 Box solar cooker.

Solar cooker continued….

Dish Solar Cooker:

- A dish solar cooker uses a parabolic dish to concentrate the incident solar radiation.
- A typical dish solar cooker has an aperture of diameter of 1.4 m with focal length of 0.8 m.
- The reflecting material is an anodized aluminum sheet having reflectivity of over 80 %.
- The cooker needs to track the sun to deliver power of about 0.6 kW.
- The temperature at the bottom of the vessel may reach up to 400°C which is sufficient for roasting, frying and boiling.
- It can meet the requirement of cooking for 15 people.

Solar drying

- Solar energy is effectively utilized for controlled drying of agriculture produce to avoid food losses between harvesting and consumption.
- High moisture crops are prone to fungus infection, attack by insects and pests.
- Solar dryers remove moisture with no ingress of dust, and the product can be preserved for a longer period of time.
- A cabinet type solar dryer consists of an enclosure with a transparent cover as shown in the next slide.
- Openings are provided at the bottom and top of the enclosure for natural circulation.

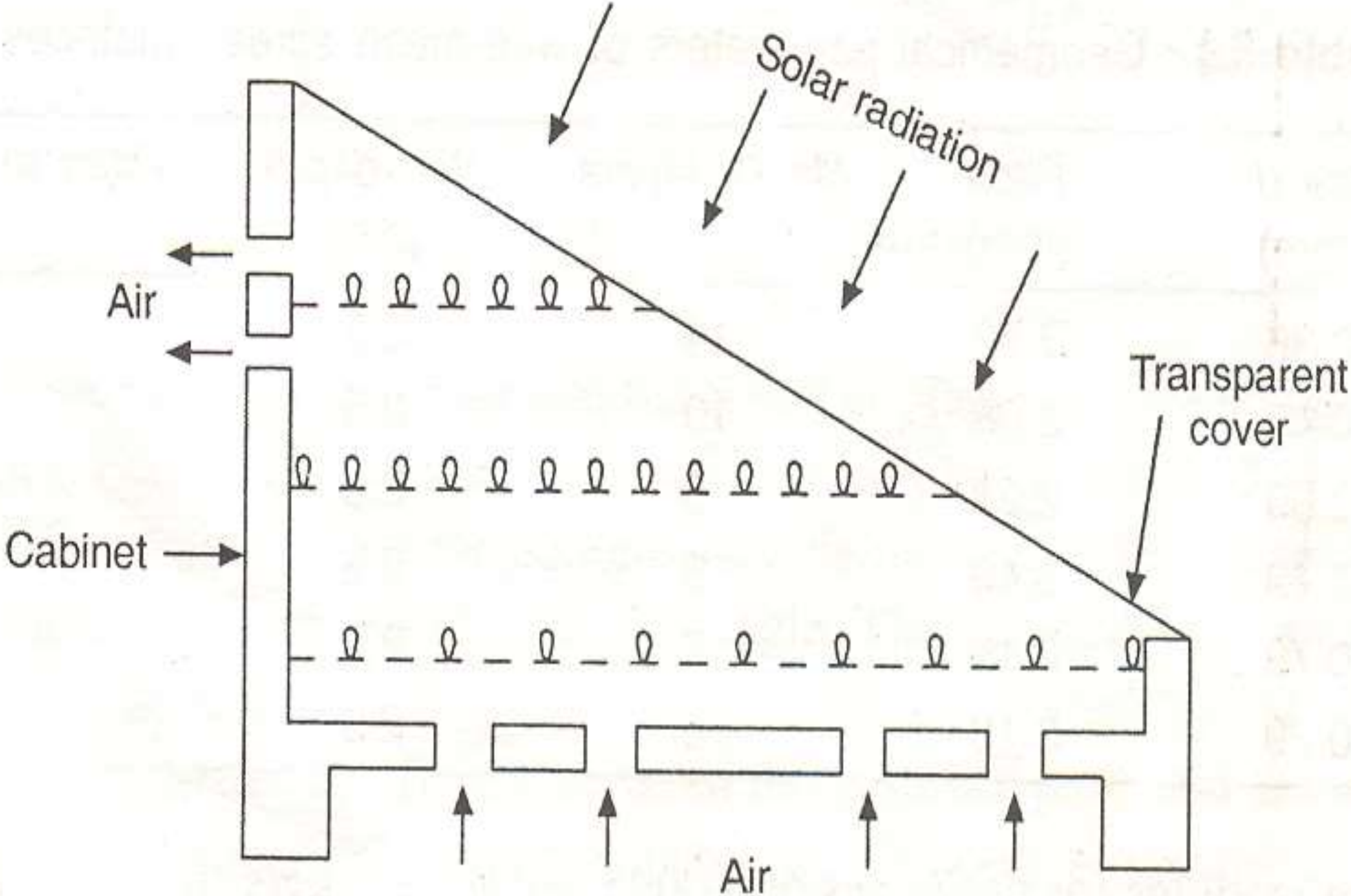


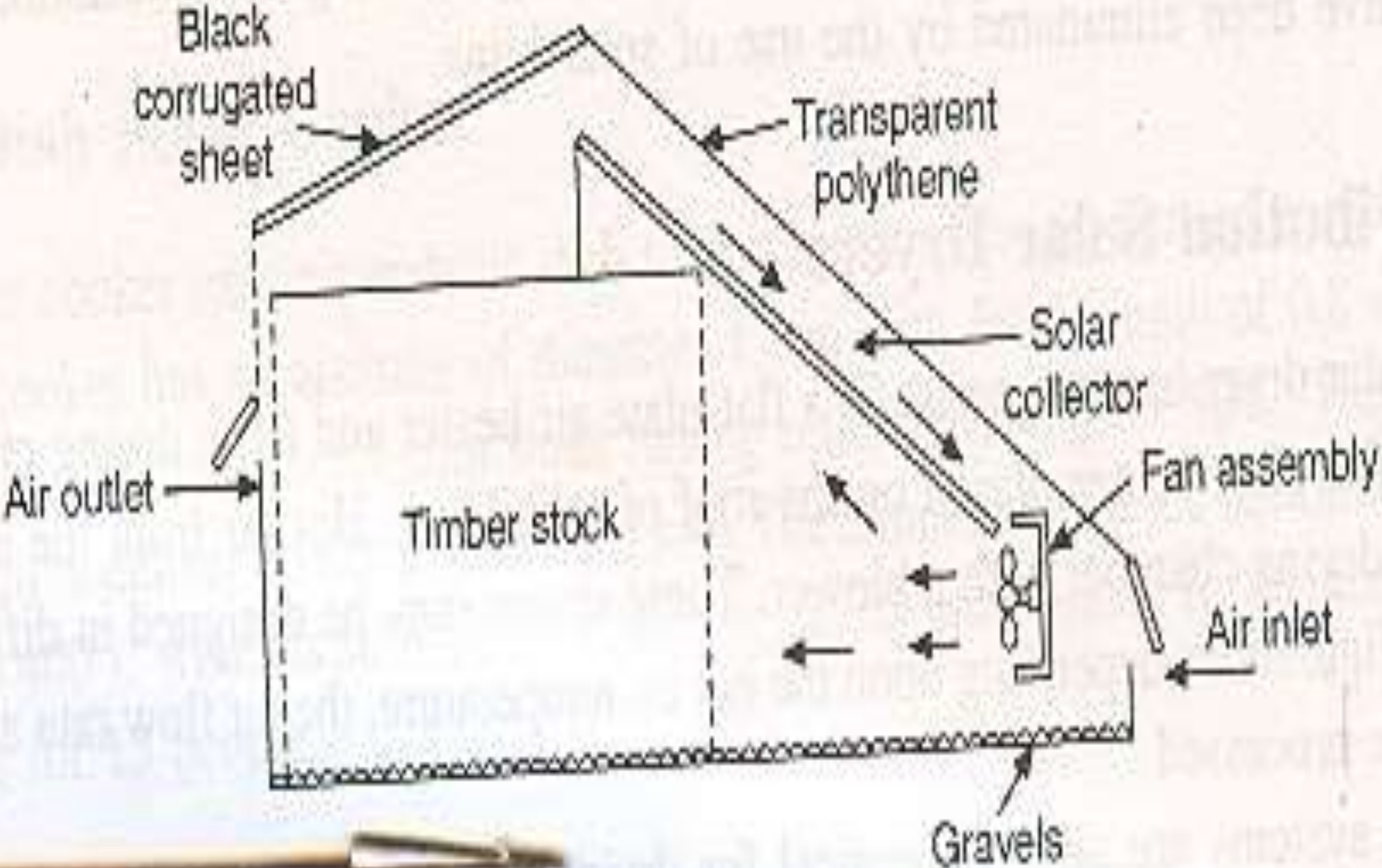
Figure 5 Cross section of a cabinet dryer.

Solar drying continued….

- The material to be dried, is spread on perforated trays. Solar radiation, entering the enclosure, is absorbed by the material and internal surfaces of the enclosure.
- Consequently, moisture from the product evaporates, the air inside is heated and natural air circulation starts.
- The temperature inside the cabinet ranges from 50ºC to 75ºC and the drying time for products like dates, grapes, apricots, cashew nuts and chillies varies from 2 to 4 days.
- For large-scale drying, i.e., seasoning of timber, corn drying, tea processing, tobacco curing, fish and fruit drying, solar kilns are used.

Solar kilns

- In a solar kiln, the heating and drying of products on a large scale, like tea, corn, fruits, timber, etc. is done by solar energy.
- It operates on the principle that a transparent glass sheet or polythene sheathing allows solar radiation to pass through into the kiln and blocks long wavelength radiation emitted by products like timber back into the atmosphere.
- The important factors affecting the drying process are relative humidity and temperature of the air, air flow rate, Initial moisture content of the product, and final desired moisture content of the product.
- A solar kiln used for seasoning of timber is shown in the next slide.



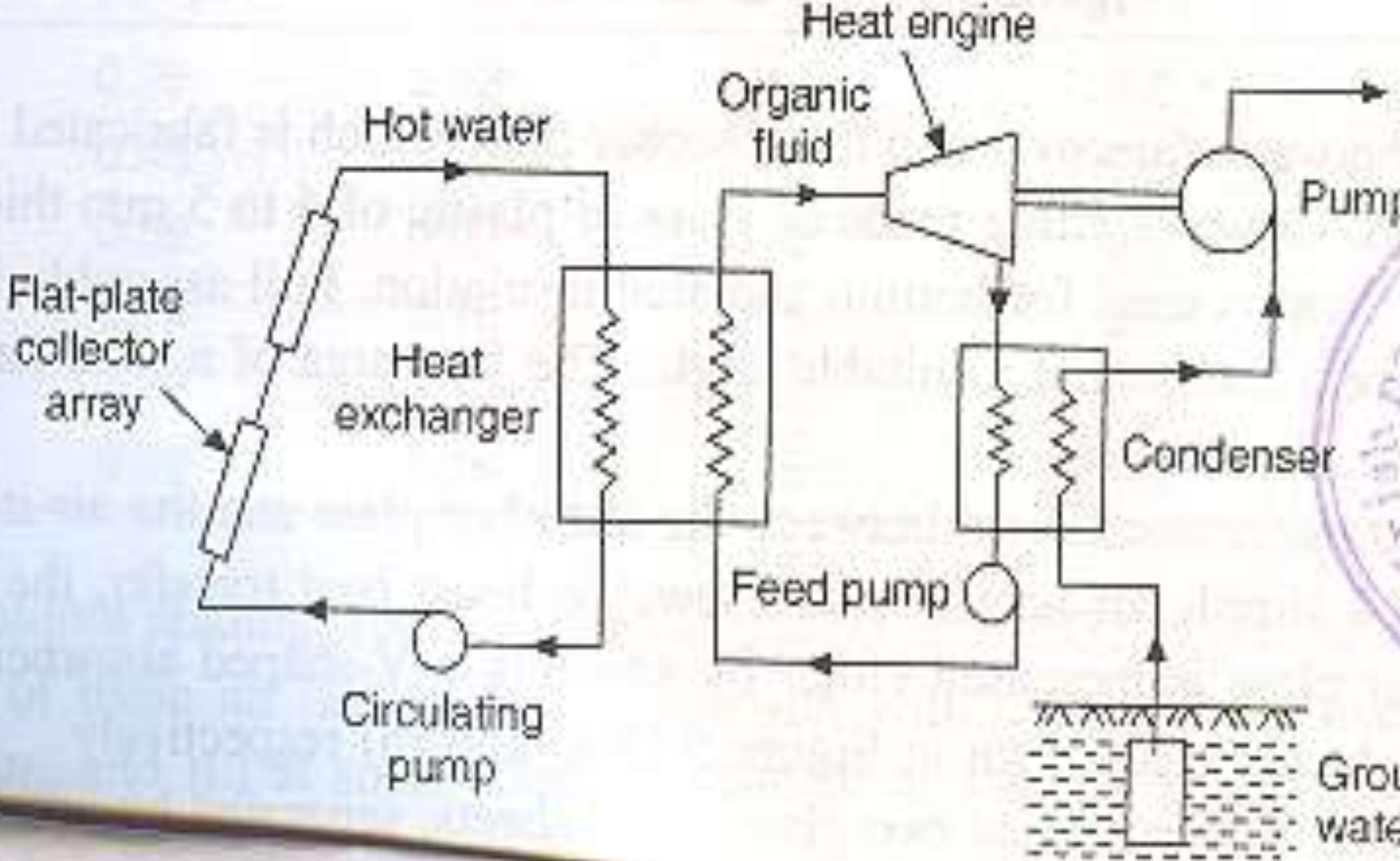
Side view of timber solar kiln.

Solar kilns continued…..

- The solar kiln consists of three major parts: (i) a wood seasoning chamber (ii) flat-plate collector, and (iii) a chimney seasoning chamber which is placed on a raised masonry platform.
- The chimney creates a natural draught in the seasoning chamber, causing hot air circulation around stacked wood.
- Circulating air carries heat from the solar absorbing plate to timber logs and evaporates moisture.
- Drying is basically a heat and mass transfer process, i.e. the moisture from surface and inside the product is vaporized and removed by circulating hot air.

Solar pumping

- Water pumps can be driven directly by solar heated water or fluid which operates either a heat engine or a turbine. For low heads, the pump driven by the vapour of a low-boiling point liquid heated by a flat-plate collector is used as shown in the next slide. For larger heads, a parabolic through concentrator or a parabolic bowl concentrator is installed to drive a steam turbine.
- Solar flat-plate collector arrays are installed to heat water or an organic fluid. Hot fluid then flows to mixing tank/storage tank and then to a heat exchanger to convert the working fluid of the heat engine from liquid to vapour. It may be noted that R-115 is an acceptable working fluid as it gives high cycle efficiency besides its low cost.



Schematic of a solar pump.

Solar pumping continued….

- Hot transport fluid or water is fed again into the collector circuit by a circulating pump. With heat engine cycle, discharged vapour from the turbine flows into the condenser where the vapour gets condensed. Working liquid is fed into the heat exchanger by a feed pump to complete the cycle. Pumped water is used as a coolant in the turbine condenser.
- A higher temperature in heat exchanger or boiler provides a high engine efficiency .An optimum range of operating temperature is used for a solar pumping system to attain maximum efficiency. Practically, energy efficiency, i.e. the percentage of solar energy collected with the quantity converted into useful work, is about 14 %.

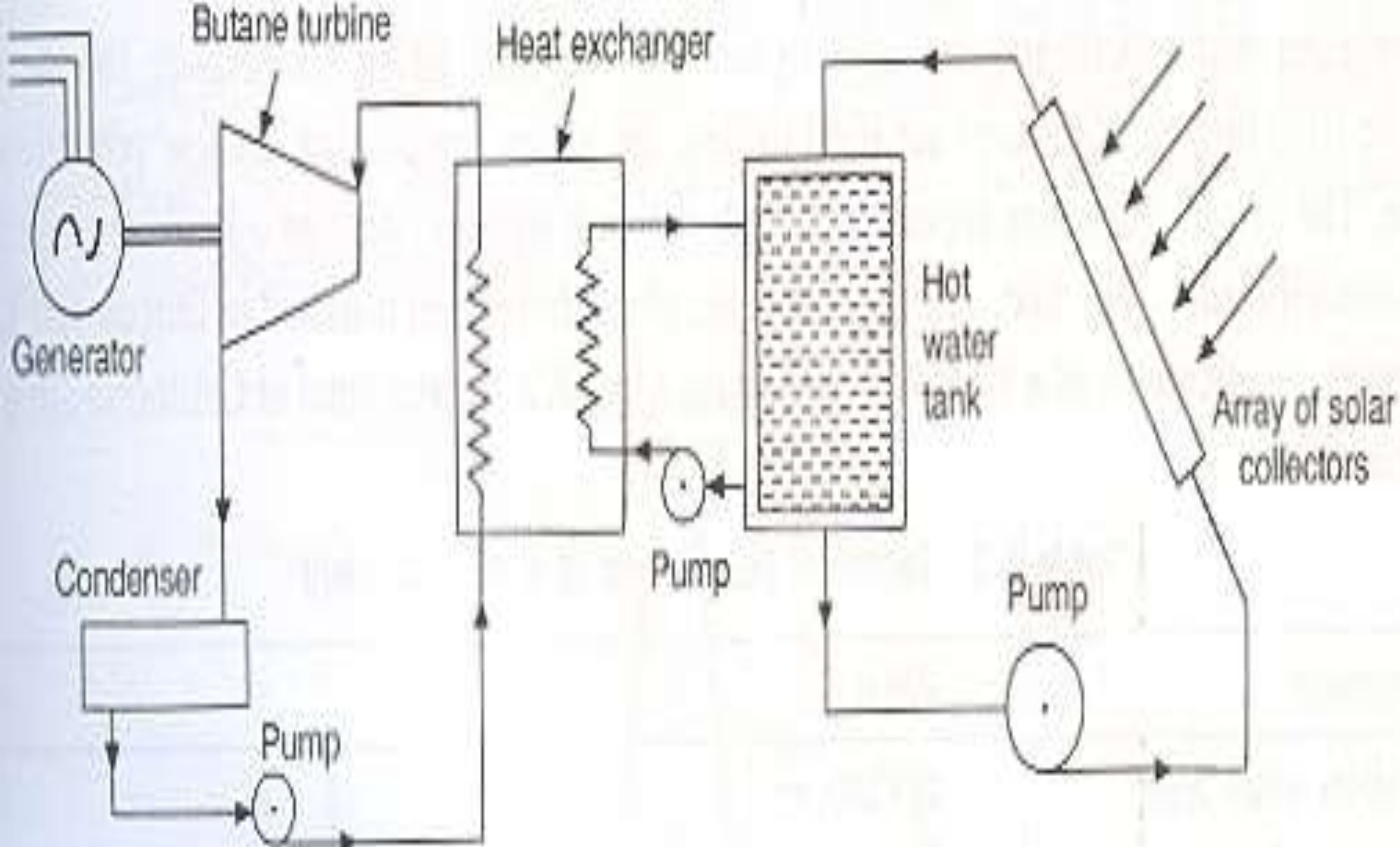
Solar thermal power plant

- Solar thermal power generation involves the collection of solar heat which is utilized to increase the temperature of a fluid in a turbine operating on a cycle such as Rankine or Brayton. In the other method, hot fluid is allowed to pass through a heat exchanger to evaporate a working fluid that operates a turbine coupled with a generator.
- Solar thermal power plants can be classified as low, medium and high temperature cycles.
- Low temperature cycles operate at about 100°C, medium temperature cycles up to 400°C, while high temperature cycles work above 500°C
- A low temperature solar power plant is discussed here.

Solar thermal power plant

continued….

- A low temperature solar power plant uses flat-plate collector arrays as shown in the next slide.
- Hot water (above 90°C) is collected in an air insulated tank.
- It flows through a heat exchanger, through which the working fluid of the energy conversion cycle is also circulated.
- The working fluid is either methyle chloride or butane having a low boiling temperature up to 90°C.
- Vapours so formed operate a regular Rankine cycle by flowing through a turbine, a condenser and a liquid pump.



Low temperature solar power plant.

Solar thermal power plant
continued…..

- As the temperature difference between the turbine outlet and the condensed liquid flowing out is small, i.e. about 50°C, the overall efficiency of the generating system is about 2 % (8% Rankine cycle efficiency x 25% collector system efficiency).
- Finally, the organic fluid is pumped back to the evaporator for repeating the whole cycle.
- To reduce the capital cost, solar ponds are used instead of flat-plate collectors.
- Such plants up to 150 kW capacity are operative in Israel for the last 25 years.

Solar photovoltaic systems.

Solar photovoltaic conversion

Solar Photovoltaic Systems:

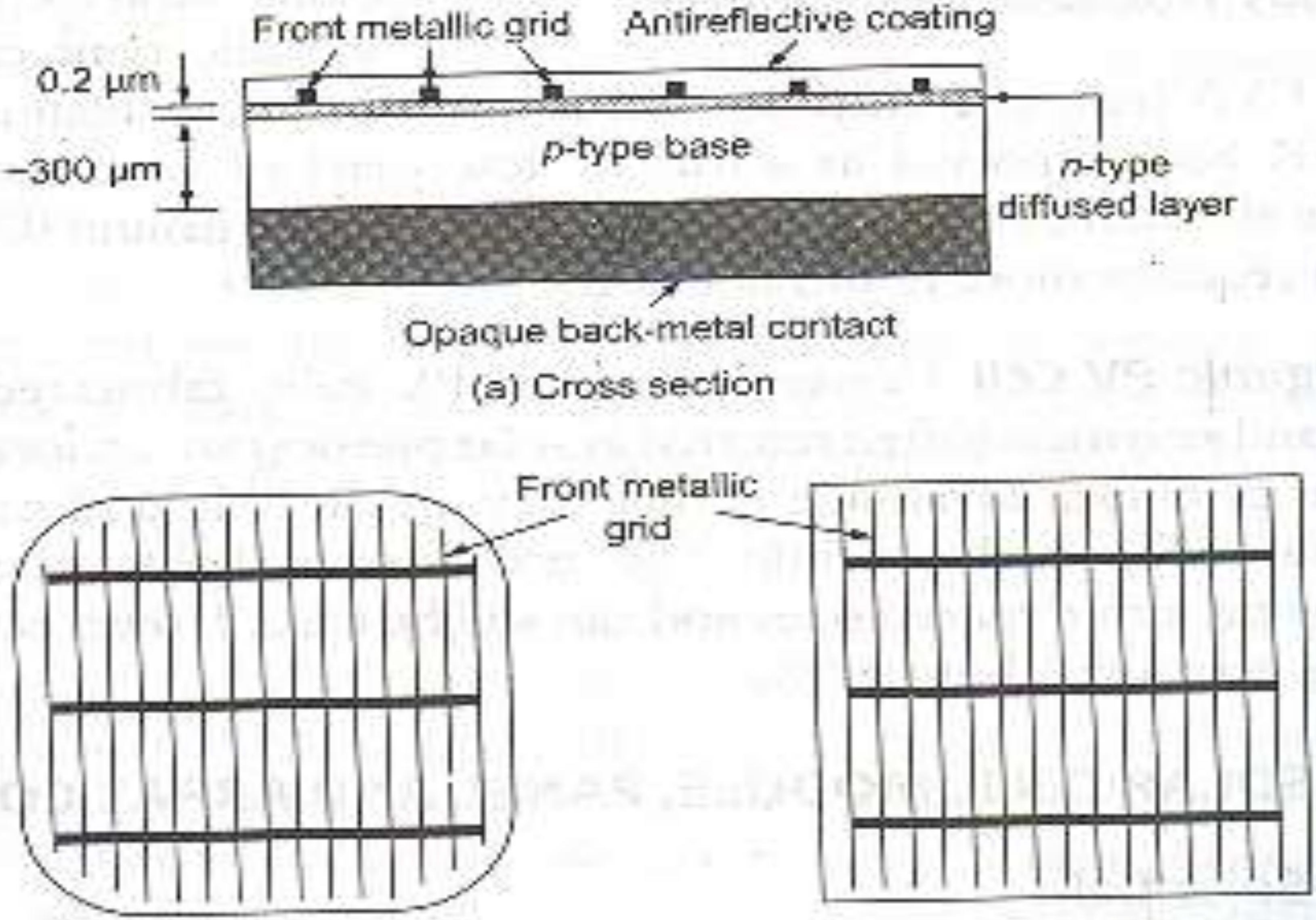
- Solar Photovoltaic (PV) systems convert solar energy directly into electrical energy.
- The basic conversion device used is known as a solar photovoltaic cell or a solar cell.
- A solar cell is basically an electrical current source, driven by a flux of radiation. Solar cells were first produced in 1954 and were rapidly developed to provide power for space satellites.
- Efficient power utilization depends not only on efficient generation in the cell, but also on the dynamic load matching in the external circuit.

Solar photovoltaic conversion
continued…

- A solar cell is the most expensive component in a solar PV system (about 60% of the total system cost) though its cost is falling slowly. Commercial photocells may have efficiencies in the range of 10-20 % and can produce electrical energy of 1-2 kWh per sq. m per day in ordinary sunshine.
- Typically, it produces a potential difference of about 0.5 V and a current density of about 200 A per sq. m of cell area in full solar radiation of 1 kW per sq. m. A typical commercial cell of 100 sq. cm area, thus produces a current of 2 A. It has a lifespan in excess of 20 years.
- As a PV system has no moving parts, it gives almost maintenance-free service for long periods and can be used unattended at inaccessible locations.

Solar cells

- The basic cell structure of a typical n-on-p, bulk silicon cell is shown in the next slide.
- The bulk material is p-type silicon with a thickness of 100 to 350 microns, depending on the technology used.
- A thin layer of n-type silicon is formed at the top surface by diffusing an impurity from the V^{th} group (phosphorus being the most common) to get a pn junction.
- The top active surface of the n layer has an ohmic contact with metallic grid structure to collect the current produced by impinging photons.



(a) Cross section

(b) Single-crystal cell (off square)

(c) Multicrystalline cell (square)

Construction of bulk *silicon cell*

Solar cells continued…….

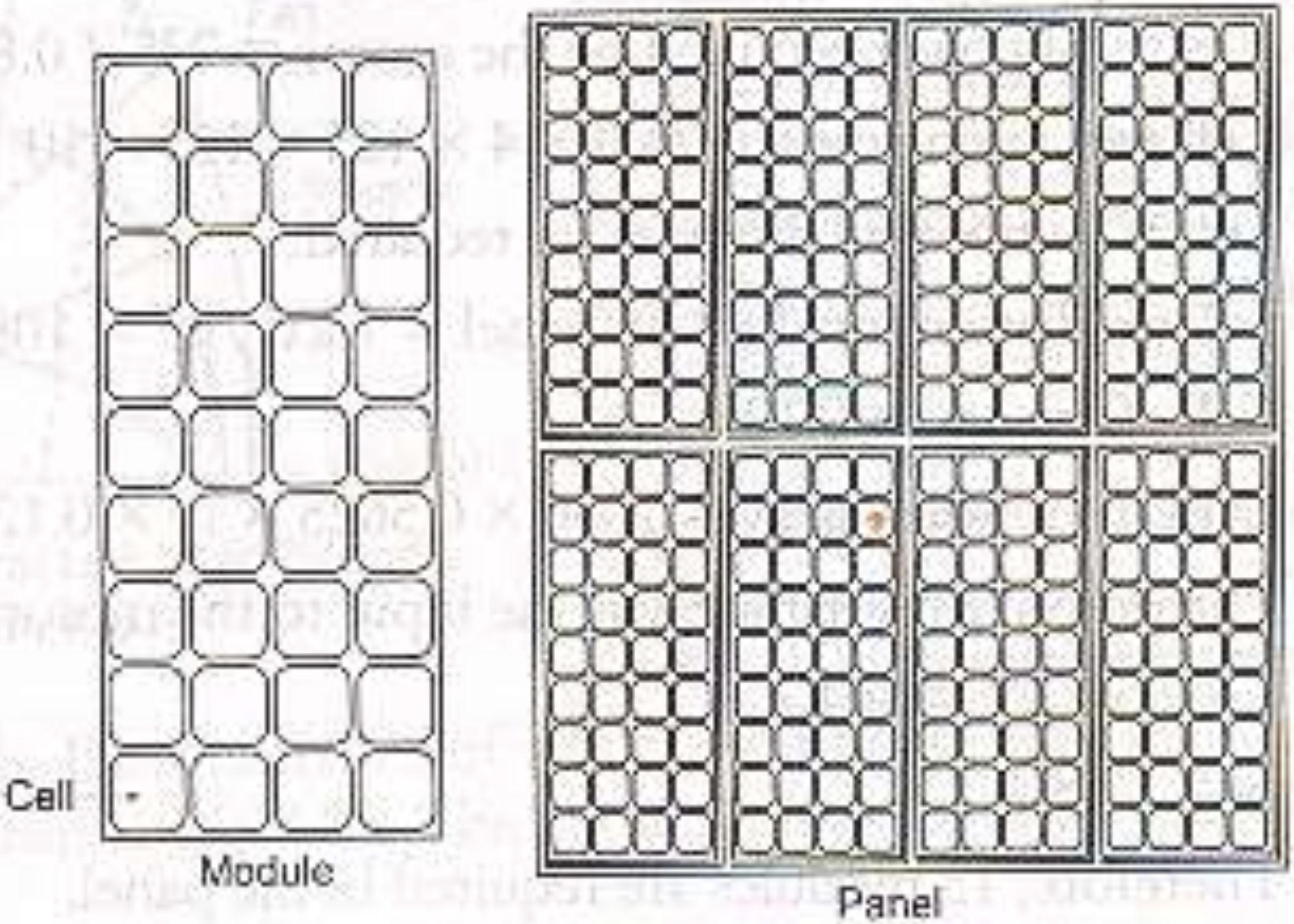
- The metallic grid covers minimum possible top surface area (less than 10% of the total area) to leave enough uncovered surface area for incoming photons.
- Similarly, the bottom inactive surface has an ohmic metallic contact over the entire area.
- These two metallic contacts on p and n layer respectively form the positive and negative terminals of the solar cell.
- In addition to basic elements, several enhancement features are also included in the construction. For example, providing antireflective coating, textured finish of the top surface and reflective, textured rear surface, to capture maximum photons and direct them toward the junction.

Solar PV module

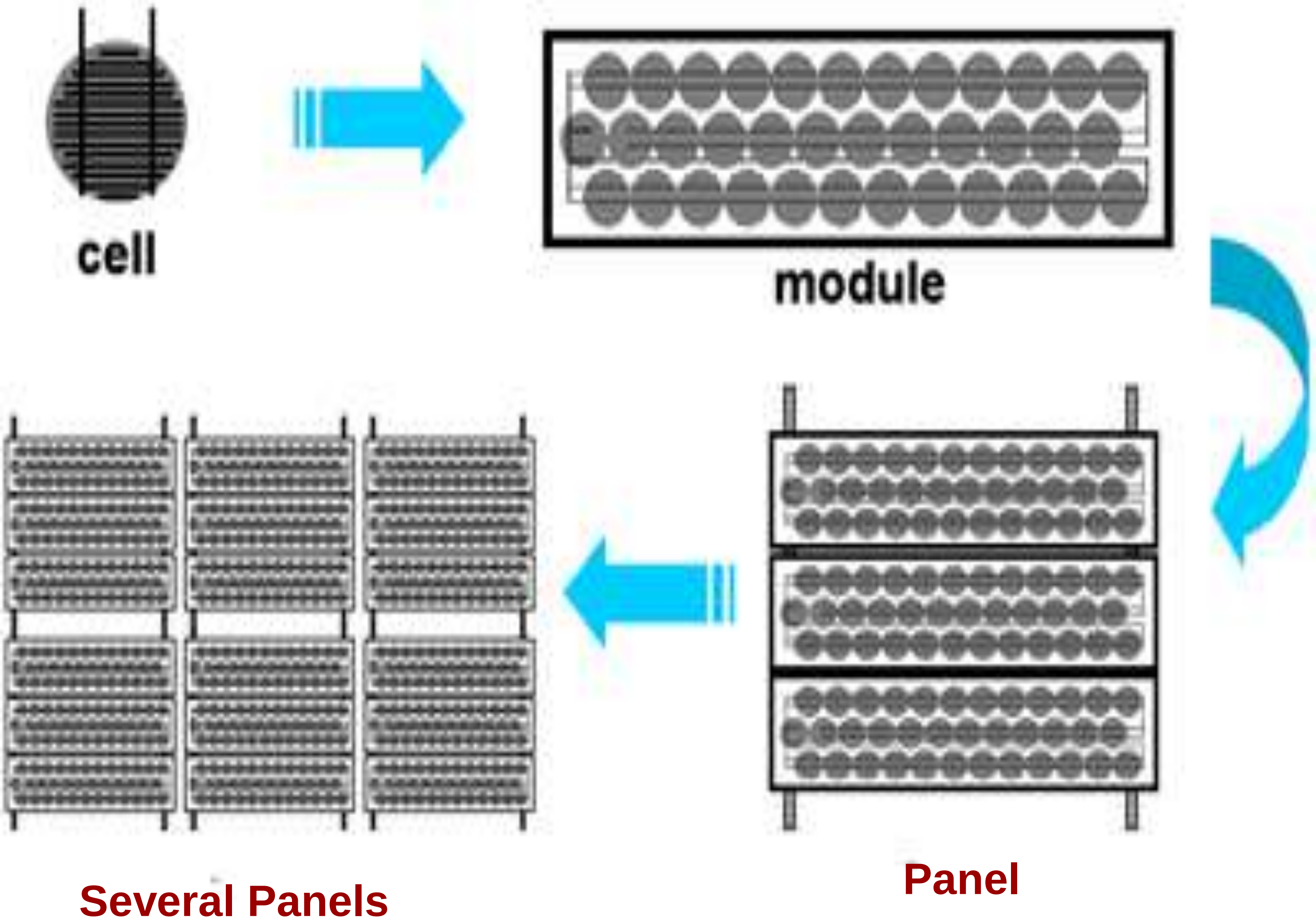
- A bare single cell cannot be used for outdoor energy generation because the output of a single cell is very small.
- Workable voltage and reasonable power is obtained by interconnecting an appropriate number of cells. The unit is fixed on a durable back cover of several square feet, with a transparent cover on the top and hermetically sealed to make it suitable for outdoor applications.
- This assembly is known as solar module, a basic building block of a PV system. The most common commercial modules have a series connection of 32 or 36 silicon cells to make it capable of charging a 12-V storage battery. However, larger and smaller capacity modules are also available in the international market.

Solar PV panel

- Several solar modules are connected in series/ parallel to increase the voltage/ current rating.
- When modules are connected in series, it is desirable to have each module's maximum power production occur at the same current.
- When modules are connected in parallel, it is desirable to have each module's maximum power production occur at the same voltage.
- Solar panel is a group of several modules connected in a series-parallel combination in a frame that can be mounted on a structure.
- Next slides show the construction of a module and a panel.

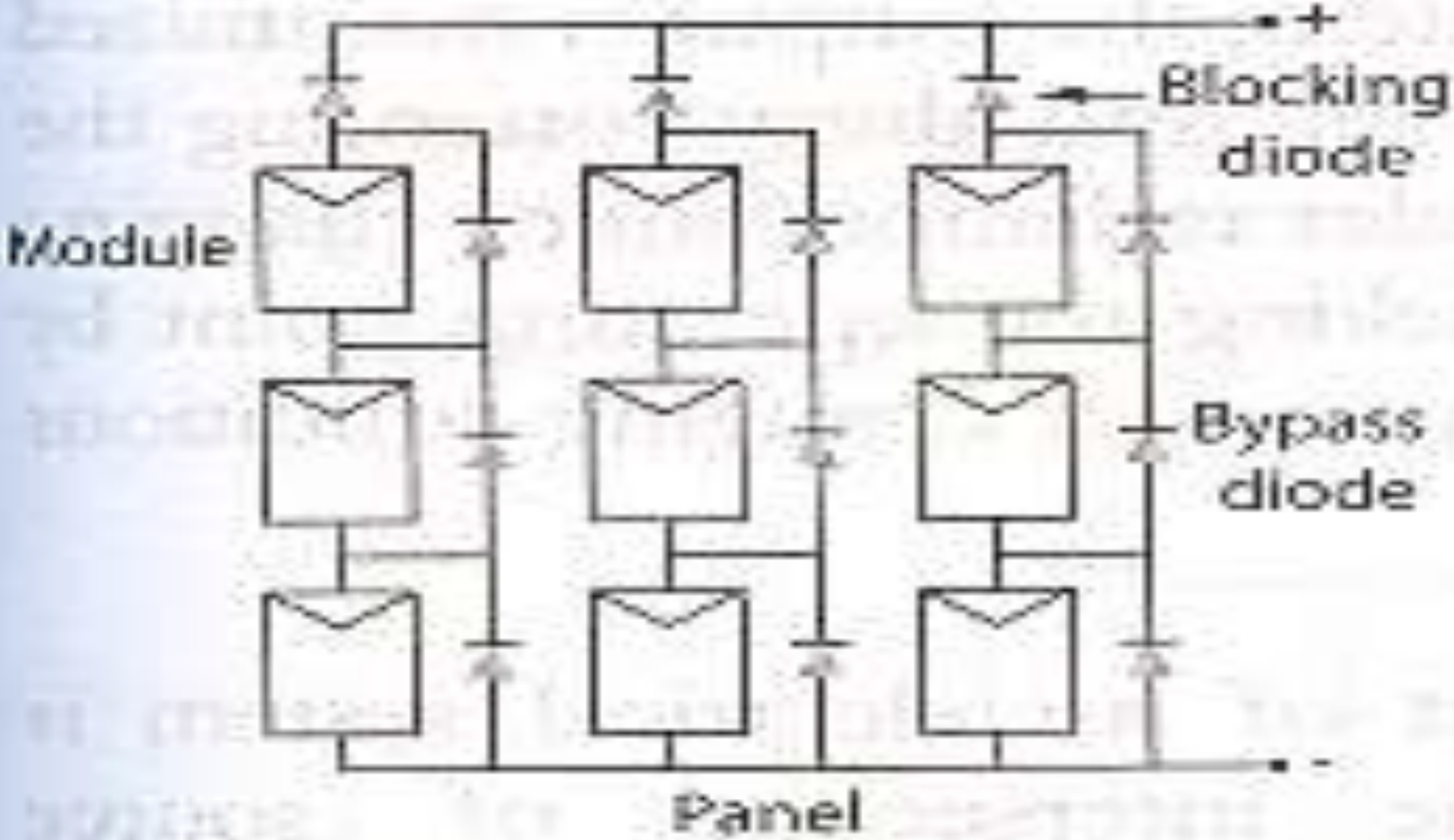


a Cell, module and panel


cell
module
Panel
Several Panels

Solar PV panel continued…..

- Next slide shows a series-parallel connection of modules in a panel.
- In a parallel connection, blocking diodes are connected in series with each series string of modules so that if any string should fail, the power output of the remaining series strings will not be absorbed by the failed string.
- Also, bypass diodes are installed across each module, so that if one module should fail, the output of the remaining modules in a string will bypass the failed module.
- Some modern PV modules come with such internally embedded bypass diodes.



A typical panet series-parallel connection of modules

Solar PV array

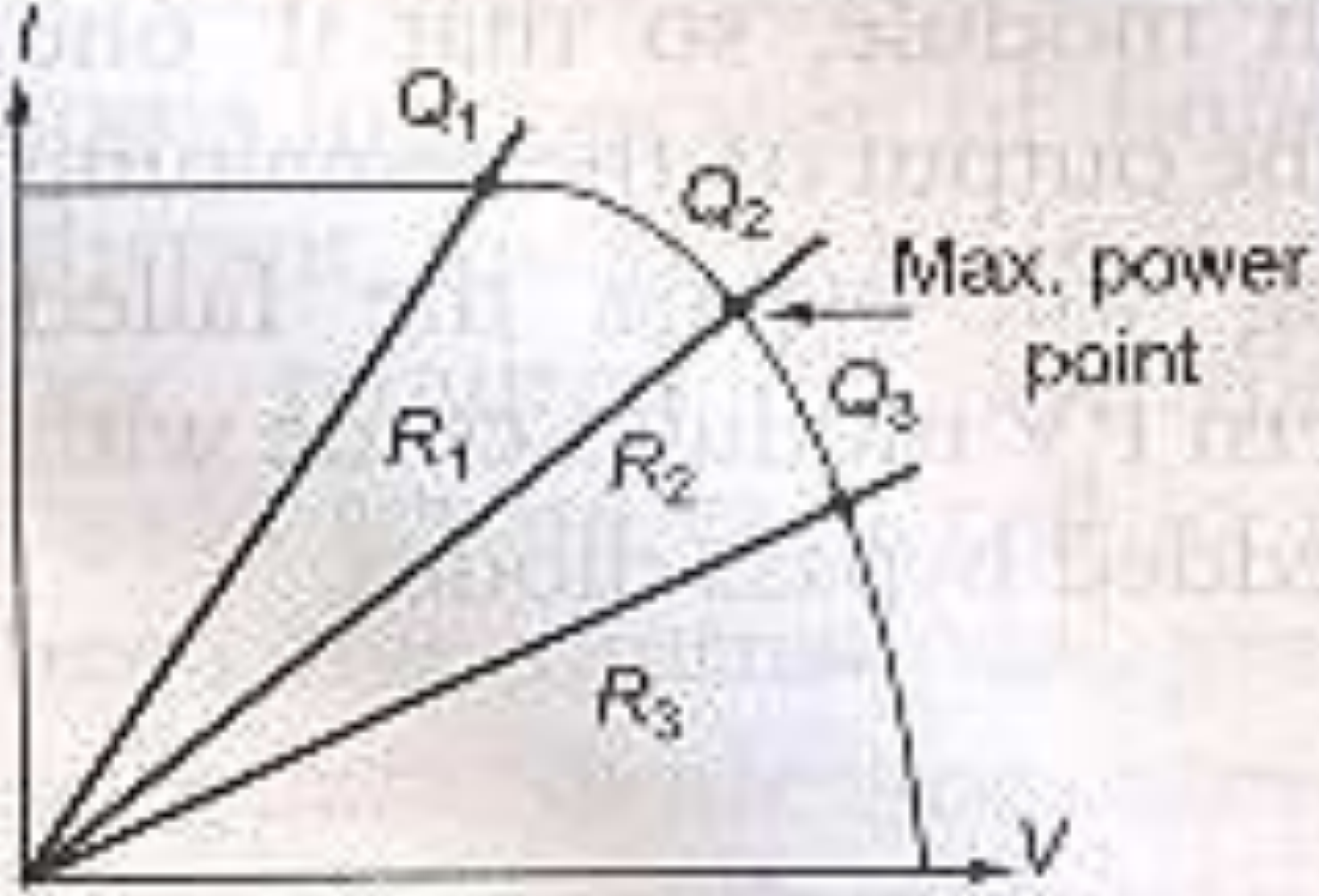
- In general, a large number of interconnected solar panels, known as solar PV array, are installed in an array field.
- These panels may be installed as stationary or with sun tracking mechanism.
- It is important to ensure that an in installed panel does not cast its shadow on the surface of its neighbouring panels during a whole year.
- The layout and mechanical design of the array such as tilt angle of panels, height of panels, clearance among the panels, etc., are carried out taking into consideration the local climatic conditions, ease of maintenance, etc.

Load matching

- To make best use of the solar PV system, output is maximized in two ways.
- The first is mechanically tracking the sun and always orienting the panel in such a direction as to receive maximum solar radiation under changing positions of the sun.
- The second is electrically tracking the operating point by manipulating the load to maximize the power output under changing conditions of insolation and temperature.
- The operating point of electrical system is determined by the intersection of source characteristics and load characteristics .

Load matching continued…..

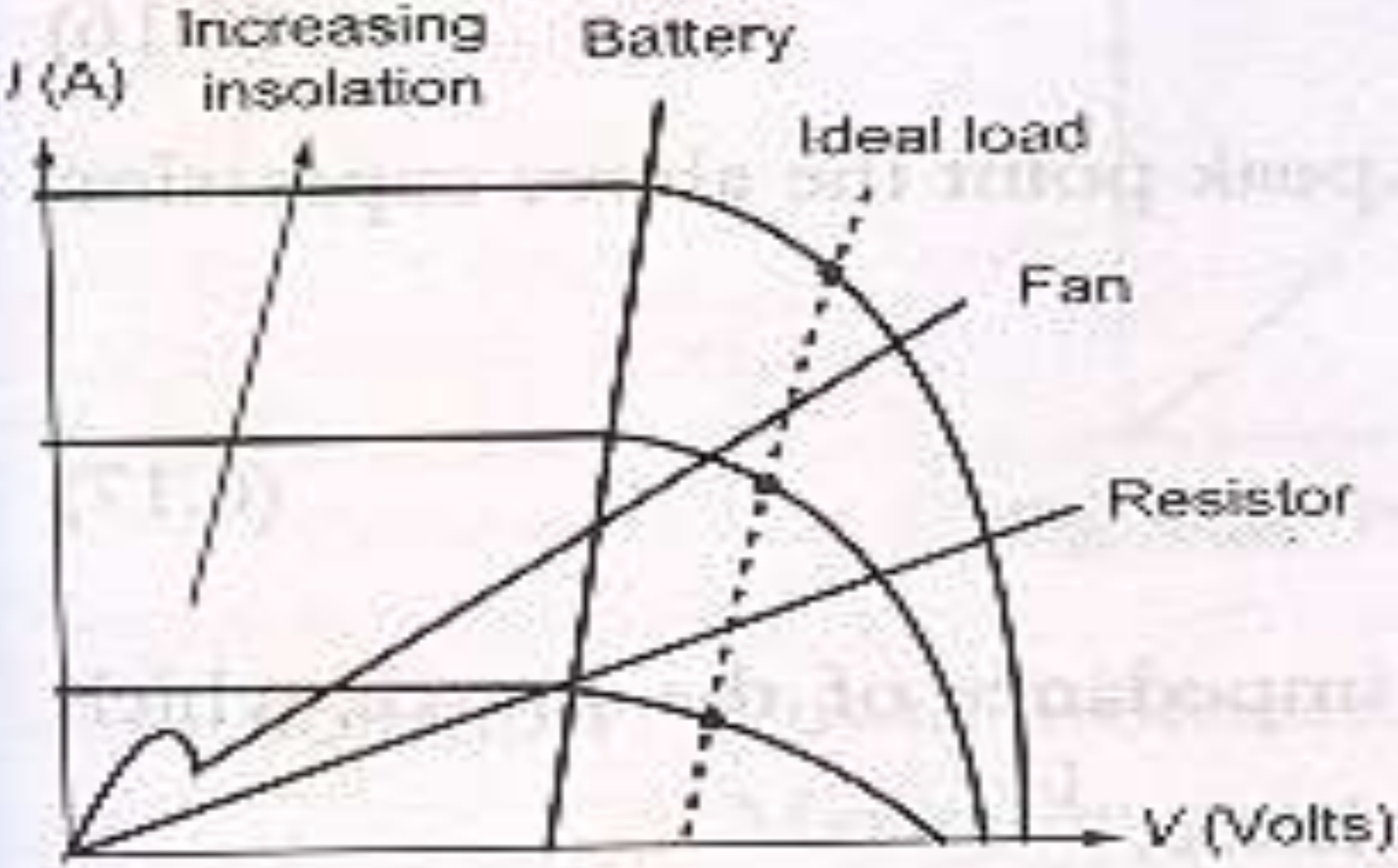
- The operation for a solar PV system connected to a resistive load is shown in the next slide.
- For a low value of resistance, R_1, the system operates at Q_1.
- As the resistance is increased to R_2 and then to R_3, the operating point moves respectively to Q_2 and Q_3.
- Maximum power is available from the PV system for a load resistance of R_2.
- Such load matching is required for extracting maximum power from a PV system.



Load matching with resistive load

Maximum power point tracker

- When a solar PV system is deployed for practical applications, the I-V characteristic keeps on changing with insolation and temperature.
- In order to receive maximum power, the load must adjust itself accordingly to track the maximum power point.
- The I-V characteristics of PV system along with some common loads are shown in the next slide.
- An ideal load is one that tracks the maximum power point.
- If the operating point departs significantly from the maximum power point, it may be desirable to interpose an electronic maximum power point tracker (MPPT) between PV system and load.

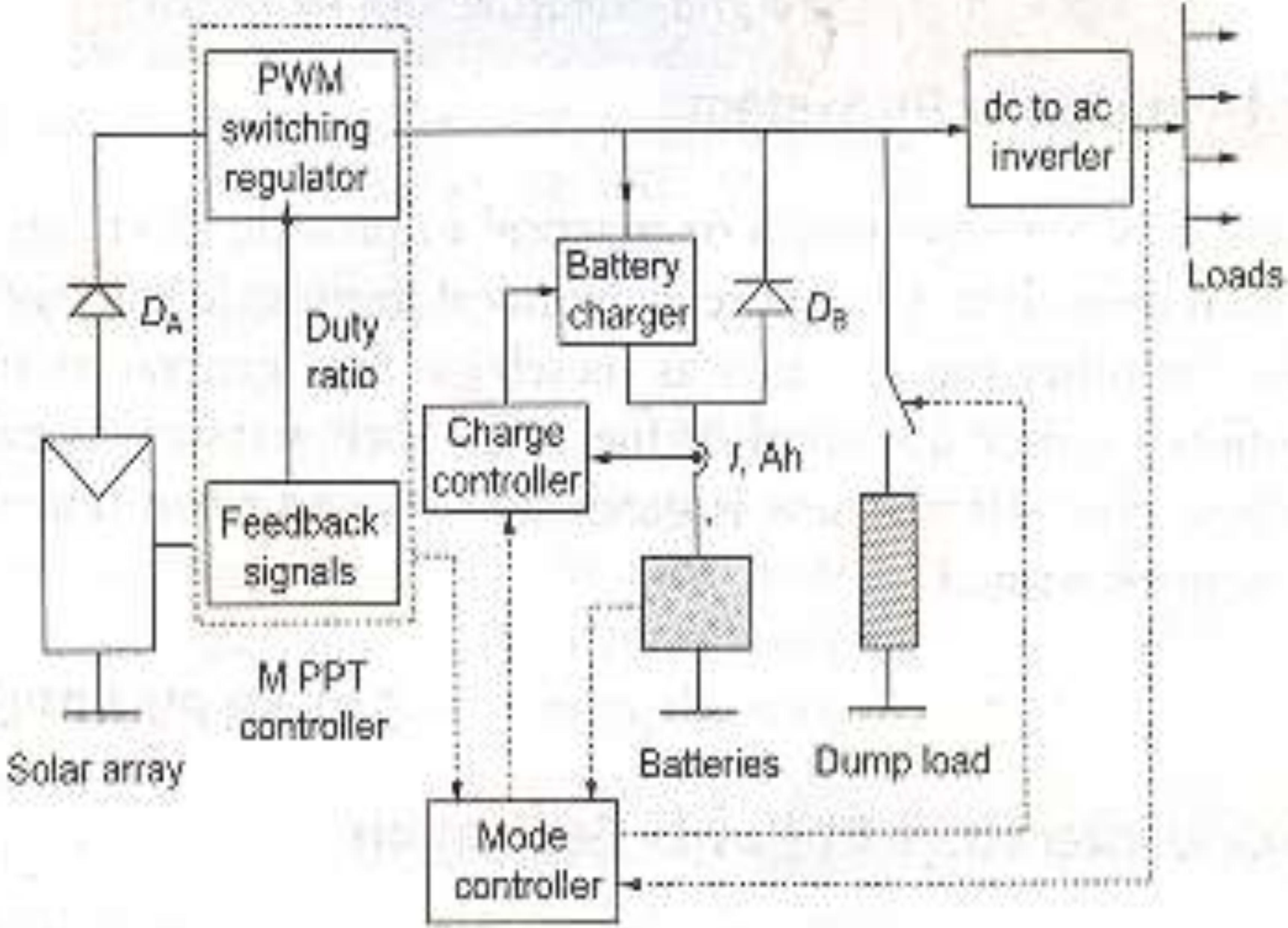


Characteristic fo PV and some loads

Solar PV systems

Stand-alone solar PV system:

- The main components of a general stand-alone solar PV system are shown in the next slide.
- The MPPT senses the voltage and current outputs of the array and adjusts the operating point to extract maximum power under the given climatic conditions.
- The output of the array after converting to ac is fed to loads. The array output in excess of load requirement is used to charge the battery. If excess power is still available after fully charging the battery, it may be shunted to dump loads. When the sun is not available, the battery supplies the load through an inverter.
- The battery discharge diode DB prevents the battery from being overcharged after the charger is opened. The array diode DA is to isolate the array from the battery to prevent battery discharge through array during nights.

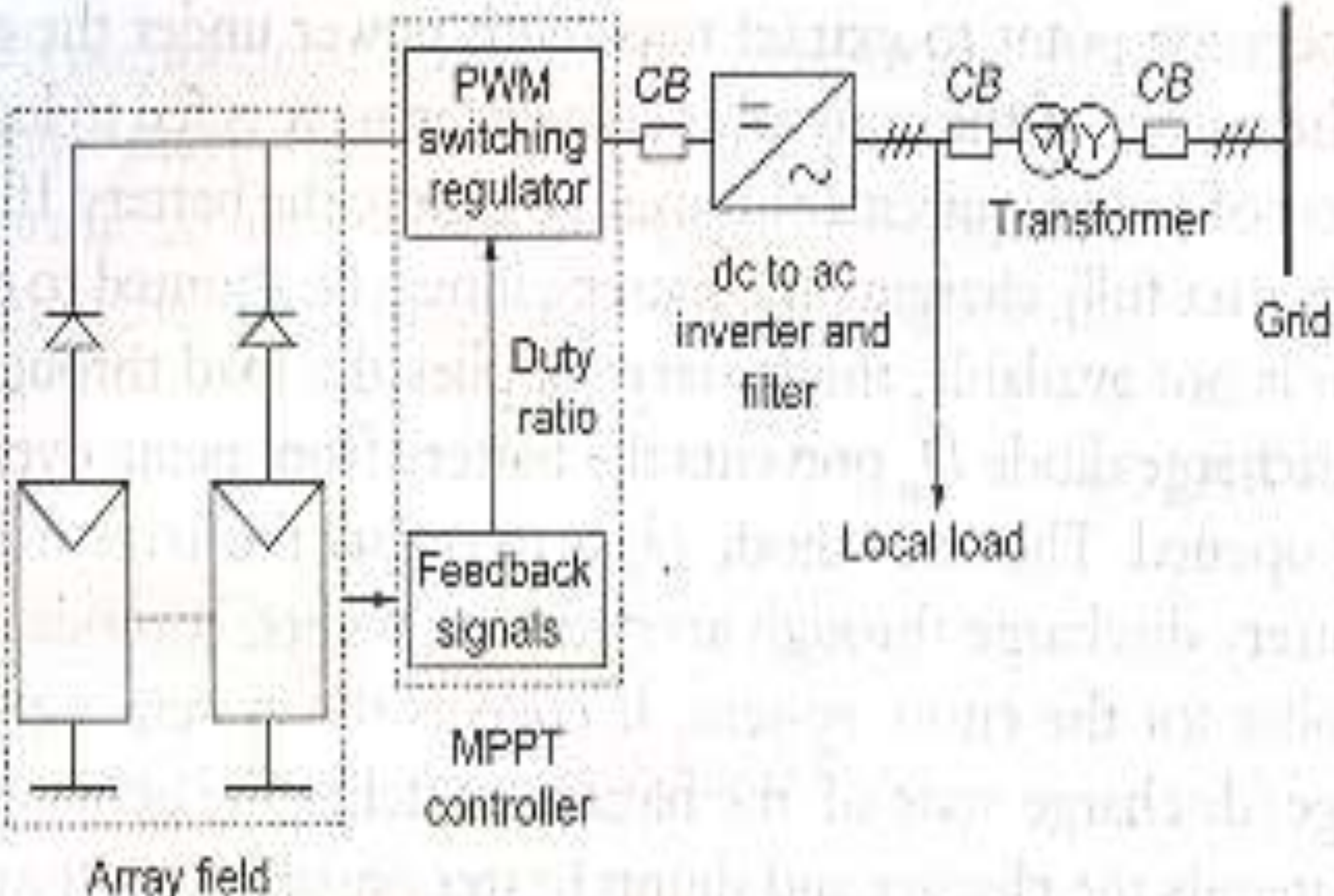


A general stand-alone solar PV system

Solar PV systems continued….

Grid-interactive solar PV system:

- In a grid-interactive system, all excess power is fed to a grid and dump loads are not required. Also, during the absence or inadequate sunshine, supply of power is maintained from the grid, and thus battery is eliminated.
- The mechanism for synchronized operation is incorporated. The dc power is first converted to ac by inverter, harmonics are filtered and then the filtered power is fed into the grid after adjusting the voltage level.
- Recently, PV modules are being made with inverters as an integral component in the junction box of the module, what is known as ac-PV modules. It provides utility grade 50 Hz power directly from the module junction box. This greatly simplifies the design of a PV system. The schematic diagram of a general grid-interactive solar PV system is given in the next slide.



A general grid-interactive solar PV system

Solar PV systems continued….

Hybrid solar PV system:

- Sometimes, it is not economical or practical to provide all energy from a PV system alone.
- In such cases, it may be more economical to provide some of the system energy needs by other means, such as diesel / gasoline generators or any other non-conventional source like wind or fuel cells. Such a system is called a hybrid system
- The best cost-effectiveness is generally obtained when none of the PV-generated energy is wasted.

Solar PV Applications

(1) Grid interactive and stand-alone power generation:

- The largest power plant was installed in California, USA. Also, some other large sized plants are operating in Italy, Switzerland, Germany, Australia Spain and Japan.
- In India 33 grid-connected plants with a total installed capacity of 2.54 MW have been installed so far. A 200 kW grid-interactive SPV plant, installed at a village in Punjab, is the biggest operating SPV plant at present in India. India's largest solar power company (Moser Baer Clean Energy Limited, MBCEL) has recently (December 2010) commissioned India's largest solar farm (5 MW) in Tamilnadu (Sivaganga District). A total of 1791 kW stand-alone SPV systems have been installed so far in our country.

Solar PV Applications continued….

(2) Water pumping:

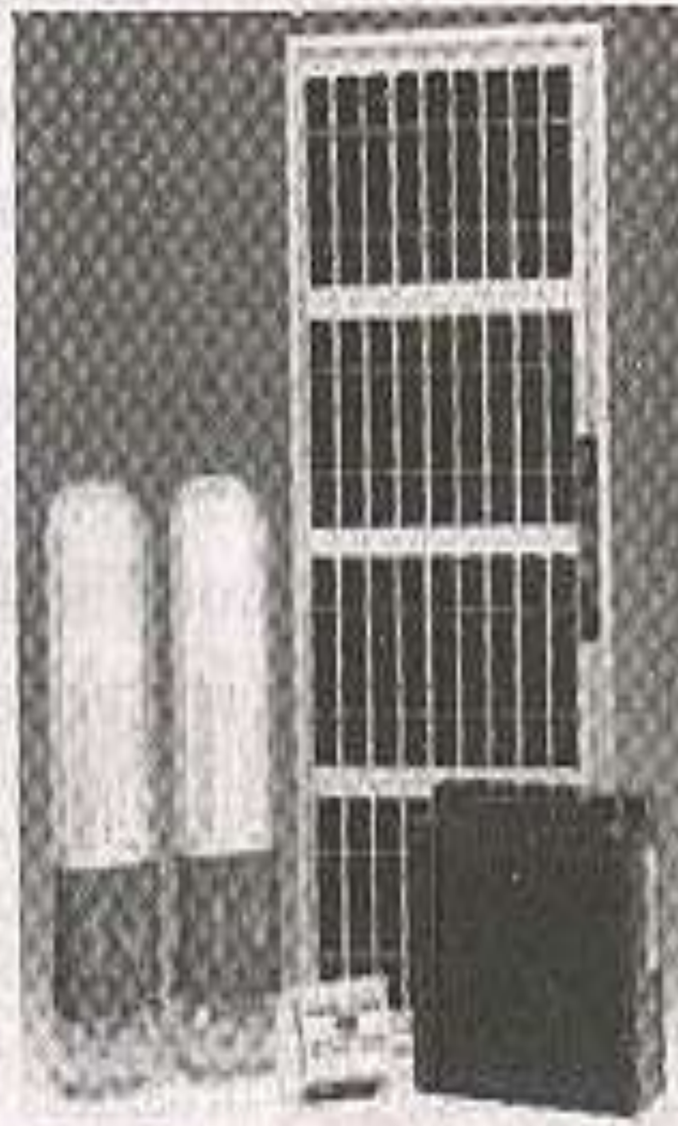
- Pumping of water for the purpose of drinking or minor irrigation during sunshine hours is a very successful application of a standalone PV system without storage.
- Water pumping appears to be most suited for solar PV applications as water demand increases during dry days when plenty of sunshine is available. There would be less need of water during the rainy season when the availability of solar energy is also low.
- SPV water-pumping systems have been successfully used in many parts of the world in the range of a few hundred watts to 5 kW.
- Three types of motors have generally been used: (1) permanent magnet dc motor (2) Brushless dc motors, and (3) Variable voltage and variable frequency ac motors, with appropriate electronic control and conversion system.

Solar PV Applications continued….

(3) Lighting:

- Next to water pumping, lighting is the second most important and extensive application of a standalone solar PV system.
- As lighting is required when the sun is not available, battery storage is essential. Energy-efficient compact fluorescent lamps (CFL) or low-pressure sodium vapour lamps (LPSVL) are used at 25-35 kHZ frequencies.
- Pole mounted outdoor lighting, shown in the next slide, is designed for 3-6 hours an evening. A typical system has two 35 W modules connected in parallel, an 11-W (900 lumens) CFL, a 90 or 120 Ah,12-V storage battery and associated electronics including inverter, battery charger and timer to switch on and off the light. The approximate cost of one pole-mounted streetlight is Rs 30,000.

Pole-mounted SPV lighting
Source: MNES Annual Report



Solar lantern Source:
Tata BP Solar Products

Solar PV Applications continued….

(4) Medical Refrigeration:

- Many life-saving supplies, particularly vaccines, require refrigeration during storage and transportation in order to remain effective.
- In many developing countries, where such life-saving vaccines are in great demand, electricity is not available to operate conventional refrigerators. World Health Organization has specified technical details for PV based refrigerators using solar energy. This has resulted in success of WHO-sponsored immunization programmes in these countries.
- The PV module size ranges from 100 W to 600 W with a 12 V/24 V battery.

Solar PV Applications continued….

(5) Village power:

- Solar PV power can be used to meet low energy demands of many remote, small, isolated and generally unapproachable villages in most developing countries.

Two approaches have generally been used:

(1) Individual SPV system for every household

(2) A centralized SPV plant to meet combined load demand of the whole village

- Both approaches have been extensively tried out in most parts of the world particularly in developing countries.
- A centralized village PV power system requires large scale integrated planning and execution.

Solar PV Applications continued….

(6) Telecommunication and signaling:

- Solar PV power is ideally suited for telecommunication applications such as local telephone exchange, radio and TV broadcasting, microwave and other forms of electronic communication links. This is because, in most telecommunication applications, storage batteries are already in use and the electrical systems are basically dc.
- Radio and TV signals may not reach hilly and mountainous terrain as they get blocked or reflected back due to the undulating terrain. At these locations low-power transmitters are installed to receive and transmit the signals for the local population.
- As these locations are generally remote and normal grid supply is not available, these are powered by solar photovoltaic electricity.

UNIT 3: Syllabus

UNIT- III: WIND ENERGY

Wind energy estimation in world and in India – Types of wind energy systems – Performance of Wind energy System– Details of wind turbine generator – Safety and Environmental Aspects

Wind energy

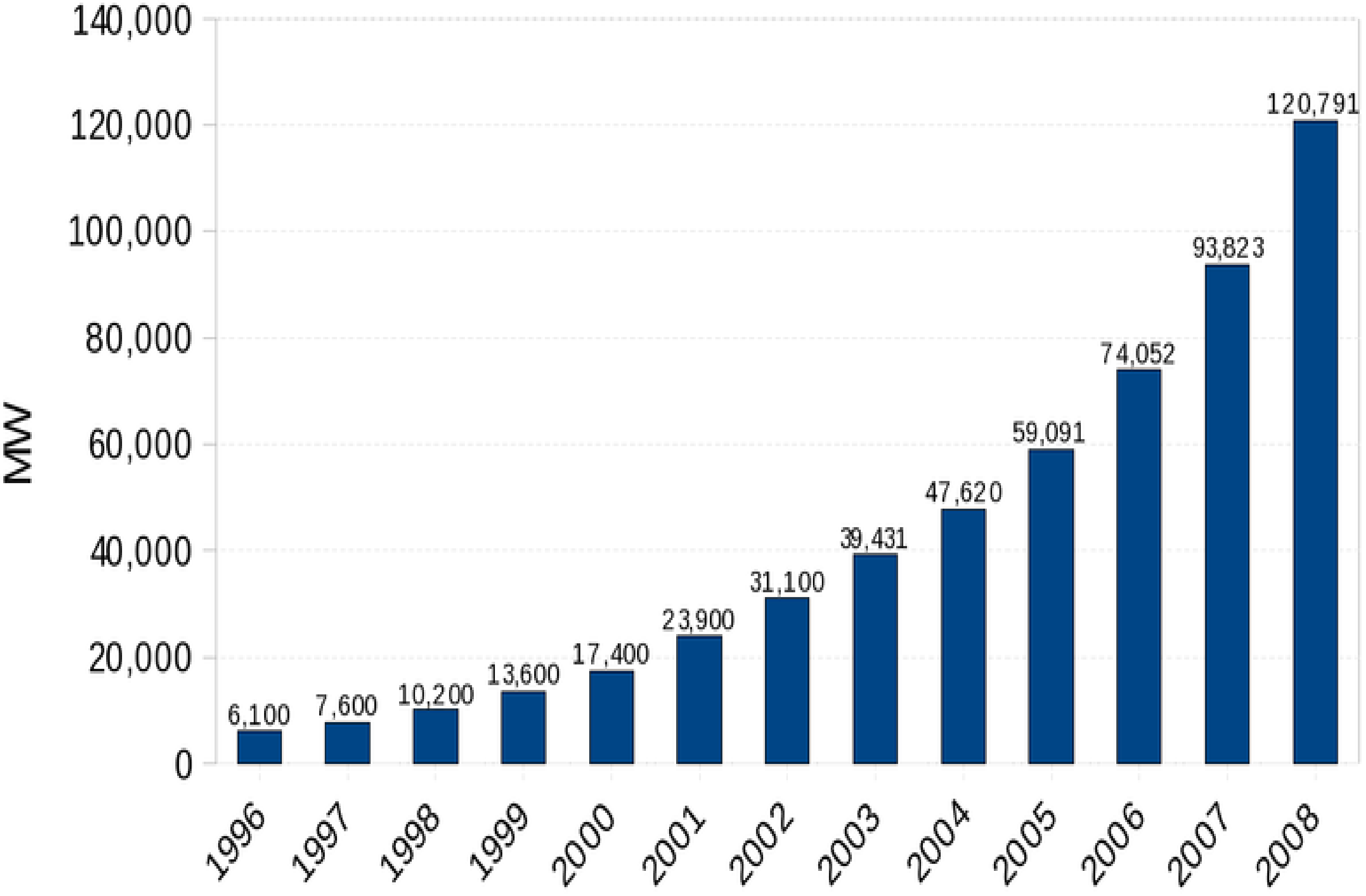
- Wind energy is the kinetic energy associated with movement of large masses of air. These motions result from uneven heating of the atmosphere by the sun, creating temperature, density and pressure differences. Wind energy is an indirect form of solar energy.
- In contrast to day time availability of direct solar radiation, wind energy can be available continuously throughout 24 hours though it can vary to a great extent including no wind periods. It is clean, cheap, and eco-friendly renewable source. However, it is dispersed, erratic and location-specific source.
- Wind energy is harnessed as mechanical energy with a help of a wind turbine. The mechanical energy thus obtained can be used as such to operate farm appliances. It can also be converted to electrical energy and used locally or fed to a grid.

Wind energy continued….

- A generator coupled to a wind turbine is known as aero-generator.
- Very slow winds are useless, having no possibility of power generation. On the other hand, very strong stormy winds cannot be utilized due to safety of turbine.
- Moderate to high-speed winds, typically from 5 m/s to about 25 m/s are considered favorable for most wind turbines.
- The global potential in winds for large-scale grid-connected power generation has been estimated as 9,000 x 10^9 kWh/year.
- It is also estimated that favorable winds for small-scale applications such as wind pumps, battery chargers, heaters, etc., are available on about 50% of the earth's surface.

Wind energy estimation in the world

- The interest in wind energy has renewed after the oil crisis of 1973.
- Most modern, large-scale wind-energy systems have been built after 1980 using modern engineering designs, materials and incorporating microelectronics monitoring and control.
- Several demonstration and commercial plants of different sizes, from few kW to MW are in operation in different parts of the world.
- The global installed capacity by end of the year 2010 had reached 198 GW.
- The global growth pattern of wind energy is shown in the next slides.



Wind power: worldwide installed capacity 1996-2008

Figure 5. Wind Power, Existing World Capacity, 1996–2010

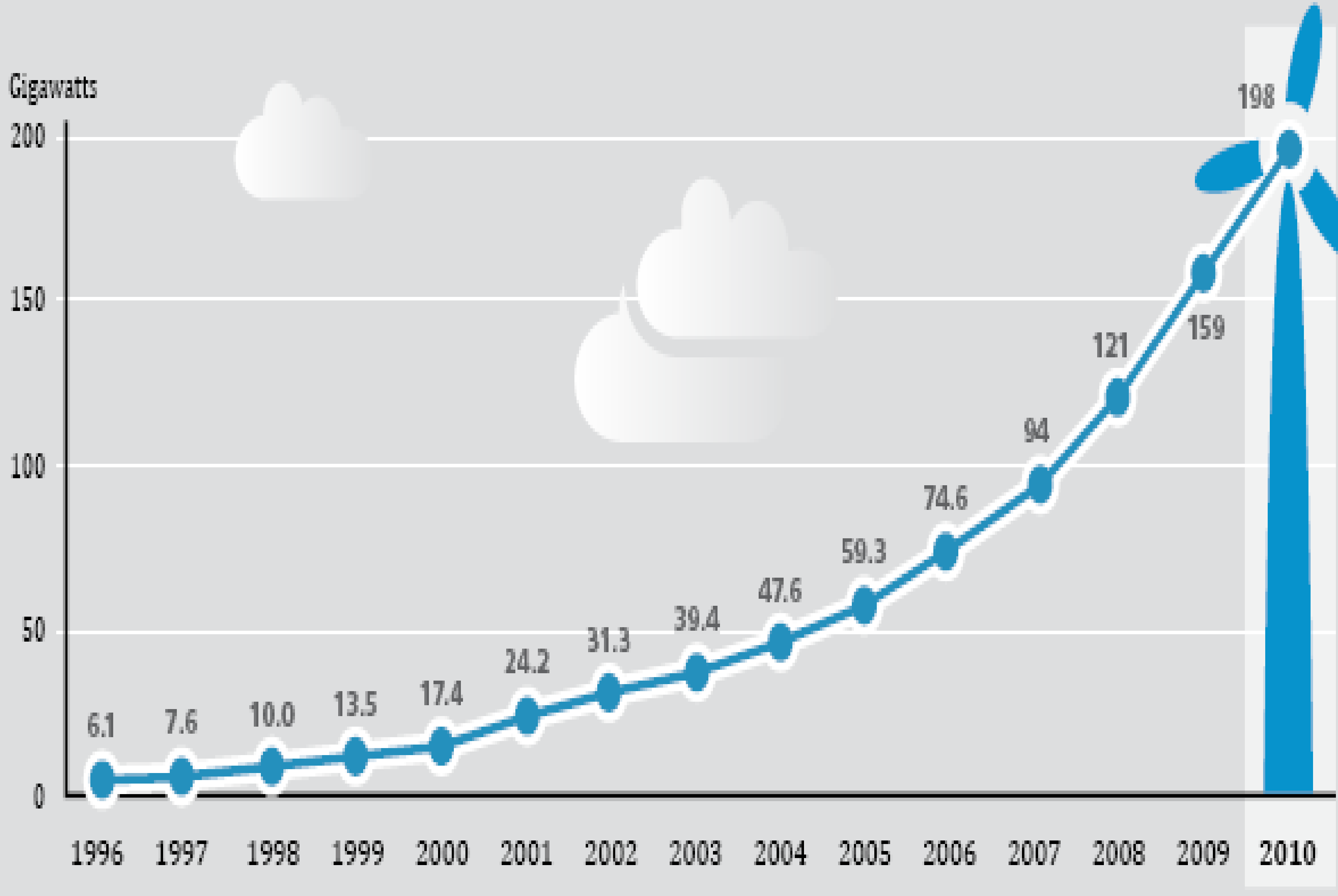
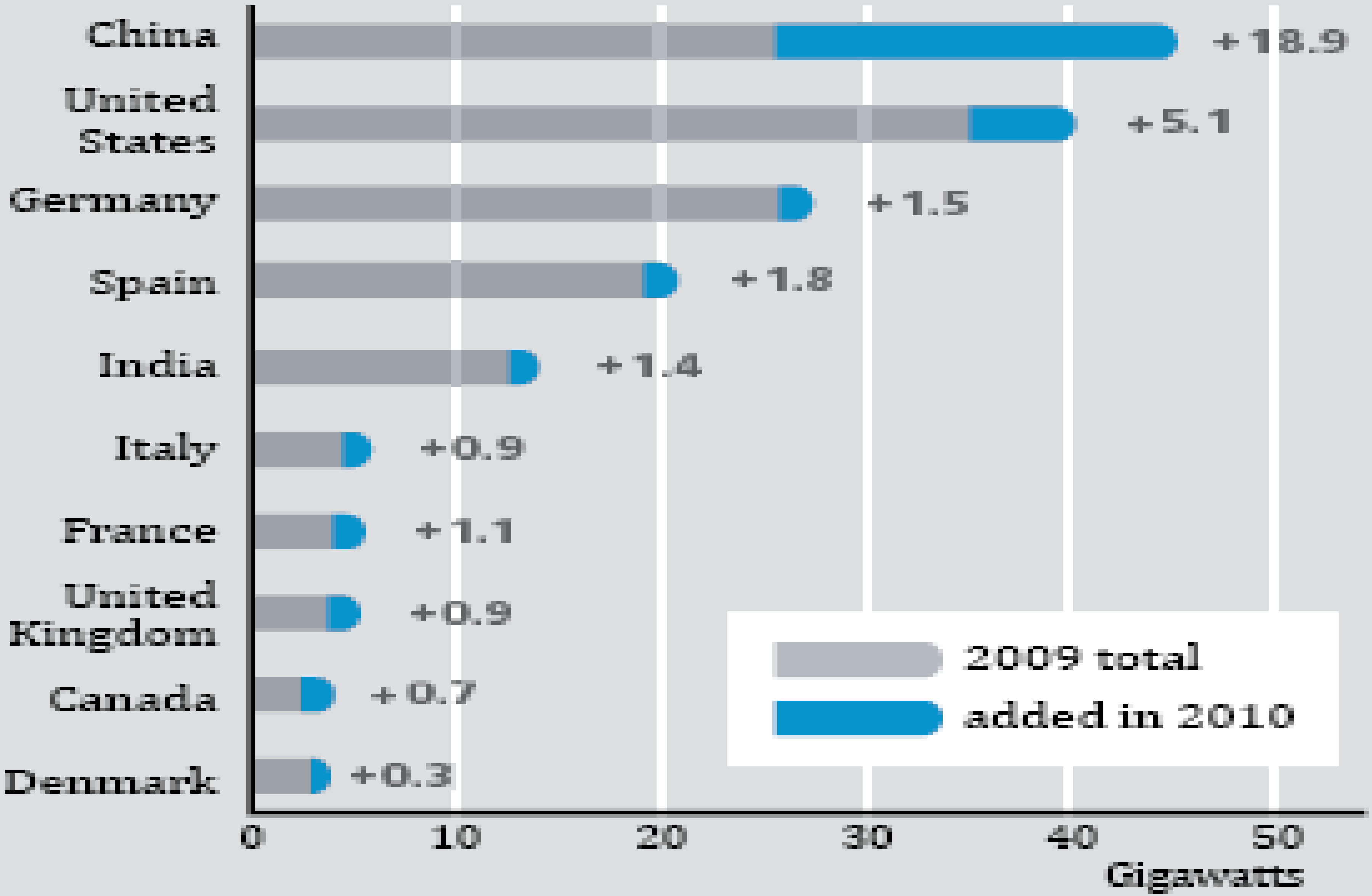


Table R2. Added and Existing Wind Power, Top 10 Countries, 2010

Country	Cumulative at end of 2009 (GW)		Added in 2010 (GW)	Cumulative at end of 2010 (GW)
China[1]	17/25.8	+	14/18.9	31/44.7
United States	35.1	+	5.1	40.2
Germany	25.7	+	1.5	27.2
Spain	18.9	+	1.8	20.7
India[2]	11.8	+	1.4	13.2
Italy	4.8	+	0.9	5.8
France	4.6	+	1.1	5.7
United Kingdom	4.4	+	0.9	5.3
Canada	3.3	+	0.7	4.0
Denmark	3.5	+	0.3	3.8
World Total	**159**	+	**39**	**198**

Figure 6. Wind Power Capacity, Top 10 Countries, 2010



WEG Installation Details Country Wise (June 2011)

Position	Country	Total Capacity (GW)
1	China	52.8
2	USA	42.432
3	Germany	27.981
4	Spain	21.15
5	India	14.55
6	Italy	6.2
7	France	6.06
8	UK	5.707
9	Canada	4.611
10	Portugal	3.96
	Rest of the World	29.5
	Total	215

Wind energy estimation in the world continued…

- Globally, wind energy has become a mainstream energy source and an important player in the world's energy markets, and it now contributes to the energy mix in more than 70 countries across the globe.
- China is, at present (January 2011) the world leader in the installed capacity followed by USA, Germany, Spain, and India. India ranks fifth in respect of installed capacity.
- By the year 2030, 20 % of the electricity may be provided through wind generation in USA.
- There are now many thousands of wind turbines operating throughout the world and wind power in Europe accounts for 48% (2009). World wind generation capacity has more than quadrupled between 2000 and 2006, doubling about every three years.

Wind energy estimation in the world continued…

- 81% of wind power installations are in the US and Europe. The share of the top five countries in terms of new installations fell from 71% in 2004 to 62% in 2006, but climbed to 73% by 2008. The top five countries — China, United States, Germany, Spain, and India — have seen substantial capacity growth in the past two years.
- Wind accounts for nearly one-fifth of electrical power generated in Denmark— the highest percentage of any country — and it is tenth in the world in total wind power generation. Denmark is prominent in the manufacturing and use of wind turbines, with a commitment made in the 1970s to eventually produce half of the country's power by wind.

Wind energy estimation in the world continued…

- China is currently the world leader in wind power generation capacity, with 52.8 GW (June 2011) in operation.
- A Chinese renewable energy law was adopted in November 2004, following the World Wind Energy Conference organized by the Chinese.
- By 2008, wind power was growing faster in China than the government had planned.
- The growth was indeed faster in percentage terms than in any other large country, having more than doubled each year since 2005. Policymakers doubled their wind power prediction for 2010, after the wind industry reached the original goal of 5 GW three years ahead of schedule.

Wind energy estimation in the world continued…

- In recent years, the US has added substantial amounts of wind power generation capacity, growing from just over 6 GW at the end of 2004 to over 40 GW at the end of 2010.
- The country as a whole generates just 2.4% of its electrical power from wind, but several states generate substantial amounts of wind power. Texas is the state with the largest amount of generation capacity with 9.4 GW installed. This would have ranked sixth in the world, were Texas a separate country.
- California was one of the incubators of the modern wind power industry, and led the US in installed capacity for many years.
- US Department studies have concluded that wind from the states of Texas, Kansas, and North Dakota could provide enough electricity to power the entire nation.

Wind energy estimation in the world continued…

- India ranks 5th in the world. The World Wind Energy Conference in New Delhi in November 2006 has given additional impetus to the Indian wind industry. Muppandal village in Tamilnadu state has several wind turbine farms in its vicinity, and is one of the major wind energy harnessing centers in India led by major companies like Suzlon, Vestas and Micon.
- Mexico recently opened La Venta II Wind power Project as a step toward reducing Mexico's consumption of fossil fuels. The 88 MW project is the first of its kind in Mexico. Another growing market is Brazil, with a wind potential of 143 GW.
- Canada experienced rapid growth of wind capacity between 2000 and 2006, with total installed capacity increasing from 137 MW to 1,451 MW, and showing an annual growth rate of 38 %.

Wind energy estimation in the world continued…

- Offshore wind power refers to the construction of wind farms in bodies of water to generate electricity from wind. Better wind speeds are available offshore compared to onshore. So, offshore wind power's contribution in terms of electricity supplied is higher. Siemens and Vestas are the leading turbine suppliers for offshore wind power. Dong Energy, Vattenfall and E.on are the leading offshore operators.
- As of October 2010, 3.16 GW of offshore wind power capacity was operational, mainly in Northern Europe. More than 16 GW of additional capacity will be installed before the end of 2014 and the UK and Germany will become the two leading markets. Offshore wind power capacity is expected to reach a total of 75 GW worldwide by 2020, with significant contributions from China and USA.

Wind energy estimation in the world continued…

- Worldwide, there are many thousands of wind turbines operating. Europe alone accounted for 48% of the total in 2009.
- Many of the operational onshore wind farms are located in USA. As of November 2010, the Roscoe Wind Farm is the largest onshore wind farm in the world at 781.5 MW, followed by the Horse Hollow Wind Energy Centre (733.5 MW). As of November 2010, the Thanet Offshore Wind Project in UK is the largest offshore wind farm in the world at 300 MW, followed by Horns Rev II (209 MW) in Denmark.
- Wind power accounts for approximately 24% of electricity use in Denmark, 15% in Portugal, 14% in Spain, 10% in Ireland, 9.5% in Germany and 6% in India.

Wind Turbine Manufacturers

Top 10 wind turbine manufacturers in 2010:

1. Vestas (14.8%)
2. Sinovel (11.1%)
3. GE Wind Energy (9.6%)
4. Goldwind (9.5%)
5. Enercon (7.2%)
6. Suzlon Group (6.9%)
7. Dongfang (6.7%)
8. Gamesa (6.6%)
9. Siemens Wind Power (5.9%)
10. United Power (4.2%)

Wind energy estimation in India

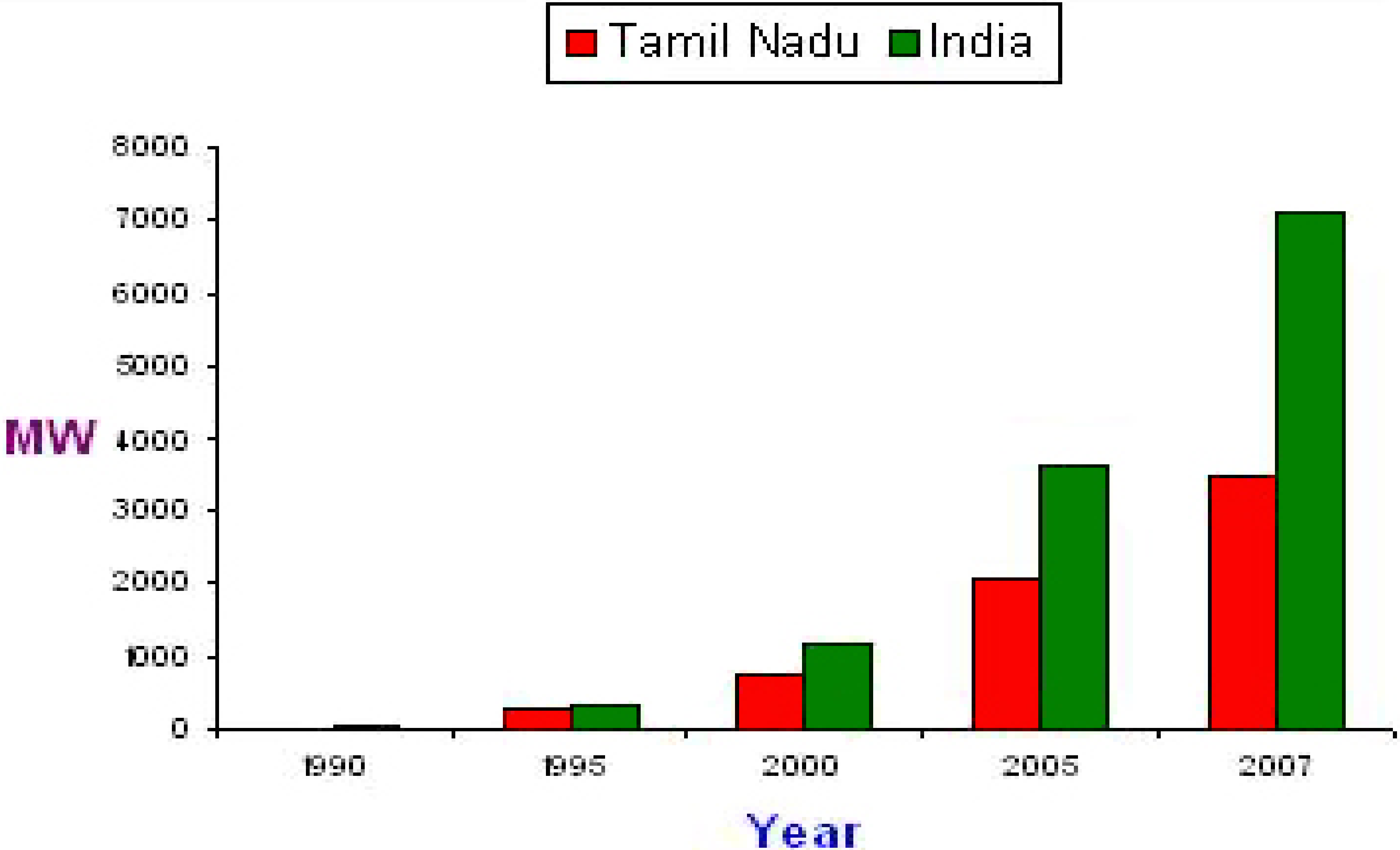
- The wind-energy programme was initiated in India in 1983-84.
- The programme was implemented and managed by the Ministry of Non-conventional Energy (Now called as the **Ministry of New and Renewable Energy, MNRE**), Government of India.
- The potential in wind has been estimated as 45,000 MW, assuming 1% of land available for wind-power generation in potential areas.
- There are 216 sites having wind-energy densities of 200 W/m^2 (corresponding to wind speeds of 6.93 m/s and above) at 50-m height. These have been identified as potential sites.
- The total installed wind-generation capacity in India, as of January 2011, has reached 13.2 GW.

Wind energy estimation in India

continued….

- This sector has been growing at over 35% in the last three years. It is estimated that 6,000 MW of additional wind-power capacity will be installed in India by 2012.
- Wind power accounts for 6 % of India's total installed power capacity.
- The state wise potential, installed capacity and growth of wind power are given in the next slides.
- The gross potential is estimated as approximately 45,000 MW in the potential areas. However, the technical potential is limited to only 13,000 MW assuming 20% grid penetration.
- Wind electric generators of unit sizes between 225 kW and 1.65 MW have been deployed across the country.

S.No	State	Gross potential (MW)	Installed Capacity (MW) as on April 2010
1.	Andhra Pradesh	8275	140.44
2.	Gujarat	9675	1,864.59
3.	Karnataka	6620	1,506.87
4.	Kerala	875	31.15
5.	Madhya Pradesh	5500	167.54
6.	Maharashtra	3650	2,071.56
7.	Rajasthan	5400	1,091.7
8.	Tamil Nadu	3050	4,875.94
9.	West Bengal		1.75
10.	Others	1700	1.3
Total		45,195	11,752.83



Courtesy of www.teda.gov.in/

Growth of wind power in India and Tamil Nadu.

Wind energy estimation in India

continued….

- As many as 15 manufactures are engaged in the production of wind turbine equipments. Wind turbines of unit size up to 750 kW are being manufactured in the country
- During 2007-08 (up to 31.12.2007), indigenously produced wind turbines valued at about US$ 425 million have been exported to USA, Europe, Australia, Spain, Portugal and Brazil. This apart, wind turbine blades valued at US$ 50 million have been exported to Germany, China and Spain.
- R and D activities are coordinated through the Centre for Wind Energy Technology (C-WET) located at Chennai.
- Wind power installed capacity at different states is given in the next slides in the order of magnitude. Tamilnadu tops the list.

Wind power installed capacity in India (As on April 2010)

Sl.No	State	Installed Capacity in MW
1	Tamilnadu	4,875.94
2	Maharashtra	2,071.56
3	Gujarat	1,864.59
4	Karnataka	1,506.87
5	Rajasthan	1,091.7
6	Madhya Pradesh	167.54
7	Andhra Pradesh	140.44
8	Kerala	31.15
9	West Bengal	1.75
Others		1.3
TOTAL		11,752.83

Indian State-wise Wind Power Installed Capacity as on 30.07.2011

Sl.No	State	Capacity in MW
1	Tamil Nadu	6160
2	Maharashtra	2358
3	Gujarat	2284
4	Karnataka	1765
5	Rajasthan	1643
6	Madhya Pradesh	276
7	Andhra Pradesh	198
8	Kerala	35
9	Others	4
	Total	14,723

Wind Turbine Manufacturers in India

- Suzlon, an Indian-owned company, emerged on the global scene in the past decade, and by 2006 had captured almost 7.7 percent of market share in global wind turbine sales. Suzlon is currently the leading manufacturer of wind turbines for the Indian market, holding some 52 percent of market share in India. Suzlon's success has made India the developing country leader in advanced wind turbine technology.
- In February 2009, Shriram EPC bagged Rs 700 million contract for setting up 60 units of 250 KW (totaling 15 MW) wind turbines in Tirunelveli district. Enercon is also playing a major role in development of wind energy in India.
- Other players are Vestas, NEG Micon, GE Wind Energy India, Elecon Engineering Company etc

Tamilnadu

- Tamilnadu is the state with the most wind generating capacity, 6160 MW (July 2011) constituting 42% of the total capacity of India.
- The districts of Coimbatore, Trippur, Tirunelveli and Kanyakumari are having more wind mills in Tamilnadu.
- **Aralvaimozhi** (or Aramboly) **(Tamil: ஆரல்வாய்மொழி)** is a panchayat town in Kanyakumari district . It is is near the Muppandal wind farm. This farm is the largest in Asia and supplies the villagers with electricity for work.
- This village had been selected as the showcase for India's $2 billion clean energy program.

Aralvaimozhi aerial view from Thovalai Chekkar Giri Malai

Wind energy estimation in India

continued….

- Ministry of New and Renewable Energy (MNRE) has been planning and developing the basic infrastructure, institutions, and resources for carrying out research and development, large scale demonstration and diffusion of the renewable energy sources.
- As a step towards achieving these broad goals and to tackle the challenges in sustaining the development and accelerating the pace of utilization of wind energy in the country, the **Centre for Wind Energy Technology (C-WET**) has been established by MNRE at Chennai as an autonomous R&D institution of Government of India.
- A Wind Turbine Test Station with technical and partial financial support by Danida, Government of Denmark, has been established at Kayathar, in Thoothukudi district of Tamilnadu.

Types of wind energy conversion systems (WECS)

- A wind energy conversion system (WECS) converts wind energy into some from of electrical energy.
- In particular, medium and large scale WECS are designed to operate in parallel with an ac grid. These are known as grid-connected systems.
- Small systems, isolated from the grid, feeding only the local loads, are known as decentralized, stand-alone or isolated power systems.
- A general block diagram of a grid-connected or stand alone WECS is shown in the next slide.
- The turbine shaft speed is stepped up with the help of gears, with a fixed gear ratio, to suit the electrical generator and fine-tuning of speed is incorporated by pitch control. This block acts as a drive for the generator.

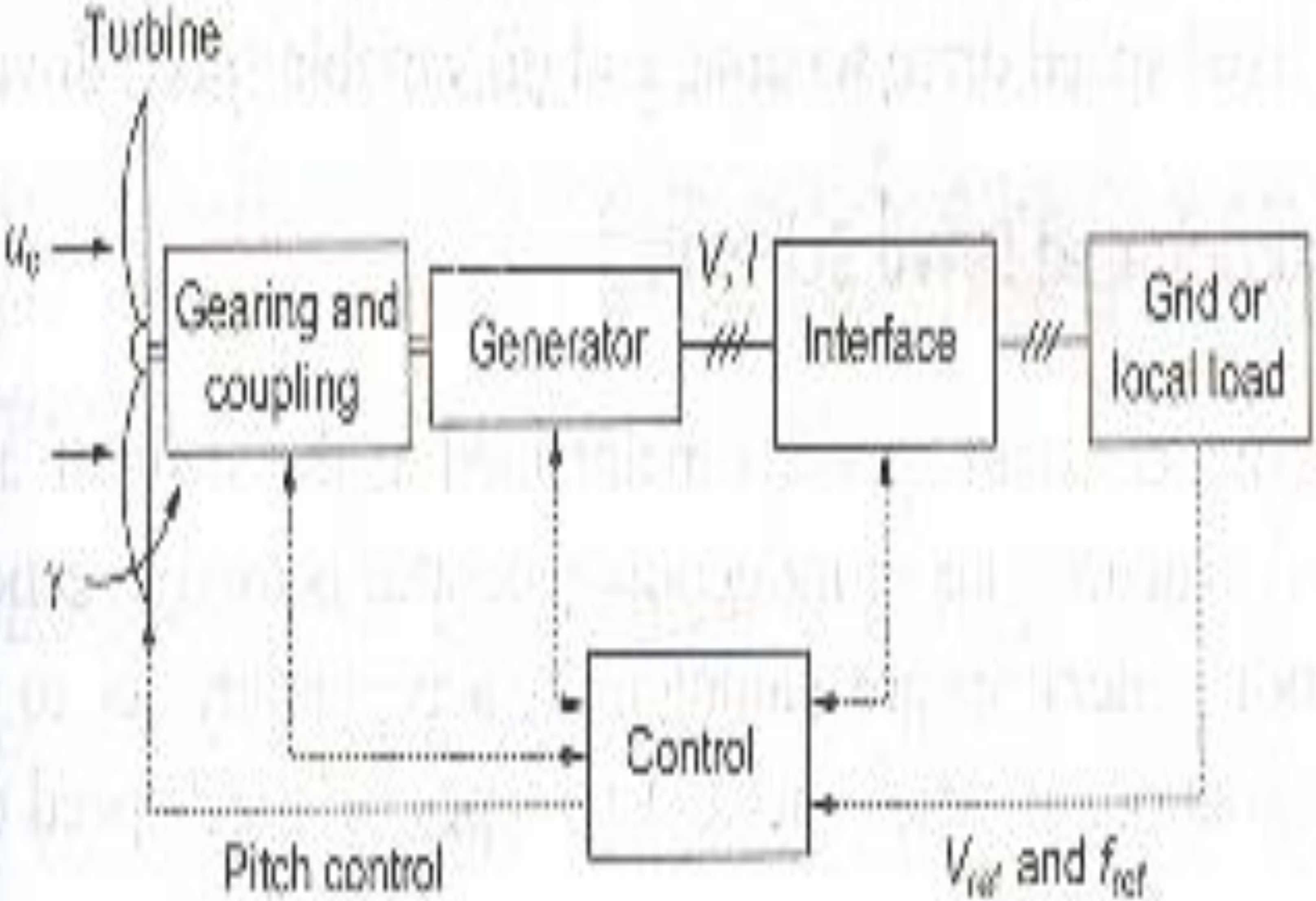


Fig. ... General block diagram of a WECS

Types of WECS continued…

- Use of variable gear ratio has been considered in the past and was found to create more problems than benefits.
- DC, synchronous or induction generators are used for mechanical to electrical power conversion depending on the design of the system.
- In the case of a grid connected system, the interface conditions the generated power to grid-quality power. The interface may consist of a power electronic converter, transformer, filter, etc. The control unit monitors and controls the interaction among various blocks. It derives the reference voltage and frequency signals from the grid, receives wind speed, wind direction, wind turbine speed signals, etc., processes them and accordingly controls various blocks for optimal energy balance.

Details of wind turbines

- Wind turbines are broadly classified into two categories.
- When the axis of rotation is parallel to the air stream (i.e., horizontal), the turbine is said to be a horizontal axis wind turbine (HAWT), and when it is perpendicular to the air stream (i.e., vertical), it is said to be a vertical axis wind turbine (VAWT).
- The size of the rotor and its speed depends on rating of the turbine.
- HAWTs have emerged as the most successful type of turbines. These are being used for commercial energy generation in many parts of the world. Their theoretical basis is well researched and sufficient field experience is also available.
- VAWTs are in the development stage and many models are undergoing field trial.

Horizontal axis wind turbine

(A) Main components: The constructional details of the most common, three-blade rotor, horizontal axis wind turbine is shown in the next slide. The main parts are as follows:

(1) Turbine Blades:

- Turbine blades are made of high-density wood or glass fibre and epoxy composites. They have an airfoil type of cross section. The blades are slightly twisted from the outer tip to the root to reduce the tendency to stall.
- The diameter of a typical, MW range, modern rotor may be of the order of 100 m.
- Modern wind turbines have two or three blades.
- Three blades are more common in Europe and other developing countries including India. The American practice, however, is in favour of two blades.

inside the hub.

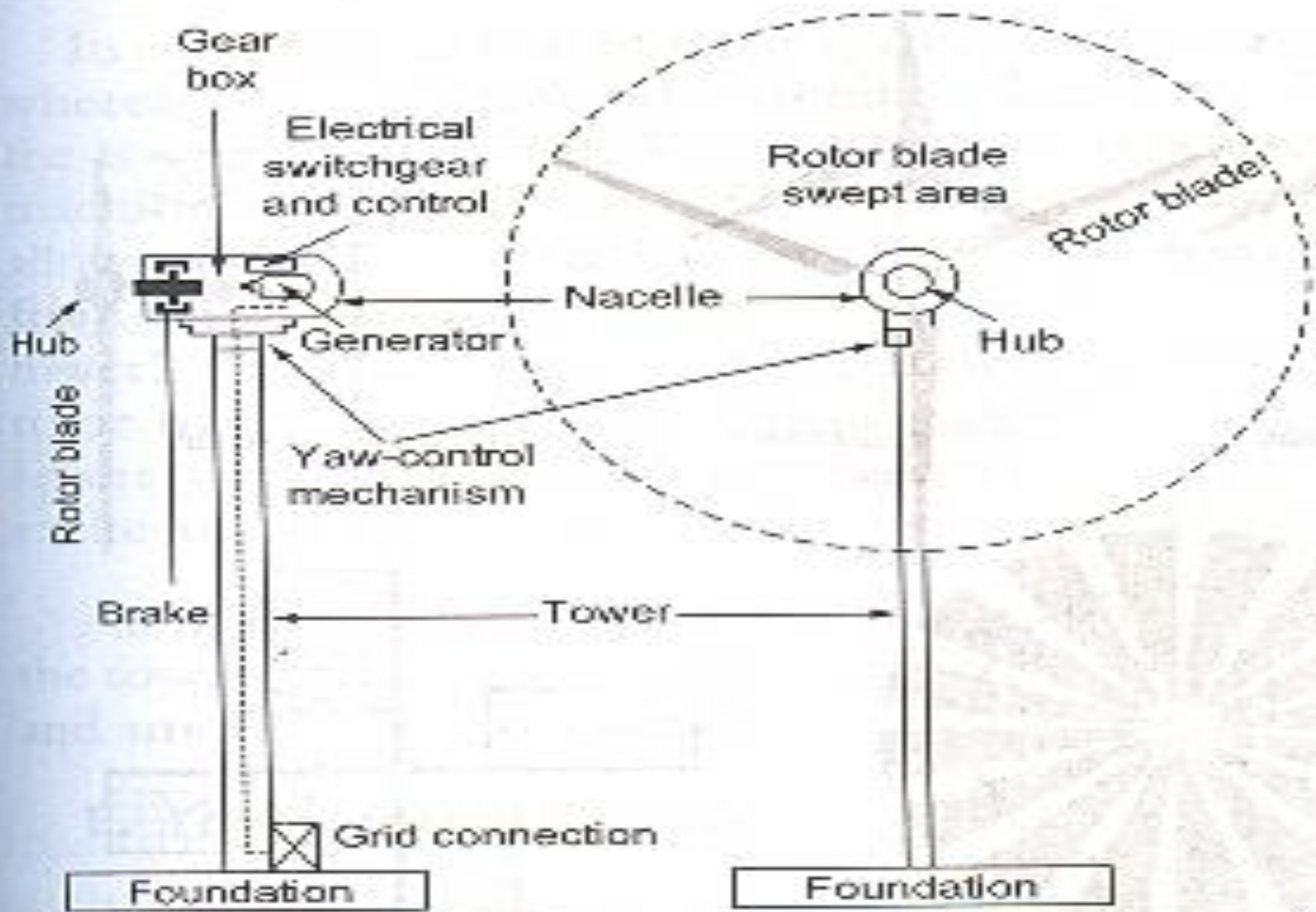


Fig. 7 Horizontal axis wind turbine

Horizontal axis wind turbine

continued…

(2) Hub:

- The central solid portion of the rotor wheel is known as hub. All blades are attached to the hub. The mechanism for pitch angle control is also provided inside the hub.

(3) Nacelle:

- The term nacelle is derived from the name for the housing of aircraft engines. The rotor is attached to the nacelle, and mounted at the top of the tower. It contains rotor brakes, gearbox, generator and electrical switchgear and control.
- Brakes are used to stop the rotor when power generation is not desired. The gearbox steps up the shaft rpm to suit the generator. Protection and control functions are provided by switchgear and control block.
- The generated electrical power is conducted to ground terminals through a cable.

Horizontal axis wind turbine
continued…

(4) Yaw-Control Mechanism:

- This is the mechanism to adjust the nacelle around the vertical axis to keep it facing the wind and is provided at the base of the nacelle.

(5) Tower:

- The tower supports the nacelle and rotor. For medium and large sized turbines, the tower is slightly taller than the rotor diameter. In case of a small sized turbine, the tower is much larger than the rotor diameter as the air is erratic at lower heights. Both steel and concrete towers are being used.
- The tower vibrations and resulting fatigue cycles under wind speed fluctuations are avoided by careful design. This requires avoidance of all resonance frequencies of tower, the rotor and the nacelle from the wind-fluctuation frequencies.

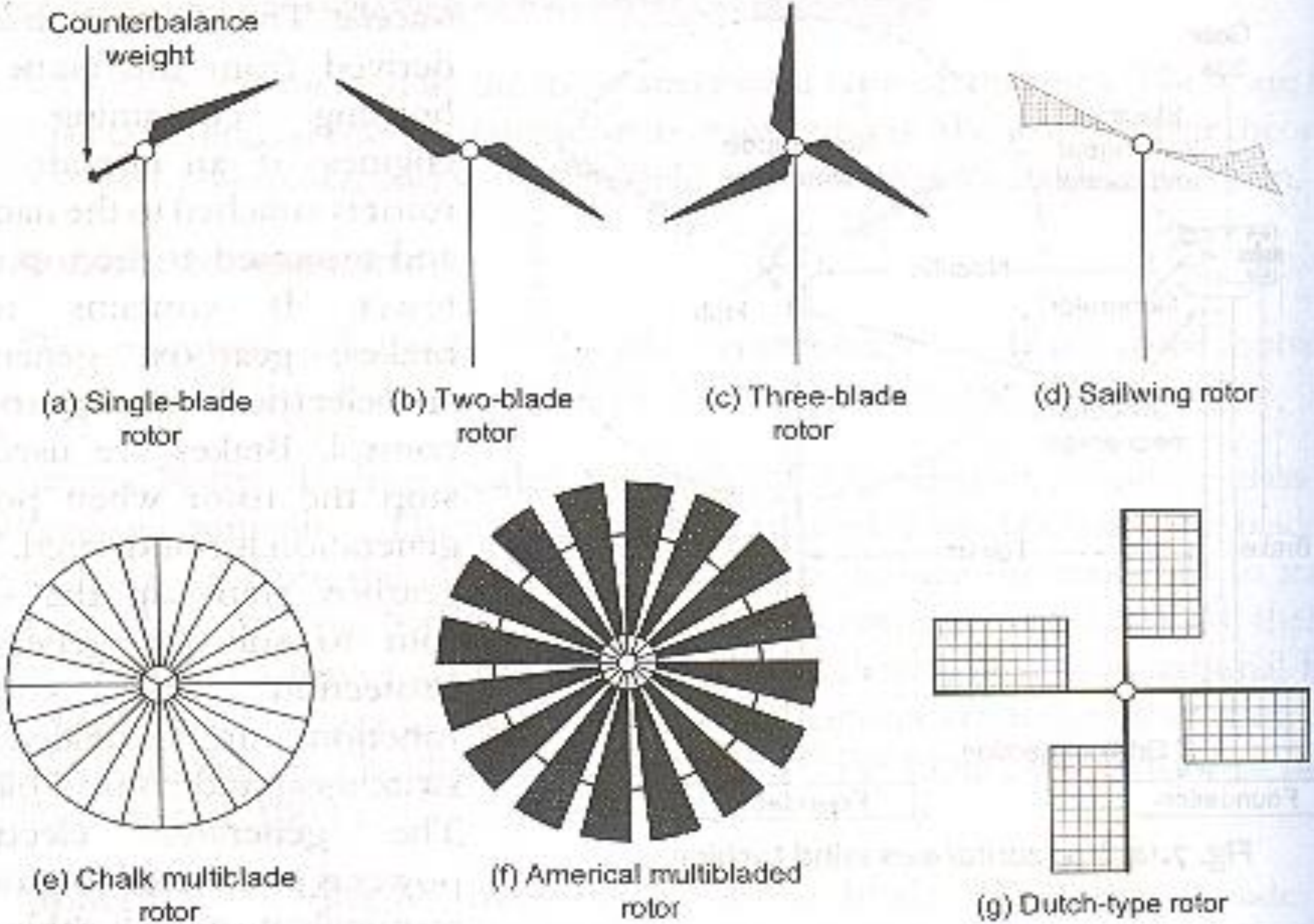

Courtesy of Vattenfall

Horizontal axis wind turbine

continued…

(B) Types of Rotors:

- Depending on the number of blades, with speed and nature of application, rotors have been developed in various types of shapes and sizes. These are sown in the next slide.
- The types of rotors shown in (a) to (e) are relatively high-speed ones, suitable for applications such as electrical power generation. Large HAWTs have been manufactured with two and three blades. A single blade rotor, with a balancing counterweight is economical, has simple controls but it is noisier and produces unbalanced forces. It is used for low-power applications.
- Those given in (f) and (g) are low-speed rotors and most suited for water-lifting applications, which require a high starting torque. They can capture power even from very slow winds.

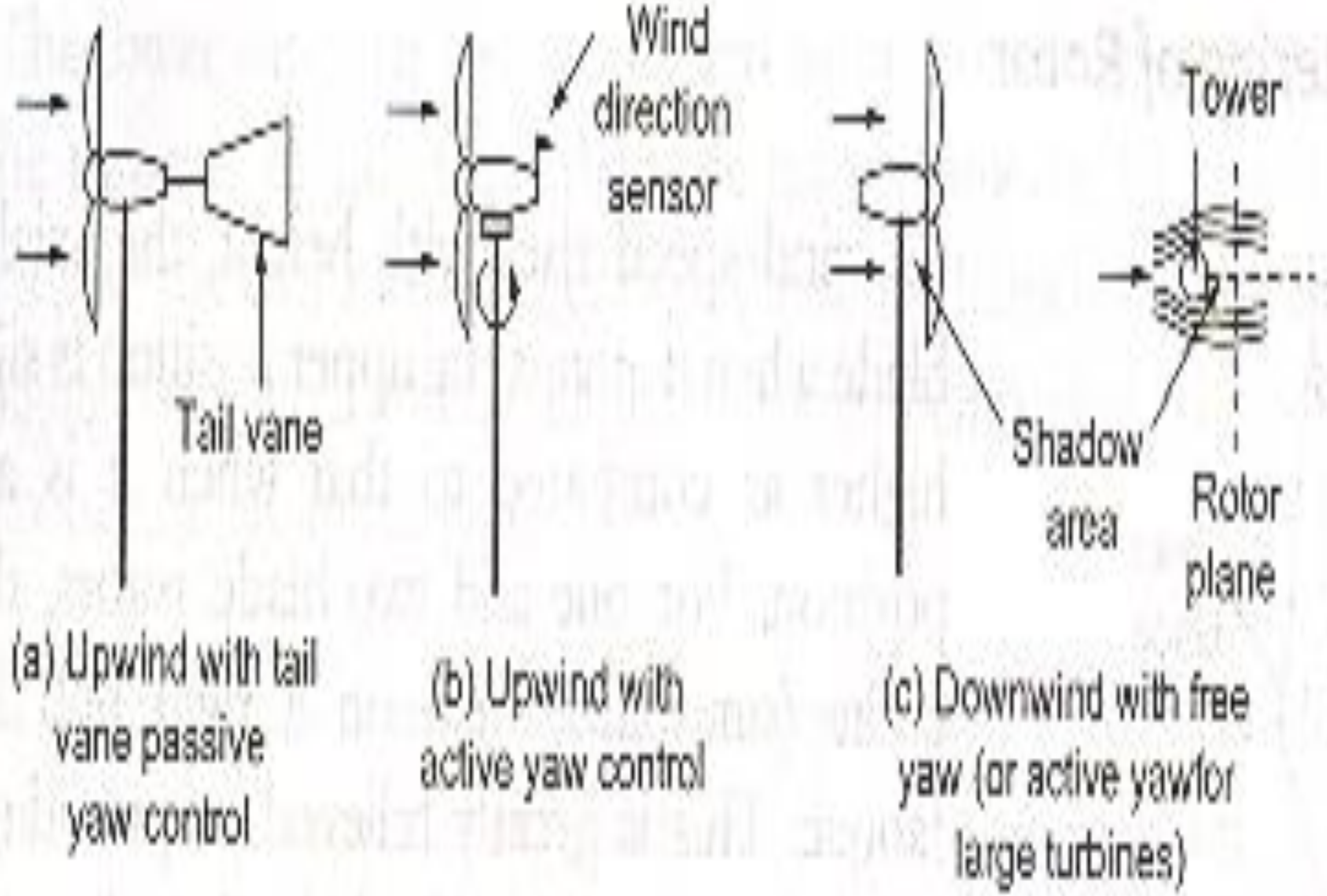


Various types of rotors for HAWT

Horizontal axis wind turbine
continued…

(C) Yaw-Control System:

- Adjusting the nacelle about the vertical axis to bring the rotor facing the wind is known as yaw control.
- The yaw control system continuously orients the rotor in the direction of wind.
- For localities with a prevailing wind in one direction only, the rotor can be in a fixed orientation. Such a machine is said to be *yaw fixed.*
- Most wind turbines however, are *yaw active.*
- In small wind turbines, a tail vane is used for passive yaw control. In large turbines however, an active yaw control with power steering and wind direction sensor is used to maintain the orientation.



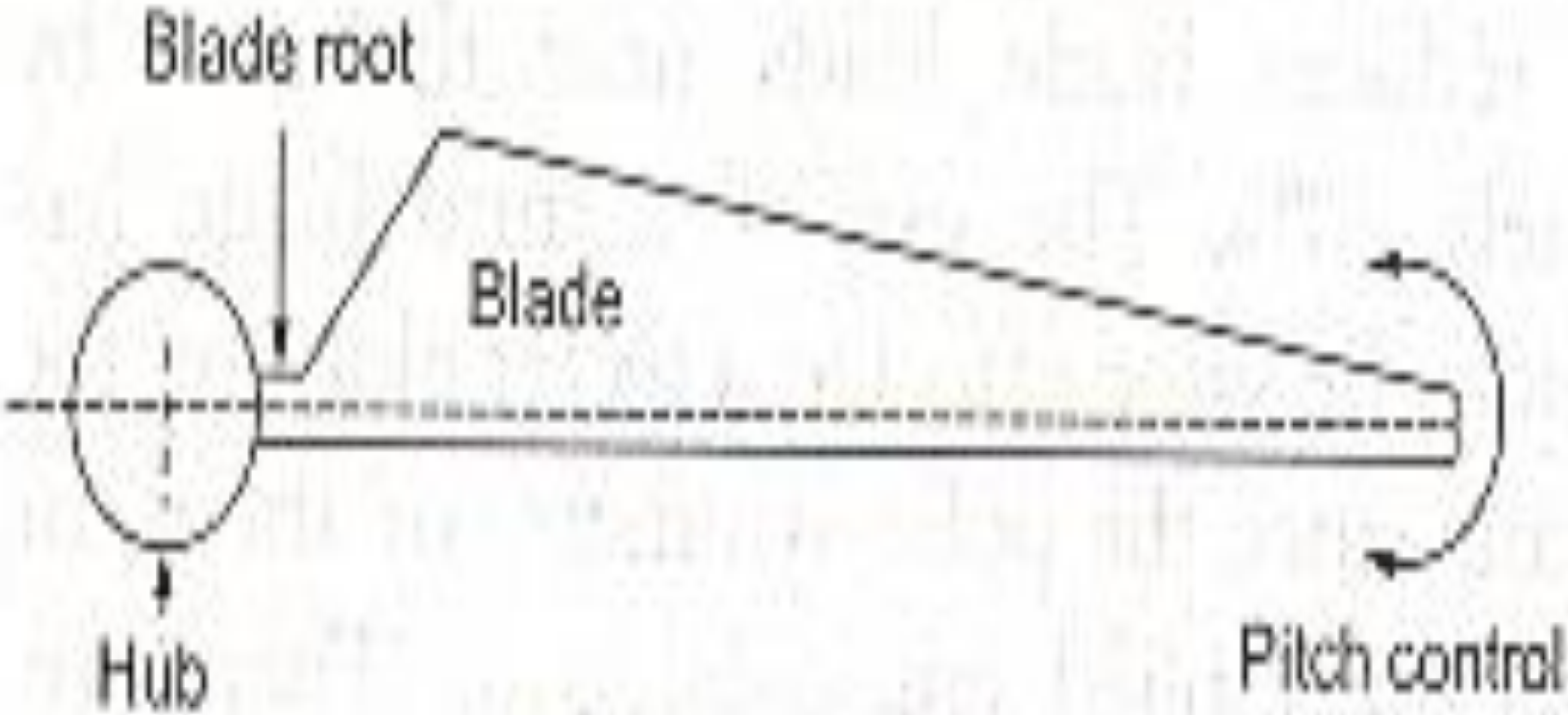
Yaw control in upwind and downwind machines

Horizontal axis wind turbine
continued…

(D) Pitch Control System:

- The pitch of a blade is controlled by rotating it from its root, where it is connected to the hub as shown in the next slide.
- The pitch control mechanism is provided through the hub using a hydraulic jack in the nacelle.
- The control system continuously adjusts the pitch to obtain optimal performance.
- In modern machines, pitch control is incorporated by controlling only the outer 20 % length of the blade (i.e., tip), keeping the remaining part of the blade as fixed.

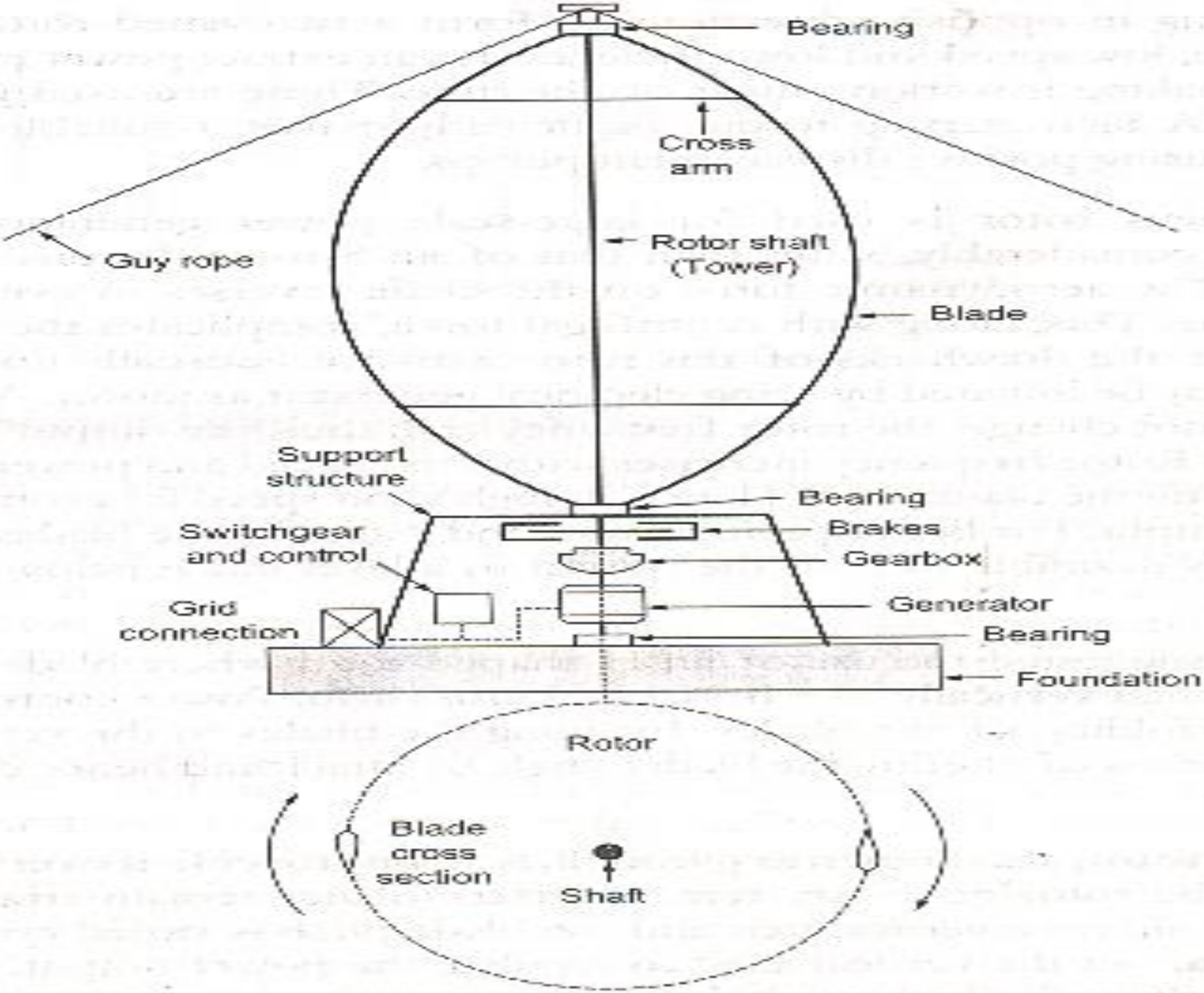
E. Pitch Control System



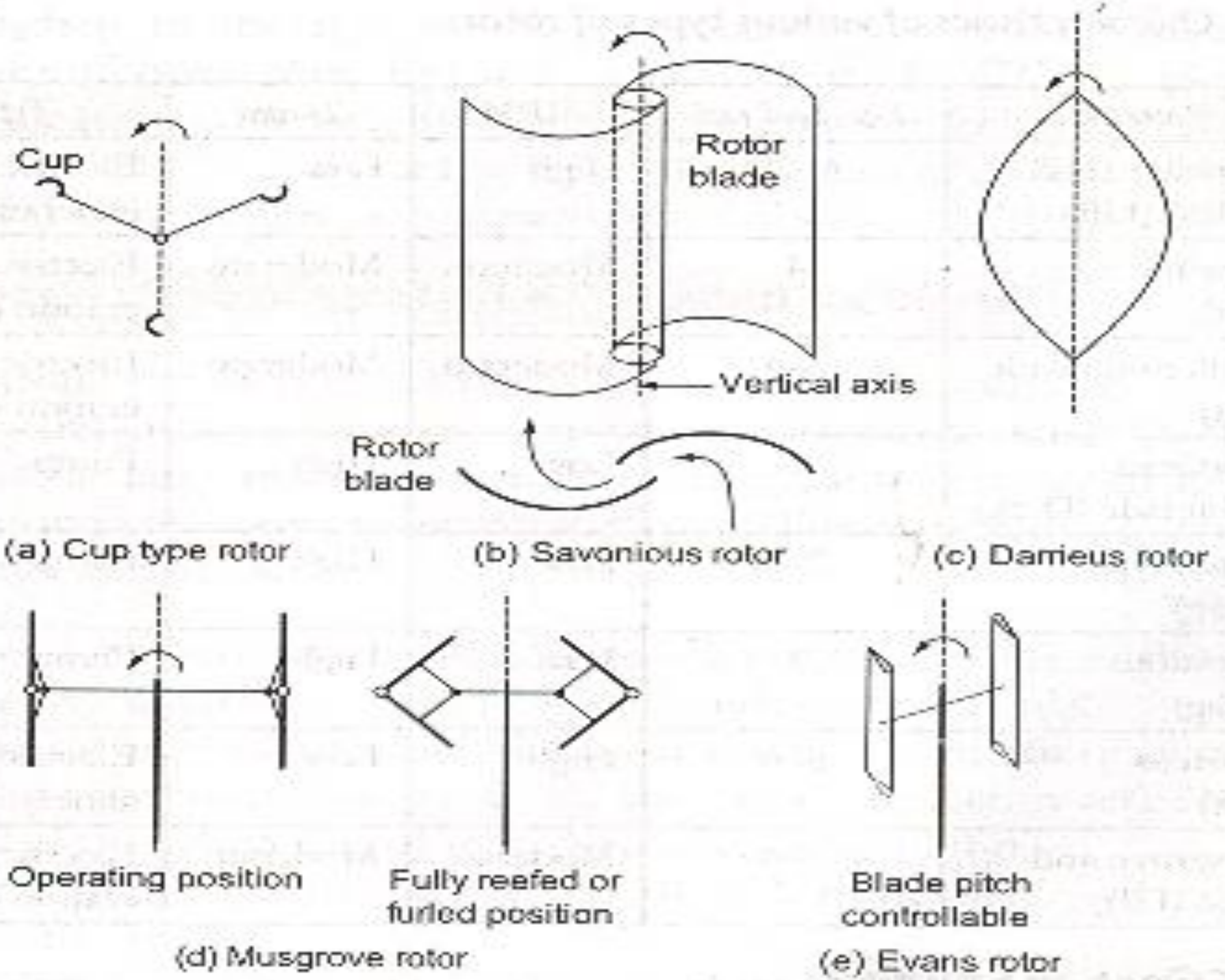
Pitch control

Vertical axis wind turbine

- Vertical Axis Wind Turbines **(VAWTs)** are in the development stage and many models are undergoing field trial. The main attractions of a VAWT are:
- It can accept wind from any direction, eliminating the need for yaw control.
- The gearbox, generator etc., are located at the ground. This eliminates the heavy nacelle at the top of the tower and simplifies the design and installation of the whole structure including the tower.
- The inspection and maintenance are easier. It also reduces the overall cost.
- The constructional details of a vertical axis wind turbine (Darrieus- type rotor) and the various types of rotors are shown in the subsequent slides.



Vertical axis wind (Darrieus) turbine



Various types of rotors for VAWT

Generators used in WECS

- The main features of various types of generators and their suitability in wind power generation are discussed below:
- **Dc generator**: Conventional dc generator is not favoured due to their high cost, weight and maintenance problems of the commutator and brushes. However, permanent-magnet (brushless and commutatorless) dc generators are considered in small-rating (below 100 kW) isolated systems.
- **Synchronous generator**: synchronous generators produce high-quality output and are universally used for power generation in conventional plants. However, they have very rigid requirement of maintaining constant shaft speed. Also, precise rotor speed control is required for synchronization.

Generators used in WECS

continued…

- Therefore, a synchronous machine is not well suited to wind power generation.
- Requirement of dc current to excite the rotor field, which needs sliding carbon brushes on the slip rings, also poses limitation on its use. Synchronization of a wind-driven generator with a power grid also poses problems especially during gusty winds. The main advantage is that it generates both active as well as reactive power.
- **Induction generator**: The primary advantages of an induction machine are the rugged and brushless construction, absence of separate dc field power and tolerance of slight variation of shaft speed.

Generators used in WECS

continued…

- Compared to dc and synchronous machines, induction machines have low capital cost, low maintenance and better transient performance. Because of these reasons, induction generators are extensively used in wind plants. The machine is available from very low to several megawatt ratings.
- Induction generator requires ac excitation current, which is mainly reactive. In the case of a grid-connected system, the excitation current is drawn from the grid and therefore, the network must be capable of supplying this reactive power. The voltage and frequency are determined by the grid. In a standalone system, the induction generator is self-excited by shunt capacitors.

Drive schemes in WECS

Based on the generator drive, two schemes have been developed for the operation of WECS:

1. Fixed speed drive scheme
2. Variable speed drive scheme

(1) Fixed speed drive scheme:

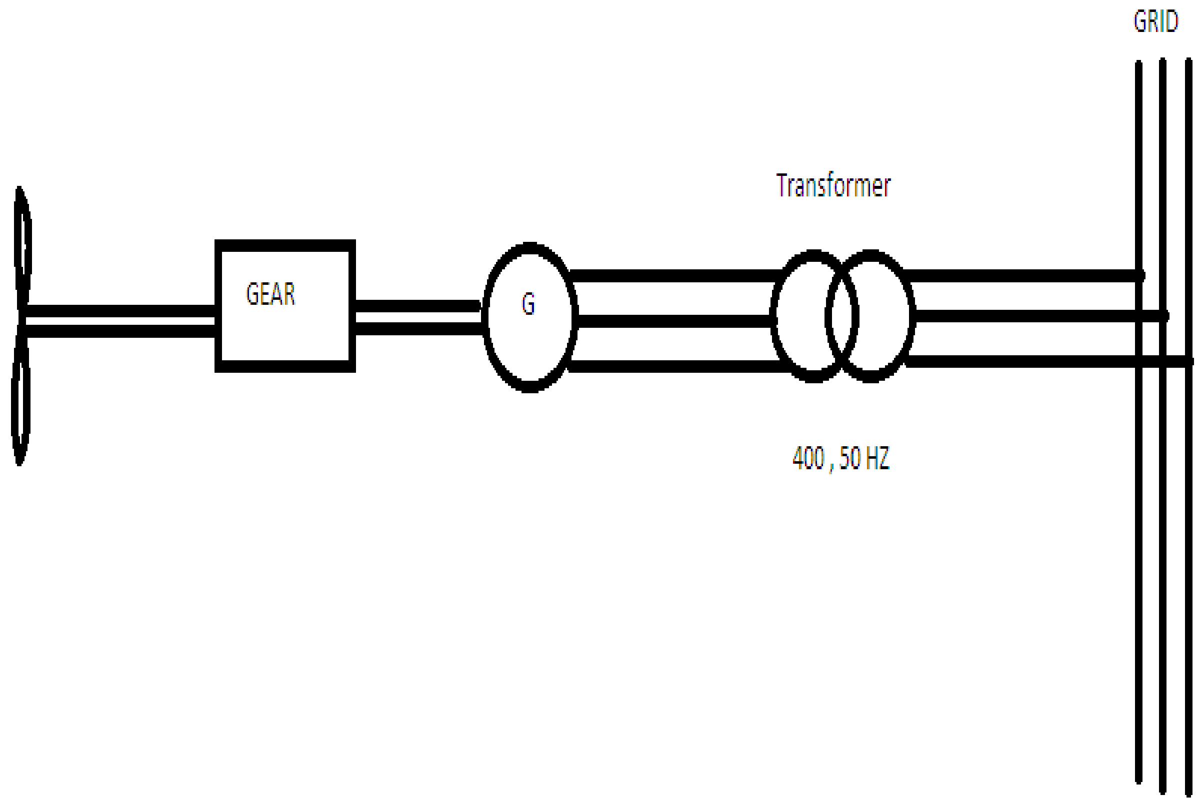
- In this scheme, constant speed is maintained at the shaft of a generator by pitch control.
- Synchronous or induction generators are used to generate electrical energy. Induction generators are gaining more acceptability due to their ability to absorb small variations in shaft speed. A block diagram of the scheme is given in the next slide.

Two types of fixed speed drive schemes:

(a) One fixed-speed drive:

- The shaft speed is held fixed for the whole range of wind speeds.

FIXED SPEED DRIVE SCHEME
(ONE OR TWO SPEED)



Drive schemes in WECS

continued…

- The major disadvantage of one-fixed speed drive is that it never captures the wind energy at the peak value of the power coefficient. Wind energy is wasted when wind speed is higher or lower than the optimal value. Because of the low annual energy yield, the use of one fixed-speed drive is limited to small machines.

(b) Two fixed-speeds drive:

- This drive increases the energy capture, reduces the electrical loses and reduces the gear noise.
- The speed setting is changed by changing the gear ratio. Two operating speeds are selected to optimize the annual energy production with expected annual wind-speed distribution at the site.
- The power production from a typical WECS using two fixed-speed drives is shown in the next slide. In this example, the gear ratio is changed at a wind speed of 10 m/s.

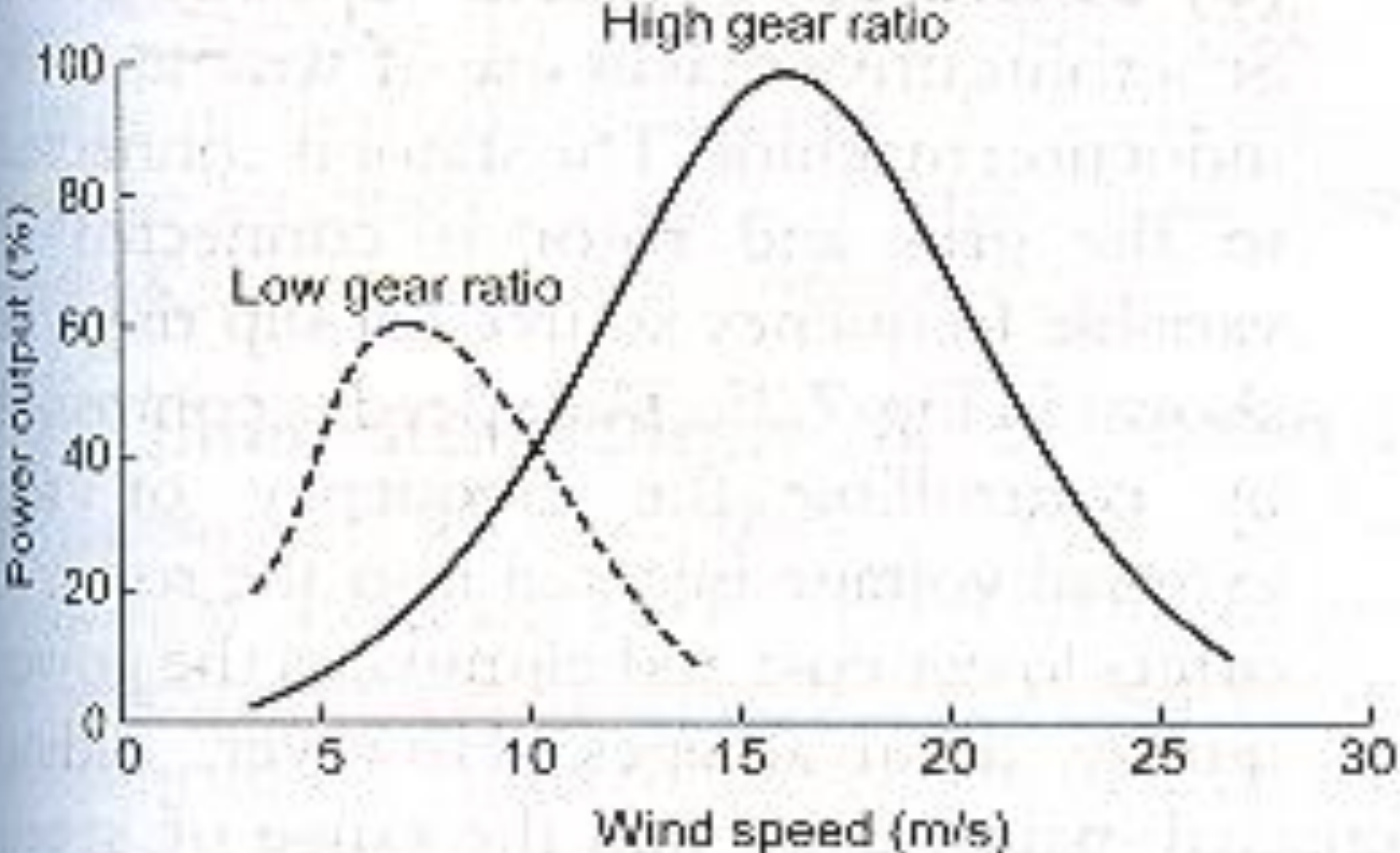


Fig. 7.5 Power output Vs wind speed for two fixed-speed drives

Drive schemes in WECS

continued…

(2) Variable speed drive scheme:

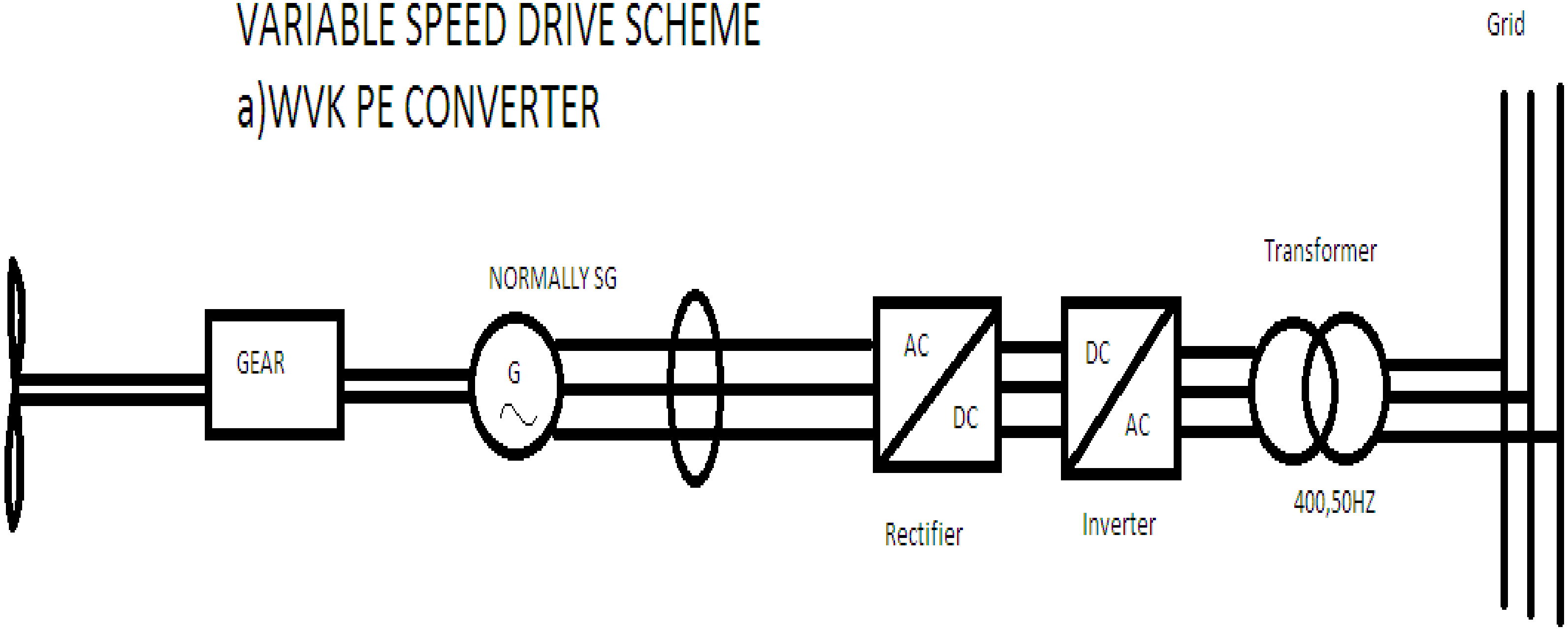
- The recent advancement in power electronics has paved the way for a variable speed drive system. In this scheme, rotor speed is allowed to vary optimally with the wind speed to capture maximum power. As a result, it can capture about one third more power per year as compared to a fixed speed drive system. The following types of variable speed-drive system are possible:

(a) Variable speed-drive using power electronics:

- Modern variable speed drive schemes make use of power electronic converters for power conditioning as shown in the next slide. The variable voltage and variable frequency output available from a generator (synchronous or self-excited induction generator) is first rectified to dc and then inverted to a fixed frequency and fixed voltage ac.

VARIABLE SPEED DRIVE SCHEME

a)WVK PE CONVERTER



Drive schemes in WECS

continued…

- The harmonics are filtered out to get grid quality output before connecting to the grid. The rectifier, inverter, filter and transformer constitute the main parts of the interface.
- Apart from the higher energy yield, use of power electronics offers remotely adjustable and controllable quality of power. This has two major benefits not available in other systems: 1. Opportunity for remote control which makes its attractive for offshore applications. 2. Fine tuning for superior grid connection, to make it better suited for meeting the demand of weak grids.
- Use of power electronic converters adds to the cost, electrical noise and losses of the system. However, the cost and benefit trade is generally positive for large machines.

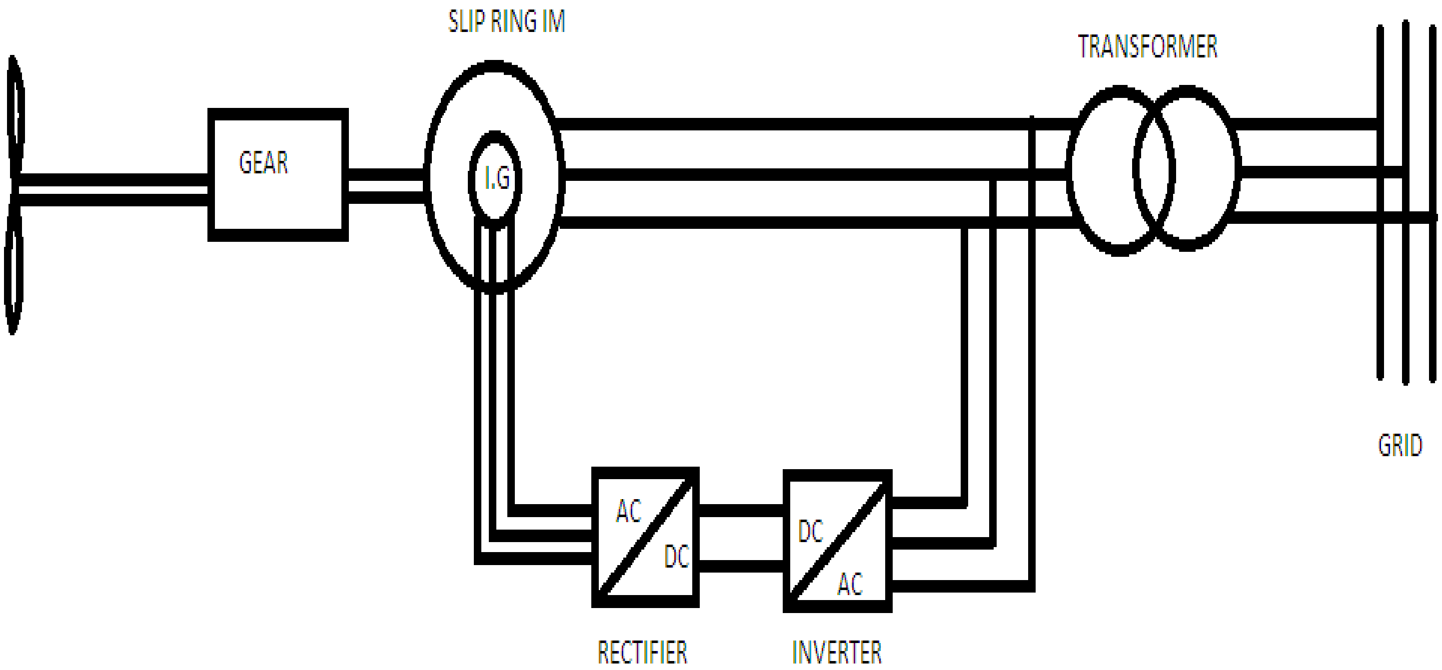
Drive schemes in WECS

continued…

(b) Scherbius variable speed drive:

- This drive makes use of wound rotor induction machine.
- The stator is connected to the grid and rotor is connected to variable frequency source via slip rings, as shown in the next slide.
- The speed is controlled by controlling the frequency of the external voltage injected into the rotor.
- It offers lower cost and eliminates the power quality disadvantage.
- However, sliding contacts at the slip rings lead to increased maintenance and the range of speed control is generally limited to 2:1.

SHERBIUS SYSTEM(DFIG)



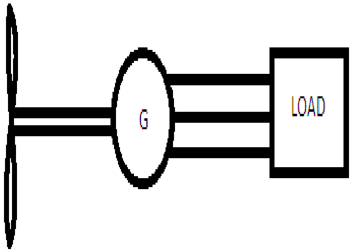
Drive schemes in WECS

continued…

(c) Variable speed direct drive:

- In this scheme, the generator is directly coupled to the turbine shaft without gear and operates at turbine speed as shown in the next slide. Also, it does not make use of power electronics.
- The main benefits are: (i) the lower nacelle weight, (ii) reduced noise and vibration, (iii) lower power loss, and (iv) less frequent servicing requirement at the nacelle, which is particularly very attractive for offshore installations.
- For small-sized turbines, where the rotor speed is high, direct coupling to the generator is possible without much difficulty. Large rotors turn slowly and direct coupling requires large number of poles on electrical machines, which impose design limitations.
- Siemens is (March 2011) now producing a 3.6 MW direct-drive turbine that has no need for gears.

DIRECT DRIVE



Normally preffered for stand alone small system

Penetration of wind power into the grid

- Wind energy is an intermittent source of power. There are variations in wind speed and, therefore, the power output (on a yearly, seasonal, monthly, daily and hourly scale) varies.
- A utility has to serve the varying load of its customers by the power available from various power plants.
- As wind power is a varying power source, conventional power plants or storage facilities have to deal with these variations. This means that output variations in wind power can give rise to extra cost due to extra power changes or start/stop of conventional units.
- If the penetration of wind power into the grid is continuously increased, it might reach to a level where economics of the total power production is affected in a negative way. This will limit the penetration of wind power into the grid.

Penetration of wind power into the grid continued…

- The optimum penetration depends on specific circumstances and characteristics of the utility system.
- In most cases, a wind-power penetration level less than 10% of the total electricity production will cause no severe problem and will not cause any economic disadvantage.
- For higher penetration, total electricity production system is to be re-optimized. This may require integration of some more peak load units or storage capacity plants.
- Also, the distance of the wind resource from the grid poses another limiting factor as it influences the economics of wind power. A distance of less than 50 km is generally considered as economically feasible.

Environmental aspects

- In general, the use of energy in any from affects the environment in one way or the other. Wind energy is no exception.
- In terms of causing stress on water resources, wind energy is one of the most benign sources of energy. A major advantage of wind generation relative to any thermal based generation (nuclear, geothermal, fossil fuel and solar thermal) is that it does not need cooling water.

The main environmental concerns:

(i) Indirect energy use and emissions: Energy is required to produce material used to construct the wind turbine and its installation. This energy is paid back in a period of few months to one year. Some pollution (emission of CO_2, etc.) is caused due to use of energy during construction. But in total, the so-called indirect CO_2 emission over the total operating life of the wind generator is very low (about 1%of the system using coal).

Environmental aspects

continued….

(ii) Bird Life**:** Large wind turbines pose a threat to bird life as a result of collision with tower or blades. Their resting and breeding patterns are also affected.

(iii) Noise: The disturbance caused by the noise produced by a wind turbine is one of the important factors that prevent its installation close to inhabited areas. The acoustic noise is composed of (a) mechanical noise due to movement of mechanical parts in the nacelle (mainly gear and also other equipments), which can be reduced by good design and acoustic insulation, and (b) aerodynamic noise (swishing sound from the rotating blades), which is a function of wind speed and which cannot be avoided. Some of this noise is of infra sound, at frequencies below the audible range. This infrasound may cause houses and other structures to vibrate.

Environmental aspects

continued….

(iv) Visual Impact: Wind turbines are massive structures quite visible over a wide area in most locations. The visual impact of wind turbines is qualitative in nature. In a study, it was found that public appreciation of a landscape decreases as more and more wind turbines are installed. A special case of visual impact is the effects shadow of the turbine, particularly of the rotor blades. The rotational frequency plays an important role in determining the disturbance level. Offshore wind farms, being away from inhabited areas, do not create the same severity of visual intrusion.

(v) Telecommunication Interference**:** Wind turbine presents an obstacle for incident electromagnetic waves (i.e., TV or microwave signals). These waves can be reflected, scattered and dithered. Thus, they interfere with telecommunication links and badly affect the quality of radio and TV reception. The effect can be mitigated by the use of cable system or by installing powerful antennas.

Environmental aspects

continued….

(vi) Safety: Accidents with wind turbines are rare but they do happen, as in other industrial activities. For example, a detached blade or its fragment may be thrown to a considerable distance and can harm people and property. However, most wind turbines are located in isolated areas, which make it less likely to cause any damage. The International Electrical Committee (ICE) has taken the initiative to produce an international standard on safety.

(vii) Effects on Ecosystem: Large-scale use of wind generation can reduce wind speed and cause stress to the ecosystem. Lakes that are downhill from the wind turbine might become warmer because of reduced evaporation from their surface. Soil moisture might also increase. Nevertheless, these impacts may not be of great consequence except in certain sensitive areas.

Advantages of power generation by wind energy

1. The capital cost is comparable with conventional power plants. For a wind farm, the capital cost ranges between 4.5 crores to 6.85 crores per MW, depending up on the type of turbine, technology, size and location.
2. Construction time is less.
3. Fuel cost is zero.
4. Operation and Maintenance costs are very low.
5. Capacity addition can be in modular form.
6. There is less adverse effect on global environment.

Disadvantages of power generation by wind energy

1. Wind machines must be located where strong and dependable winds are available most of the time.
2. Because winds do not blow strongly enough to produce power all the time, energy from wind machines is considered "intermittent," that is, it comes and goes. Therefore, electricity from wind machines must have a back-up supply from another source.
3. As wind power is "intermittent," utility companies can use it for only part of their total energy needs.

Disadvantages of power generation by wind energy continued….

4. Wind towers and turbine blades are subjected to damage from high winds and lighting. Repairing the rotating parts, which are located high off the ground, is difficult and expensive.
5. Electricity produced by wind power sometimes fluctuates in voltage and power factor, which can cause difficulties in linking its power to a utility system.
6. The noise made by rotating wind machine blades can be annoying to neighbours.
7. People have complained about aesthetics of wind machines.

RENEWABLE ENERGY SOURCES

By

Dr V Subbiah
Dean, Electrical Sciences

RES Unit 4

UNIT 4: Syllabus

- **BIOMASS ENERGY**
- Biomass direct combustion – Biomass gasifier – Biomass: Types – Advantages & Drawbacks - Biogas plant – Ethanol production – Bio diesel – Cogeneration: steam turbine cogeneration systems, gas turbine cogeneration systems, reciprocating IC engine cogeneration systems, combined cycle cogeneration systems – Applications of Cogeneration in utility sector – Biomass applications.

RES Unit 4

Biomass

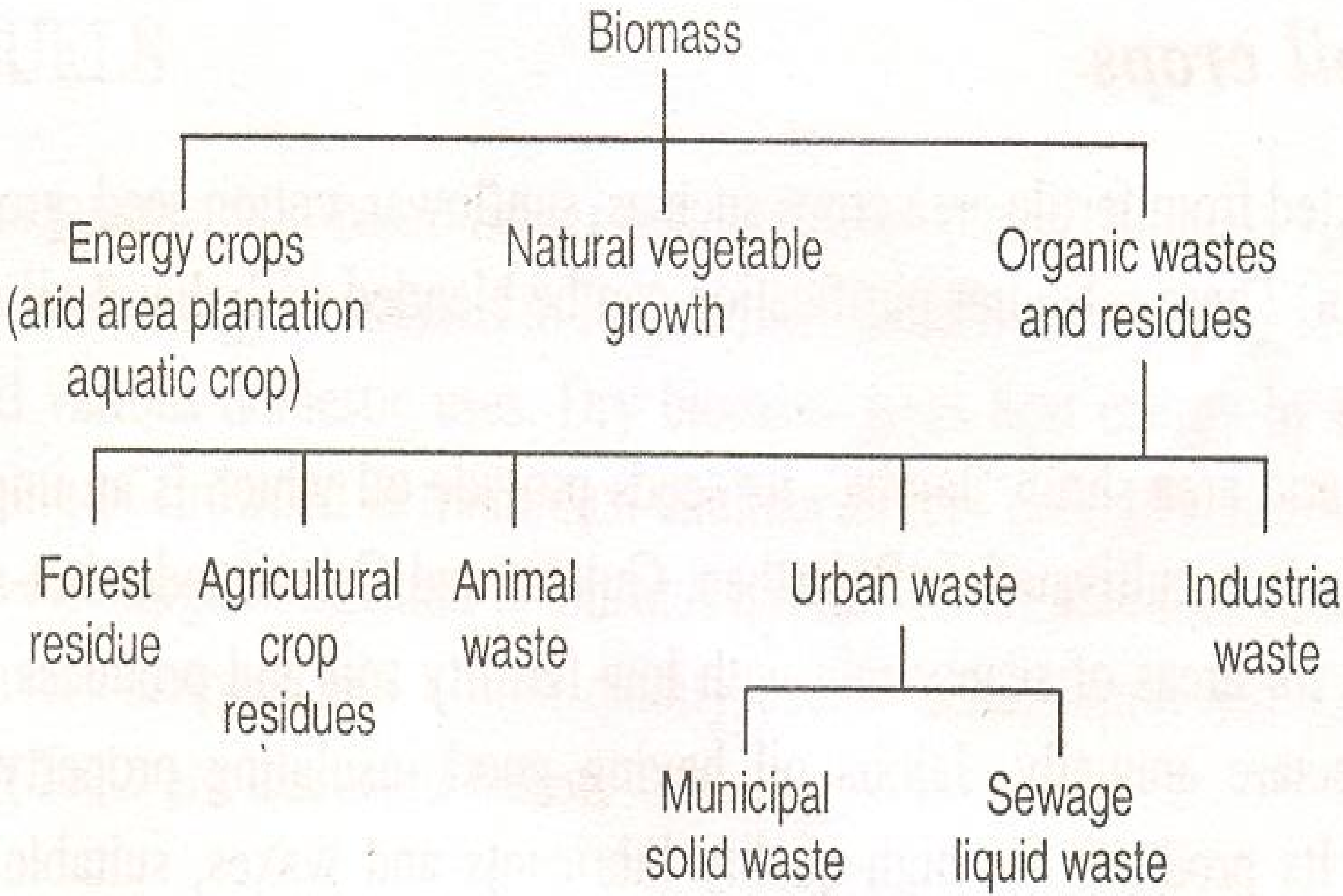
- Biomass refers to solid carbonaceous material derived from plants and animals. These include residues of agriculture and forestry, animal waste and discarded material from food processing plants.
- Biomass, being organic matter from terrestrial and marine vegetation, renews naturally in a short span of time, thus, classified as a renewable source of energy.
- It is a derivative of solar energy as plants grow by the process of photosynthesis by absorbing CO_2 from the atmosphere.
- Biomass does not add CO_2 to the atmosphere as it absorbs the same amount of carbon in growing the plants as it releases when consumed as fuel.
- It is a superior fuel as the energy produced from biomass is 'carbon cycle neutral'.

RES Unit 4

Biomass continued….

- Biomass fuel is used in over 90% of rural households and in about 15% of urban dwellings.
- Agriculture products rich in starch and sugar like wheat, maize, sugarcane can be fermented to produce ethanol (C_2H_5OH). Methanol (CH_3OH) is also produced by distillation of biomass that contains cellulose like wood and bagasse. Both these alcohols can be used to fuel vehicles and can be mixed with diesel to make biodiesel.
- Biomass resources for energy production are widely available in forest areas, rural farms, urban refuse and organic waste from agro- industries. Biomass classification is illustrated in the next slide.
- India produces over 550 million tonnes of agricultural and agro-industrial residues every year. Similarly, 290 million cattle population produces about 438 million tonnes of dung annually.

RES Unit 4



Biomass classification.

Biomass resources

- Forests
- Agricultural crop residues (rice husk, wheat straw, corn cobs, cotton sticks, sugarcane bagasse, groundnut shell, coconut shell etc)
- Energy crops (fast growing plants)
- Vegetable oil crops (rapeseed, sunflower, cotton seed, palm, groundnut, coconut etc)
- Aquatic crop (water plants)
- Animal waste
- Urban waste
- Industrial waste

RES Unit 4

Biofuels

- Charcoal (smokeless dry solid fuel with high energy density)
- Briquetting (densification of loose biomass into a high density solid fuel)
- Vegetable oil (rapeseed, palm, coconut and cotton seed oil)
- Biogas (can be produced by digestion of plant, animal and human waste)
- Producer gas (mixture of a few gases - obtained by partial combustion of wood or any cellulose organic material of plant origin)
- Liquid fuel (ethanol – inflammable colourless biofuel – produced by fermentation of any feedstock which contains sugar or starch and even cellulose material)

RES Unit 4

Advantages of biomass energy

1. It is a renewable source.
2. Energy storage is an inbuilt feature of it.
3. It is an indigenous source requiring little or no foreign exchange.
4. The pollutant emissions from the combustion of biomass are usually lower than those from fossil fuels.
5. Commercial use of biomass may avoid the problems of waste disposal in urban centers.
6. Use of biogas plants leads to improved sanitation and better hygienic conditions.
7. It is available in all the seasons.
8. The nitrogen rich slurry and sludge from a biogas plant improves the fertility of the soil.
9. The forestry and agricultural industries associated with biomass provide substantial economic development opportunities in the rural areas.

Disadvantages of biomass energy

1. It is dispersed and land intensive.
2. It is of low energy density.
3. It is labour intensive.
4. The cost of collecting large quantities of biomass is significant.
5. It is not suitable for varying loads.
6. It is not feasible to set up biomass power plants in all locations.

RES Unit 4

Biomass conversion technologies

- Biomass material from a variety of sources can be utilized optimally by adopting efficient and state of the art conversion technologies such as:
- Densification
- Direct combustion and incineration
- Thermo-chemical conversion
- Bio-chemical conversion
- **Direct combustion** is the main process adopted for utilizing biomass energy. It is burnt to produce heat that can be utilized for cooking, space heating, industrial processes and for electricity generation. This utilization method is very inefficient with heat transfer losses of 30 to 90 %. The problem is addressed through the use of more efficient cook-stove for burning solid fuels.

RES Unit 4

Biomass gasifiers

- Biomass gasification is thermo-chemical conversion of solid biomass into a combustible gas fuel through partial combustion with no solid carbonaceous residue. Gasifiers use wood waste and agriculture residue.
- Gasifiers (fixed bed type) can be of 'updraft' or 'downdraft' type depending upon the direction of the air flow.
- In the updraft gasifier, fuel and air move in a countercurrent manner .
- In the downdraft gasifier, fuel and air move in co-current manner. However, the basic reaction zones remain the same.
- A typical downdraft gasifier is shown in the next slide.

RES Unit 4

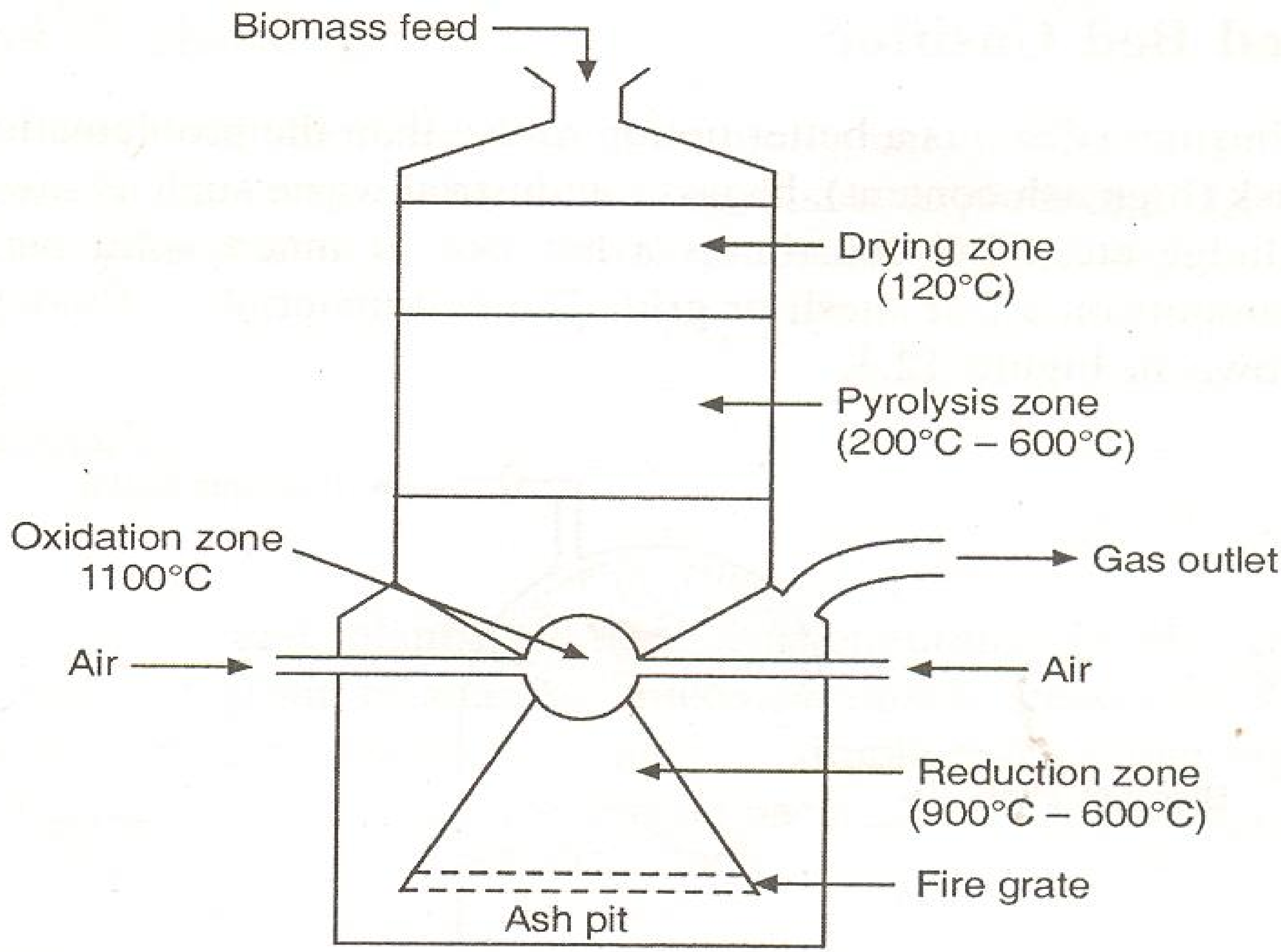


Figure Downdraft gasifier.

Downdraft gasifiers

- Fuel is loaded in the reactor from the top.
- As the fuel moves down, it is subjected to drying (120□c) and then pyrolysis (200□-600□C) where solid char, acetic acid, methanol and water vapour are produced.
- Descending volaties and char reach the oxidation zone where air is injected to complete the combustion. It is the reaction zone and the temperatures rises to 1100ºC. This helps in breaking down the heavier hydrocarbons and tars.
- As these production move downwards, they enter the 'reduction zone' (900-600ºC, reaction being endothermic) where producer gas is formed by the action of CO_2 and water vapour on red hot charcoal.

RES Unit 4

Downdraft gasifiers continued….

- Producer gas formed in the reduction zone contains combustible products like CO, H_2 and CH_4. Hot gas flowing out is usually polluted with soot, tar and vapour. For purifying, it is passed through coolers. Tar is removed by condensation, whereas soot and ash are removed by centrifugal separation.
- Clean producer gas provides the process heat to operate stoves (for cooking), boilers, driers, ovens and furnaces. The major applications is in area of electric power generation. A biomass gasifier-based electricity generation system costs from Rs. 4.0 crores to 4.5 crores per MW.
- Fixed bed gasifiers can attain efficiency up to 75% for conversion of solid biomass to gaseous fuel. However, the performance depends on fuel size, moisture content, volatiles and ash content.

RES Unit 4

Fluidized bed gasifier

- Fluidized Bed Combustion (FBC) is a better option to use for the problematic biomass of farm residues like rice husk (high ash content), bagasse , industrial waste such as saw dust and pulping effluents, sewage sludge etc.
- FBC constitutes a hot bed of inert solid particles of sand or crushed refractory support on a fine mesh or grid.
- The bed material is fluidized by an upward current of air as shown in the next slide.
- Pressurized air starts bubbling through the bed and the particles attain a state of high turbulence, and the bed exhibits fluid like properties.
- A uniform temperature within the range of 850-1050□C is maintained.

RES Unit 4

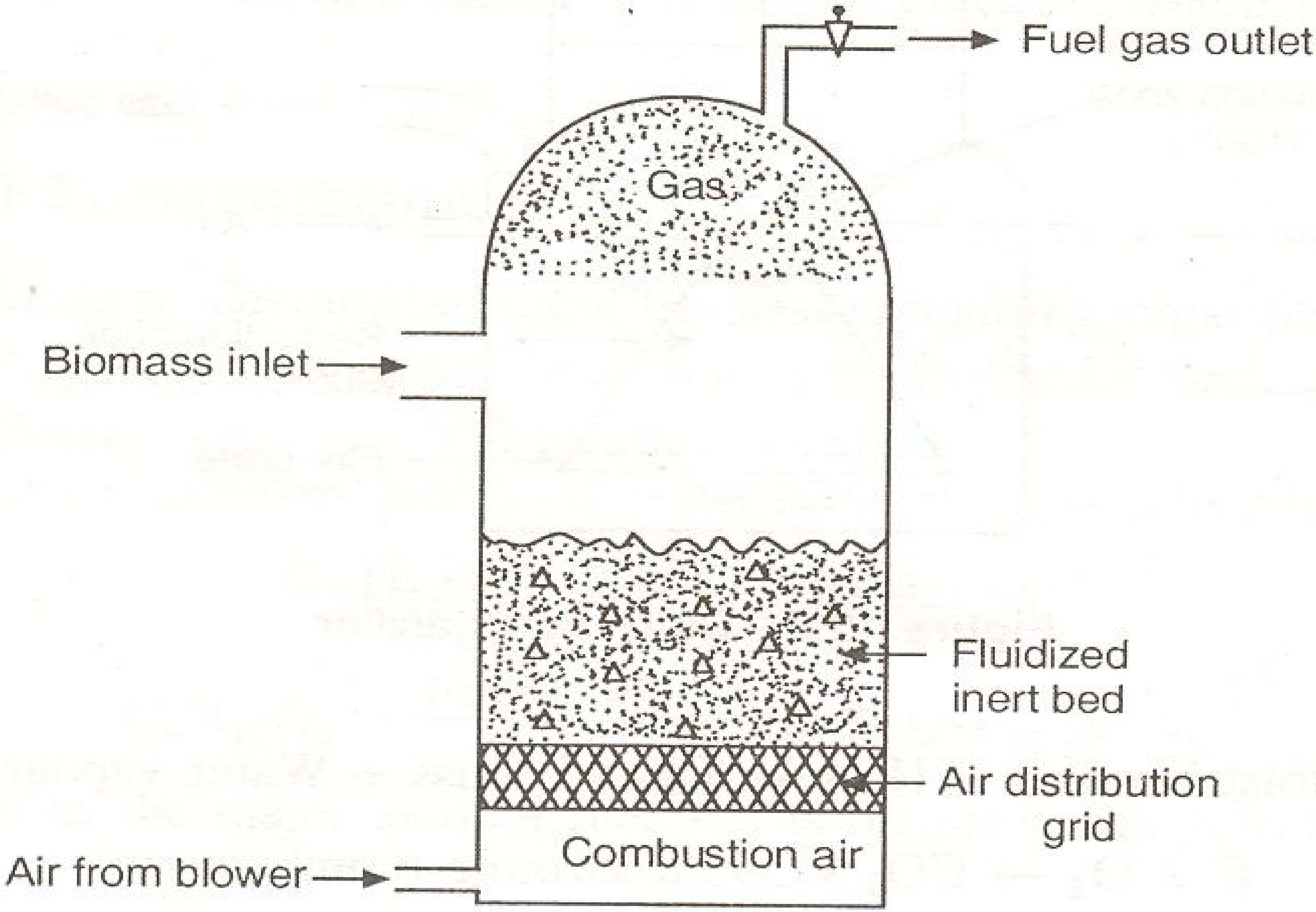


Figure Fluidized bed gasifier.

Fluidized bed gasifier

continued….

- Large surface area is created in the fluidized bed and the constantly changing area per unit volume provides a higher conversion efficiency at low operating temperatures compared to the fixed beds.
- High heating capacity of sand and the uniform temperature of fluidized bed makes possible to gasify low-grade fuels of even non-uniform size and high moisture content.
- When the gasifier is put in use, the bed material is heated to ignition temperature of the fuel and biomass is then injected causing rapid oxidation and gasification.
- Fuel gas so produced contains impurities, dust, char particles and tar. It needs conditioning and cleaning for utilization as an engine fuel.

RES Unit 4

Biogas plant

- Biogas is an inflammable gas derived from organic wastes such as cattle dung, human waste etc. It is a safe fuel for cooking and lighting.
- Biogas consists of CH_4, CO_2 and traces of other gases such as H_2, CO, N_2, O_2 and H_2S. The methane content of biogas is about 60% which provides a high calorific value to find use in cooking, lighting and power generation.
- Biogas plant converts cattle dung and other organic matter into biogas and good quality organic manure.
- There are two popular designs of biogas plants:
- (i) Floating drum (constant pressure) type
- (ii) Fixed dome (constant volume) type

RES Unit 4

Floating drum type biogas plant

- A popular model, shown in the next slide, comprises an underground cylindrical masonry digester having an inlet pipe for feeding animal dung slurry and an outlet pipe for sludge.
- There is a steel dome for gas collection which floats over the slurry. It moves up and down depending upon accumulation and discharge of gas guided by the dome guide shaft.
- A partition wall is provided in the digester to improve circulation necessary for fermentation
- The floating gas holder builds gas pressure of about 10 cm of water column, sufficient to supply gas up to 100 metres. Gas pressure also forces out the spent slurry through a sludge pipe.

RES Unit 4

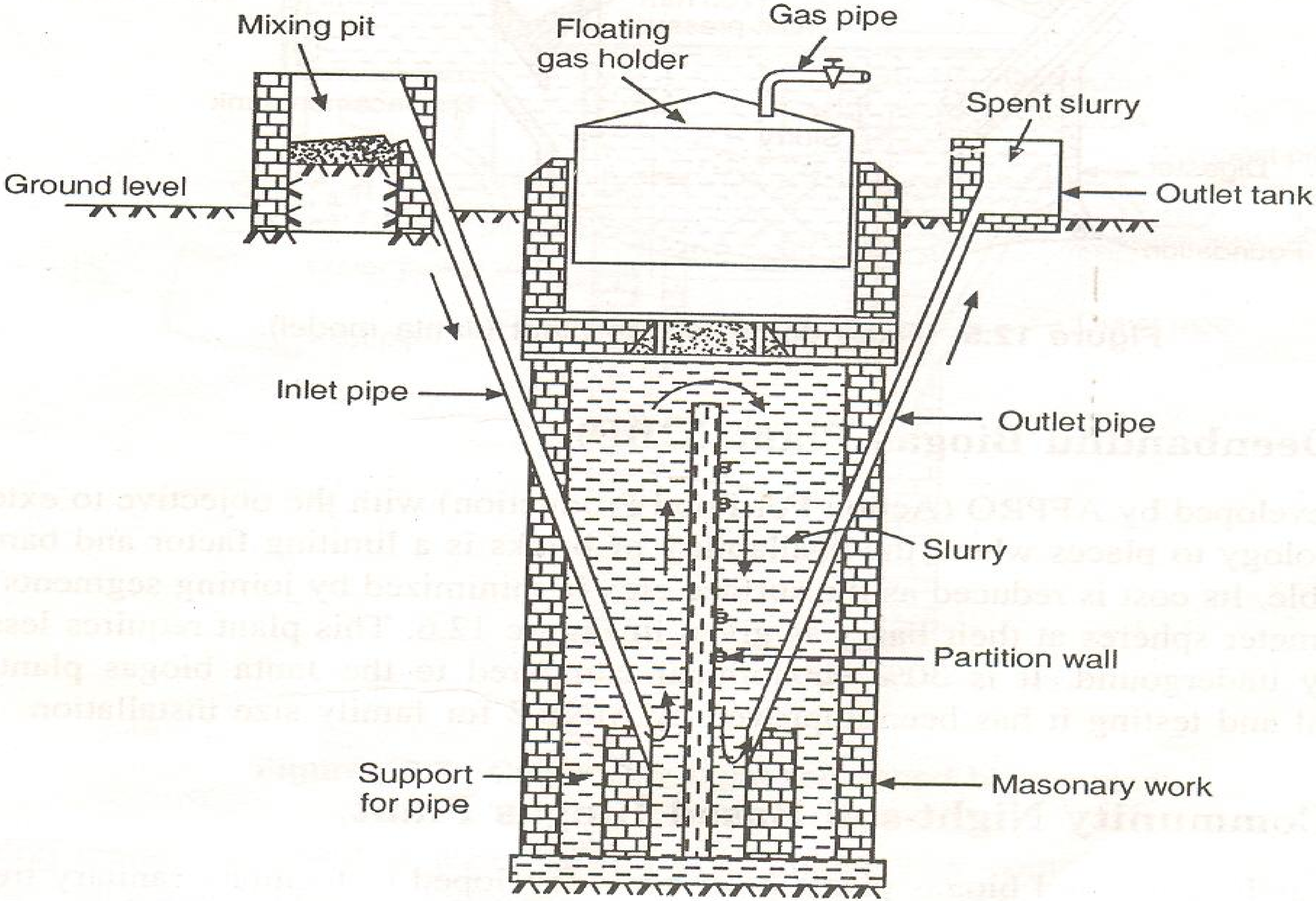


Figure 1 Floating drum biogas plant (KVIC model).

Fixed dome type biogas plant

- It is an economical design where the digester is combined with a dome-shaped gas holder as shown in the next slide.
- It is known as Janata model. The composite unit is made of brick and cement masonry having no moving parts, thus ensuring no wear and tear and longer working life.
- When the gas is produced, the pressure in the dome changes from 0 to 100 cm of water column.
- It regulates gas distribution and outflow of spent slurry.

RES Unit 4

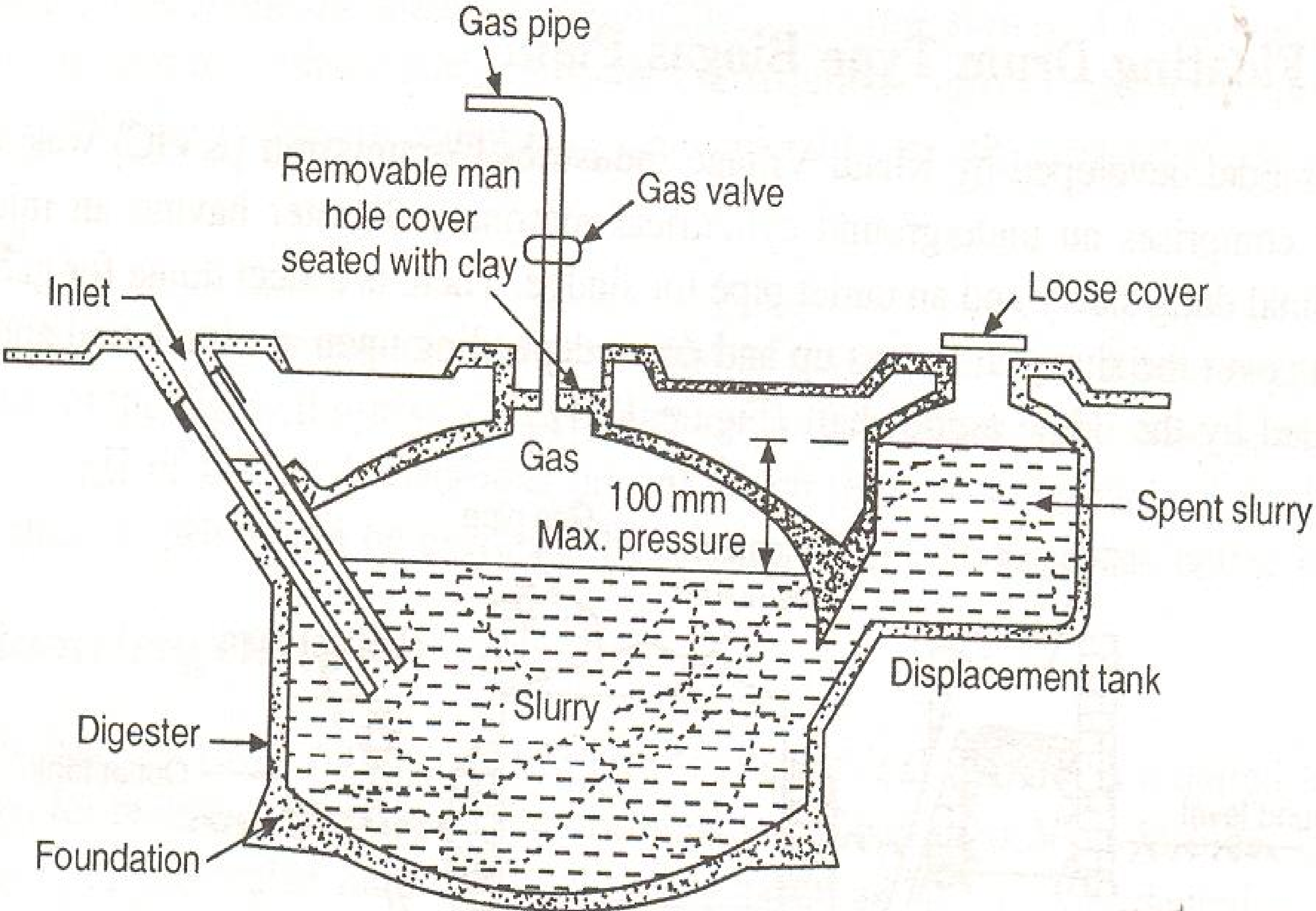


Figure Fixed dome biogas plant (Janta model).

Ethanol production

- Ethanol is ethyl alcohol (C_2H_5OH), a colourless, flammable liquid.
- It is a renewable energy source which can substitute petroleum products.
- Ethanol can be produced from a variety of biomass materials containing sugar, starch and cellulose.
- The best-known feedstock under three categories are:
- Sugars: sugarcane, sugar beet, sweet sorghum, grapes, molasses
- Starches: maize, wheat, barley, potatoes, cassava, rice
- Cellulose: wood, straw, stems of grasses, bamboo, sugarcane bagasse

Ethanol production continued….

- **Production Process**:
- Sugar rich crops, especially the sugarcane which contains the valuable raw material for crystal sugar, and by-products from sugar mills are molasses that contain 50 to 55% sugar content.
- It is monosaccharide form of sugar which refers to the glucose ($C_6H_{12}O_6$) and fructose ($C_6H_{12}O_6$) content in cane.
- Sweet fruits like ripe grapes, mangoes, etc. contain glucose in natural form.
- Juice containing sugar can easily be fermented into ethanol by adding yeast. Yeasts are micro-organisms, which produce enzymes that convert sugar to ethanol.
- $$C_6H_{12}O_6 \xrightarrow[\text{Yeast}]{} 2C_2H_5OH + 2CO_2$$

RES Unit 4

Ethanol production continued….

- Molasses also contain fermentable sugar comprising glucose, sucrose and fructose which are converted into alcohol. One tonne of sugarcane with average sugar content of 12.5% yields 70 litres of ethanol by direct fermentation of juice. One tonne of molasses yields nearly 230 litres of ethanol.
- Directly fermented sugarcane juice yields much higher ethanol compared to molasses. Production of ethanol from three biomass resources is given in the next slide.
- The level of sugar production in India is 18 million tones per year, ensuring ethanol production to 1700 million litres. It is assessed that the requirement for potable purpose and chemical sector shall be 1200 million litres, leaving a clear balance of 500 million litres, sufficient for 5% blending with petrol in the country.

RES Unit 4

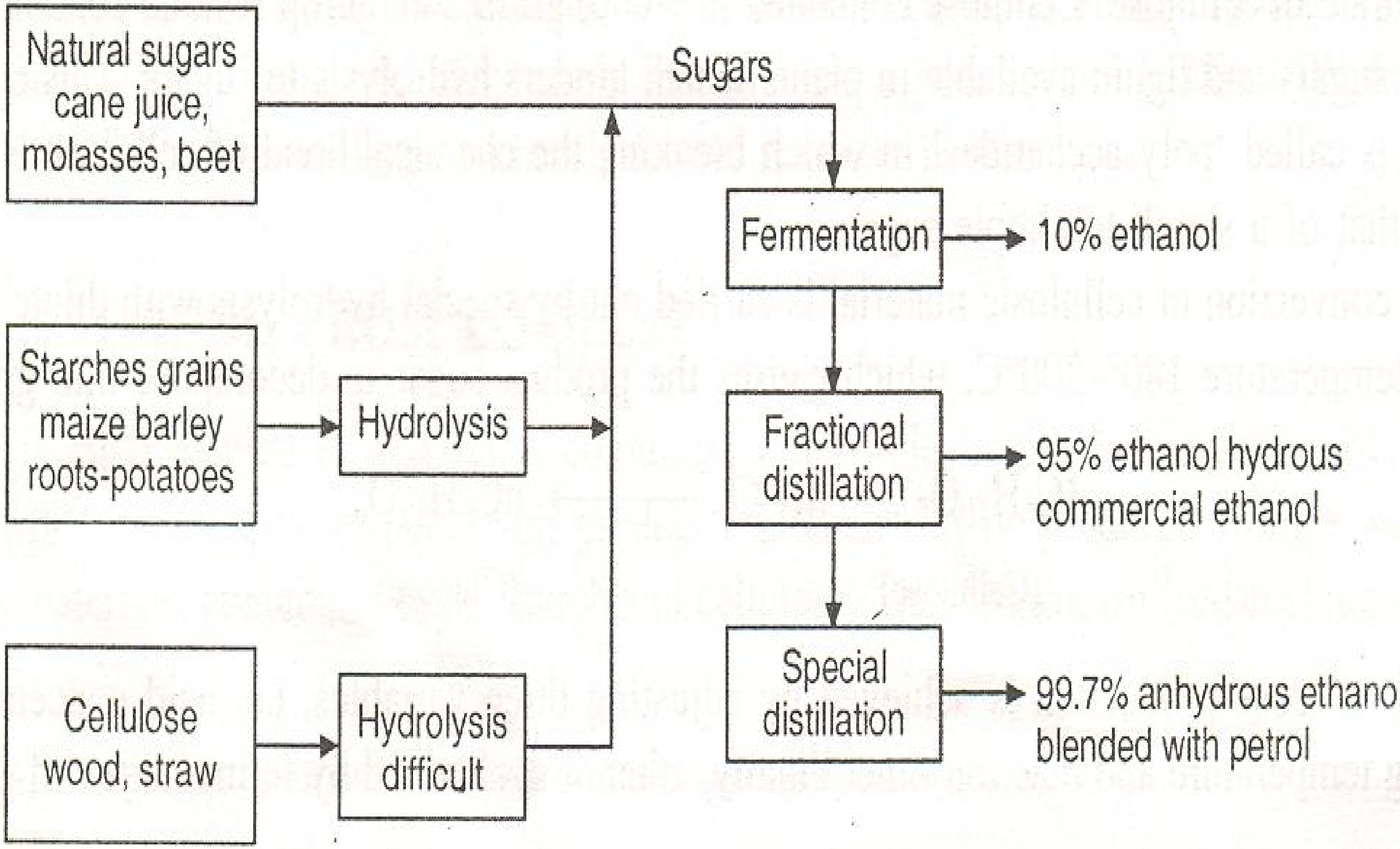


Figure Ethanol production from biomass.

Biodiesel

- Biodiesel is a liquid fuel produced from non-edible oil seeds such as Jatropha, pongamia pinnata (Karanja), etc. which can be grown on wasteland.
- However, the oil extracted from these seeds has high viscosity (20 times that of diesel) which causes serious lubrication, oil contamination and injector chocking problems.
- These problems are solved through trans-esterification, a process where the raw vegetable oils are treated with alcohol (methanol or ethanol with a catalyst) to form methyl or ethyl esters. The monoesters produced by trans-esterifying vegetable oil are called 'biodiesel' having low fuel viscosity with high octane number and heating value.
- Endurance tests show that biodiesel can be adopted as an alternative fuel for existing diesel engines without modifications.

RES Unit 4

Biodiesel continued…

- In EU and USA, edible vegetable oils like sunflower, groundnut, soya bean and cotton seed are used to produce biodiesel.
- India is endowed with a number of non-edible vegetable oil producing trees which thrive in inhospitable conditions of heat, low water, rocky and sandy soils, a renewable resource of economic significance (Jojoba in Rajasthan).
- Biodiesel is the name of diesel fuel made from vegetable oil or animal fats. The concept dates back to 1885, when Dr.Rudoff Diesel developed the first diesel engine to run on vegetable oil.
- The use of bio oil as an alternative renewable fuel to compete with petroleum was proposed in 1980.

RES Unit 4

Biodiesel continued…

- The Ministry of Petroleum and Natural Gas has opened a biofuel centre in Delhi for the manufacture of biodiesel. The Indian Oil Corporation has already established a biodiesel plant at Faridabad and another one is being established in Panipat refinery to prepare 30,000 litres of biodiesel daily.
- 5 % replacement of petroleum diesel by biodiesel would save the country approximately Rs 4000 crores in foreign exchange yearly.
- **The advantages of biodiesel as engine fuel**:
- (i) Biodegradable and produces 80 % less CO_2 and 100 % less SO_2 emissions
- (ii) Renewable
- (iii) Higher octane number
- (iv) Can be used as neat fuel (100 % biodiesel) or mixed in any ratio with petroleum diesel
- (v) Has a higher flash point making it safe to transport
-

RES Unit 4

Cogeneration

- In general, a cogeneration facility is defined as one which simultaneously produces two or more forms of useful energy such as electrical power and steam, electrical power and mechanical power etc.
- Cogeneration facilities, due to their ability to utilize the available energy in more than one form, use significantly less fuel input to produce electricity, steam, mechanical power or other forms of energy than would be needed to produce them separately.
- Thus, by achieving higher efficiency, cogeneration facilities can make a significant contribution to energy conservation.
- In particular, cogeneration is a procedure for generating electrical power and useful heat in a single installation. Heat may be supplied in the form of steam, hot water or hot air. The net result is overall increase in the efficiency of fuel utilization.
-

RES Unit 4

Cogeneration continued…

- Types of Cogeneration Principles:
- Topping cycle: Primary heat (heat at high temperature) is used to generate high pressure and high temperature steam for electrical energy generation. The discharged low grade heat, which would otherwise be dispersed to the environment, is utilized in an industrial process, e.g., sugar industry.
- Bottoming cycle: Primary heat at high temperature is used directly for industrial process requirements. The remaining low grade heat is then used for electrical power generation, e.g., high temperature cement kiln.

RES Unit 4

Types of cogeneration systems

- There are three general types of cogeneration systems:

i. Waste Heat Utilization:

- The major purpose of this system is to generate electricity with heated water as a byproduct. The heat thus available can be used at a location near an electric power plant for some beneficial purposes.
- About 50 to 65% of the heat supplied either by fossil fuel or nuclear fuel in existing steam plants is removed by cooling water. This heat is dissipated into the environment by direct discharge of warm water to the ocean or to a nearby river.
- Various possibilities like space heating, warm water to agriculture and warm water to aquaculture can be considered for the large amount of heat that is lost otherwise.

RES Unit 4

Types of cogeneration systems

continued….

- (ii) Total/Integrated Energy System for residential complex:
- This system is designed to meet both the electrical demand (for lighting, refrigeration, domestic electrical appliances, elevators, etc) and heat demand (for hot water, space heating and cooling) of a large building complex or a community.
- Total Energy System, TES, is a self-contained system, which works independent of external power sources.
- Integrated Energy System, IES, is a more flexible utility-connected system and energy can be bought from or sold to utility depending upon power demand and availability situation.

RES Unit 4

Types of cogeneration systems

continued….

- A total energy system utilizes a heat engine (diesel engine, gas turbine or steam turbine) to convert a part of heat to useful mechanical energy, which in turn is converted to electrical energy by a generator.
- The remaining rejected heat is used for thermal requirements.
- The electric generation efficiency of total energy system may be lower than that of a central station power plant.
- But, the utilization of rejected heat that would otherwise be dissipated into surroundings can result in an increase of around 25% in overall fuel utilization efficiency.

RES Unit 4

Types of cogeneration systems

continued….

- (iii) Total Energy System for Industry:
- Here, the objective is to produce both electricity and industrial process heat for an industry.
- The heat component may be supplied in the form of steam, hot water and/or hot air.
- Many industries (e.g., petroleum refineries, chemical plants, pulp and paper industries, etc.) use a large amount of process heat as well as electrical energy to operate pumps, etc.
- In these cases, cogeneration can result in 30% saving of fuel compared to separate generation of electricity and process heat.

RES Unit 4

Steam turbine cogeneration systems

- A steam turbine is a mechanical device that extracts thermal energy from pressurized steam and converts it into rotary motion. Its modern manifestation was invented by Sir Charles Parson in 1884.
- It has almost completely replaced the reciprocating piston steam engine primarily because of its greater thermal efficiency and higher power to weight ratio. Because the turbine generates rotary motion, it is particularly suited to be used to drive an electrical generator.
- About 80% of all electricity generation in the world is by the use of steam turbines.
- The steam turbine is a form of heat engine that derives much of its improvement in thermodynamic efficiency through the use of multiple stages in the expansion of the steam, which results in a closer approach to the ideal reversible process.

RES Unit 4

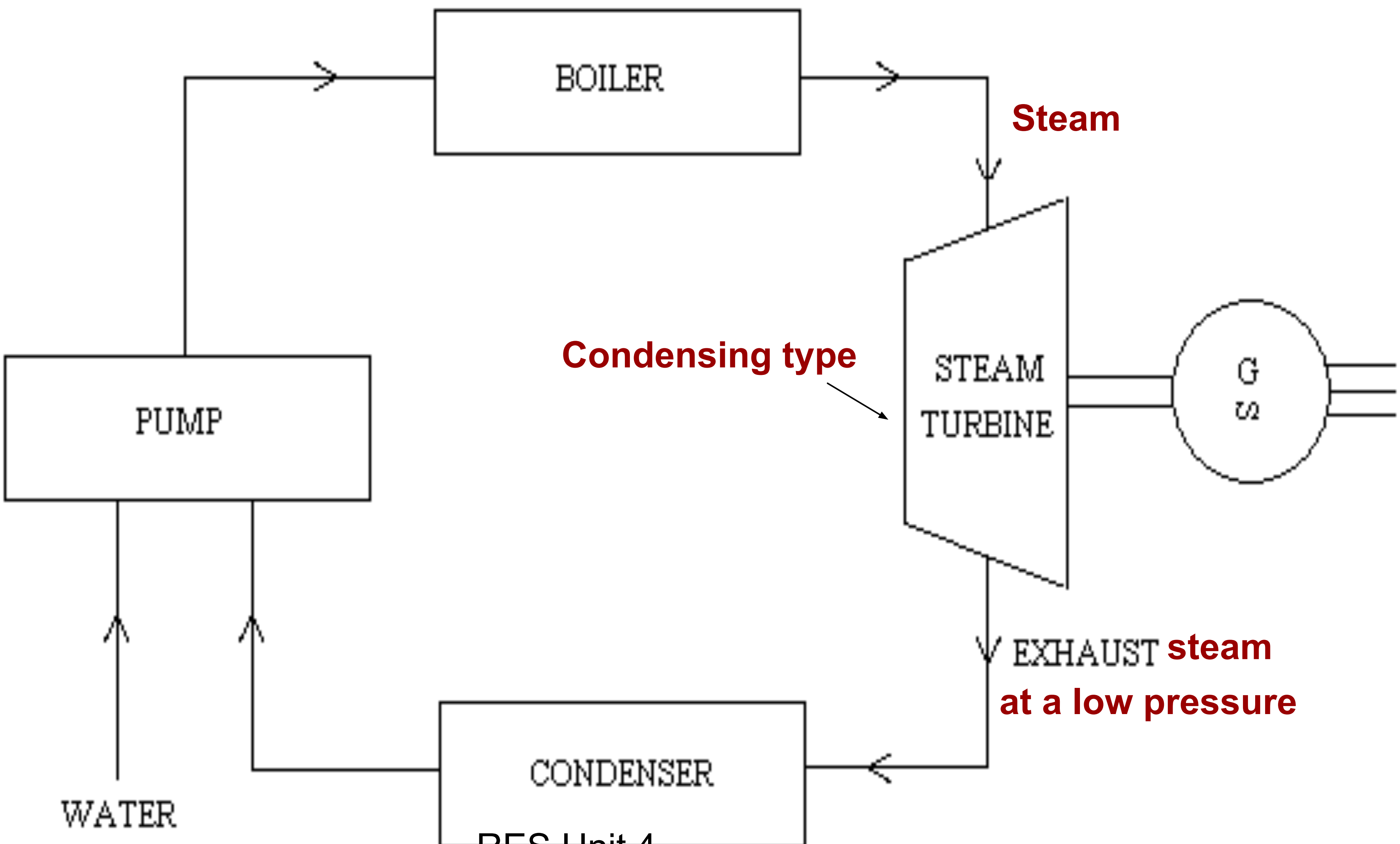
Steam turbine cogeneration systems

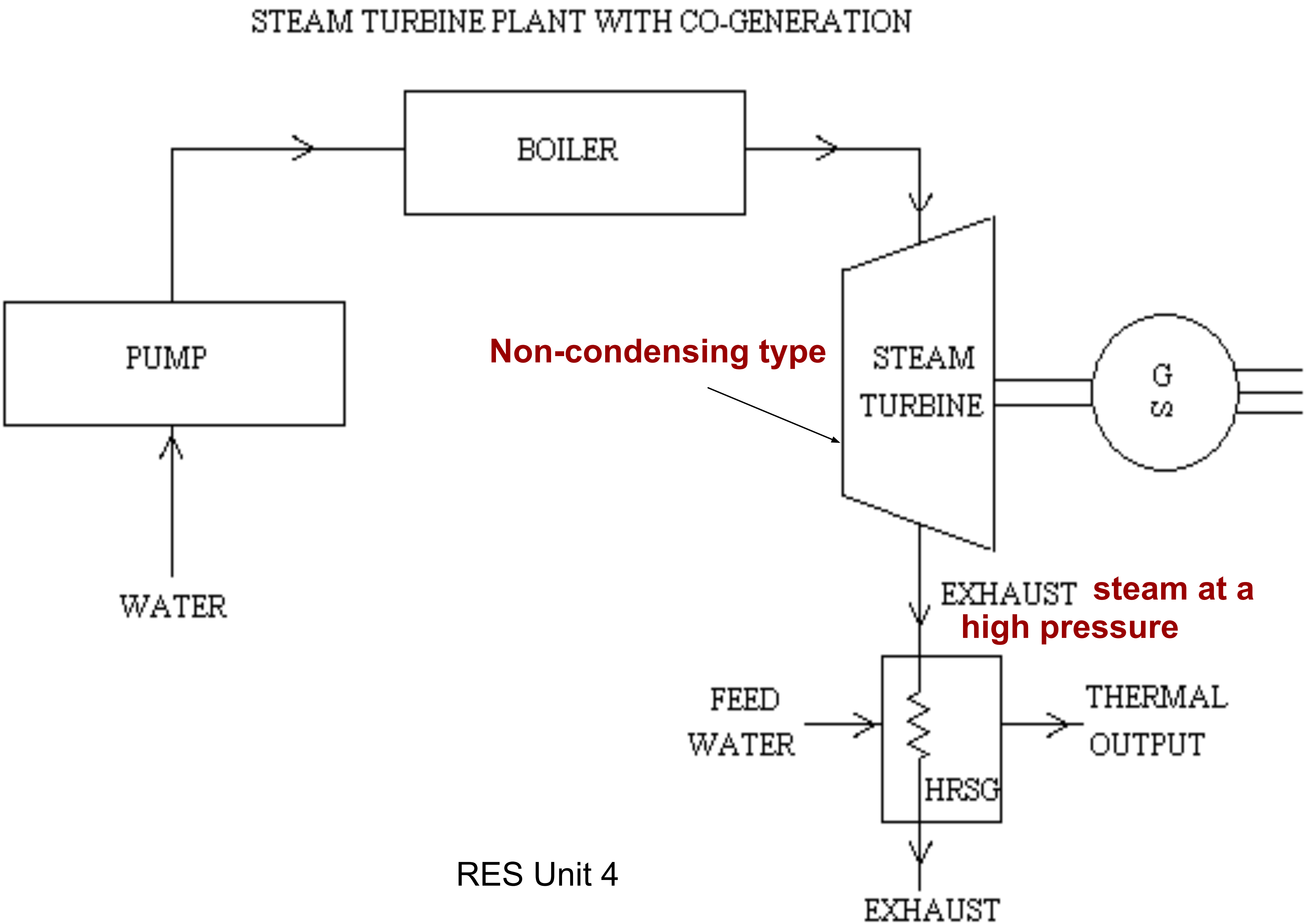
continued…

- In using a steam turbine for cogeneration, the exhaust steam is not condensed (as it is done in the case of a conventional steam turbine power plant) but is withdrawn at the desired pressure for process use as shown in the next two slides.
- The turbines are thus of the non-condensing (or back pressure) type in which the steam leaves the turbine at a significant pressure rather than at a very low pressure as in the case of a condensing type steam turbine.
- Steam is discharged from the back pressure turbine at a higher temperature than a condensing turbine. The discharged steam is used for the industrial process.
- Elimination of condenser and cooling water requirements reduces the capital and operating costs of power generation in the cogeneration system.

RES Unit 4

STEAM TURBINE POWER PLANT




STEAM TURBINE PLANT WITH CO-GENERATION
BOILER
PUMP
WATER
Non-condensing type
STEAM
TURBINE
G
EXHAUST steam at a
high pressure
FEED
WATER
HRSG
THERMAL
OUTPUT
EXHAUST

Gas turbine cogeneration systems

- If natural gas or a suitable petroleum product is available as fuel, it may be used in a gas turbine or a diesel engine, to drive an electric generator.
- These prime movers have fairly high thermal efficiency because they take advantage of the high temperature of the combustion gases that are the heat source.
- Instead of being discharged to the atmosphere, the hot exhaust gases, at temperatures above 315^0 C, pass to a waste heat boiler (Heat recovery steam generator).
- Water under pressure is converted into steam at the desired temperature and pressure with the help of the hot exhaust gases. Process steam is usually in the temperature range of 150 to 220° C.
- The subsequent slides show the block diagrams for gas turbine and diesel engine cogeneration systems.

RES Unit 4

Gas turbine cogeneration systems

continued…

- Heat Recovery Steam Generator (HRSG) is a steam boiler that uses hot exhaust gases from the gas turbines or reciprocating engines in a cogeneration plant to heat up water and generate steam. This steam in turn drives a steam turbine and/or is used in industrial processes that require heat
- HRSGs used in the cogeneration industry are distinguished from conventional steam generators by the following main features:
- The HRSG is designed based upon the specific features of the gas turbine or reciprocating engine that it will be coupled to.
- Since the exhaust gas temperature is relatively low, heat transmission is accomplished mainly through convection .
- The exhaust gas velocity is limited by the need to keep head losses down. Thus, the transmission coefficient is low, which calls for a large heating surface area.

RES Unit 4

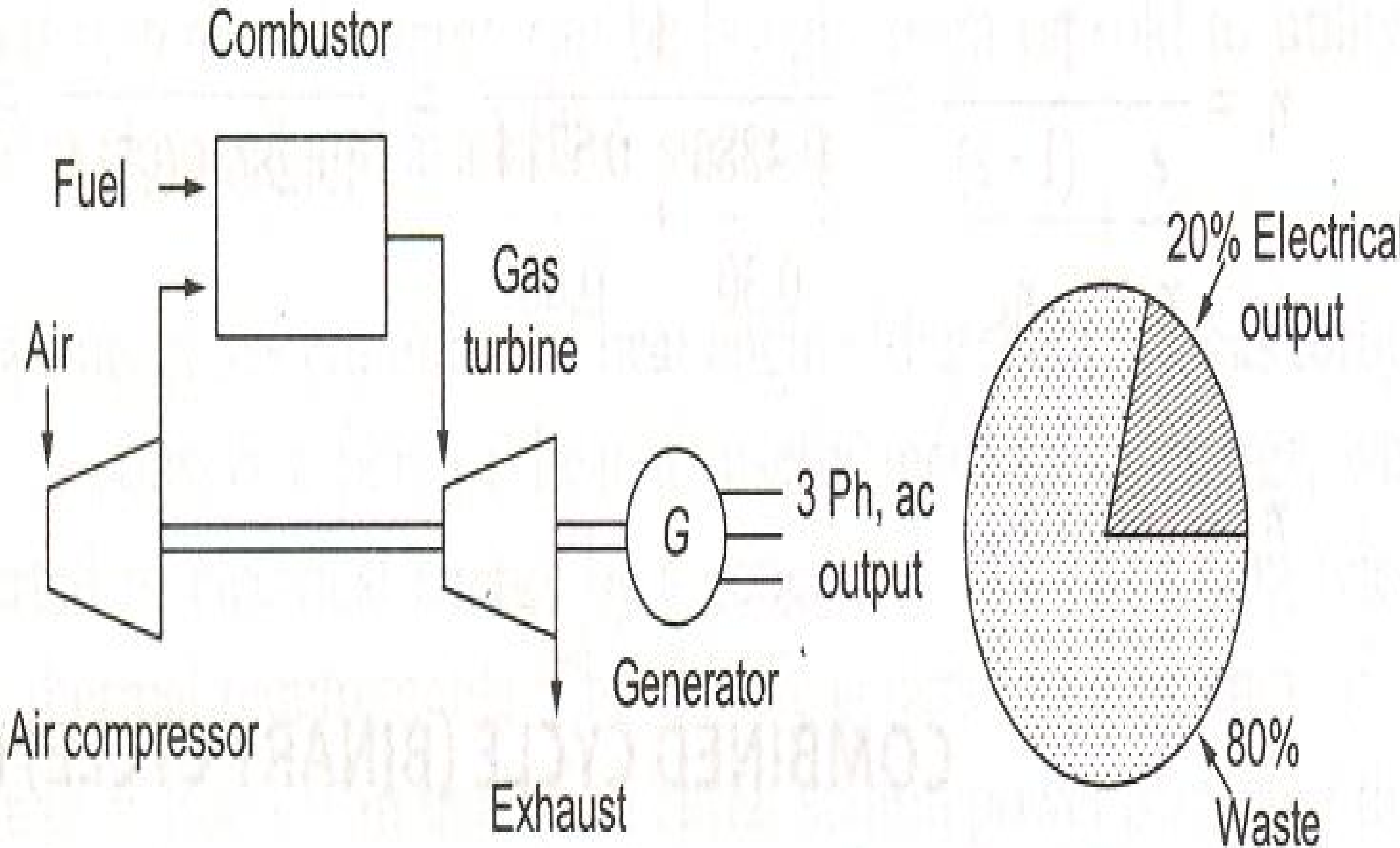
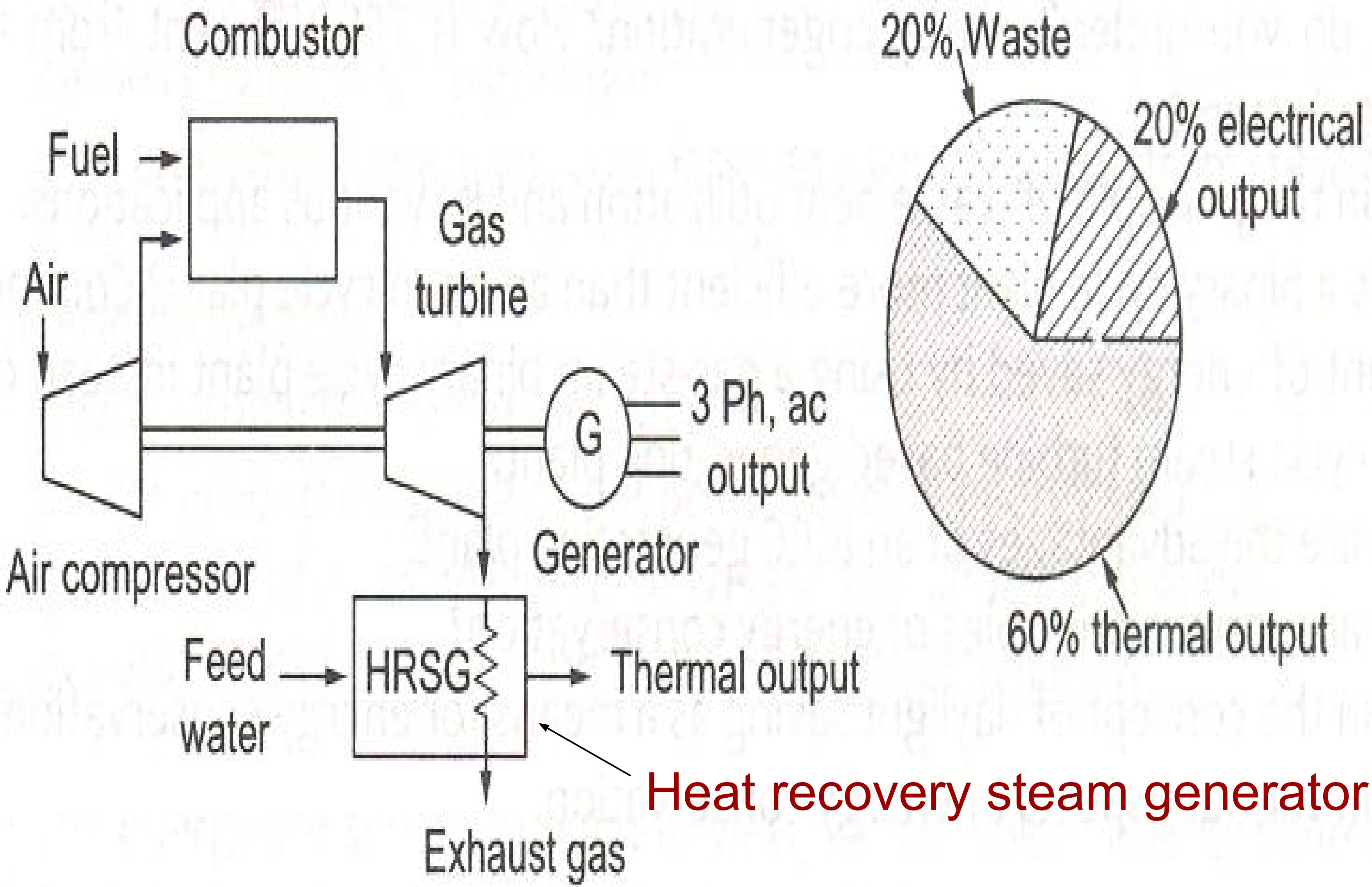


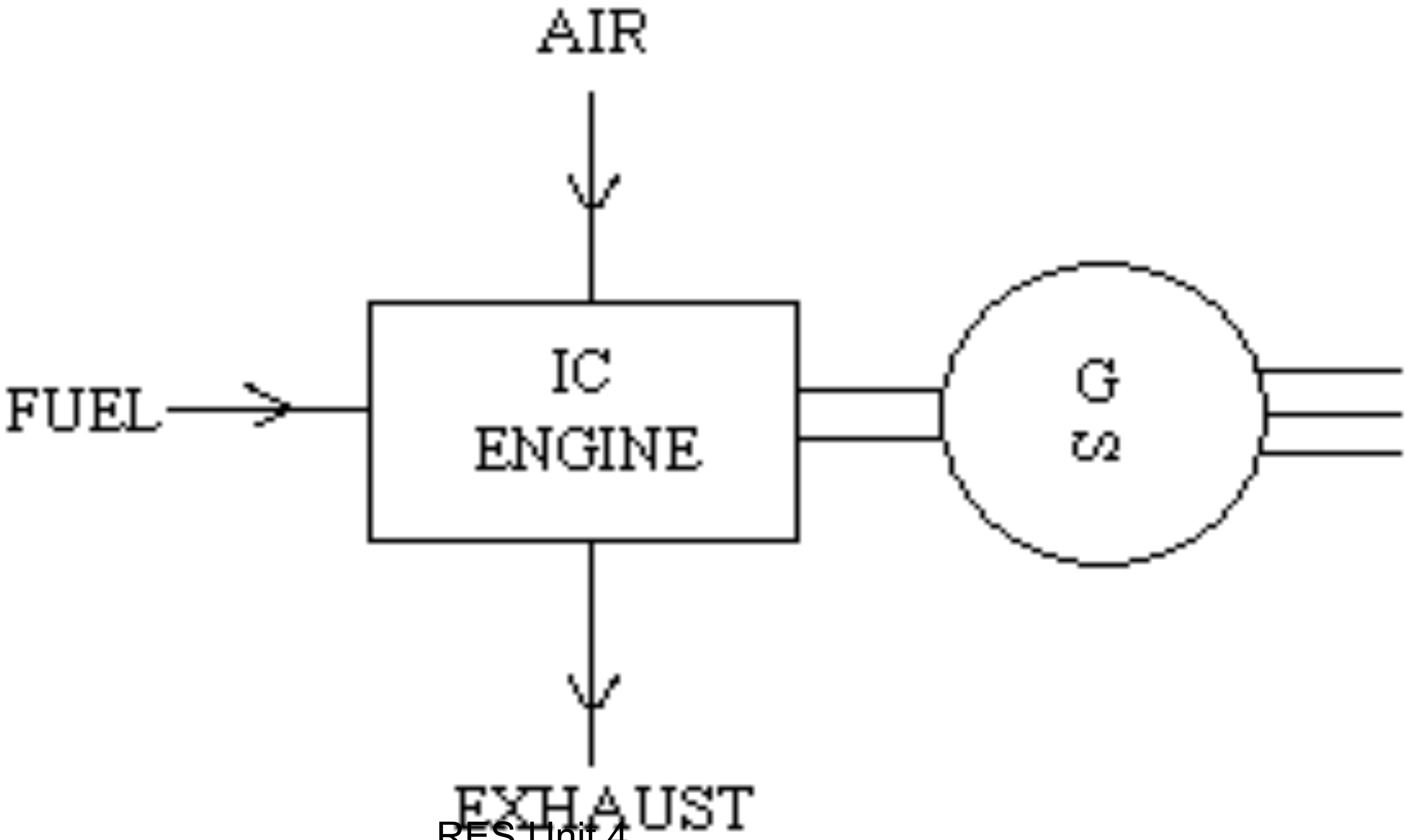
Fig Open cycle (simple cycle) gas turbine power plant



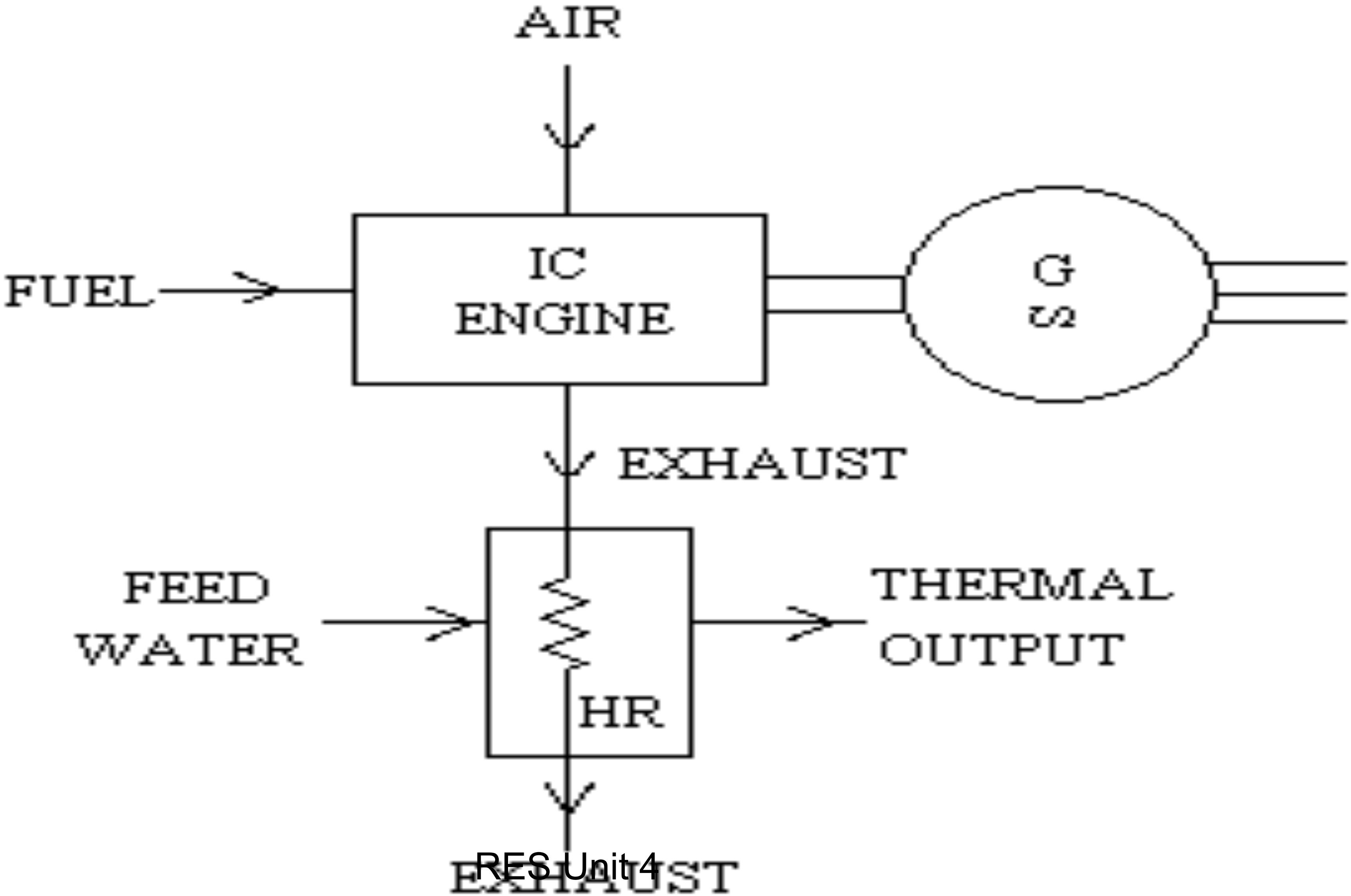
Heat recovery steam generator

~~Fig. Open cycle (simple cycle)~~ *gas turbine power plant with cogeneration*

IC ENGINE POWER PLANT



IC ENGINE POWER PLANT WITH CO-GENERATION



Combined Cycle cogeneration systems

- In a combined cycle power plant, electric power is produced using two heat engines in tandem as prime movers.
- The heat discharged from one heat engine is not wasted into the atmosphere but serves as the source for the next heat engine. The net result is greater overall operating temperature range (i.e., between the initial heat source and final heat sink) than is possible with a single heat engine.
- Thermal efficiency of a combined cycle system is thus greater than that for two heat engines operating independently.
- The highest inlet steam temperature for a steam turbine is limited to about 540□C by the properties of the materials.

RES Unit 4

Combined Cycle cogeneration systems continued….

- However, the flame temperatures of burning fossil fuel in a boiler may be more than 1650□C.
- Consequently, in a combined cycle system, steam turbine is preceded by a topping cycle heat engine, which can utilize heat at higher temperatures.
- The working fluid leaves the topping cycle at a sufficiently high temperature to generate steam for the steam turbine.
- Because the technology is well developed for the gas turbine, it is most commonly used as a topping cycle engine.
- The turbine exhaust gases at a temperature of 600□C or more pass through a waste heat (heat recovery steam generator) boiler where steam is produced from water under pressure.

RES Unit 4

Combined Cycle cogeneration systems
continued….

- In addition to using fuel more efficiently, a combined gas and steam turbine generating system requires lesser condenser cooling water for a given electrical output than a steam turbine generator alone.
- Gas turbine works on the Brayton cycle and has an efficiency of about 20%.
- Steam turbine works on the Rankine cycle and has an efficiency of about 35%.
- The efficiency of combined cycle power plant is 45-50%.
- Subsequent slides show the combined cycle power plant without and with cogeneration.

RES Unit 4

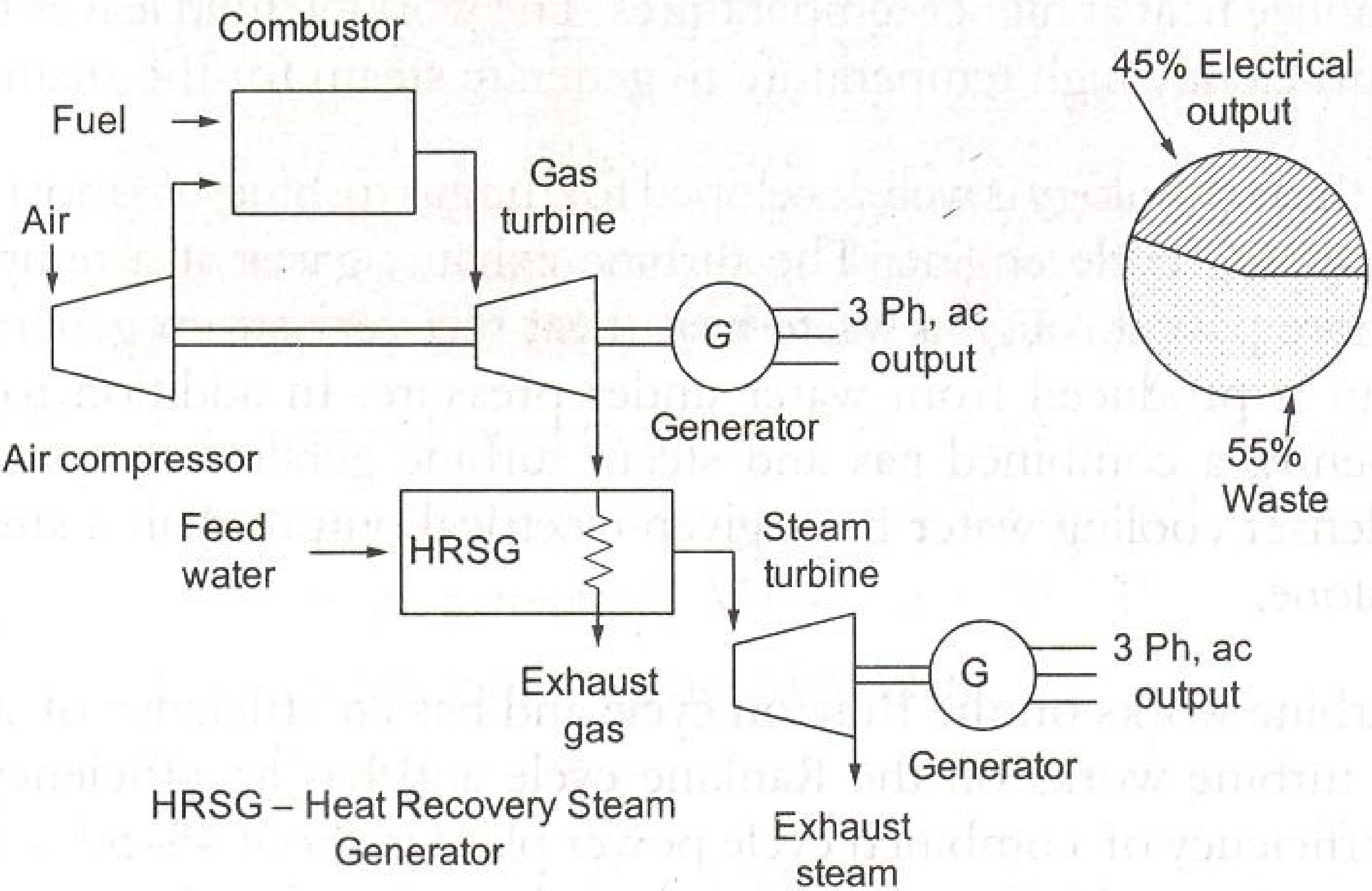


Fig. 2.[illegible] *Combined-cycle power plant*

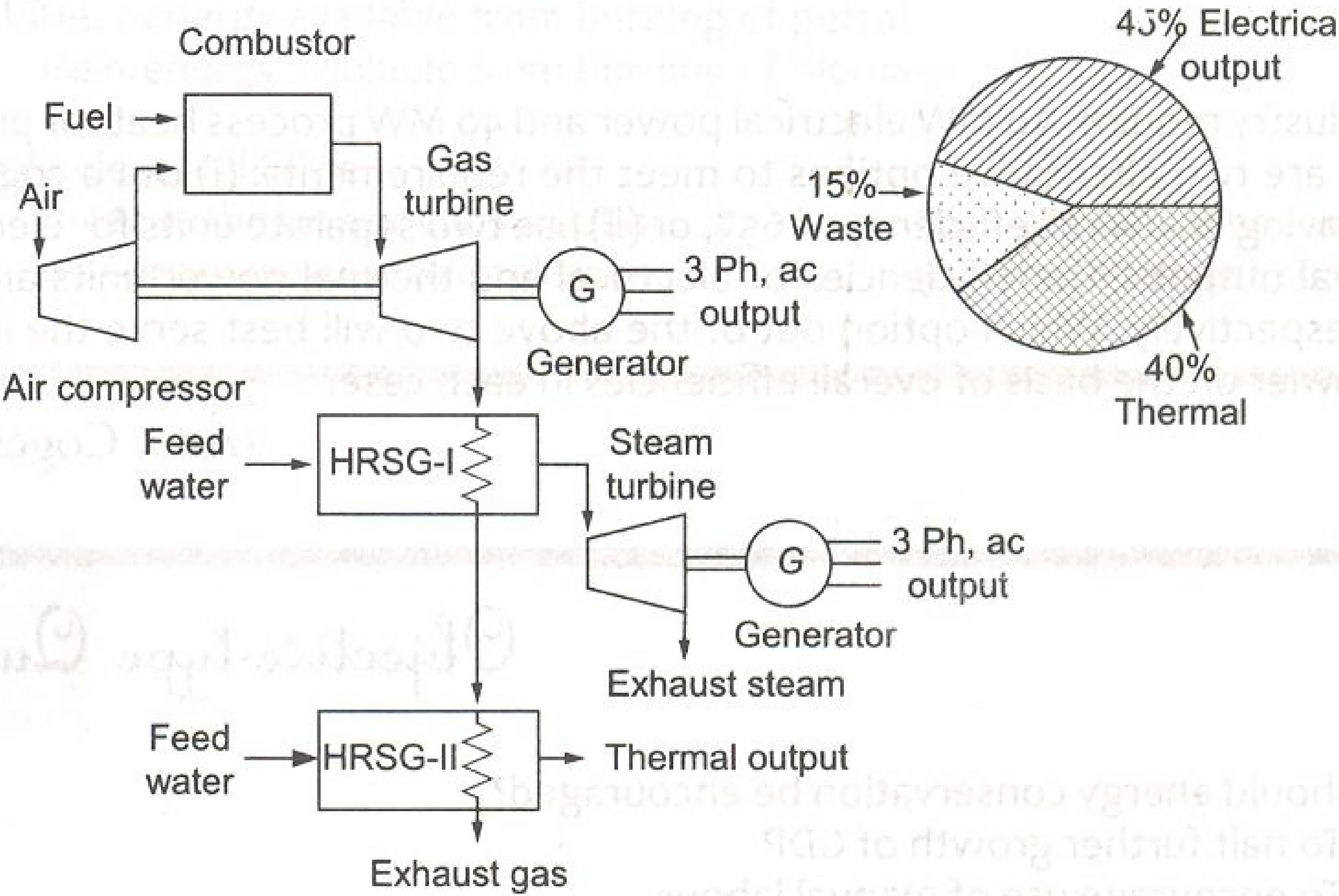


Fig. 2. *Combined cycle power plant with cogeneration*

RES Unit 4

(Slides: 51 to 54)

RENEWABLE ENERGY UTILIZATION

PAST, PRESENT AND FUTURE

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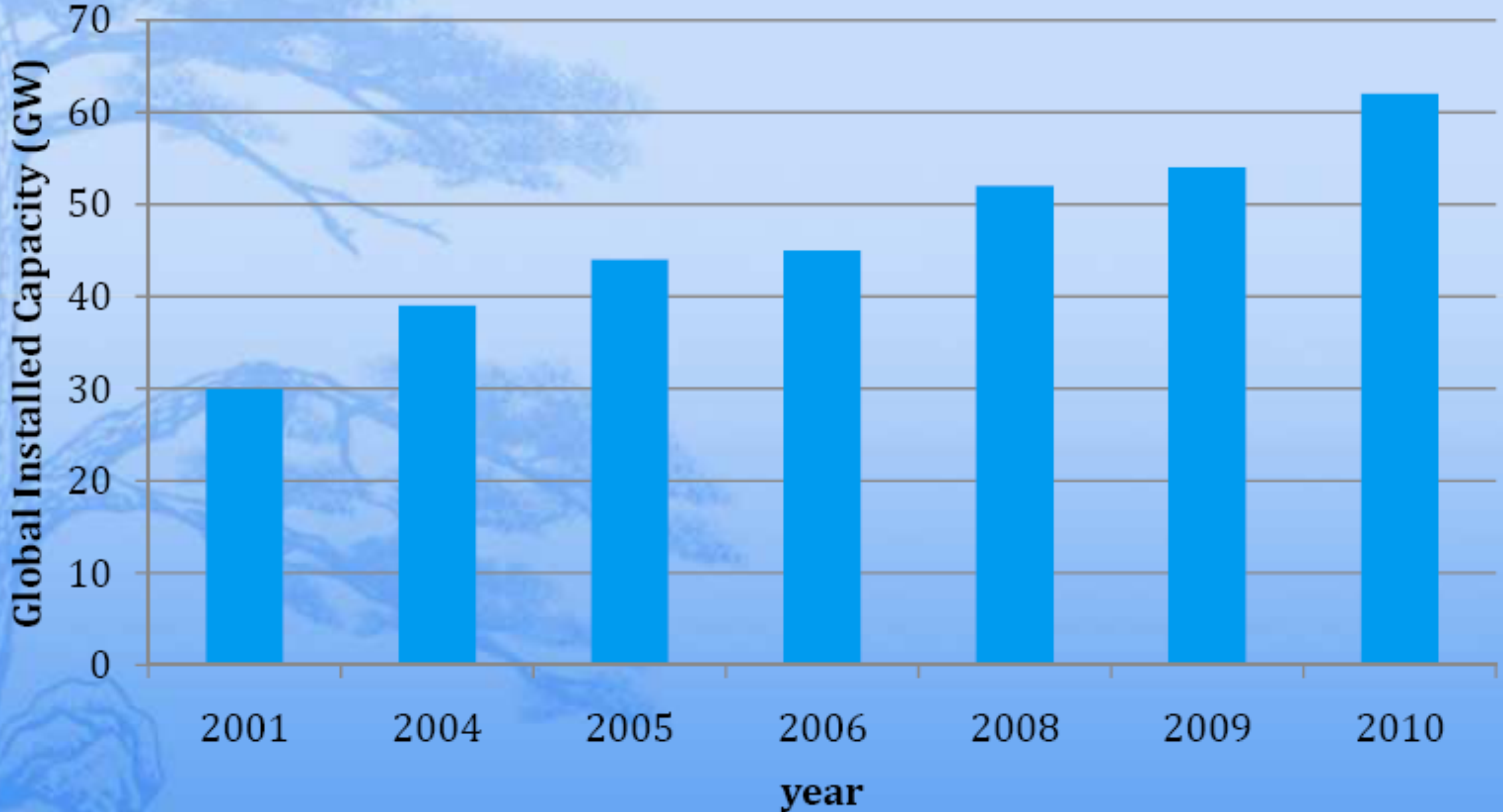
Biomass

- One of the earliest forms of energy resource used by humans and still in use
- Only 1% of insolation on plants contributes to photosynthesis and production of biomass
- Biomass use recycles carbon and does not add green house gases
- Core commercial sectors:
  - Thermal/combustion
  - Solid wastes/landfill gas
  - Anaerobic digestion
    - Animal wastes
    - Agricultural wastes
    - Human wastes
- Biomass-to-electricity options:
  - Combustion/thermal/steam/turbine/generator
  - Gasification/turbine/generator
  - Biogas/fuel cell
  - Pyrolysis
  - Biogas (landfill or anaerobic digestion)/engine/generator

Biomass Global Prospects

- Estimated installation during 2004-2013:
  - Large-scale thermal: 9,868 MW
  - Landfill gas : 1,887 MW
  - Anaerobic digestion: 417 MW
- Biomass Thermal Technologies
  - Fluidized bed combustor (FBC) 36-38% overall efficiency
  - EPS(whole tree burner) 34-36%
  - Biomass integrated gasifier/steam injected gas turbine (BIG/STIG) 38-47%

Global Installed Capacity of Biomass Power Plants



Ref: Renewables 2011, Global Status Report

Ocean energy

- Oceans cover about 71% of the earth's surface.
- As per present technological status, recoverable energy in oceans exists mainly in the form of (1) tides, (2) waves and (3) temperature difference (between surface and deep layers).
- Tides and waves produce mechanical energy whereas temperature difference produces thermal energy.
- Tidal energy technology is relatively more developed compared to the other two.
- The main disadvantages common to all of them are (i) low energy density, and (ii) their occurrence at distances remote from the consumption centre.

Tidal energy

- Tidal energy exploits the natural rise and fall of coastal tidal waters caused principally by the interaction of the gravitational fields of the sun and the moon.
- All surfaces of earth are pulled towards the moon and the sun. The oceans, which are liquid, are greatly affected by the two forces of nature:

  1. The gravitational pull of the sun and moon
  2. The centrifugal forces the earth applies as it spins.

- Since the moon is four hundred times closer to earth, it has more influence on tides than the sun.
- The ocean level difference caused due to tides contains large amount of potential energy. The highest level of the tidal water is known as flood tide or high tide. The lowest level is known as low tide or ebb.

Tidal energy continued….

- The level difference between the high and low tide is known as tidal range. Only sites with large tidal ranges (about 5 m or more) are considered suitable for power generation. The total combined potential at these sites is estimated as 1, 20,000 MW (120 GW). Tidal mills were in use on the coasts of Spain, France, UK and China.
- The principle used for harnessing this energy consisted of filling a pond through sluice (rapid controlled gates) during high tides and emptying it during low tides via an undershot waterwheel, producing mechanical power.
- Even now, the same basic principle with improvements in the design, material and operation techniques is being used to generate electricity in the same manner as in a hydroelectric plant.

Tidal power plant

The main components of a tidal plant:

- Dam, barrage or dyke: A barrier constructed to hold water
- Sluice ways: Rapid controlled gates used to fill a basin during high tides or to empty the basin during low tides
- A special, bulb-type power turbine-generator set: Steel shell containing an alternator and special Kaplan turbine with variable pitch blades

The main tidal energy conversion schemes:

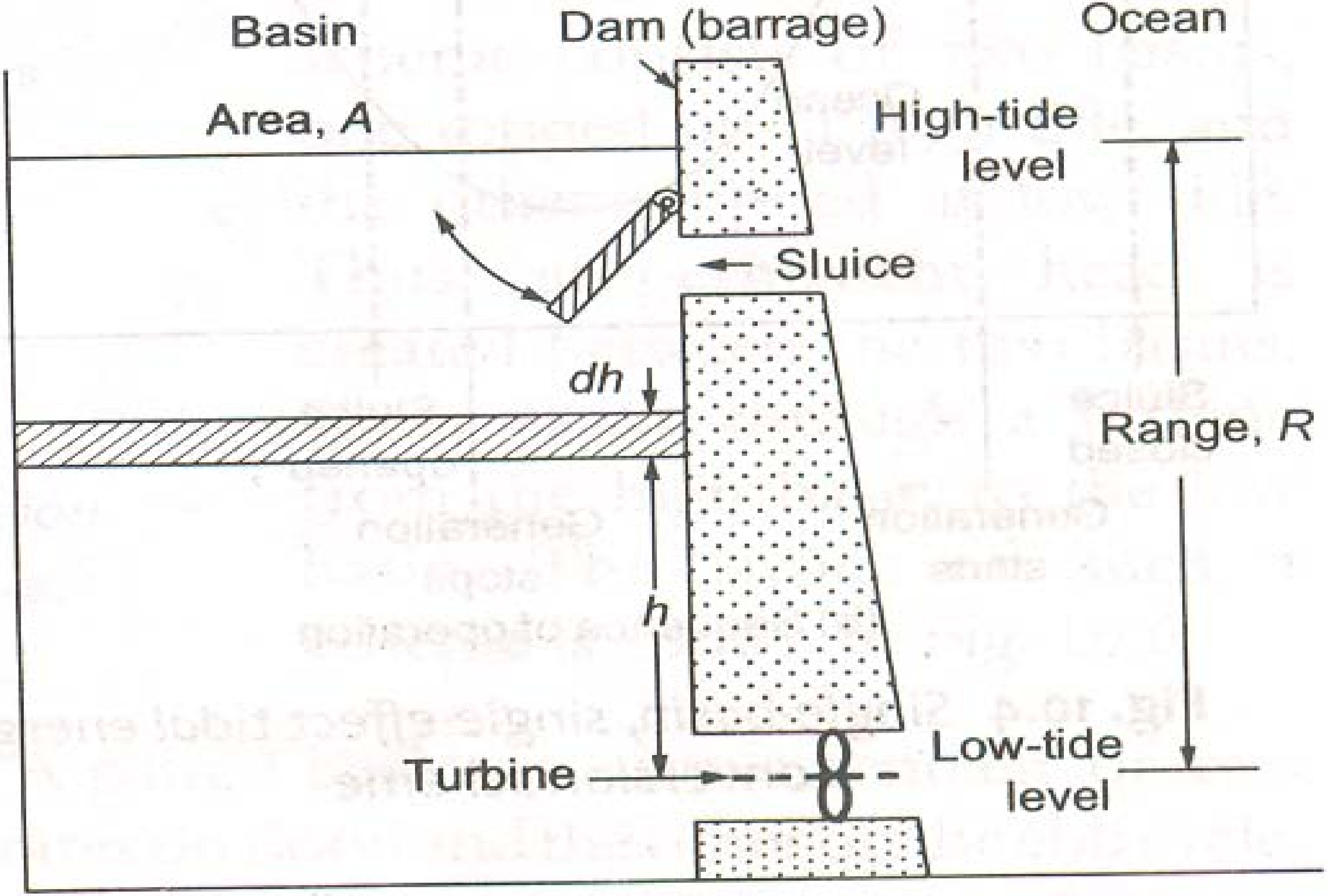
(i) Single basin: single effect

(ii) Single basin: double effect

(iii) Two basin: linked basin

(iv) Two basin: paired basin

(v) Tidal flow (or tidal current) schemes

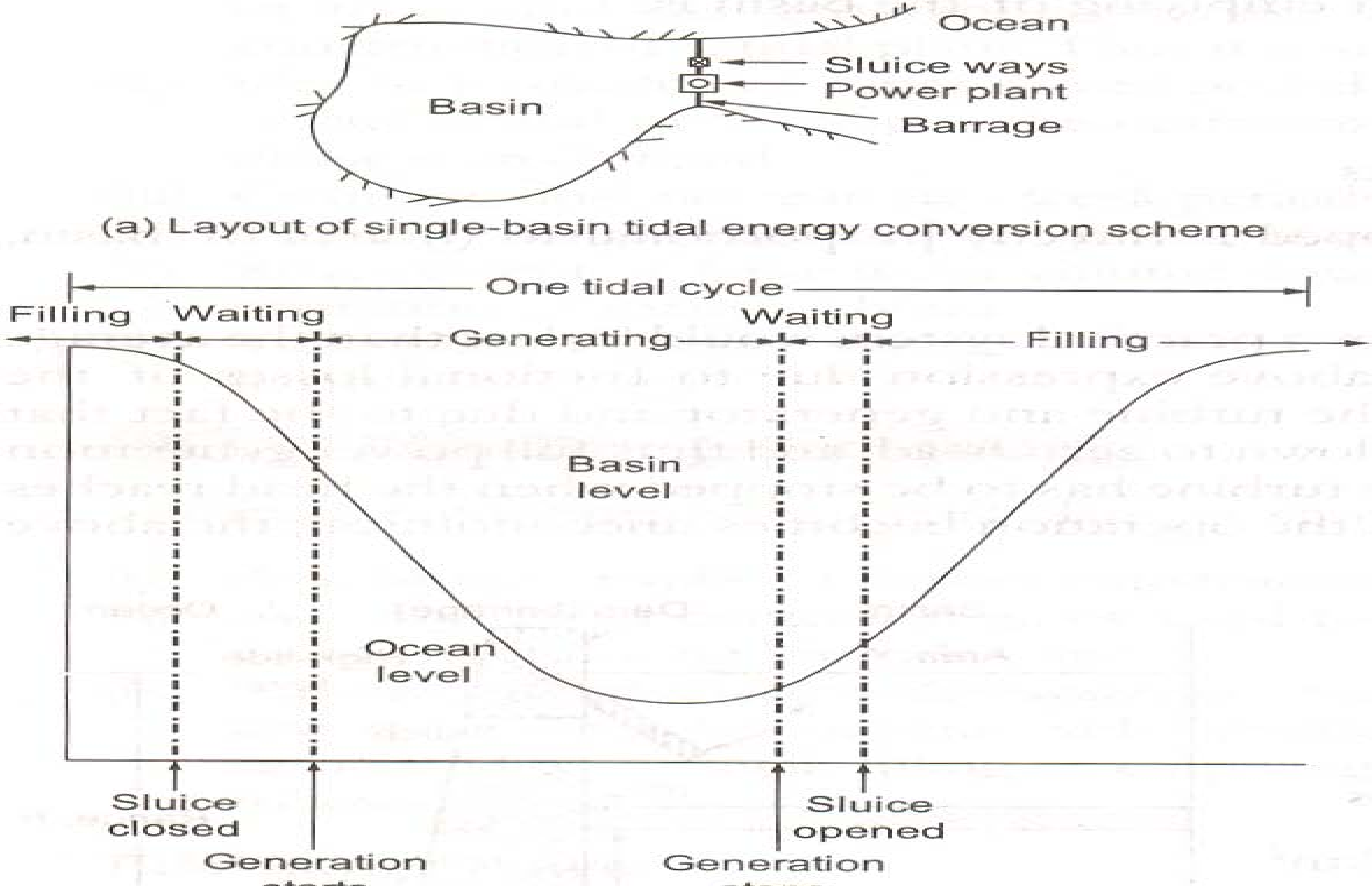


Power generation from tides

Tidal power plant continued….

Single basin: Single-effect scheme

- This scheme has only one basin as shown in the next slide. Power is generated either during filling or emptying the basin.
- In one type of operation, called ebb generation cycle operation, the sluice way is opened to fill the basin during high tide. Once filled, the impounded water is held till the receding cycle creates a suitable head. Water is now allowed to flow through the turbine coupled to the generator till the rising tide reduces the head to the minimum operating point. The flow is held till the next generating cycle.
- The sequence of events is illustrated in the next slide. This cycle is repeated and power is generated intermittently.



(a) Layout of single-basin tidal energy conversion scheme

(b) Sequence of operation

Single-basin, single-effect tidal energy conversion scheme

Tidal power plant continued….

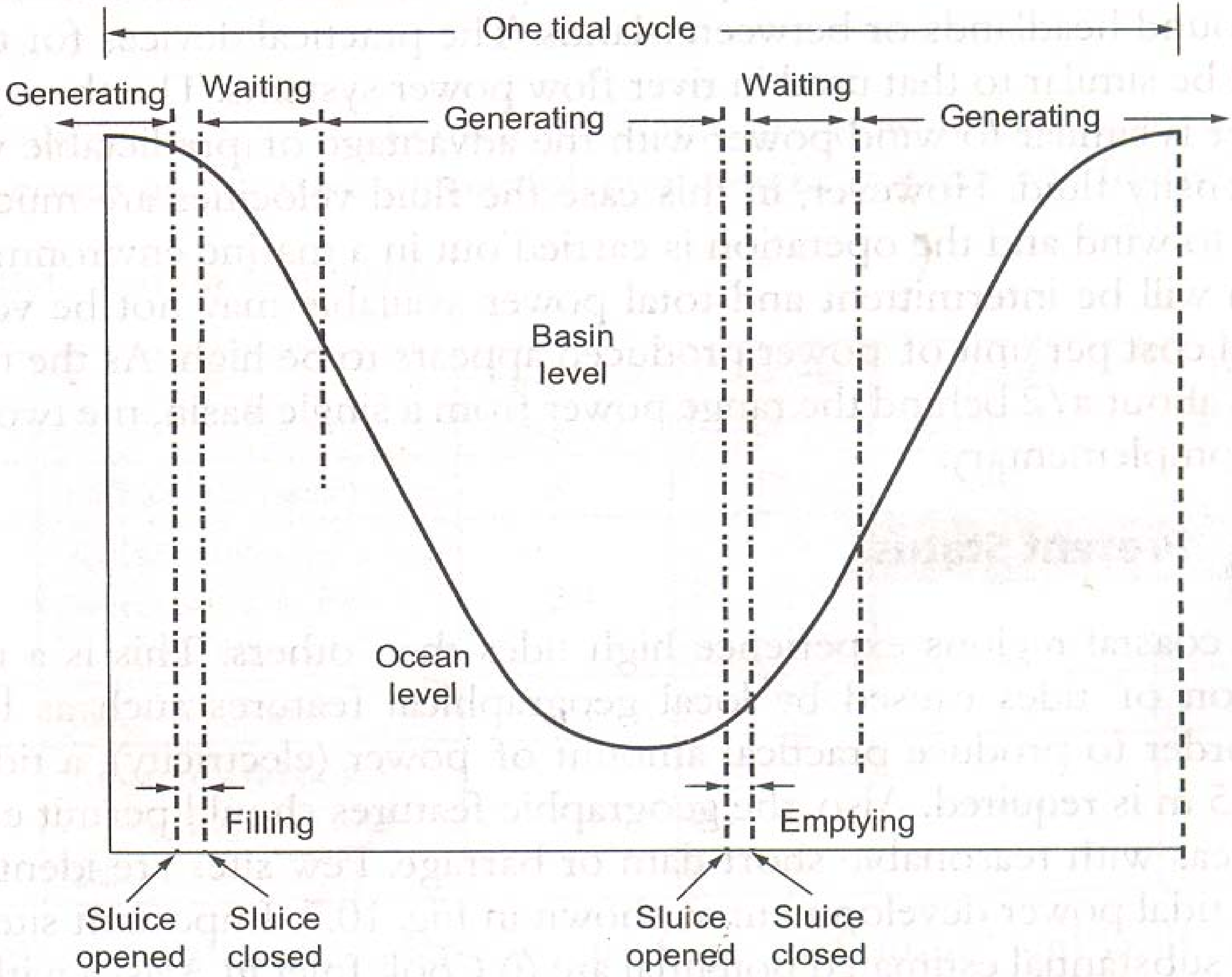
Single Basin: Double-effect scheme

- In this scheme, power is generated during both flood (high tide) and ebb (low tide). Two-way (reversible) hydraulic turbines are used. Pumping may also be used to increase the output.

The routine is as follows:

- Inward sluicing to fill the basin
- Holding period
- Ebb generation
- Outward sluicing to empty the basin
- Holding period
- Flood generation

The routine is shown graphically in the next slide.



Single-basin, double-effect tidal energy conversion scheme

Tidal power status in India

- Potential sites identified are Gulf of Cambay and Gulf of Kutch in Gujarat with maximum tidal ranges of 11m and 8 m, average tidal range of 6.77 m and 5.23 m and power generation potentials of 7,000 MW and 1,200 MW respectively.
- A potential of 100 MW with a maximum tidal range of 5 m and an average tidal range of 2.97 m has been estimated at the Durgadurani creek of the Sundarbans area in West Bengal. Some potential also exists at Belladonna creek in West Bengal with a mean tidal range of 3.6 m.
- It is proposed to commission a 50 MW tidal power project off the coast of Gujarat in 2013. This tidal plant will be first in Asia. London-based marine energy developer Atlantis Resources Corporation, along with Gujarat Power Corporation Ltd, has signed a memorandum of understanding (MOU) with the Gujarat government to start this project. The cost for the plant is expected to be around Rs 750 crores.

Advantages of tidal power

1. Tidal power is predictable.
2. It is always available irrespective of summer or winter & sunny or rainy day.
3. It is free from pollution.
4. It is inexhaustible and renewable source of energy.
5. It does not require valuable land.
6. Cost of power generation is very low once the capital cost is paid off.

Disadvantages of tidal power

1. Tidal power plant output varies with tidal range.
2. Power produced is intermittent.
3. Capital cost is quite high.
4. Turbines are required to operate at variable head.
5. Tidal plant disrupts marine life.
6. Silting of basins is a problem.

Wave energy

- Waves are caused by the transfer of energy from surface winds to the sea. The rate of energy depends upon the wind speed and the distance over which it interacts with water.
- The power in the waves is directly proportional to the square of the amplitude and the period of the wave.
- The energy stored is dissipated through friction at shore and turbulence at rates depending on the characteristics of wave and water depth.
- Larger waves in deep sea lose energy quite slowly and can effectively store it for many days and transmit it over great distances.
- The resource potential near coastlines is estimated to be greater than 20, 00,000 MW (2000 GW).

Wave energy continued….

Main advantage of wave power:

1. Availability of large energy fluxes
2. Predictability of wave conditions

Main disadvantages of wave power:

(1) Irregularity of wave patterns in amplitude, phase and direction makes it difficult to extract power efficiently. (2) The power extraction system is exposed to occasional extreme stormy conditions (Tsunami etc.). (3) Large power is available in waves of deep water. However, it is difficult to construct, operate and maintain a power system in deep water and transmit power to the shore. (4) The slow and irregular motion of a wave is required to be coupled to an electrical generator requiring high and constant speed motion.

Wave energy technology

- Energy in the waves is harnessed basically in the form of mechanical energy using wave energy converters, also known as wave devices or wave machines.
- A wave device may be placed in the ocean in various possible situations and locations. The fluctuating mechanical energy obtained is smoothened to drive a generator.
- Depending on the location, wave energy devices can be classified as (i) off-shore or deep-water (water depth of 40 m or more) devices, and (ii) shoreline devices.
- The availability of wave power at deep ocean sites is three to eight times that of adjacent coastal sites. However, the cost of installation, operation and power transformation is quite large.
- Shoreline devices, on the other hand, have the advantages of relatively easier maintenance and installation and they do not require deep-water moorings and long underwater cables.

Wave energy technology

continued….

- Depending on the actuating motion used in capturing the wave power, these devices are classified as (i) Heaving float type, (ii) Pitching type (iii) Heaving and pitching float type (iv) Oscillating water column type and (v) Surge devices.
- For each of these types, several designs have been developed and tested with many more still at the design stage. Some of the designs will be discussed here.

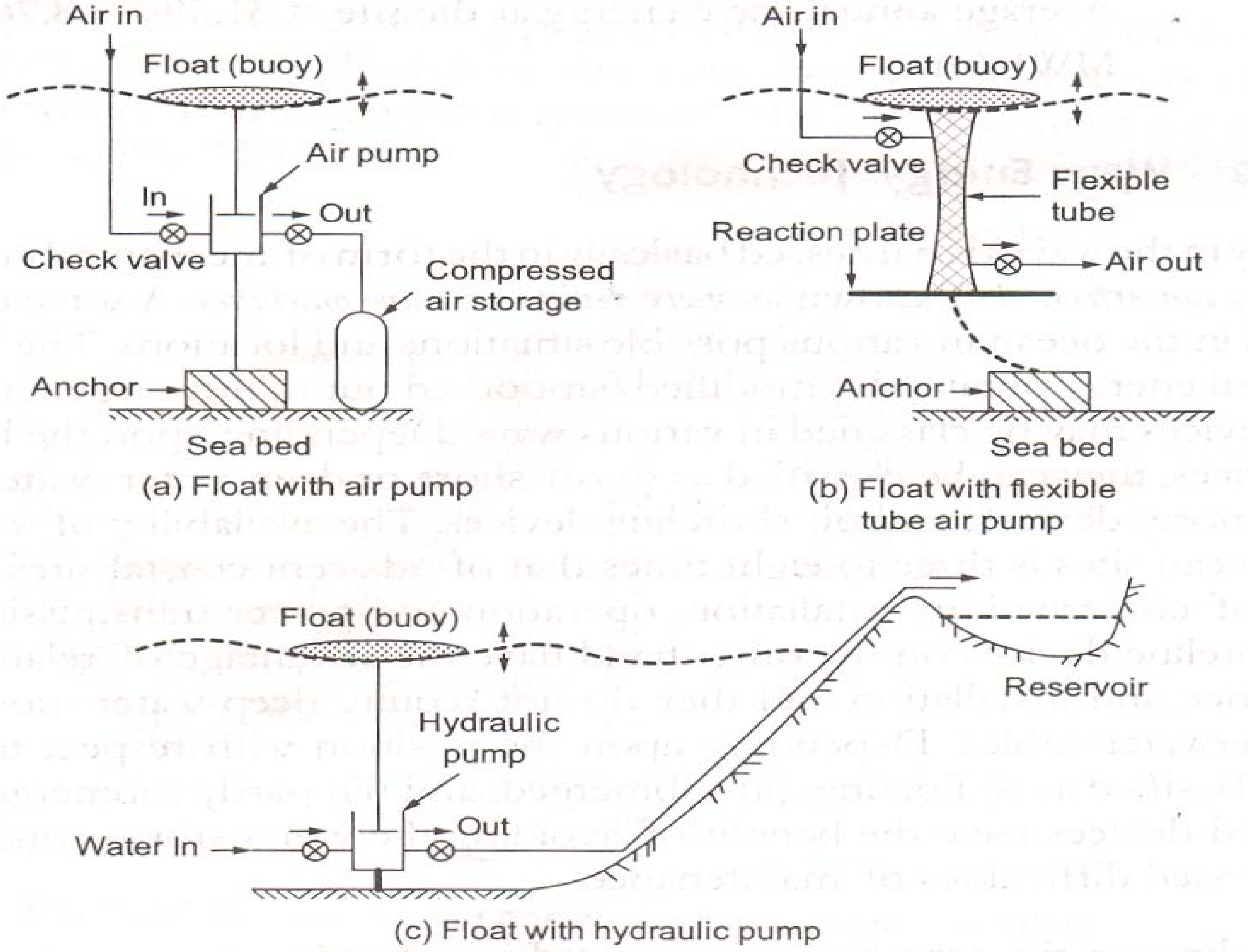
Heaving float type:

- A float (buoy), placed on the surface of water heaves up and down with waves due to the rise and fall of the water level.
- The resulting vertical motion is used to operate the piston of an air pump through linkage. The pump may be anchored or moored to the sea bed.

Wave energy technology

continued….

- Several float-operated air pumps are used to store energy in a compressed air storage. The compressed air is used to generate electricity through an air turbine coupled to a generator.
- Power may also be extracted from a buoy by means of an internally suspended weight, with high inertia but free to swing. Energy is extracted from the differential motion of buoy and pendulum.
- In another version, a hydraulic pump is operated by the motion of a buoy to raise water to an onshore reservoir and passed through a turbo-generator to generate electricity.
- In a Swedish design, a submerged flexible tube attached to a buoy is used as an air pump. The motion of the buoy stretches the tube and decreases its volume to provide the pumping action. These designs are shown in the next slide.



Heaving-float type devices

Wave energy technology
continued….

Oscillating water-column type:

- This device comprises a partly submerged concrete or steel structure.
- The structure has an opening to the sea below the waterline, thereby enclosing a column of air above a column of water.
- The wave impinging on the device causes the water column to rise and fall, which alternately compresses or depressurizes the air column.
- The air is allowed to flow through a turbine, which drives the generator.

Wave energy technology

continued….

- The specially developed axial flow Well's turbine, which operates with either direction of air flow, is used to extract energy as shown in the next slide.
- A conventional (unidirectional) air turbine with rectifying valves can also be used.

Main advantages:

- The air velocity can be increased by reducing the cross section area of the air channel. Thus, the slow wave motion can be coupled to high-speed turbine motions.
- Generating equipments are kept away from immediate saline water environment.

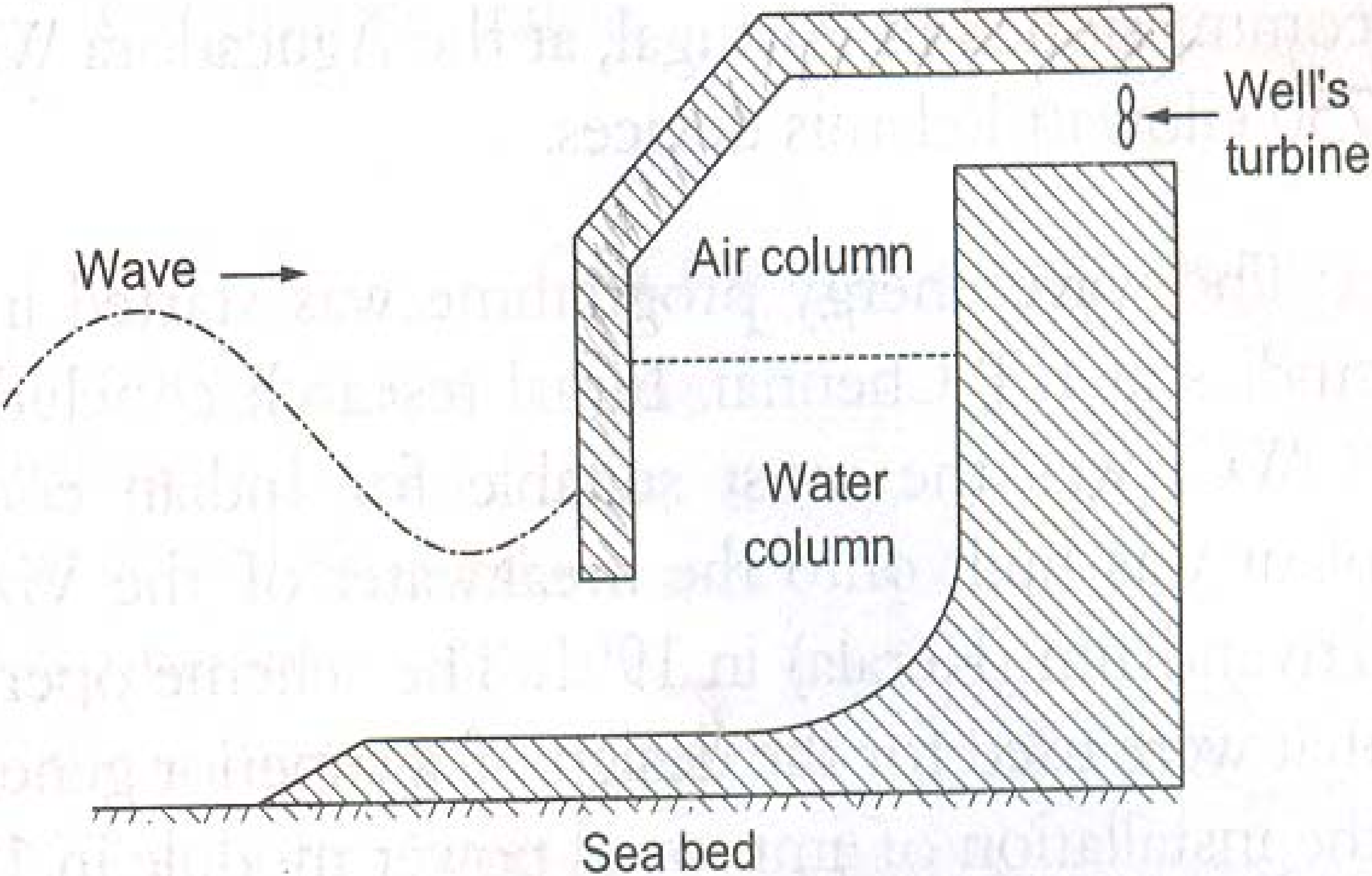


Fig. 5.24 Oscillating water column device

Present status of wave energy

- Wave energy is passing through R & D (Research and Development) phase and has not reached maturity from several points of view.
- Main countries involved in its development are Denmark, India, Ireland, Japan, Norway, Portugal, UK and USA. These efforts have largely been uncoordinated and so a wide variety of technologies have emerged. Some of them have been deployed in the sea as demonstration schemes.
- Large-scale offshore devices are likely to remain uneconomical in the near future. The development of small-scale modular shoreline devices at shore-based sites seems to become more economical and competitive. Few small-scale devices are already operating satisfactorily.

Present status of wave energy

continued….

- The wave energy programme was started in India in 1983 with preliminary studies at IIT Madras.
- Initial research concluded that oscillating water column (OWC) device is most suitable for Indian conditions.
- A 150 kW pilot OWC plant was built onto the breakwater of the Vizhingam Fisheries Harbour, near Trivandrum (Kerala) in 1991. This scheme operated successfully, producing data that were used for the design of a superior generator and turbine. This has led to the installation of improved power module in 1996. A plant of total capacity of 1.1 MW is being developed at the same site.

Environmental impacts of wave energy

- Wave power is essentially non-polluting.
- No appreciable environmental effects are foreseen from isolated floating wave power devices.
- However, onshore wave energy installations may change visual landscape and degrade scenic ocean front views.
- It may also cause disturbance to marine life including changes in distribution and types of life near the shore, and possible threat to navigation from collision due to low-profile floating wave devices.
- It would usually be both possible and necessary to avoid hazards to or from marine traffic with the help of navigation aids.

Ocean thermal energy

- Ocean thermal energy exists in the form of temperature difference between the warm surface water and the colder deep water.
- A heat engine generates power utilizing a well-established thermodynamic principle, where heat flows from a high temperature source to a low temperature sink through an engine, converting a part of the heat into work.
- In the present case, the surface water works as a heat source and the deep water as a heat sink to convert part of the heat to mechanical energy and hence into electrical energy.
- The facility proposed to achieve this conversion is known as **OTEC** (Ocean Thermal Energy Conversion).
- A minimum temperature difference of 20º C is required for practical energy conversion.

Ocean thermal energy conversion

- Ocean Thermal Energy Conversion (***OTEC***) uses the difference between cooler deep and warmer shallow or surface waters of the ocean to run a heat engine and produce useful work, usually in the form of electricity.
- A heat engine gives greater efficiency and power when run with a large temperature difference. In the oceans, the temperature difference between surface and deep water is greatest in the tropics, although still a modest 20 to 25 °C. In most tropical and some subtropical regions, the surface temperature may reach 27 °C while at 1 km depth, water stays at 4 °C.
- OTEC has the potential to offer global amounts of energy that are 10 to 100 times greater than other ocean energy options such as tidal energy and wave energy.

OTEC Continued….

- OTEC plants can operate continuously providing a base load supply for an electrical power generation system. The main technical challenge of OTEC is to generate significant amounts of power efficiently from small temperature differences. It is still considered an emerging technology.
- Early OTEC systems were of 1 to 3% thermal efficiency, well below the theoretical maximum of 6 to 7%. Current designs are expected to be closer to the maximum.
- The first operational system was built in Cuba in 1930 and generated 22 kW. Modern designs allow performance approaching the theoretical maximum Carnot efficiency and the largest built in 1999 by the USA generated 250 kW .

OTEC Continued….

- The most commonly used heat cycle for OTEC is the Rankine cycle using a low-pressure turbine.
- Systems may be either closed-cycle or open-cycle. Closed-cycle engines use working fluids that are typically thought of as refrigerants such as ammonia or R-134a. Open-cycle engines use vapour from the seawater itself as the working fluid.
- OTEC can also supply quantities of cold water as a by-product . This can be used for air conditioning and refrigeration and the fertile deep ocean water can feed biological technologies. Another by-product is fresh water distilled from the sea.

Ocean thermal energy

continued….

Main advantages of OTEC:

(i) The resource supplies steady power without fluctuations and independent of vagaries of weather.

(ii) The availability hardly varies from season to season.

(iii) At a suitable site, the resource is essentially limited only by the size of the system.

(iv) The machinery requires only marginal improvements in devices like heat exchanger and turbine.

(v) It also has the ability to create some useful by-products such as desalinated water and nutrients for mariculture.

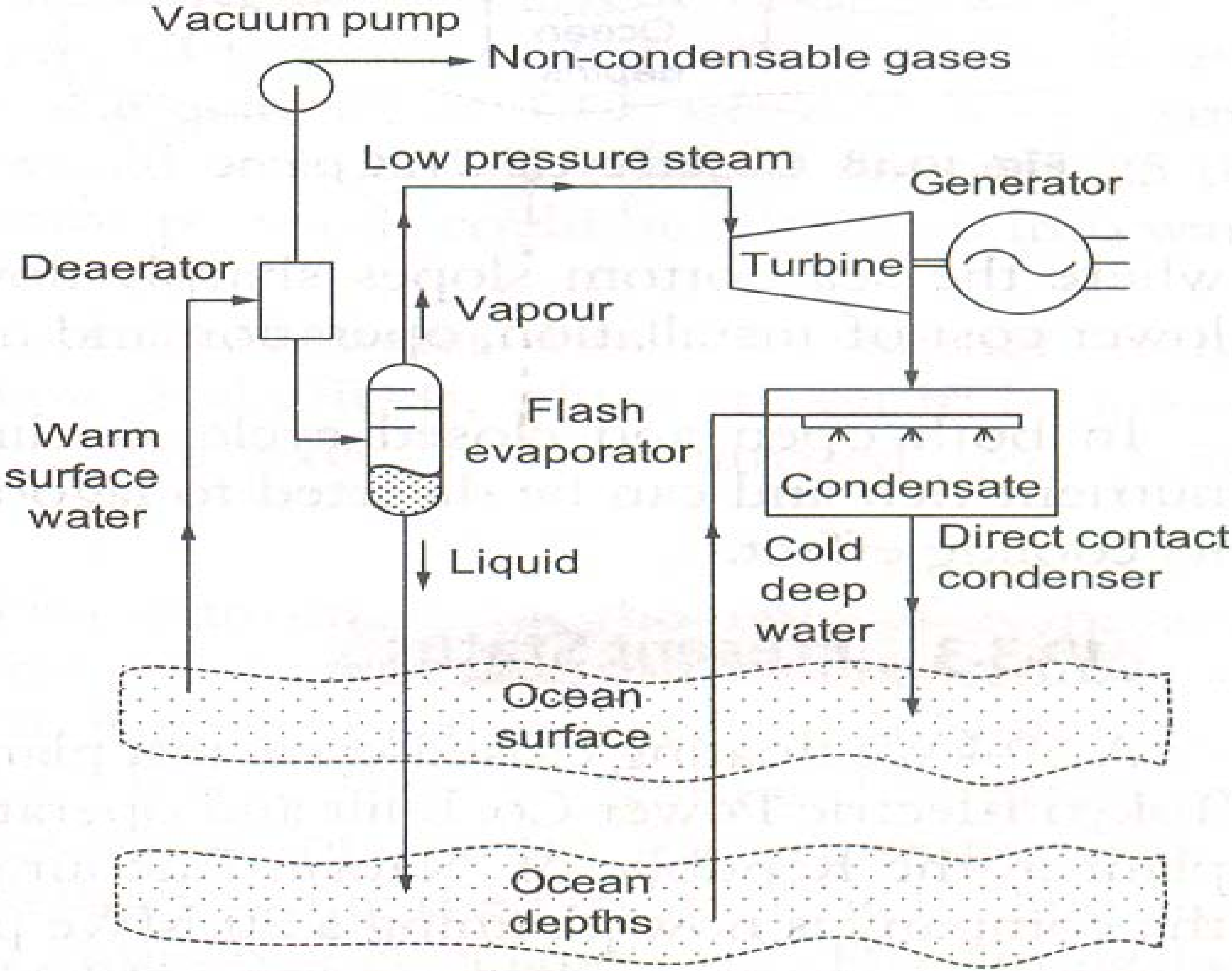
Main disadvantages of OTEC:

(i) Low efficiency

(ii) High installation cost

Open cycle OTEC plant

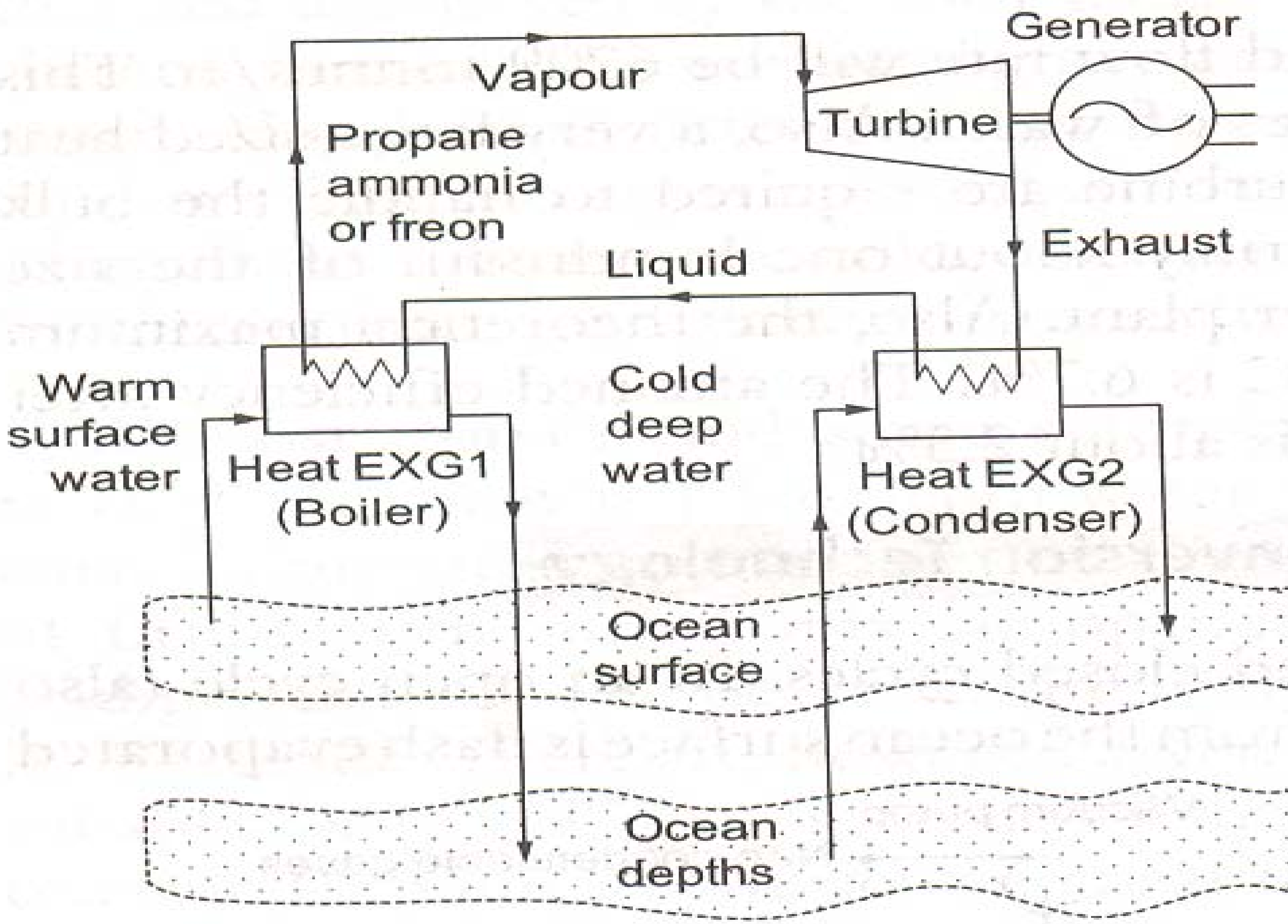
- OETC plants can operate on open and closed cycles.
- In an open cycle plant, warm water from the ocean surface is flash evaporated under partial vacuum.
- Low-pressure steam obtained is separated and passed through a turbine to extract energy.
- The exhaust of the turbine is condensed in a direct contact condenser.
- Cold water drawn from a depth of about 1000 m is used as cooling water in a direct contact condenser. The resulting mixture of used cooling water and condensate is disposed into the sea. If a surface contact condenser is employed, the condensate could be used as desalinated water. Thus, an open loop OETC plant can provide a substantial quantity of desalinated water.
- The scheme is shown in the next slide.



Open cycle OTEC plant

Closed cycle OTEC plant

- In a closed cycle plant, warm surface water is used to evaporate a low-boiling-point working fluid such as ammonia, freon or propane.
- The vapour flows through the turbine and is then cooled and condensed by cold water pumped from the ocean depths. Because of the low quality of the heat, large surface areas of heat exchangers (evaporator and condenser) are required to transfer significant amount of heat. A large amount of water, therefore, needs to be circulated.
- The schematic diagram of a closed loop OETC plant is shown in the next slide.
- The operating pressures of the working fluid at the boiler/ evaporator and condenser are much higher and its specific volume is much lower as compared to that of water in an open-cycle system.



Closed-cycle OTEC plant

Closed cycle OTEC plant

continued….

- Such pressures and specific volumes result in turbine that is much smaller in size and hence less costly as compared to that in an open cycle system.
- Although both systems are being explored, the closed-cycle system appears to be more promising in the near future.
- Both open and closed cycle plants can be mounted on a ship or built on shore.
- The ship option requires submarine power cable for power transport.
- However, if the plant is located far (more than about 50 km) from the shore, the transmission cost becomes prohibitive.

Closed cycle OTEC plant

continued….

- Alternatively, for a plant, which is hundreds of kilometers from the shore, it has been suggested that electricity be used on board to produce chemical storage of energy (e.g.: H2).
- The hydrogen could be liquefied and transported by a tanker to the point of use.
- The shore option is feasible only at certain favorable locations, where the sea bottom slopes sharply downwards. Their main advantage is the lower cost of installation, operation and maintenance.
- In both open and closed cycle, cooling water taken from the sea depth is nutrient-rich and can be diverted to lagoon to develop mariculture after utilizing its cooling effect.

Present status of OTEC

- A 50 kW floating closed-cycle test plant was installed off Hawaii in 1979. The Tokyo electric power Company built and operated a 100 kW shore-based closed cycle plant in the republic of Nauru.
- In India, conceptual studies on OETC plants at Kavaratti (Lakhshadweep Island), Andaman Nicobar Islands and Kulasekharapatnam (Tamilnadu) were initiated in 1980.
- A preliminary design for a 1 MW (gross) closed Rankine cycle floating plant was prepared by IIT Madras in 1984.
- In 1997, the National Institute of Ocean Technology (NIOT) signed a memorandum of understanding with saga university, Japan, for joint development of 1-MW plant near the port of Tuticorin (Tamilnadu).
- NIOT plans to build 10-25 MW shore-based plants in due course by scaling up the 1-MW test plant and possibly a 100 MW range of commercial plant thereafter.

Environmental impacts of OTEC

- It is feared that biota including eggs, larvae and fish could be destroyed due to intake and expulsion of large volumes of water.
- Changes in local temperature and salinity might also affect the local ecosystem, impact coral and influence ocean currents and climate.
- In an open-cycle OETC system, CO_2 dissolved in warm water is released to the atmosphere. However, the quantity of CO_2 released is very small and under worst conditions would be only 1/15 that of oil or 1/25 that of coal-based generation of same power.
- Release of large quantities of cold water into the warmer surface environment may also have biological effects.

Small hydro energy

- Hydropower is the most established renewable resource for electricity generation. Large-scale hydropower is a well established, mature and proven technology. However, the concept of small hydro resources is recent and is expanding very fast.
- In large-scale surveys and studies, the potential for small-scale generation from rivers has been greatly neglected due to techno-economic reasons.
- Recently, due to advancements in the design of low head turbines, improvements in construction technology and availability of better control techniques, small hydro resources have become viable.
- About 18% of potential large-scale hydropower sites have already been developed, but there is strong opposition from environmentalists for the development of the remaining sites.

Small hydro energy
continued….

- Small hydro resources are largely free from such environmental effects and therefore their potential is increasingly being utilized.
- Small hydro plant projects include those installations that have low head (generally under 40 m) and small capacity.
- There is no international consensus on the definition of small hydropower. Different countries follow different norms. In India, hydropower projects of ratings less than 25 MW are regarded as small hydropower projects. Depending on the capacities, these plants are classified as micro (less than 100 kW), mini (100 kW to1 MW) and small (1 MW to 25 MW). These boundaries, however, are not very rigid.

Small hydro energy

continued….

The small/mini/micro schemes are further classified as

(i) Storage scheme

(ii) Run-of –the-river scheme

- A storage scheme makes use of a dam to stop river flow, building up reservoir of water behind the dam. The water is then released through turbines when power is needed. The advantage of this approach is that rainfall can accumulate during the wet season of the year and then release power during some or all of the drier periods of the year.
- A run-of-the-river scheme does not stop the river flow. Instead, it diverts a part of the flow into a channel and pipe and then through a turbine.

Small hydro energy
continued….

- Micro-hydro schemes are almost always run-of-the-river type.
- The disadvantage of this approach is that water is not carried over from rainy to dry seasons of the year and power generation depends on the availability of flow.
- The advantages of this approach are: (i) The scheme can be built locally at low cost, and its simplicity gives rise to better long-term reliability (ii) The environmental damage is negligible, as the river-flow pattern downstream of the plant is not affected (iii) There is no flooding upstream of the plant (iv) The scheme does not displace large number of people as large projects with big dams sometimes do.

Advantages of Small Hydro Schemes

(1) Hydroelectric energy is continuously renewable energy source. (2) It is a much more concentrated energy resource than either wind or solar power. (3) It is non-pulling and no heat or noxious gases are released. (4) This energy has low operating and maintenance costs. (5) The technology is a proven technology that offers reliable and flexible operation. (6) The civil-engineering work does not need elaborate construction plans. Also, no expensive powerhouses or highly optimized electro mechanical equipments are required. (7) It has a short gestation period. (8) The possibility of retrofits, and additional turbines and generators makes the upgrading of the existing installations attractive.

Disadvantages of Small Hydro Schemes

(1) Hydro systems, unlike solar components for example, do require some maintenance. (2) The majority of the plants are located in remote places and are not connected to the grid. (3) The rotation of turbines can kill fishes, especially young fishes, swimming downstream. (4) Spilling of water over spillways can result in super saturation of water with gases from the air. The gas bubbles, absorbed into fish tissue, may cause damage and ultimately kill the fish. (5) Most hydroelectric facilities require construction of dams. Dams present a migratory barrier that can effect the free movement of fish species and their reproduction cycle. (6) The existence of a reservoir can make the water become stratified, with warmer water collecting at the surface and cooler water lying at the bottom.

Layout of a Micro-Hydro Scheme

- The layout of a typical micro-hydro scheme is shown in the next slide. The main components of the scheme:

(i) Diversion weir

(ii) Water-conductor system with regulating gates and spillways

(iii) Desilting tank with spillway

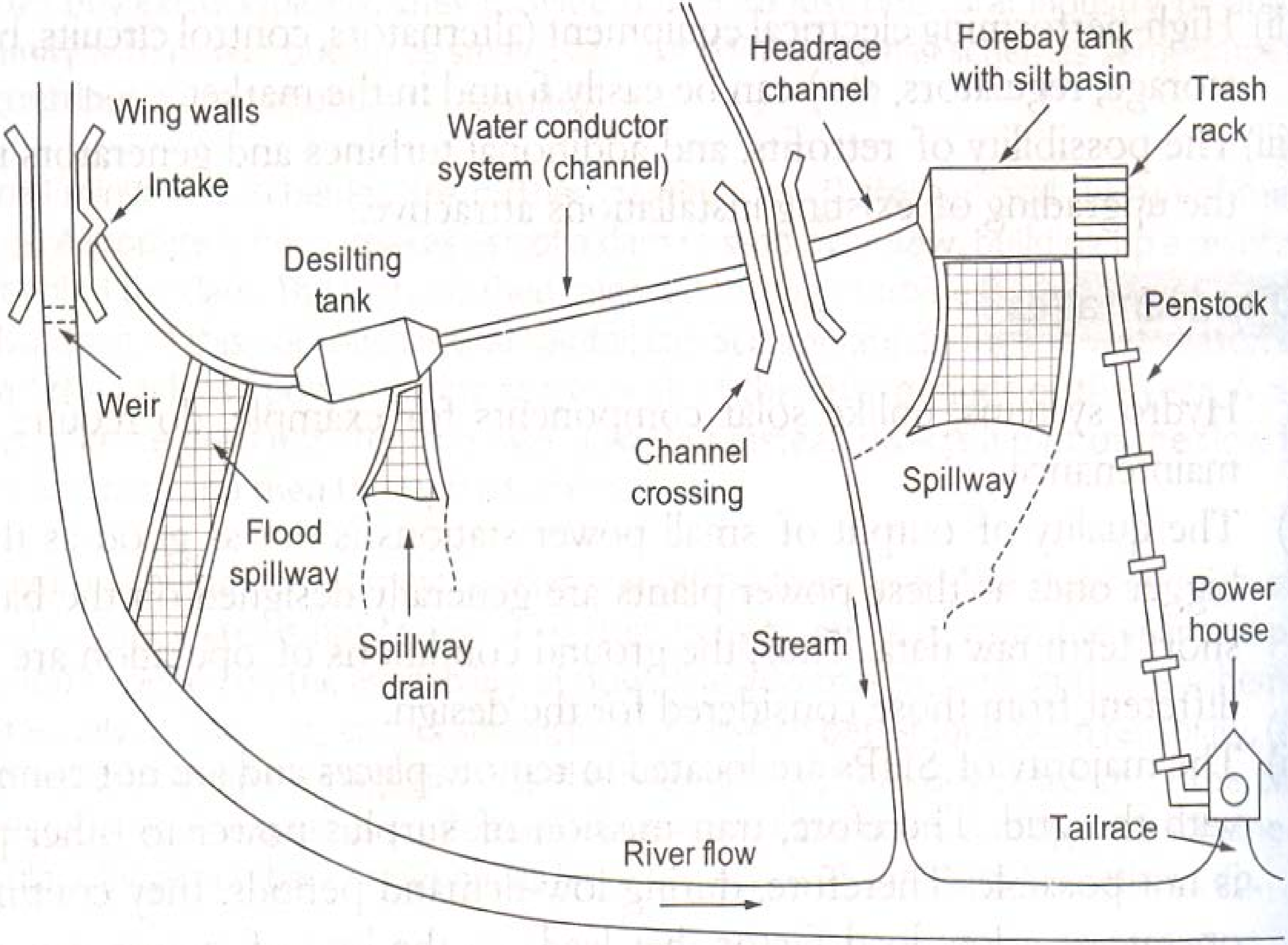
(iv) Headrace channel

(v) Fore bay tank with desilting basin and spillway

(iv) Penstock

(vii) Powerhouse

(viii) Tailrace channel



Typical layout of a microhydro power station

Layout of a Micro-Hydro Scheme

continued….

- **Diversion weir and channel:** A diversion weir is designed to divert and maintain constant flow in the channel for variable flow in the river through the year.
- **Desilting tank:** A desilting tank is usually provided in the initial reaches of water to trap the suspended silt load and pebbles, so as to minimize erosion damages to the turbine.
- **Forebay, penstock and tailrace:** A forebay is a temporary storage of water, to be finally utilized for energy generation. Trash racks are also provided to prevent entry of trash, debirs and ice. A penstock is a water conduit joining a forebay and a turbine. It should be sized such that frictional losses do not reduce the head unduly. A bell-mouth entry is provided to reduce the head loss and to ensure smooth entry of water. A tailrace is a simple water channel to transport discharge from the turbine back to the river.

Layout of a Micro-Hydro Scheme

continued….

Powerhouse:

- It houses the sped governor, water turbine and generator.
- Governors are used to control the speed.
- Turbines convert energy available in the form of falling water into rotating shaft power. They operate on the principle of either impulse or reaction.
- Generation of electrical power is possible both by dc as well as ac generators. DC generators above 2 kW are expensive. Both synchronous and induction type ac generators are suitable for micro hydro power generation. Induction generators are less common but are increasingly used in small schemes. The main advantage of induction generators is that they are easily and cheaply available. Further, they are rugged, reliable, require less maintenance and can withstand 100 % over speed.

Present Status of hydro power

- The present global installed capacity of hydropower plants is about 6,27,000 MW, which accounts for about 23% of the world's total installed electrical power generation. A number of large and medium sized hydro schemes have been developed. Large hydro schemes are commonly associated with large reservoirs, which give rise to much environmental concern.
- Small hydro plants generally do not displace large number of people as large projects sometimes do or cause other environmental problems. River courses suitable for accommodating hydro plants of up to 10 MW capacities are more common than larger ones. The total global installed capacity of small hydro plant is about 66,000 MW (year 2006).
- India's small hydroelectric power capacity has been estimated as 15,000 MW, out of which 2,045 MW has been developed by the end of 2007 from 611 projects. Many other schemes are at various levels of construction and planning.

Geothermal energy

- Geothermal energy originates from the earth's interior in the form of heat.
- Volcanoes, geysers, hot springs and boiling mud pots are visible evidence of the great reservoirs of the heat that lie beneath the earth.
- Although the amount of thermal energy within the earth is very large, useful geothermal energy is limited to certain sites only, as it is not feasible to access and extract heat from a very deep location.
- Where it is available near the surface and is relatively more concentrated, its extraction and use may be considered feasible. These sites are known as geothermal fields.
- As per US Geological survey, the entire heat content of the earth's crust up to a depth of 10 km and above 15º C is defined as geothermal resource.

Geothermal energy continued…..

- As such, the geothermal resource of the earth is estimated to be more than 2.11x 10^{25} J, which is equivalent to 10^9 MTOE (million tonnes of oil equivalent).
- This is a huge amount of energy, enough to supply our energy needs at current rates for 3, 50,000 years. Thus, it is considered as inexhaustible and renewable source. However, it is a low grade thermal energy and its economic recovery is not feasible everywhere on the surface of the earth. Practically, it is not the size of the resource that limits its use but the availability of technology that can tap the resource in an economic manner.
- Most geothermal resources produce low-grade heat at about 50-70 ºC, which can be used directly for thermal applications.

Geothermal energy

continued…..

- Occasionally, geothermal heat is available at temperatures above 90ºC, and so electrical power production from turbines can be contemplated.
- By the end of 2005, the world's total installed electrical power-generating capacity from geothermal resources was about 9,031 MW and direct thermal use installed capacity is 29,668 MW.
- Globally, generation of geothermal power is growing steadily at a rate of above 3% per year as electrical energy and 8.5% per year as direct thermal energy.
- The International Geothermal Association (IGA) has reported that 10,715 MW of geothermal power in 24 countries is online, which is expected to generate 67,246 GWh of electricity in 2010. This represents a 20% increase in online capacity since 2005.

Geothermal energy

continued…..

- IGA projects growth to 18,500 MW by 2015, due to the projects presently under consideration, often in areas previously assumed to have little exploitable resource.
- In 2010, USA led the world in geothermal electricity production with 3,086 MW of installed capacity from 77 power plants. The largest group of geothermal power plants in the world is located at The Geysers, a geothermal field in California.
- The Philippines is the second highest producer, with 1,904 MW of capacity online. Geothermal power makes up approximately 18% of the country's electricity generation.

Geothermal energy

continued…..

Major advantages:

(i) It is reliable and cheap source of energy.

(ii) It is available 24 hours per day.

(iii) Its availability is not dependent on weather.

(iv) It has inherent storage feature and hence no extra storage facility is required.

(v) Geothermal plants require little land area.

(vi) Feasibility of modular approach leads to a lot of opportunities for the development of relatively quick and cost-effective geothermal projects.

Geothermal energy continued…..

Major disadvantages:

(i) It is site specific. There are not many places where you can build a geothermal power station.

(ii) Generally, energy is available as low-grade heat.

(iii) Continuous extraction of heated ground water may lead to subsidence (setting or slumping) of land.

(iv) Geothermal fluid also bring with it dissolved gases and solute (as high as 25 kg/m3) which leads to air and land pollution.

(v) Drilling operation leads to noise pollution.

(vi) The available thermal energy cannot be transported easily over long distances.

(vii) Corrosive and abrasive geothermal fluid reduces the life of the power plant.

Applications of Geothermal energy

(i) Direct Heat Use:

- In general, although abundant geothermal energy is accessible, its thermodynamic quality is low.
- The source shares many similarities with industrial waste heat. The low and moderate temperature hydrothermal fluids can be used as direct heat source for space and water heating, for industrial processes such as drying applications in food, chemical and textile industries, crop drying, washing, for warming fish ponds in aquaculture and for agricultural applications such as soil and space heating of glasshouses.

Applications of Geothermal energy

continued….

(ii) Electric Power Generation:

- If temperatures are high enough (> 90ºC), then the preferred use of a geothermal resource is the generation of electricity, which would either be fed into the utility grid or be used to power the industrial processes on the site.
- It is normally used for base load power generation.
- Several important electric power plants are fully established, especially in Italy, New Zealand and USA.
- Electricity was first generated from naturally occurring geothermal steam at Italy in 1940. This was followed by commercial plants in New Zealand in 1958 and in California in1960.

Types of Geothermal Resources

Four types of geothermal resources:

(i) Hydrothermal

(ii) Geopressured

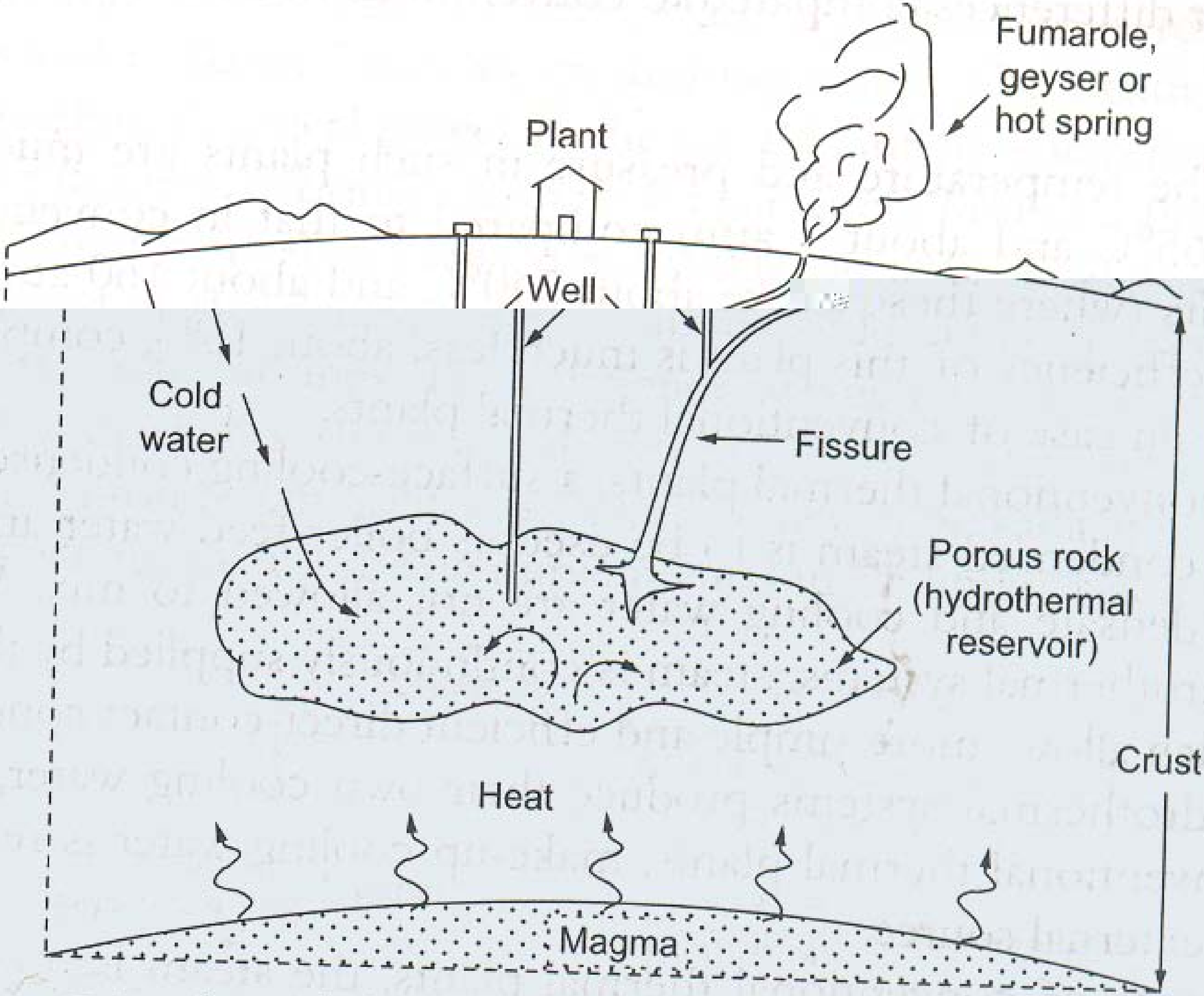
(iii) Hot dry rock

(iv) Magma

- At present, the technology for economical recovery of energy is available for hydrothermal resources only. Thus, this is the only commercially used resource at present.
- Other resources are going through a development phase and have not become commercial so far.

Hydrothermal resources

- Hydrothermal resources occur when underground water has access to high temperature porous rocks, capped by a layer of solid impervious rock.
- Thus, water is trapped in the underground reservoir and is heated by surrounding rocks. Heat is supplied by magma by upward conduction through solid rocks below the reservoir. Thus, it forms a giant underground boiler. Under high pressure, the temperature can reach as high as 350ºC.
- In order to utilize the hydrothermal energy, wells are drilled into the hydrothermal reservoir as shown in the next slide.



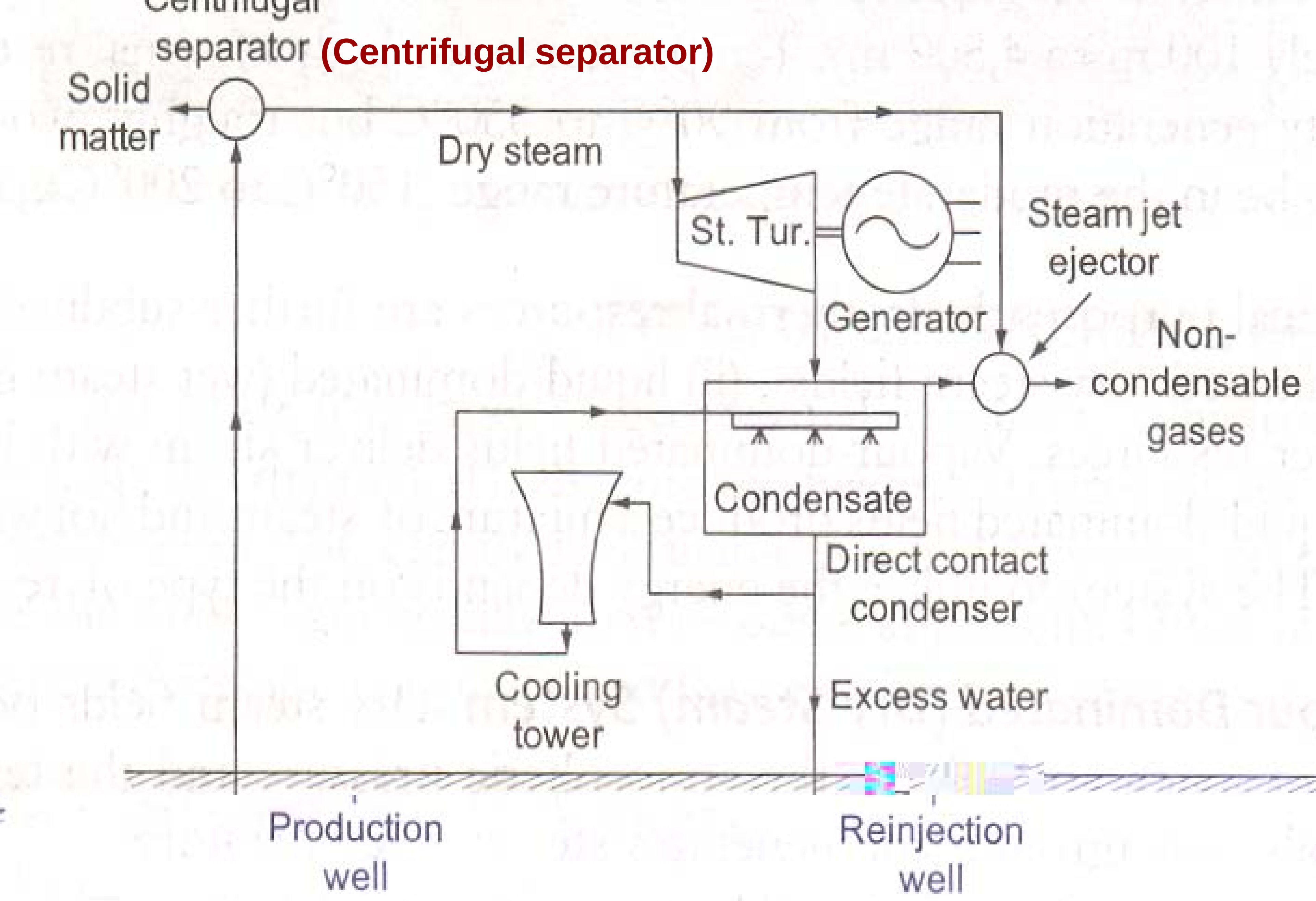
General simpiified structure of hydrothermal resource

Hydrothermal resources continued….

- The hydrothermal resources are located at shallow to moderate depths (from approximately 100 m to 4,500 m). Temperatures for hydrothermal reserves used for electricity generation range from 90ºC to 350ºC but roughly two-thirds are estimated to be in the moderate temperature range of 150ºC to 200ºC.
- For practical purposes, hydrothermal resources are further subdivided into (i) vapour dominated (dry steam fields), (ii) liquid-dominated (wet steam fields), and (iii) hot water resources. Vapour-dominated fields deliver steam with little or no water and liquid-dominated fields produce a mixture of steam and hot water or hot water only. The dry steam hydrothermal system alone will be discussed here.

Dry steam hydrothermal system

- Dry steam fields occur when the pressure is not much above the atmospheric pressure and the temperature is high.
- Water boils underground and generates steam at temperatures of about 165ºC and a pressure of about 7 atmosphere.
- The most important dry steam fields are (a) The Geysers region in California, which may be the largest, (b) the Larderello and some smaller areas in Italy, and (c) small fields at Matsukawa, Japan.
- A dry steam hydrothermal system is shown in the next slide.



Dry-steam hydrothermal system

Dry steam hydrothermal system

continued….

- Steam is extracted from the well, cleaned in a centrifugal separator to remove solid matter and then piped directly to a turbine.
- The exhaust steam of the turbine is condensed in a direct contact condenser, in which the steam is condensed by direct contact with cooling water.
- The resulting warm water is circulated and cooled in a cooling tower and returned to the condenser.
- The condensation of the steam continuously increases the volume of cooling water. Excess water is re-injected into the ground for disposal. The non-condensable gases are removed from the condenser by steam jet ejection.

Geothermal energy in India

- A systematic collaborative, research, development and demonstration progamme has been undertaken with different organizations, viz, IIT Delhi, National Aeronautic Limited Bangalore, Geological Survey of India, National Geophysical Research Institute (NGRI) Hyderabad, Oil and Natural Gas Corporation, etc.
- As a result of various resource assessment studies/ surveys, nearly 350 potential hot springs, distributed in seven geothermal provinces, have been identified throughout the country. These springs are perennial and their surface temperatures range from 37 to 90ºC with a cumulative surface discharge of over1000 l/m. Most of them are low-temperature hot water resources and can best be utilized for direct thermal applications.

Geothermal energy in India

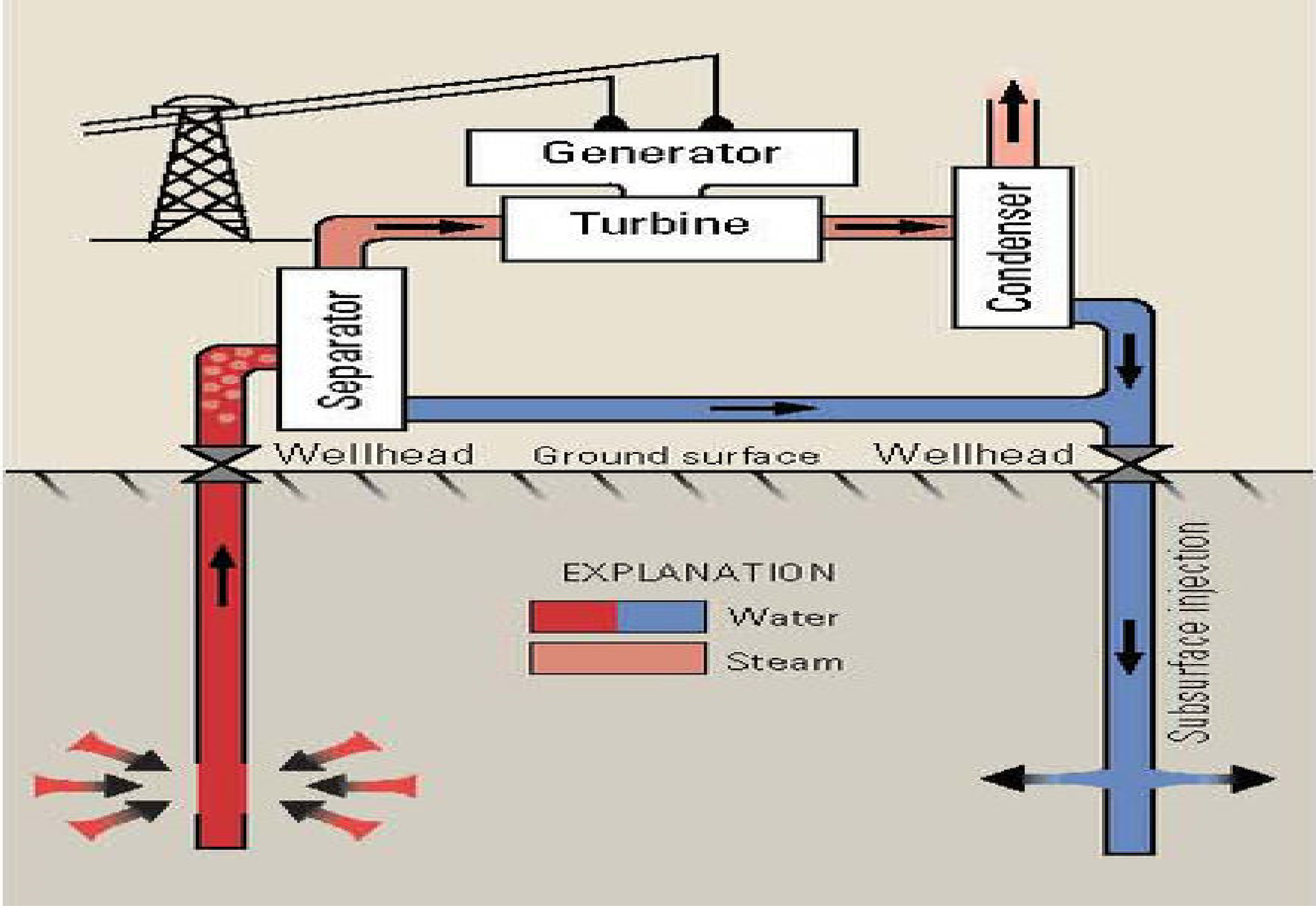
continued…

- Only some of them can be considered suitable for electrical power generation. The potential for power generation at these sites has been estimated to be around 10,000 MW.
- The use of geothermal energy has already been demonstrated in the country for small- scale power generation and thermal applications.
- Small direct heat pilot plants have been installed at Puga and Chumathang (in Ladakh Jammu and Kashmir) and Manikaran (Himachala Pradesh).
- The seven geothermal provinces include

  The Himalayas: Sohana

  West coast: Cambay

  Sonata: Godavari and Mahanadi



Geothermal: Flash steam power plant

Geothermal: Dry steam power plant

Fuel cell systems

- Fuel-cell technology is relatively new and in the initial stages of development.
- The principle of the fuel cell was discovered way back in 1838 by the German scientist Christian Friedrich Schonbein, and published in one of the scientific magazines of that time. Based on this work, the first fuel cell was demonstrated by the Welsh scientist Sir William Robert Grove in February 1839. However, turning this idea into a practical means of energy conversion has proved to be elusive.
- Its widespread use is hindered mainly due to its high cost as compared to other available technologies. Many companies are working on techniques to reduce the cost in a variety of ways including reducing the amount of platinum needed in each individual cell.

Fuel cells

- A fuel cell is an electrochemical cell that converts energy from a fuel into electrical energy.
- Electricity is generated from the reaction between a fuel supply and an oxidizing agent.
- The reactants flow into the cell, and the reaction products flow out of the cell, while the electrolyte remains within it.
- Fuel cells can operate continuously as long as the necessary reactant and oxidant flows are maintained.
- Fuel cells are different from conventional electrochemical cells (batteries).
- Fuel cells consume reactant from an external source, which must be replenished and hence represent a thermodynamically open system.

Fuel cells

continued…

- By contrast, batteries store electrical energy chemically and hence represent a thermodynamically closed system.
- Many combinations of fuels and oxidants are possible.
- A hydrogen fuel cell uses hydrogen as its fuel and oxygen (usually from air) as its oxidant.
- Other fuels include hydrocarbons and alcohols.
- Other oxidants include chlorine and chlorine dioxide.
- A fuel cell is an electrochemical energy conversion device that continuously converts chemical energy of a fuel directly into electrical energy.

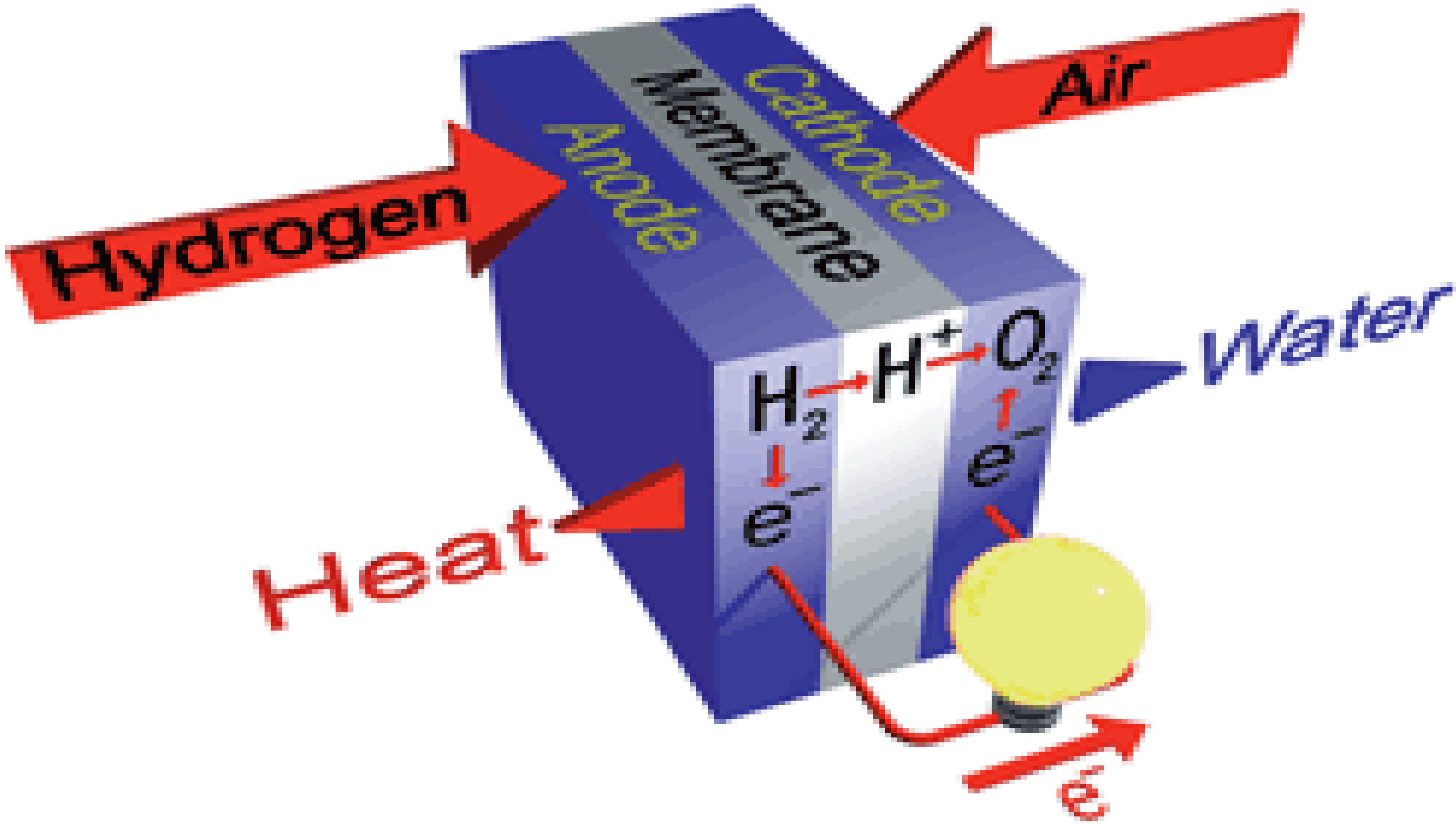
Fuel cells continued…

- Continuous operation requires supply of fuel & oxidant and removal of water vapor, spent fuel, spent oxidant, inert residue and heat.
- It is known as a cell because of some similarities with a primary cell. Like a conventional primary cell it also has two electrodes and an electrolyte between them and produces dc power.
- It is also a static power-conversion device. However, active materials are generally supplied from outside unlike a conventional cell where it is contained inside the cell.
- Fuel is supplied at the negative electrode, also known as fuel electrode or anode and the oxidant is supplied at positive electrode also known as oxidant electrode or cathode.

Fuel cells continued…

- The only exhaust of a fuel cell , if pure hydrogen is used as fuel (and pure oxygen as oxidant), is water vapour, which is not a pollutant.
- In case of a hydrocarbon fuel, carbon dioxide is also produced. If air is used as oxidant, nitrogen (spent air) is also produced in the exhaust.
- No other pollutant such as particulate matter, NO**x** and SO**x** are produced.
- Some amount of heat is also produced, which can be easily dissipated to the atmosphere or used locally for heating purposes.
- No cooling water is required unlike conventional thermal power-conversion devices where a substantial quantity of cooling water is required.
- A schematic of fuel cell principle is shown in the next slide.

Fuel Cell Principle - Schematic



Fuel cells continued…

- As the conversion of chemical energy of fuel to electrical energy occurs directly without intermediate thermal stage, the efficiency of conversion is better and not limited by Carnot efficiency of thermal stage.
- The efficiency of a practical fuel cell may be around 50%.
- The average cell voltage is typically about 0.7 V at full load and several cells may be connected in series to increase the voltage. The current depends on the electrode area and can be increased by connecting several cells in parallel.
- Thus, modules of different sizes can be constructed by series-parallel connection of the required number of cells. A general large-scale use will require the development of a low-cost fuel cell with a reasonably long life.

Advantages of fuel cell

(i) It is quiet in operation as it is a static device.

(ii) Pollution is quite less.

(iii) Its conversion efficiency is more.

(iv) Fuel cell plant can be installed near the point of use, thus transmission and distribution loses are avoided.

(v) No cooling water is needed as required in the condenser of a conventional steam plant.

(vi) Because of the modular nature, any voltage/ current level can be realized and the capacity can be added later on as the demand grows.

(vii) Fuel-cell plants are compact and require less space.

(viii) Availability of choice from large number of possible fuels.

(ix) Can be used efficiently at part load from 50% to 100% .

(x) No charging is required.

Classification of fuel cells

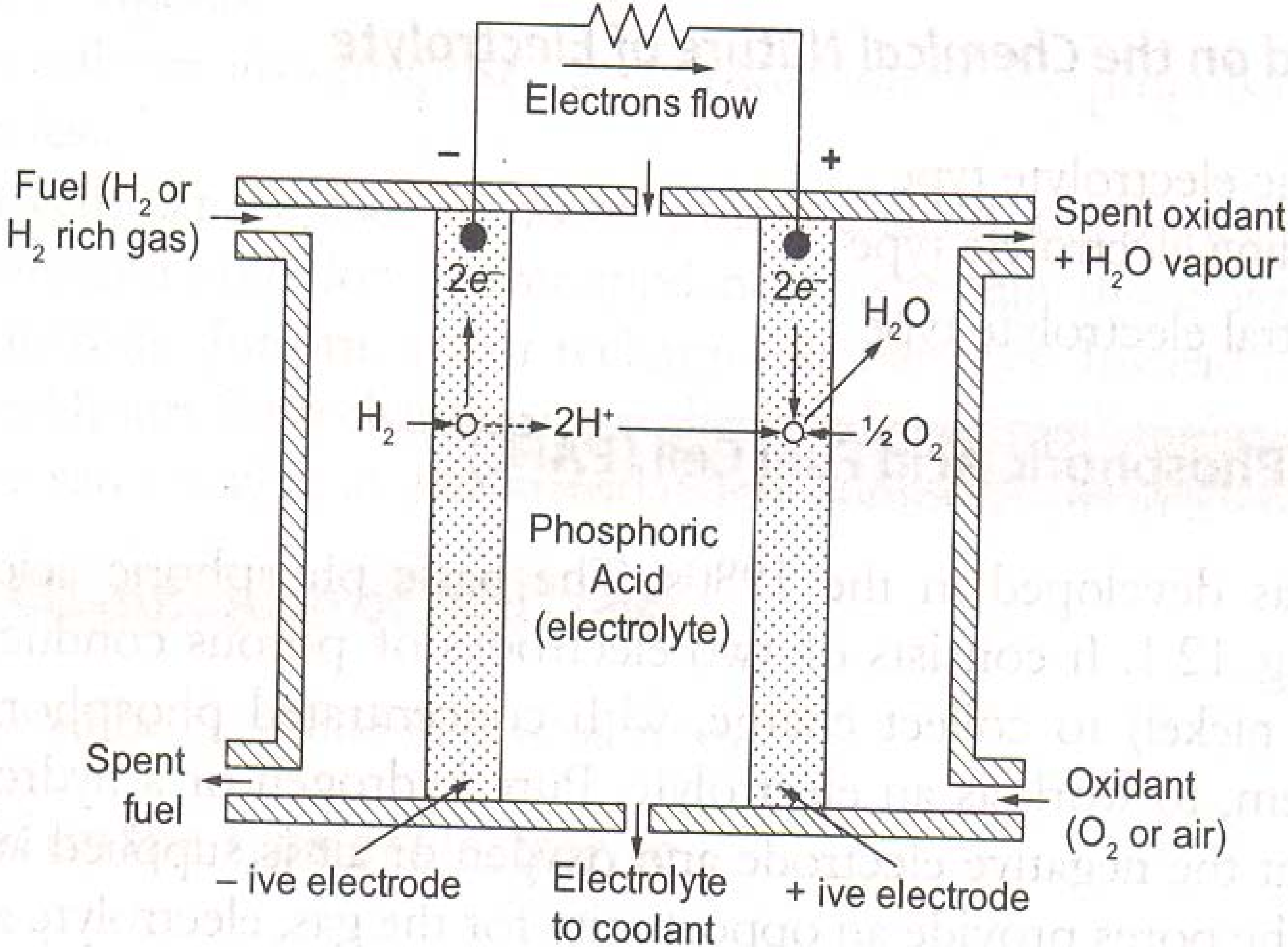
Fuel cells can be classified in several ways based on the type of electrolyte, chemical nature of electrolyte, type of fuel and oxidant, operating temperature and application.

Classification based on the type of electrolyte:

- Phosphoric acid fuel cell (PAFC)
- Alkaline fuel cell (AFC)
- Polymer electrolytic membrane fuel cell (PEMFC)
- Molten carbonate fuel cell (MCFC)
- Solid oxide fuel cell (SOFC)

Phosphoric acid fuel cell (PAFC)

- PAFC was developed in the 1980s. The basic phosphoric acid fuel cell is shown in the next slide.
- It consists of two electrodes of porous conducting material (commonly nickel) to collect charge, with concentrated phosphoric acid filled between them, to work as an electrolyte.
- Pure hydrogen or a hydrogen-rich gas is supplied at the negative electrode and oxygen or air is supplied at the positive electrode.
- The pores provides an opportunity for the gas , electrolyte and electrode to come into contact for electrochemical reaction.
- The reaction is normally very slow and a catalyst is required in the electrode to accelerate the reaction.



Phosphoric Acid Fuel Cell

Phosphoric acid fuel cell

continued….

- Platinum serves as the best catalyst for both the electrodes and is used for premium fuel cells.
- In general, a less expensive material such as nickel (for negative electrode) and silver (for positive electrode) are used wherever possible.
- Thus, finely divided platinum or nickel / silver deposited on the outer surface of electrodes are used as catalyst.
- During the usage of the cell, the catalyst gradually loses its activity. This loss of activity is often attributed to 'poisoning' (inactivation) of the catalyst by the impurities (mostly sulphur compounds) in the fuel.
- At the negative electrode, hydrogen gas is converted to hydrogen ions (H^+) and an equal number of electrons (e^-). Thus

$$H_2 \rightarrow 2\,H^+ + 2\,e^-$$

- The electrons originating at the negative electrode flow through the external load to the positive electrode.

Phosphoric acid fuel cell

continued….

- Also, the H^+ ions migrate from the negative electrode towards the positive electrode through the electrolyte. On reaching the positive electrode, they interact with O_2 to produce water. Thus,

$$\tfrac{1}{2}\ O_2 + 2\ H^+ + 2\ e^- \longrightarrow H_2O$$

- The above equations indicate that a fuel cell combines H_2 and O_2 to produce water (plus electrical energy). The overall reaction is therefore,

$$H_2 + 1/2\ O_2 \longrightarrow H_2O$$

- This is true for any type of hydrogen-oxygen cell. The operating temperature of PAFC is 150ºC-200ºC.
- At atmospheric pressure, it produces an ideal emf of 1.23 V at 25ºC, which reduces to 1.15 V at 200ºC. The actual value is always less than this and decreases with current. Normally, at rated values of current, the voltage lies between 0.7 V and 0.8 V

Fuels for fuel cells

- Hydrogen is a primary fuel and the main source of energy for all fuel cells. Thus, pure hydrogen or hydrogen-rich gases are generally used in fuel cells. some fuel cells can also use CO along with H_2
- All types of fuels can be classified into two categories:

  (i) Direct type (ii) Indirect type
- Direct type fuels are directly introduced in the cell as such, without any transformation or reforming, to serve as active material. Examples are pure hydrogen, mixture of hydrogen with other gases, hydrazine (N_2H_4) and methanol.
- Indirect fuels are hydrogen-rich fuels, which are first converted to a mixture of H_2 and some other products, e.g.: CO, CO_2 and N_2. Hydrocarbon fuels are decomposed by reaction with steam with high temperature in the presence of a catalyst. The products containing mainly H_2, CO and CO_2 are then supplied to the fuel cell.

Fuels for fuel cells

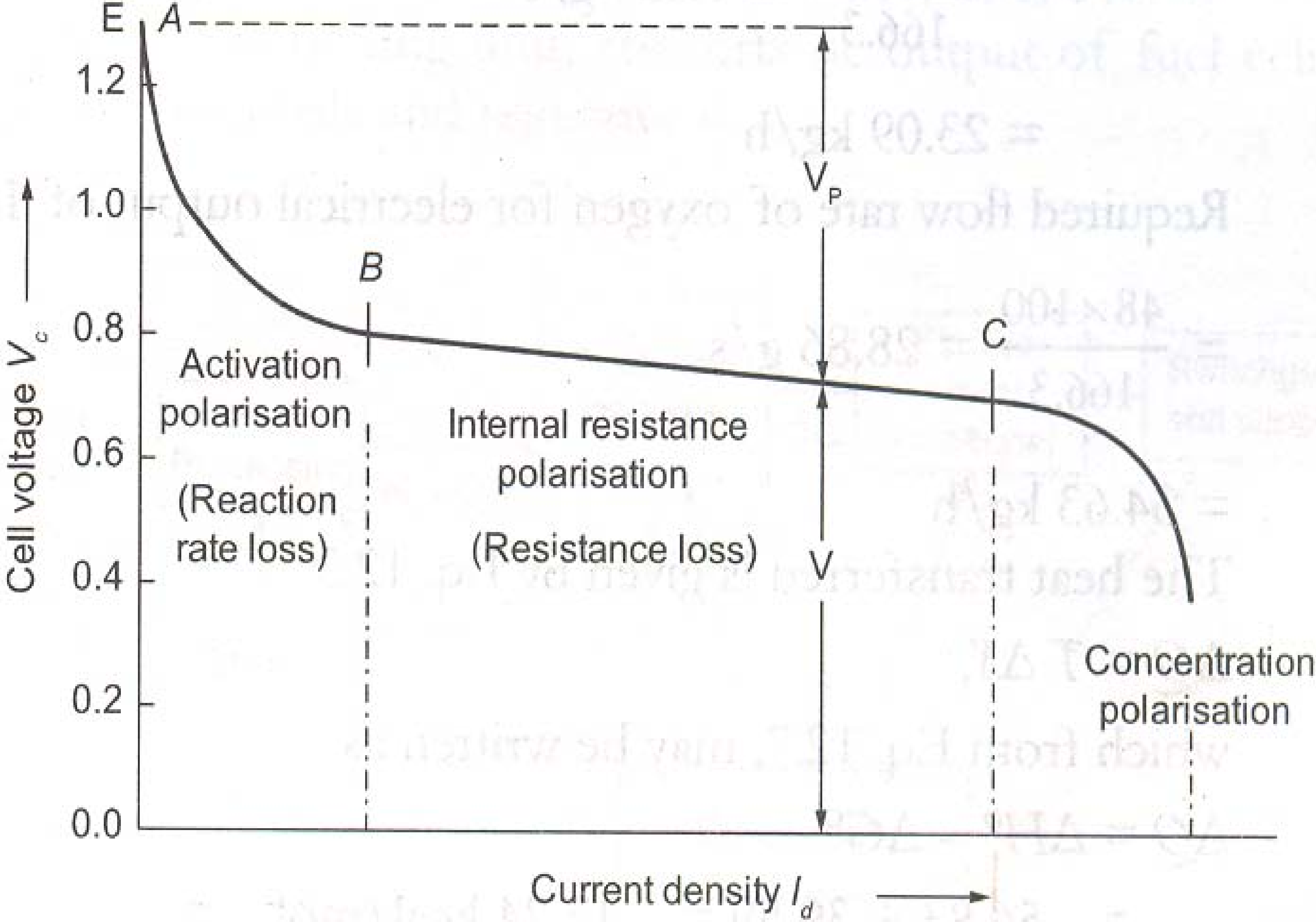
continued….

Common fuels used in fuel cells:

1. **Hydrogen**
2. **Hydrazine (N_2H_4)**
3. **Ammonia (NH_3)**
4. **Hydrocarbons (gases)**
5. **Hydrocarbons (liquid)**
6. **Synthesis Gas**
7. **Methanol**

VI Characteristics of Fuel Cell

- The VI characteristics of a fuel cell is shown in the next slide.
- Voltage regulation is poor for small and large values of output current.
- Therefore, in practice, the operating point is fixed in the range BC of the characteristics where the voltage regulation is the best and the output voltage is roughly around 0.6 - 0.8 V.
- At no load, the terminal voltage is equal to the theoretical open-circuit voltage.
- As the cell is loaded (current is supplied to load), voltage and hence efficiency drops significantly.
- All the losses in the fuel cell are reduced as operating temperature is increased. Therefore, in practice, a fuel cell is usually operated at the higher end of its operating temperature range.



VI characteristic of fuel cell

Fuel cell power plant

- The block diagram showing the main components of a fuel-cell power plant is shown in the next slide.
- Electrical energy is generated from primary fossil fuels through a fuel cell.
- Fuel is managed and supplied by a fuel processing unit. In this unit, fuel is received, stored, reformed, purified and supplied to fuel-cell modules.
- Fuel-cell modules convert fuel energy electrochemically into dc power using ambient air as oxidant.
- Basic configurations of cell, module and plant are shown in a subsequent slide. A number of cells are stacked to form a module.
- Several modules are interconnected to form a power-generating unit.

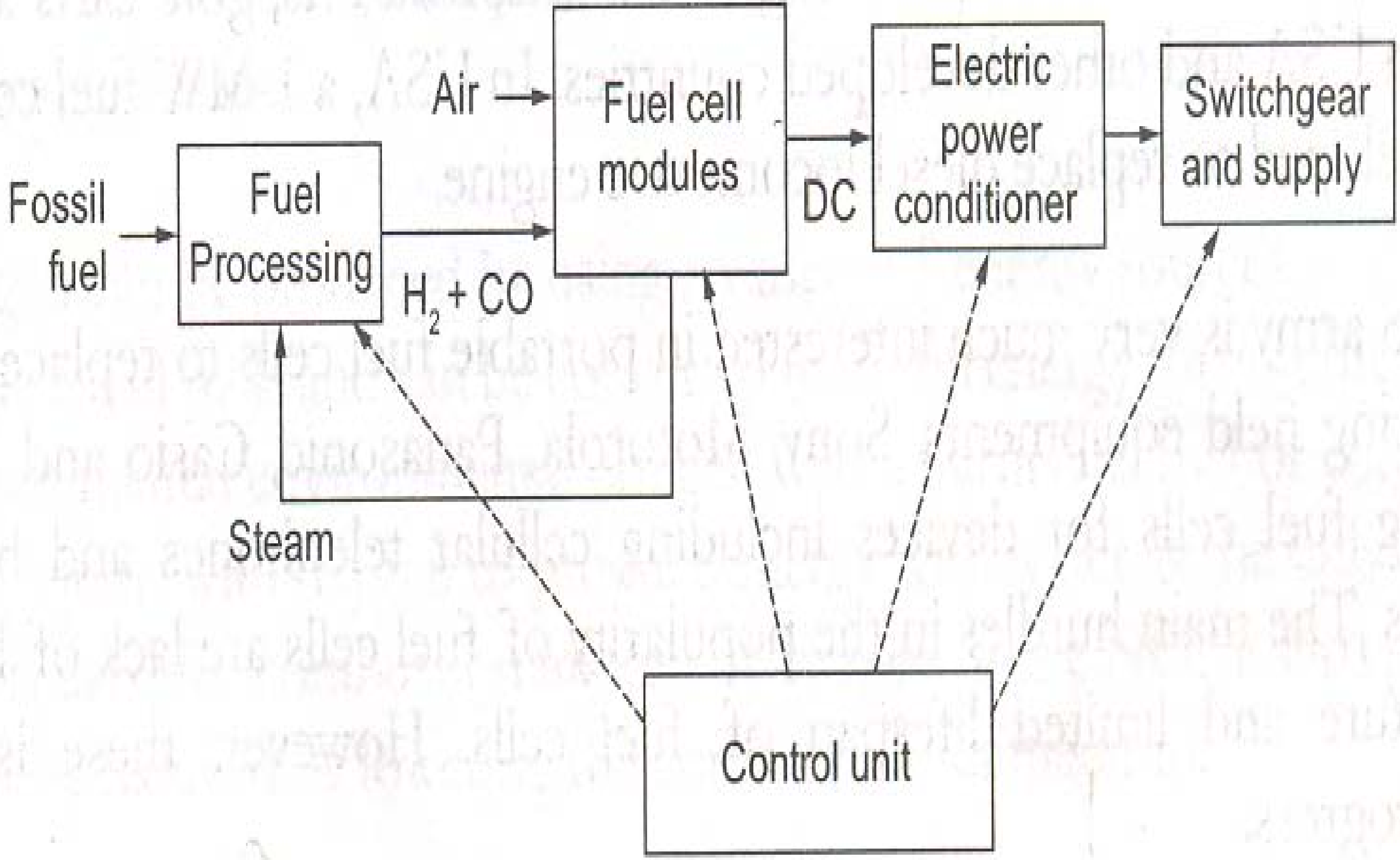


Fig. 1 Fuel-cell based electrical power-generation scheme

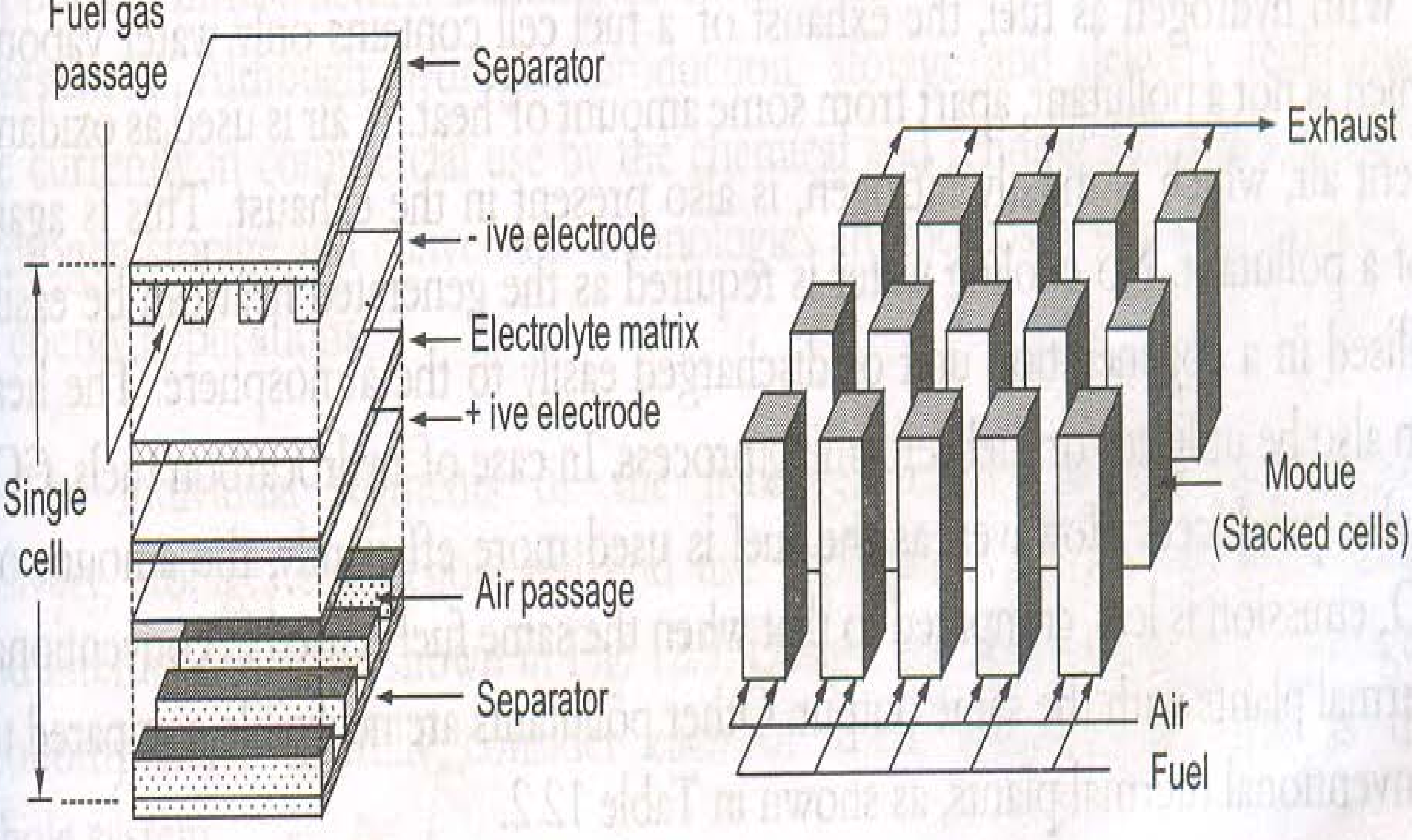


Fig. *Power-generation unit*

Fuel cell power plant

continued….

- Fuel gas and air are supplied to modules from common supply pipes.
- The exhaust is collected in a common pipe and discharged to the atmosphere either directly or after recovery of heat in a cogeneration unit.
- The power-generating unit generates electrical power as dc.
- Industrial / commercial loads are rated for standard ac supply such as 3-phase, 400 V or single phase 230 / 110 V, 50 / 60 Hz.
- The electrical power-conditioning unit converts dc output of fuel cell to ac using inverter. It also controls and regulates the ac output.

Present status of fuel cell

- Fuel-cell technology and its application in various fields are at the development stage.
- Stackable modules of size 200-250 kW are available. Demonstration projects are being installed at different places.
- A number of companies are engaged in manufacturing fuel cell. For example, the company UTC Fuel Cells has delivered more than 250 fuel-cell power plants around the world that can run on waste methane such as landfill gas. Another company, Fuel Cell Energy, offers 1.5 MW and 3 MW sized plants for stationary applications utilizing natural gas or waste methane gas as fuel.
- Fuel cell units for homes and small commercial applications are in the initial stages of commercialization. Avista Labs is marketing fuel cells with capacities 100 -5000 W to USA and European Union.

Present status of fuel cell

continued….

- All major automakers are working on fuel cell and/ or hydrogen vehicle programmes. A number of demonstration vehicles are being tested including cars, buses, trucks and locomotives, etc, in USA, Canada, Europe, Japan, China and Australia.
- Fuel cells are also powering boom lifts, fork lifts, golf carts and utility vehicles in USA and other developed countries. In USA, a 1 MW fuel cell power plant is being developed to replace diesel locomotive engine.
- The US army is very much interested in portable fuel cells to replace batteries for powering field equipments.
- Sony, Motorola, Panasonic, Casio and NEC are developing fuel cells for devices including cellular telephones and hand-held computers.
- The main hurdles in the popularity of fuel cells are lack of hydrogen infrastructure and limited lifespan of fuel cells.

Present status of fuel cell

continued….

- The world leader in Solid Oxide Fuel Cells (SOFC) is M/S Siemens Westinghouse Power Corporation of USA. The company installed a power plant that feeds 109 kW into the grid.
- In Asia, NKK of Japan introduced 5 kW and 50 kW units as distributed power generators for residential and commercial consumers. NKK also plans to introduce 250 kW and 550 kW SOFC units for use in offices, shopping malls, multistoried buildings, hospitals and hotels.
- In India, SOFC research is being carried out at the Central Glass & ceramic Research Institute, Kolkata. Various materials and electrode processing technologies have been developed in BHEL Hyderabad. Both have assembled and tested SOFC single cells.

Environmental effects of fuel cell

- With hydrogen as fuel, the exhaust of a fuel cell contains only water vapour, which is not a pollutant, apart from some amount of heat.
- If air is used as oxidant, spent air, which is mostly nitrogen, is also present in the exhaust. This is again not a pollutant.
- No cooling water is required as the generated heat can be easily utilized in a cogeneration unit or discharged easily to the atmosphere. The heat can also be utilized for fuel-reforming process.
- In case of hydrocarbon fuels, CO_2 is also produced. However, as the fuel is used more efficiently, the amount of CO_2 emission is less compared to that of conventional thermal power plants with the same output.
- Other pollutants are negligible.

Stirling engines

- A Stirling engine is a heat engine operating by cyclic compression and expansion of air or other gas (the *working fluid)* at different temperature levels such that there is a net conversion of heat energy to mechanical work.
- Like the steam engine, the Stirling engine is traditionally classified as an external combustion engine, as all heat transfers to and from the working fluid take place through the engine wall.
- This contrasts with an internal combustion engine where heat input is by combustion of a fuel within the body of the working fluid.
- Unlike a steam engine's (or more generally a Rankine cycle engine's) usage of a working fluid in both its liquid and gaseous phases, the Stirling engine encloses a fixed quantity of permanently gaseous fluid such as air.

Stirling engines
continued….

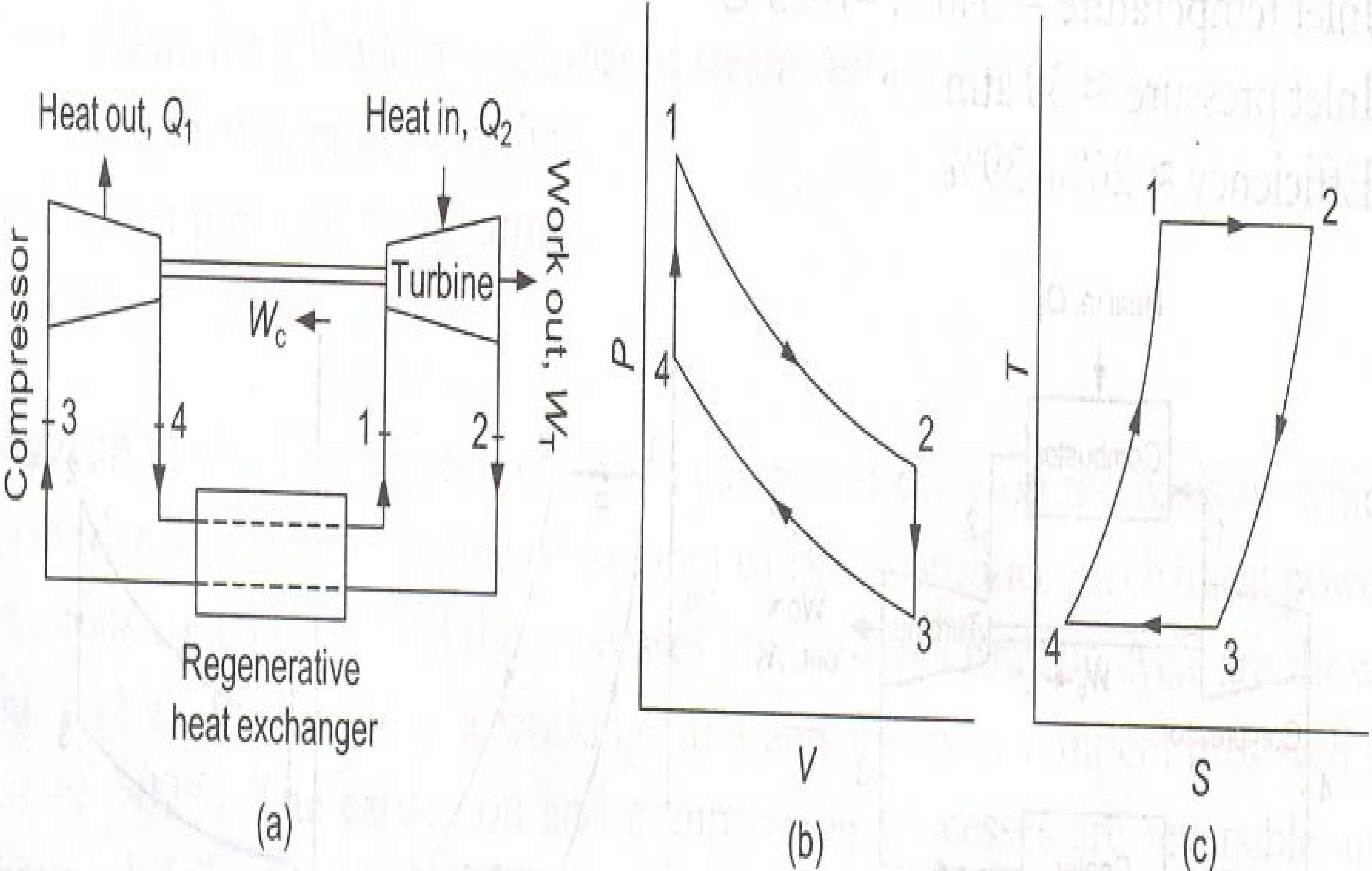
- Typical of heat engines, the general cycle consists of compressing cool gas, heating the gas, expanding the hot gas, and finally cooling the gas before repeating the cycle.
- Originally conceived in 1816 as an industrial prime mover to rival the steam engine, its practical use was largely confined to low-power domestic applications for over a century.
- The Stirling engine is noted for its high efficiency (up to 40% in practice), quiet operation, and the ease with which it can use almost any heat source. This compatibility with alternative and renewable energy sources has become increasingly significant as the price of conventional fuels rises, and also in light of concerns such as climate change.

Stirling cycle

- The Stirling cycle is similar to a Carnot cycle, except that two adiabatic processes are replaced by two constant volume processes.
- A suitable gas or air is used as working fluid.
- The system components are shown in the next slide.
- The heat addition and rejection takes place at constant temperatures.

The cycle comprises of the following processes:

- Process 4-1: The working fluid receives heat at constant volume in a regenerative heat exchanger from the exhaust fluid returning from the turbine.
- Process1-2: In this process, the working fluid receives heat at constant (high) temperature and expands in a turbine producing W_T output.
- Process 2-3: The working fluid loses heat at constant volume to the fluid incoming to the turbine.



Stirling cycle

Stirling cycle continued….

- Process 3-4: The working fluid is compressed at constant (low) temperature and heat Q_2 is rejected to the ambient.
- The heat transfer in a regenerative heat exchanger is accomplished reversibly by a matrix of wire gauze of small tubes.
- The main difficulty in a stirling cycle lies in making an efficient regenerator of reasonable size which can operate at a temperature comparable to that used in internal combustion engines.

Typical data for a stirling-cycle-based gas turbine:

Turbine inlet temperature = 750ºC-800ºC

Inlet pressure = 30 atmosphere

Efficiency ≈ 30 % to 40 %