RVS AGRICULTURAL COLLEGE

(Affiliated to Tamil Nadu Agricultural University, Coimbatore-3)

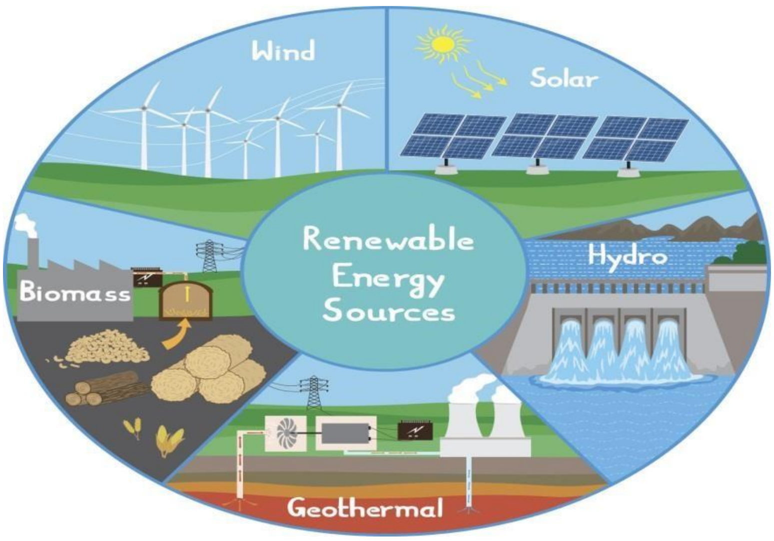
THANJAVUR -613 402

ERG 211 –RENEWABLE ENERGY AND GREEN TECHNOLOGY (1+1)

Theory Lecture Notes

B.Sc. (Hons.) Agriculture

IV Semester



COURSE TEACHER

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syllabus

Unit I – Introduction to Renewable energy Sources

Energy crisis – classification of energy sources – renewable energy – significance – potential - achievements in India. Biomass – methods of energy conversion.

Unit II – Biochemical Energy Conversion

Biofuels – importance – biodiesel and bioethanol production method – flowchart – by products utilization. Biogas technology – classification - types - factors affecting biogas plants alternate feedstocks – applications - biodigested slurry and enrichment.

Unit III – Thermochemical Energy Conversion

Briquetting –methods- advantages and disadvantages -combustion –definition- Improved chulhas – types – construction features - applications. Pyrolysis – methods for charcoal /biochar production- comparion of slow and fast pyrolysis. Gasification – chemistry – types – updraft gasifier -downdraft gasifier – working principles – operation and applications.

Unit IV – Solar Energy Conversion

Solar Energy – characteristics - types of radiation – solar constant-solar thermal devices – solar water heater – solar cooker – solar pond – solar distillation – working principles and applications. Solar PV systems – principle – solar lantern - water pumping. Solar driers – natural and forced convection types – solar tunnel drier – working principles and operation.

Unit V – Wind and other Renewable Energy Sources

Wind – formations - Wind mills – types – horizontal and vertical axis – components – working principles – applications. Geothermal energy – wave energy – tidal energy – ocean energy – principle and operation - types – advantages and disadvantages

Lecture Schedule

1. Energy crisis – renewable energy sources – significance – potential and achievements in India – energy requirements of agricultural and horticultural crops.
2. Biomass – methods of energy conversion – biochemical conversion methods – thermochemical conversion methods.
3. Biofuels – importance – biodiesel and bioethanol production method – flowchart – by products utilization
4. Biogas technology – classification - types of biogas plants – KVIC and Deenabandhu model biogas plants – factors affecting biogas plants.
5. Alternate feedstock for biogas production – applications of biogas cooking, lighting and engine operations - biodigested slurry and enrichment.
6. Briquetting – MED – VED – methods – need for briquetting - benefits of biomass briquettes.
7. Combustion – improved chulha – single pot – double pot – conventional chulha – biomass gas stove – constructional features – principles and applications.
8. Pyrolysis – methods for charcoal production –biochar production– comparison between slow and fast pyrolysis.
9. Mid semester examination
10. Gasification – chemistry – types – updraft gasifier – working principles operations – application
11. Downdraft gasifier – working principles – operation and applications
12. Solar energy – characteristics of solar radiation - types of radiation – solar constant.
13. Solar thermal devices – solar water heater – solar cooker – solar pond – solar distillation – working principles and applications.
14. Solar PV systems – principle – solar lantern - water pumping applications.
15. Solar driers – natural and forced convection types – solar tunnel drier – working principles and operation.
16. Wind mills – types – horizontal and vertical axis – components – working principles – applications.
17. Energy from ocean, waves, tides. Geothermal energy sources – principles and operation.

Lecture 1

Renewable Energy Sources

Topics Covered: **Energy crisis – Renewable energy sources – Significance – Potential and achievements in India – Energy requirements of agricultural and horticultural crops**

Energy

In physics, energy is the quantitative property that must be transferred to an object in order to perform work on, or to heat the object. Energy is the capacity to do work.

Energy can neither be created nor destroyed, it only can be changed from one form to another. Energy is the ability to cause change in an object. The change can involve either the motion or position of an object or its particles.

In the International System of Units (SI), energy is measured in joules (J). One joule is equal to the work done by a one-newton force acting over a one-metre distance.

Global Energy Crisis

The energy crisis is the concern that the world's demands on the limited natural resources that are used to power industrial society are diminishing as the demand rises. These natural resources are in limited supply. While they do occur naturally, it can take hundreds of thousands of years to replenish the stores.

Governments and concerned individuals are working together to make the use of renewable resources a priority and to lessen the irresponsible use of natural supplies through increased conservation.

The energy crisis is a broad and complex topic. Most people don't feel connected to its reality unless the price of gas at the pump goes up or there are lines at the gas station. The energy crisis is something that is ongoing and getting worse, despite many efforts.

Various Causes of the Global Energy Crisis

It would be easy to point the finger at one practice or industry and lay the blame for the entire energy crisis at their door, but there are several realistic causes of the crisis.

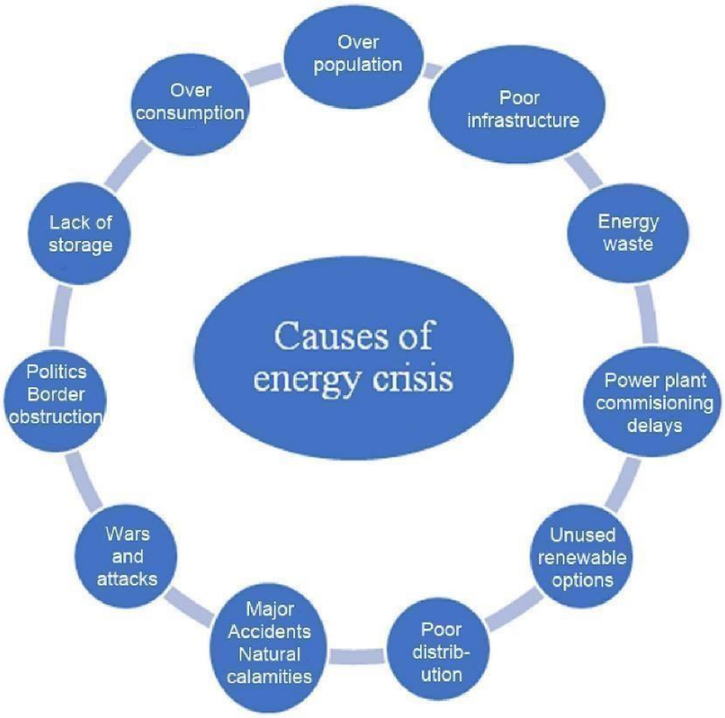


Figure 1 Causes of Energy Crisis

1. Overconsumption

The energy crisis is a result of many different strains on our natural resources, not just one. There is a strain on fossil fuels such as oil, gas, and coal due to overconsumption – which then, in turn, can put a strain on our water and oxygen resources by causing pollution.

2. Overpopulation

Another cause of the crisis has been a steady increase in the world's population and its demands for fuel and products. No matter what type of food or products you choose to use – from fair trade and organic to those made from petroleum products in a sweatshop – not one of them is made or transported without a significant drain on our energy resources.

3. Poor Infrastructure

Aging infrastructure of power generating equipment is yet another reason for energy shortage. Most of the energy-producing firms keep on using outdated equipment that restricts the production of energy. It is the responsibility of utilities to keep on upgrading the infrastructure and set a high standard of performance.

4. Unexplored Renewable Energy Options

Renewable energy still remains unused in most of the countries. Most of the energy comes from non-renewable sources like coal. It, therefore, remains the top choice to produce energy. Unless we give renewable energy a serious thought, the problem of energy crisis cannot be solved. Renewable energy sources can reduce our dependence on fossil fuels and also helps to reduce greenhouse gas emissions.

5. Delay in Commissioning of Power Plants

In a few countries, there is a significant delay in the commissioning of new power plants that can fill the gap between demand and supply of energy. The result is that old plants come under huge stress to meet the daily demand for power. When supply doesn't match demand, it results in load-shedding and breakdown.

6. Wastage of Energy

In most parts of the world, people do not realize the importance of conserving energy. It is only limited to books, the internet, newspaper ads, lip service, and seminars. Unless we give it a serious thought, things are not going to change anytime sooner. Simple things like switching off fans and lights when not in use, using maximum daylight, walking instead of driving for short distances, using CFL instead of traditional bulbs, proper insulation for leakage of energy can go a long way in saving energy.

7. Poor Distribution System

Frequent tripping and breakdown are a result of a poor distribution system.

8. Major Accidents and Natural Calamities

Major accidents like pipeline burst and natural calamities like the eruption of volcanoes, floods, earthquakes can also cause interruptions to energy supplies. The huge gap between supply and demand for energy can raise the price of essential items, which can give rise to inflation.

9. Wars and Attacks

Wars between countries can also hamper the supply of energy, especially if it happens in Middle East countries like Saudi Arabia, Iraq, Iran, Kuwait, UAE, or Qatar. That's what happened during the 1990 Gulf war when the price of oil reached its peak causing global shortages and created major problems for energy consumers.

10. Miscellaneous Factors

Tax hikes, strikes, military coup, political events, severe hot summers or cold winters can cause a sudden increase in demand for energy and can choke supply. A strike by trade unions in an oil-producing firm can cause an energy crisis.

Various Effects of the Global Energy Crisis

The growth of human civilization has led to an increase in the consumption of traditional sources of energy. The very basic source of energy is precious fossil fuels. The usage of all these sources is bound to produce certain effects. Some important effects of the global energy crisis are as follows:

1. Environmental Effects

Energy is produced by the burning of non-renewable fossil fuels. This does not only affect the global resources of fossil fuels, but it also affects the environment. The burning of fossil fuels releases greenhouse gases like carbon dioxide and others. These gases create a blanket on the earth's surface, which prevents the release of the short rays of the sun by night. Thus, the energy crisis facilitates making the earth a warmer place by promoting global warming.

2. Increasing Prices of the Fuel Resources

As the use of fossil fuels increases, the cost of these resources increases too. We must remember that the quantity in which these fossil fuels are available is limited. As we keep on using these resources, the amount of these fossil fuels further decreases.

With every passing day, the demand for these fuels increases daily while their available quantity decreases every day. This leads to an immense increase in the price of fossil fuels, causing the price to increase day in and day out. This creates a huge economic disturbance across the globe.

3. Political Disturbances

The fact that the energy crisis creates some socio-economic disturbances, also tells us that this global energy crisis also creates a lot of political disturbances across the globe. The quest for fossil fuels is one of the major causes of the same. Besides, with the failure of the energy markets, we see a crash in not only the global economy but also a crash of the energy available. All these are enough to give rise to the various socio-political disturbances.

4. The Effect on the Tourism Industry

The tourism industry is largely dependent on the rise and fall of fuel prices. The tremendous rise of the fuel prices that comes as a result of the energy crisis affects the tourism industry pretty adversely. With the increase in fuel prices, there is an increase in the costs of tourism as well. As a result of this, there are many who cannot afford the same. And as a result of all this, it is the tourism industry that suffers.

Possible Solutions to the Problem of Global Energy Crisis

Many of the possible solutions are already in place today, but they have not been widely adopted.

1. Move towards Renewable Resources

The best possible solution is to reduce the world's dependence on non-renewable resources and to improve overall conservation efforts. Much of the industrial age was created using fossil fuels, but there is also known technology that uses other types of renewable energies – such as steam, solar, and wind. The major concern isn't so much that we will run out of gas or oil, but that the use of coal is going to continue to pollute the atmosphere and destroy other natural resources in the process of mining the coal that it has to be replaced as an energy source. This isn't easy as many of the leading industries use coal, not gas or oil, as their primary source of power for manufacturing.

2. Buy Energy-Efficient Products

Replace traditional bulbs with CFLs and LEDs. They use fewer watts of electricity and last longer. If millions of people across the globe use LEDs and CFLs for residential and commercial purposes, the demand for energy can go down, and an energy crisis can be averted.

3. Lighting Controls

There are a number of new technologies out there that make lighting controls that much more interesting, and they help to save a lot of energy and cash in the long run. Pre-set lighting controls, slide lighting, touch dimmers, integrated lighting controls are few of the lighting controls that can help to conserve energy and reduce overall lighting costs.

4. Easier Grid Access

People who use different options to generate power must be given permission to plug into the grid and getting credit for the power you feed into it. The hassles of getting credit for supplying surplus power back into the grid should be removed. Apart from that, subsidy on solar panels should be given to encourage more people to explore renewable options.

5. Energy Simulation

Energy simulation software can be used by big corporates and corporations to redesign the building unit and reduce running business energy costs. Engineers, architects, and designers could use this design to come with most energy-efficient buildings and reduce carbon footprint.

6. Perform Energy Audit

The energy audit is a process that helps you to identify the areas where your home or office is losing energy and what steps you can take to improve energy efficiency. Energy audit, when done by a professional, can help you to reduce your carbon footprint, save energy and money, and avoid energy crisis.

7. Common Stand on Climate Change

Both developed and developing countries should adopt a common stand on climate change. They should focus on reducing greenhouse gas emissions through an effective cross border mechanism. With current population growth and overconsumption of resources, the consequences of global warming and climate change cannot be ruled out. Both developed and developing countries must focus on emissions cuts to halve their emissions from current levels by 2050.

Indian scenario of energy sources

About 70% of India's energy generation capacity is from fossil fuels, with coal accounting for 40% of India's total energy consumption followed by crude oil and natural gas at 24% and 6% respectively. India is largely dependent on fossil fuel imports to meet its energy demands — by 2030, India's dependence on energy imports is expected to exceed 53% of the country's total energy consumption. In 2009- 10, the country imported 159.26 million tonnes of crude oil which amount to 80% of its domestic crude oil consumption and 31% of the country's total imports are oil imports. The growth of electricity generation in India has been hindered by domestic coal shortages and as a consequence, India's coal imports for electricity generation increased by 18% in 2010.

Due to rapid economic expansion, India has one of the world's fastest growing energy markets and is expected to be the second-largest contributor to the increase in global energy demand by 2035, accounting for 18% of the rise in global energy consumption. Given India's growing energy demands and limited domestic fossil fuel reserves, the country has ambitious plans to expand its renewable and nuclear power industries. India has the world's fifth largest wind power market and plans to add about 20GW of solar power capacity by 2022. India also envisages to increase the contribution of nuclear power to overall electricity generation capacity from 4.2% to 9% within 25 years. The country has five nuclear reactors under construction (third highest in the world) and plans to construct 18 additional nuclear reactors (second highest in the world) by 2025.

Types of Energy

Basically energy can be classified into two types:

Potential Energy

Potential energy is stored energy and the energy of position (gravitational). It exists in various forms.

Kinetic Energy

Kinetic energy is energy in motion i.e. the motion of waves, electrons, atoms, molecules and substances. It exists in various forms.

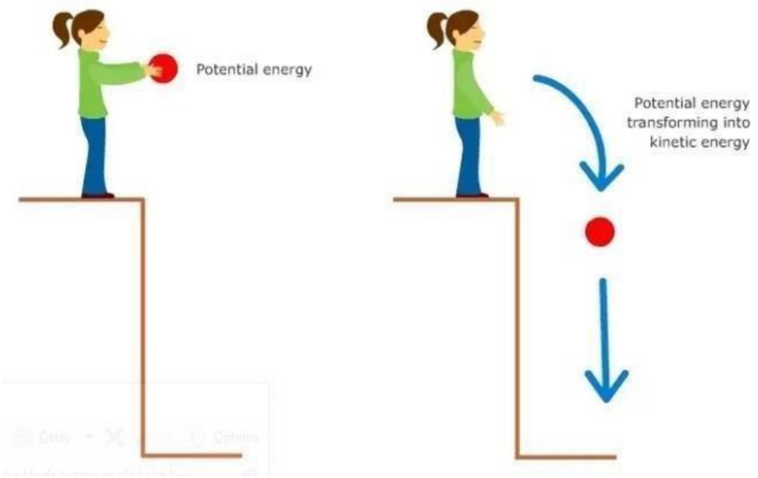


Figure 2 Illustration of Potential and Kinetic Energy

Various Forms of Energy

Chemical Energy

Chemical energy is the energy stored in the bonds of atoms and molecules. Biomass, petroleum, natural gas, propane and coal are examples of stored chemical energy. For example, solar energy is used by plant to create chemical energy in the form of sugar.

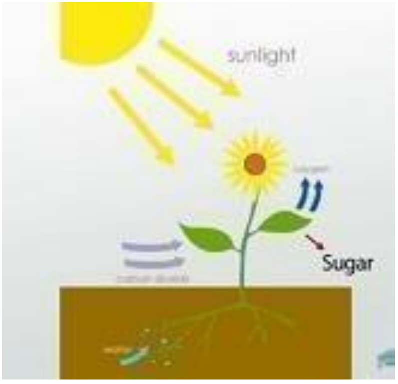


Figure 3 Illustration of Chemical Energy from Photosynthesis

Nuclear Energy

Nuclear energy is the energy stored in the nucleus of an atom i.e. the energy that holds the nucleus together. The nucleus of a uranium atom is an example of nuclear energy.

Figure 4 Nuclear Power Plants

Stored Mechanical Energy

Stored mechanical energy is energy stored in objects by the application of a force. Compressed springs and stretched rubber bands are examples of stored mechanical energy.

Figure 5 Illustration of Stored Mechanical Energy - Stretched Strings

Gravitational Energy

Gravitational energy is the energy of place or position. Water in a reservoir behind a hydropower dam is an example of gravitational energy. When the water is released to spin turbines, it becomes rotational energy.

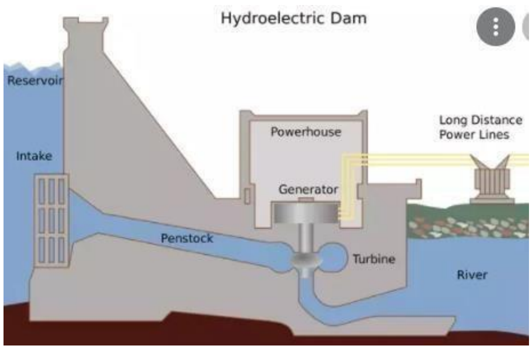


Figure 6 Gravitational Energy of water in a reservoir

Radiant Energy

Radiant energy is electromagnetic energy that travels in transverse waves. Radiant energy includes visible light, x-rays, gamma rays and radio waves. Solar energy is an example of radiant energy.

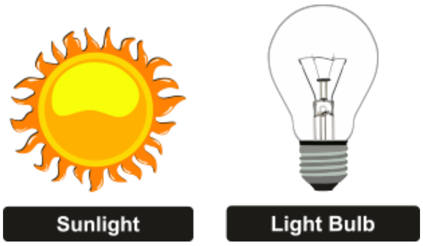


Figure 7 Examples of Radiant Energy

Thermal Energy

Thermal energy (or heat) is the internal energy in substances due to the vibration and movement of atoms and molecules within substances. Geothermal energy is an example of thermal energy.

Figure 8 Examples of Thermal Energy

Electrical Energy

Electrical energy is the movement of electrons. Lightning and electricity are examples of electrical energy.

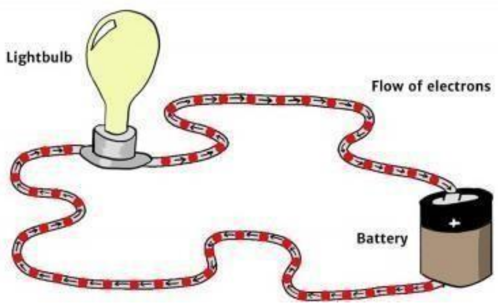


Figure 9 Illustration of Electrical Energy

Motion

The movement of objects or substances from one place to another is motion. Wind and hydropower are examples of motion.

Sound

Sound is the movement of energy through substances in longitudinal (compression/rarefaction) waves.

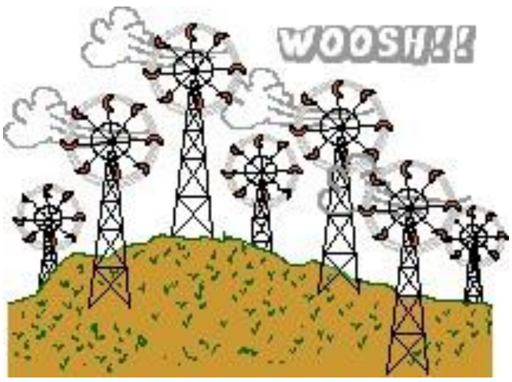


Figure 10 Illustration of Motion Energy

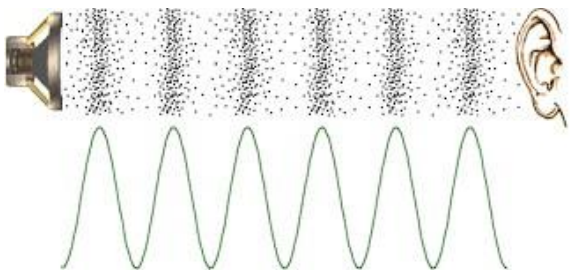


Figure 11 Illustration of Sound Energy

Classification of Energy Sources

Energy sources are classified as follow as:

Primary Energy sources (Coal, Oil, natural gas and biomass like wood)

Secondary Energy sources (refined crude oil products)

Commercial Energy sources (electricity)

Non-commercial Energy sources (firewood)

Renewable Energy sources (wind power, solar power, geothermal energy, tidal power & hydroelectric power)

Non-renewable Energy sources (coal, oil, gas & nuclear energy)

Primary Energy sources

Primary energy is the energy that's harvested directly from natural resources. Sources of primary energy fall into two basic categories, fuels and flows. The fuels in primary energy are all primary fuels. A country's different sources of primary energy are aggregated into a quantity called *total primary energy supply (TPES)*.

All of human energy must come from one of these primary energy sources, there are no energy alternatives. Primary energy is contrasted with end use energy. Primary energy almost always needs to be converted through an energy conversion technology to make this primary energy source into an energy currency or a secondary fuel before it can be used.

For example, Coal is usually put into a coal-fired power plant to generate electricity. Wind must be harnessed by a wind turbine before it can generate electricity.

Secondary Energy sources

Secondary energy sources are derived from primary sources in a form of either final fuel or energy supply. Involvement of technological processes in this transformation in between causes drop in primary energy on the way to consumers. Secondary energy sources are also referred to as energy carriers, because they move energy in a useable form from one place to another. The two most well-known energy carriers are: Electricity Hydrogen

For example, Crude oil is refined and converted in products like petrol, diesel, and kerosene.

Commercial Energy sources

The energy sources that are available in the market for a definite price are known as commercial energy. By far the most important form of commercial energy are electricity, coal and refined petroleum products. Commercial energy forms the basis of industrial, agriculture, transport, and commercial development in modern world. In industrialized countries, commercialized fuels are predominant sources not only for economic production, but also for many household tasks of general population. Examples: Electricity, Lignite, Coal, oil etc.

Non-commercial Energy sources

The energy sources that are not available in the market for a price are known as non-commercial energy sources. Non-commercial energy sources include fuels such as firewood, cattle dung and agriculture waste, which are traditionally gathered, and not bought at a price used especially in households. These are also called as traditional fuels. Non-commercial energy is often ignored in energy accounting.

Example: Firewood, agro waste from rural areas.

Renewable Energy sources

This is the energy acquired from never ending sources of energy available in nature. The main feature of this is, it can be extracted without causing pollution. Renewable energy is energy that is collected from renewable resources, which are naturally replenished on a human timescale, such as sunlight, wind, rain, tides, waves, and geothermal heat. Renewable energy often provides energy in four important areas: electricity generation, air and water heating/cooling, transportation, and rural (off-grid) energy services. Example Solar energy, wind energy, tidal energy.

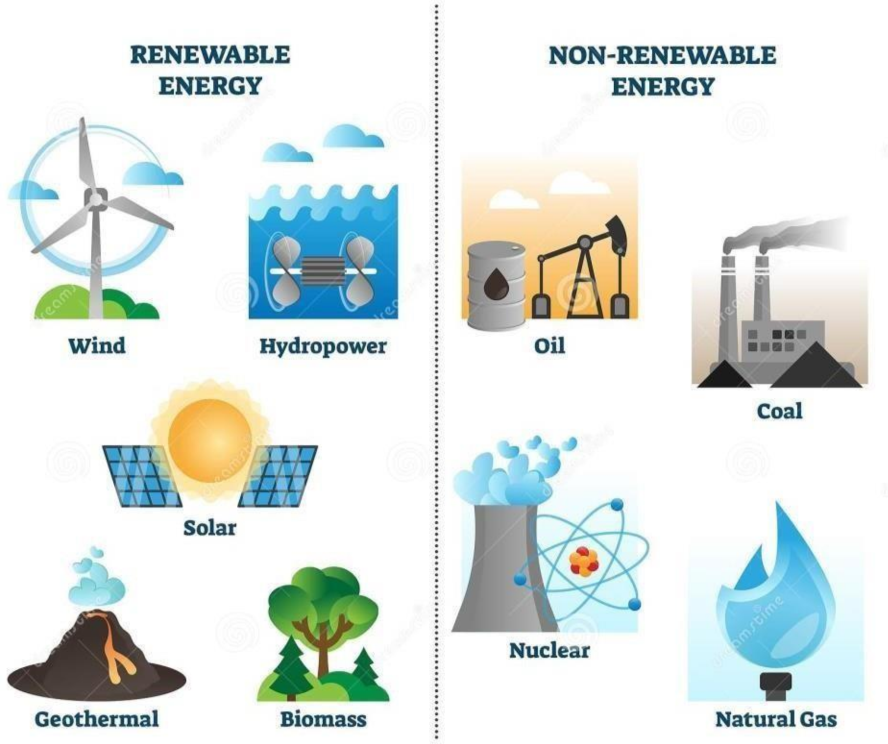


Figure 12 Renewable and Non-renewable Energy

Non-renewable Energy sources

Non-renewable energy is the energy obtained from the conventional fuels which are exhaustible today or tomorrow with time. A non-renewable resource (also called a finite resource) is a resource that does not renew itself at a sufficient rate for sustainable economic extraction in meaningful human time-frames. An example is carbon-based, organically-derived fuel. The original organic material, with the aid of heat and pressure, becomes a fuel such as oil or gas. Earth minerals and metal ores, fossil fuels (coal, petroleum, and natural gas) and groundwater in certain aquifers are all considered non-renewable resources, though individual elements are always conserved. Example Coal, oil, gas, Hydro power, Diesel power.

Conventional sources of energy

Conventional sources of energy are the natural energy resources which are present in a limited quantity and are being used for a long time. They are called non-renewable sources as once they are depleted, they cannot be generated at the speed which can sustain its consumption rate. They are formed from decaying matter over hundreds of millions of years.

These resources have been depleted to a great extent due to their continuous exploitation. It is believed that the deposits of petroleum in our country will be exhausted within few decades and the coal reserves can last for a hundred more years. Some common examples of conventional sources of energy include coal, petroleum, natural gas and electricity.

Non-conventional sources of energy

Non-conventional sources of energy are the energy sources which are continuously replenished by natural processes. These cannot be exhausted easily, can be generated constantly so can be used again and again, e.g. solar energy, wind energy, tidal energy, biomass energy and geothermal energy etc. The energy obtained from non-conventional sources is known as non-conventional energy. These sources do not pollute the environment and do not require heavy expenditure. They are called renewable resources as they can be replaced through natural processes at a rate equal to or greater than the rate at which they are consumed.

Some of the key differences between conventional and non-conventional sources of energy are as follows:

Conventional sources of energy	Non-conventional sources of energy
These sources of energy are not abundant, present in limited quantity, e.g. coal, petroleum, natural gas.	These sources of energy are abundant in nature, e.g. solar energy, wind energy, tidal energy, biogas from biomass etc.
They have been in use for a long time.	They are yet in development phase over the past few years.
They are not replenished continuously. They are formed over a million years.	They are replenished continuously by natural processes.
They are called non-renewable sources of energy.	They are called renewable sources of energy.
They can be exhausted completely due to over-consumption except for hydel power.	They cannot be exhausted completely.
They pollute the environment by emitting harmful gases and also contribute to global warming.	They are environment-friendly, do not pollute the environment.
They are commonly used for industrial and commercial purposes.	They are used commonly used for household purposes.
Heavy expenditure is involved in using and maintaining these sources of energy.	Using these sources is less expensive.
They are used extensively, at a higher rate than the non-conventional sources.	They are not used as extensively as conventional sources.

Sources of Renewable Energy

Figure 13 Sources of Renewable Energy

1. Solar Energy

Solar energy is the first such renewable source. Solar energy systems use radiation from the sun to produce heat and electricity. Electricity can be generated with the help of solar energy, using photovoltaic technology or heat powered engines. Most of these technologies are able to capture the sunlight and convert it into electricity that can be stored in batteries until needed. Some of the more common uses of such renewable sources of energy is solar cooking, heating water and battery powered electronics. Solar power has also been adapted to industrial uses.

Figure 14 Solar Energy Gadgets

2. Wind Energy

Wind energy has been harnessed over the last few decades by way of wind turbines. Wind turbines use blades to collect the wind's kinetic energy. When the wind speed is high enough to move the turbines, electricity can be produced by the movement. Higher the speed of the wind, more the amount of electricity can be produced. This is why most wind powered turbines are found in high altitude areas or near shores with constant breeze.

Figure 15 Wind Mill

3. Hydro Electric (Water) Power

Another way in which the sun is able to provide us with clean energy is through water. Whether it is the currents in the ocean or the tides in the sea, all of it happens due to the sun. As of now, there a number of ways in which hydroelectric energy (water based electricity) can be captured. Dams are a common way to generate electricity on a large scale basis. The fall of water powers turbines, which are able to produce energy when they turn. Small waterfalls occurring naturally are another source, along with systems that derive kinetic energy from the movement of water in rivers, streams and oceans.

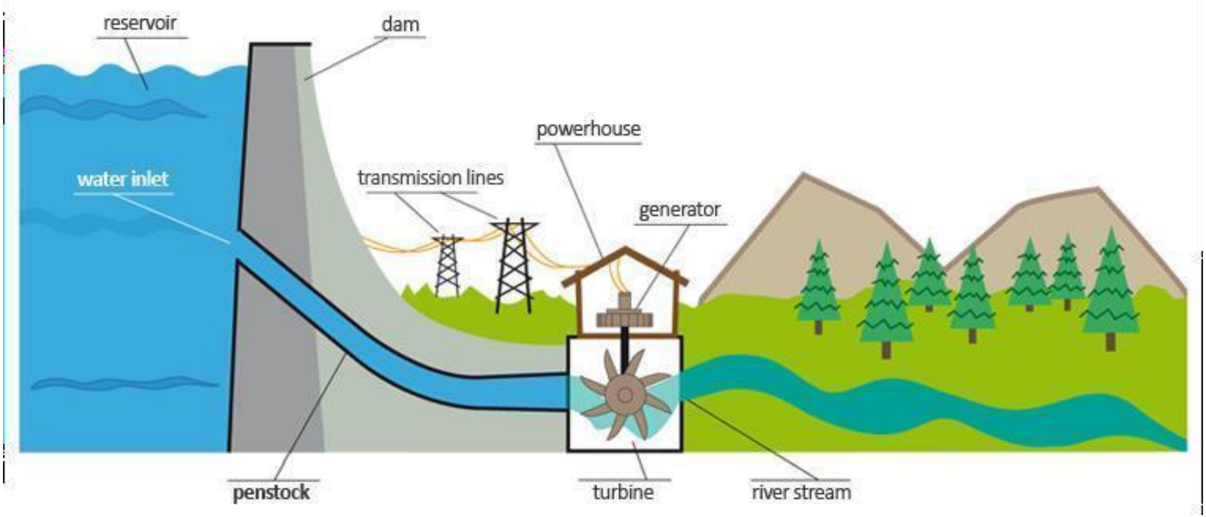


Figure 16 Hydro-electric Power

4. Geothermal Energy

There is a tremendous amount of energy stored within the Earth that is not fossil fuels. It is known as geothermal energy. Since the Earth was formed, there has been a constant decay of minerals that were part of the make-up. Many are radioactive in nature and release great amounts of heat when they do. This heat makes it away to crust and finds a way out when cracks appear in the surface of the Earth. These are thermal vents, which release super-heated steam and boiling water. Such vents can be adapted for the generation of electrical power, providing us with more renewable sources of energy.

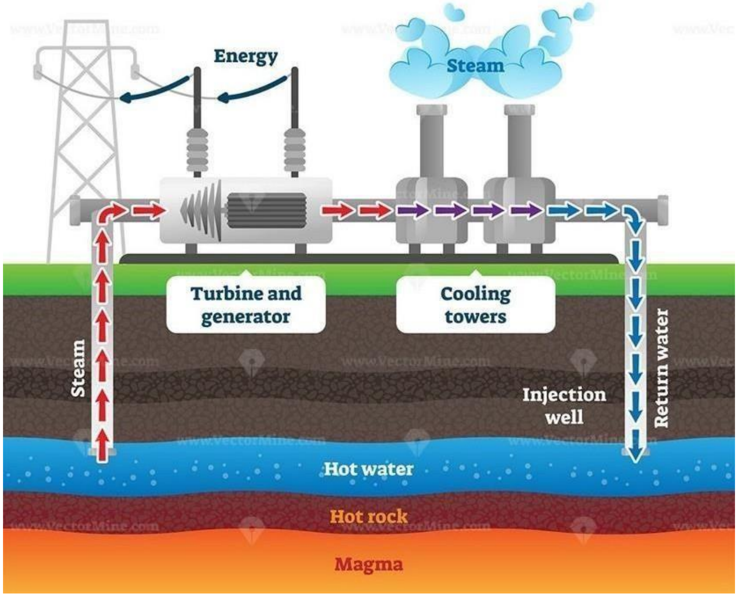


Figure 17 Geo-thermal Energy

5. Biomass Energy

A more simple form of clean energy is biomass. This has been used in different ways by humans for thousands of years. Biomass is plants and their residues, both of which are renewable sources of energy. Plants contain energy that is stored within them during the process of photosynthesis. This energy is broken down and made usable when the plants are burnt. Biomass plants are basically furnaces that can break down large amounts of raw material. Leftover parts of crops, rotten plants, diseases vegetables and even waste wood parts are usable as raw material.

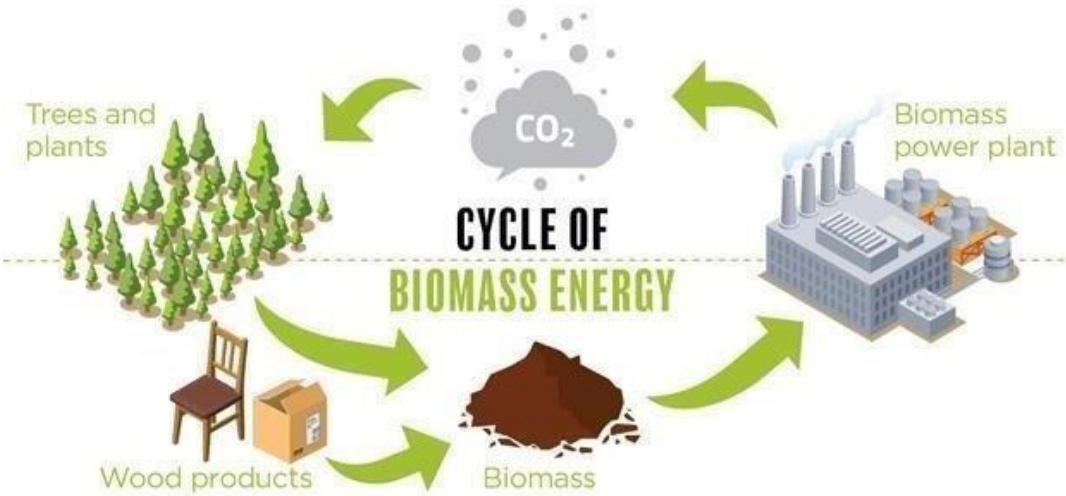


Figure 18 Biomass Energy

6. Biofuels

Biofuels are extracted from plants and crops as well. They differ from biomass as renewable sources of energy since they are synthetic in nature and are not utilized to directly create electricity. Biofuels include ethanol and biodiesel. Ethanol is the main form of biofuel, which is created by the fermentation of sugar. It is regularly blended with gasoline as a form of car fuel, since it produces lesser carbon dioxide when it burns. Biodiesel is made from grain oils and animal fats.

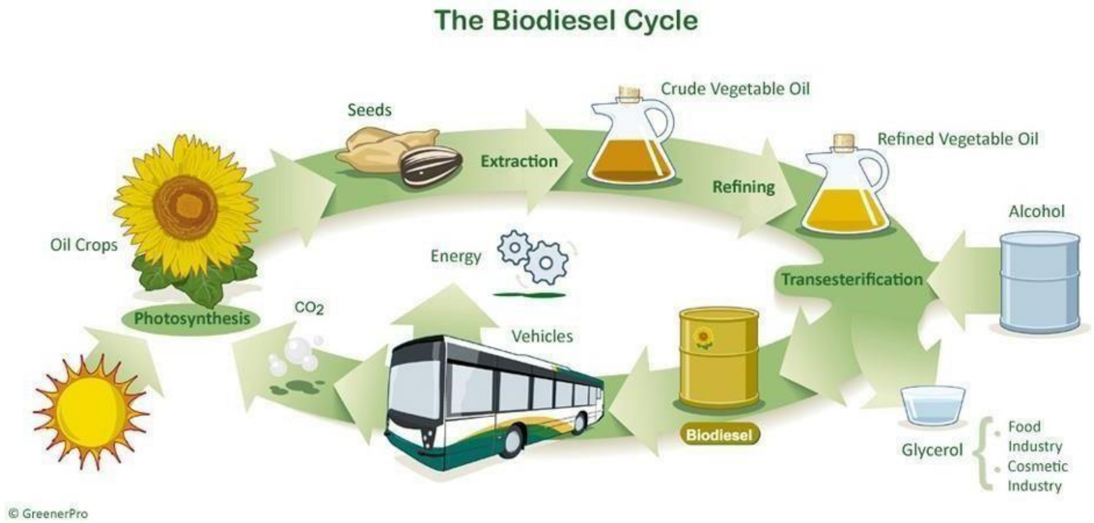


Figure 19 Bio-diesel Production

7. Hydrogen Energy

Hydrogen has tremendous energy and can be used to power homes and industries. Hydrogen is available with water and is the most common element available on earth. Water contains two-thirds of hydrogen but in nature it is found in combination with other elements. Once it is separated, it can be used as a fuel or could be used for generating electricity. Hydrogen energy is completely renewable since it is extracted from water which is available in abundant supply. It is completely environment friendly and do not leave any toxic emissions in the atmosphere. It can be produced on demand but the technology to produce it is still in early stages.

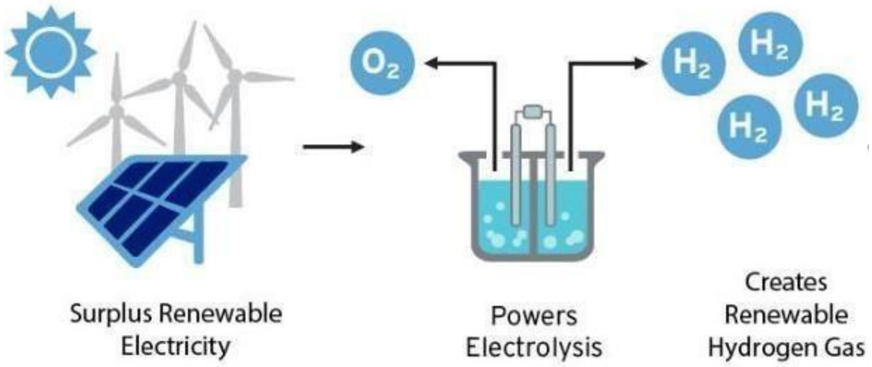


Figure 20 Hydrogen Fuel Cells

8. Ocean Energy

Almost 70% of the earth is covered with water. Due to the massive size of oceans, this form of energy has much better potential to produce power than any other source of energy. Ocean energy can be harnessed via 3 ways: wave energy, tidal energy and Ocean thermal energy conversion (OTEC). The rise and fall of tides is used by the tidal energy generators, which is then used to move turbines, which in turn generate electricity. The tidal energy converts the kinetic energy to electrical energy.

Wave energy, on the other hand, is captured directly from the surface of the waves produced in the oceans. Waves are nothing, but regular disturbances produced on the surface of water. The main disadvantage of wave energy is that it involves costly set up and water conditions are not same in every part of the world.

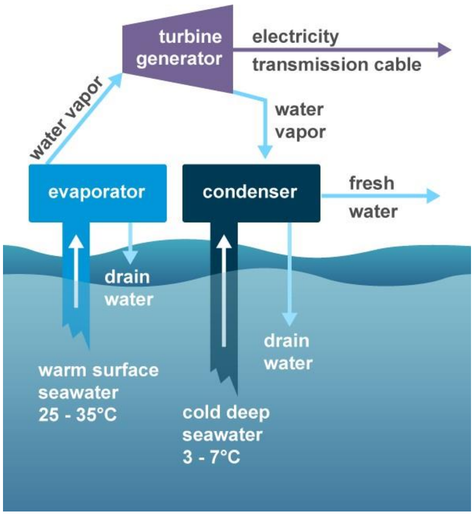


Figure 21 Ocean thermal energy conversion

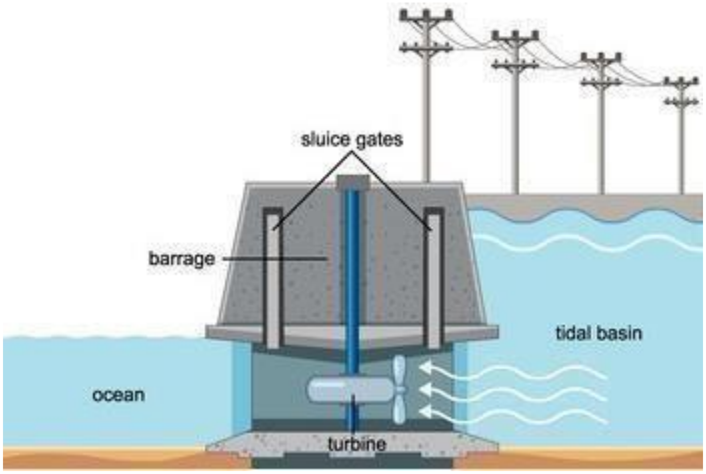


Figure 22 Tidal Energy

Potential and achievements in India

The Renewable energy sector in India has experienced tremendous changes in the policy framework during the last few years. Mainly, the solar energy and Wind energy sectors are experiencing accelerated and ambitious plans to increase the contribution of these sectors out of the total energy contribution in India. The following case study report is given to understand the present status of renewable energy potential in India.

INDIAN RENEWABLE ENERGY INDUSTRY REPORT - (dated MAY, 2021)

Introduction

Indian renewable energy sector is the fourth most attractive renewable energy market in the world1. India was ranked fifth in wind power, fifth in solar power and fourth in renewable power installed capacity, as of 2019.

Installed renewable power generation capacity has gained pace over the past few years, posting a CAGR of 17.33% between FY16-20. With the increased support of Government and improved economics, the sector has become attractive from investors perspective. As India looks to meet its energy demand on its own, which is expected to reach 15,820 TWh by 2040, renewable energy is set to play an important role. The government is aiming to achieve 227 GW of renewable energy capacity (including 114 GW of solar capacity addition and 67 GW of wind power capacity) by 2022, more than its 175 GW target as per the Paris Agreement. The government plans to establish renewable energy capacity of 523 GW (including 73 GW from Hydro) by 2030.

Market Size

As of February 2021, installed renewable energy capacity stood at 94.43 GW. The country is targeting about 450 Gigawatt (GW) of installed renewable energy capacity by 2030 – about 280 GW (over 60%) is expected from solar.

From April 2015 to February 2021, India has added 117.9 GW of power generation capacity, including 64.5 GW of conventional source and 53.4 GW from renewable sources.

By December 2019, 15,100 megawatts (MW) of wind power projects were issued, of which, projects of 12,162.50 MW capacity have already been awarded2. Power generation from renewable energy sources in India reached 127.01 billion units (BU) in FY20.

With a potential capacity of 363 GW and with policies focused on the renewable energy sector, Northern India is expected to become the hub for renewable energy in India.3

Investments/ Developments

According to the data released by Department for Promotion of Industry and Internal Trade (DPIIT), FDI inflow in the Indian non-conventional energy sector stood at US$ 9.83 billion between April 2000 and December 2020. More than US$ 42 billion has been invested in India's renewable energy sector since 2014. New investment in clean energy in the country reached US$ 11.1 billion in 2018. According to the analytics firm British Business Energy, India ranked 3rd globally in terms of its renewable energy investments and plans in 2020.

Some major investments and developments in the Indian renewable energy sector are as follows:

In May 2021, Adani Green Energy Ltd. (AGEL), signed share purchase agreements for the acquisition of 100% interest in SB Energy India from SoftBank Group (SBG) and Bharti Group. The total renewable portfolio is 4,954 MW spread across four states in India.

In May 2021, Virescent Infrastructure, a renewable energy platform, acquired 76% of India's solar asset portfolio of Singapore-based Sindicatum Renewable Energy Company Pte Ltd.

In April 2021, Central Electricity Authority approved the uprating of JSW Energy Karcham Wangtoo hydro power plant to 1,091 megawatt (MW) from 1,000 MW.

In April 2021, GE Power India's approved the acquisition of 50% stake in NTPC GE Power Services Pvt. Ltd. for Rs 7.2 crore (US$ 0.96 million).

The NTPC is expected to commission India's largest floating solar power plant in Ramagundam, Telangana by May-June 2022. The expected total installed capacity is 447MW.

In March 2021, Edelweiss Infrastructure Yield Plus (EIYP), an alternative investment fund managed by Edelweiss Alternative Asset Advisors, acquired a 74% stake in the solar portfolio of Engie Group in India.

In March 2021, the US Agency for International Development (USAID) and the US International Development Finance Corporation (DFC) reported a loan guarantee programme worth US$ 41 million to support Indian SME investments in renewable energy.

In March 2021, Adani Green Energy announced plan to acquire a 250 MW solar power project in the northern state of Rajasthan (commissioned by Hero Future Energies). The expected deal value stands at ~Rs.10 billion (US$ 136.20 million).

In March 2021, Adani Green Energy Ltd. (AGEL) signed a contract to acquire a 100% stake in SkyPower Global's 50 MW solar power project in Telangana. This would increase its operational renewable capacity to 3,395 MW, with a total renewable portfolio of 14,865 MW.

In March 2021, JICA (Japan International Cooperation Agency) entered a loan agreement with Tata Cleantech Capital Limited (TCCL) for JPY 10 billion (US$ 90.31 million) to enable the firm provide loans to companies in India for renewable energy production, e-mobility solutions and energy conservation in order to help offset the effects of climate change by reducing greenhouse gas (GHG) emissions (in line with the Green Loan Principles).

In March 2021, the European Union joined the Coalition for Disaster Resilient Infrastructure (CDRI), an India-led initiative aimed at ensuring long-term development while addressing the climate change's adverse effects.

In March 2021, India and the US agreed to restructure their strategic energy partnership to concentrate on cleaner energy sectors including biofuels and hydrogen production.

India added 2,320 MW of solar capacity amidst COVID-19 pandemic from January to September 2020.

In October 2020, post approval from NITI Aayog and the Department of Investment and Public Asset Management, NTPC set up a wholly owned company for its renewable energy business—NTPC Renewable Energy Ltd. NTPC is targeting to generate ~30% or 39 GW of its overall power capacity from renewable energy sources by 2032.

The Solar Energy Corporation of India (SECI) implemented large-scale central auctions for solar parks and has awarded contracts for 47 parks with over 25 GW of combined capacity.

In April 2020, Vikram Solar bagged a 300 megawatt (MW) solar plant project for Rs. 1,750 crore (US$ 250.39 million) from National Thermal Power Corporation Ltd (NTPC) under CPSU-II scheme in a reverse bidding auction.

Adani Group aims to become the world's largest solar power company by 2025 and the biggest renewable energy firm by 2030.

Around Rs. 36,729.49 crore (US$ 5.26 billion) investment was made during April-December 2019 by private companies in renewable energy.

Government initiatives

Some initiatives by Government of India to boost India's renewable energy sector are as follows:

In April 2021, the Central Electricity Authority (CEA) and CEEW's Centre for Energy Finance (CEEW-CEF) jointly launched the India Renewables Dashboard that provides detailed operational information on renewable energy (RE) projects in India.

In April 2021, the Ministry of Power (MoP) released the draft National Electricity Policy (NEP) 2021 and has invited suggestions from all stakeholders such as Central Public Sector Undertakings, Solar Energy Corporation of India, power transmission companies, financial institutions like Reserve Bank of India, Indian Renewable Energy Development Agency, HDFC Bank, ICICI Bank, industrial, solar, and wind associations, and state governments.

In March 2021, the Union Cabinet approved a Memorandum of Understanding (MoU) in the field of renewable energy cooperation between India and the French Republic.

In March 2021, Haryana announced a scheme with a 40% subsidy for a 3 KW plant in homes, in accordance with the Ministry of New and Renewable Energy's guidelines, to encourage solar energy in the state. For solar systems of 4-10 KW, a 20% subsidy would be available for installation from specified companies.

In March 2021, India introduced Gram Ujala, an ambitious programme to include the world's cheapest LED bulbs in rural areas for Rs. 10 (US$ 0.14), advancing its climate change policy and bolstering its self-reliance credentials.

In the Union Budget 2021-22, Ministry for New and Renewable Energy was allocated Rs. 5,753 crore (US$ 788.45 million) and Rs. 300 crore (US$ 41.12 million) for the 'Green Energy Corridor' scheme.

Under Union Budget 2021-22, the government has provided an additional capital infusion of Rs. 1,000 crore (US$ 137.04 million) to Solar Energy Corporation of India (SECI) and Rs. 1,500 crore (US$ 205.57 million) to Indian Renewable Energy Development Agency.

To encourage domestic production, customs duty on solar inverters has been increased from 5% to 20%, and on solar lanterns from 5% to 15%.

In November 2020, Ladakh got the largest solar power project set-up under the central government's 'Make In India' initiative at Leh Indian Air Force Station with a capacity of 1.5 MW.

In November 2020, the government announced production-linked incentive (PLI) scheme worth Rs. 4,500 crore (US$ 610.23 million) for high-efficiency solar PV modules manufacturing over a five-year period.

On November 17, Energy Efficiency Services Limited (EESL), a joint venture of PSUs under the Ministry of Power and the Department of New & Renewable Energy (DNRE), Goa, signed a memorandum of understanding to discuss roll-out of India's first Convergence Project in the state.

In October 2020, the government announced a plan to set up an inter-ministerial committee under NITI Aayog to forefront research and study on energy modelling. This, along with a steering committee, will serve the India Energy Modelling Forum (IEMF), which was jointly launched by NITI Aayog and the United States Agency for International Development (USAID).

India plans to add 30 GW of renewable energy capacity along a desert on its western border such as Gujarat and Rajasthan.

Delhi Government decided to shut down thermal power plant in Rajghat and develop it into 5,000 KW solar park

The Government of India has announced plans to implement a US$ 238 million National Mission on advanced ultra-supercritical technologies for cleaner coal utilisation.

Indian Railways is taking increased efforts through sustained energy efficient measures and maximum use of clean fuel to cut down emission level by 33% by 2030.

Road Ahead

The Government is committed to increased use of clean energy sources and is already undertaking various large-scale sustainable power projects and promoting green energy heavily. In addition, renewable energy has the potential to create many employment opportunities at all levels, especially in rural areas. The Ministry of New and Renewable Energy (MNRE) has set an ambitious target to set up renewable energy capacities to the tune of 227 GW by 2022, of which about 114 GW is planned for solar, 67 GW for wind and other for hydro and bio among other. India's renewable energy sector is expected to attract investment worth US$ 80 billion in the next four years. About 5,000 Compressed Biogas plants will be set up across India by 2023.

It is expected that by 2040, around 49% of the total electricity will be generated by renewable energy as more efficient batteries will be used to store electricity, which will further cut the solar energy cost by 66% as compared to the current cost. *Use of renewables in place of coal will save India Rs. 54,000 crore (US$ 8.43 billion) annually3. Renewable energy will account for 55% of the total installed power capacity by 2030.

As per the Central Electricity Authority (CEA) estimates, by 2029-30, the share of renewable energy generation would increase from 18% to 44%, while that of thermal is expected to reduce from 78% to 52%.

According to the year-end review (2020) by the Ministry of New and Renewable Energy, another 49.59 GW of renewable energy capacity is under installation and an additional 27.41 GW of capacity has been tendered. This puts the total capacity of renewable energy projects (already commissioned or in the pipeline) at ~167 GW.

The Government of India wants to develop a 'green city' in every state of the country, powered by renewable energy. The 'green city' will mainstream environment-friendly power through solar rooftop systems on all its houses, solar parks on the city's outskirts, waste to energy plants and electric mobility-enabled public transport systems. **References:**

- Central Electricity Authority, Ministry of New and Renewable Energy, Media Reports, Press Releases
- https://www.ibef.org/industry/renewable-energy.aspx

Energy requirements of agricultural and horticultural crops

Energy use in agriculture can be divided into two categories, viz. direct use of energy for pumping and mechanization (tractors, power tiller, etc.) and indirect use of energy in the form of fertilizers and pesticides. The structure of energy consumption in Indian agriculture has changed with a marked shift from animal and human power to tractors, electricity and diesel power. The main concerns of our decision makers relate to managing growing demand for energy in agriculture to achieve the target growth and to match the domestic supplies with the demand.

Actions will be needed on two fronts. First, on utilization of the available energy resources more efficiently to partially address the supply constraints and obviously, technological solutions have an advantage in this task. The second approach should be on promoting alternative renewable sources of energy involving technologies, institutions and policy measures.

Use of renewable energy in farming systems can mean several different things. For example, fossil fuels such as oil are non-renewable, so finding alternative ways of fertilising the land and controlling pests that do not depend on chemicals, will normally involve the use of renewable resources. Such methods reduce farmers' vulnerability to the rising price of oil.

Renewable energy also includes generation of power to do a number of farm tasks: pumping water for irrigation, for livestock or for domestic use; lighting farm buildings; powering processing operations and others. These forms of renewable energy include solar energy, wind and water power, oil from plants, wood from sustainable sources, other forms of biomass (plant material), and biogas (gas produced from fermentation of manure and crop residues).

Lecture 2

Biomass Energy Conversion

Topics Covered: **Biomass – methods of energy conversion – biochemical conversion methods – thermochemical conversion methods.**

Biomass

Biomass is organic material made from plants and animals. Biomass contains stored energy from the sun. Plants absorb the sun's energy in a process called photosynthesis. The chemical energy in plants gets passed on to animals and people that eat them. The energy content of biomass is in the range of 15 – 20 MJ kg^{-1}.

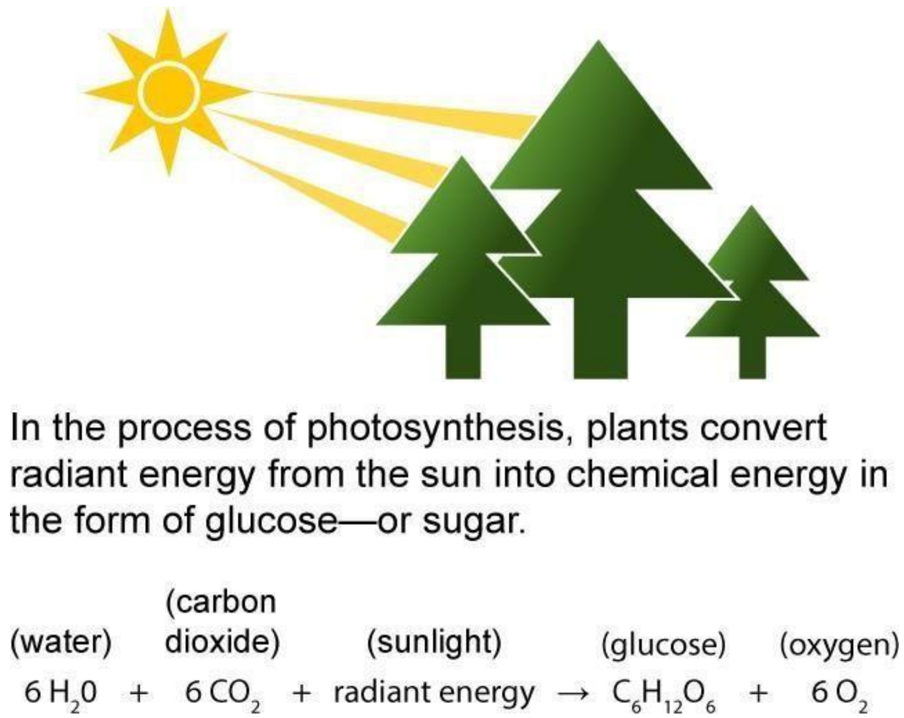


Figure 23 Energy stored in Biomass

Biomass is a renewable energy source because we can always grow more trees and crops, and waste will always exist. Some examples of biomass fuels are wood, crops, manure, and some garbage.

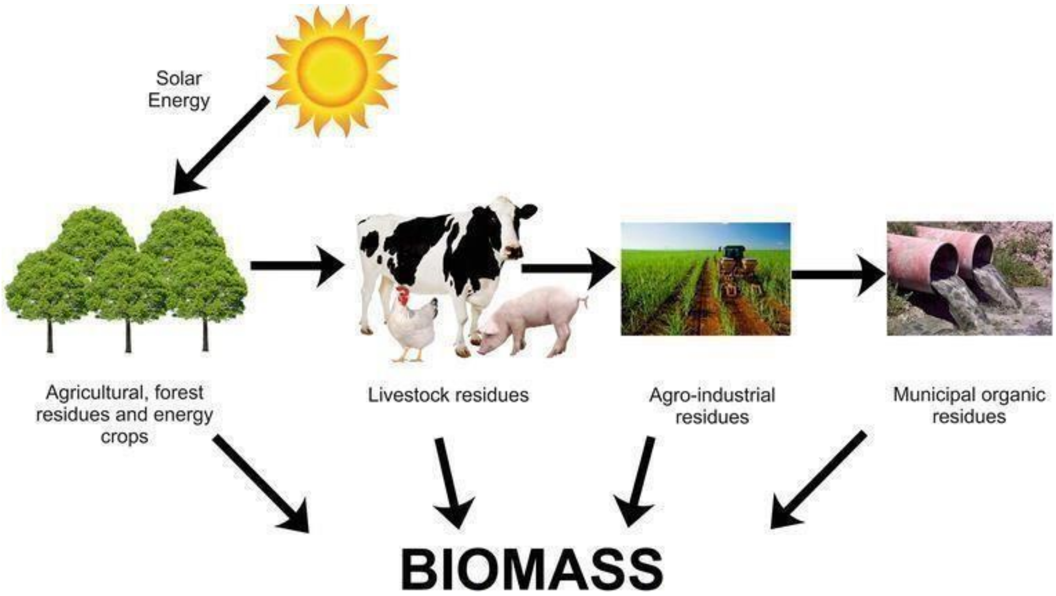


Figure 24 Biomass - Renewable Energy Source

When burned, the chemical energy in biomass is released as heat. If you have a fireplace, the wood you burn in it is a biomass fuel. Wood waste or garbage can be burnt to produce steam for generating electricity, or to provide heat to industries and homes.

Burning biomass is not the only way to release its energy. Biomass can be converted to other usable forms of energy like methane gas or transportation fuels like ethanol and biodiesel. Methane gas is the main ingredient of natural gas. Smelly stuff, like rotting garbage, and agricultural and human waste, release methane gas - also called "landfill gas" or "biogas". Crops like corn and sugarcane can be fermented to produce the transportation fuel, ethanol. Biodiesel, another transportation fuel, can be produced from left-over food products like vegetable oils and animal fats.

Sources of Biomass

Typical biomass supply is derived from:

Woody forest residue, fuelwood, mill residues, short rotation crops, Non-woody agricultural crops, crop residue, processing residues; and

Animal waste such as manure from feed lots and municipal sewage and waste.

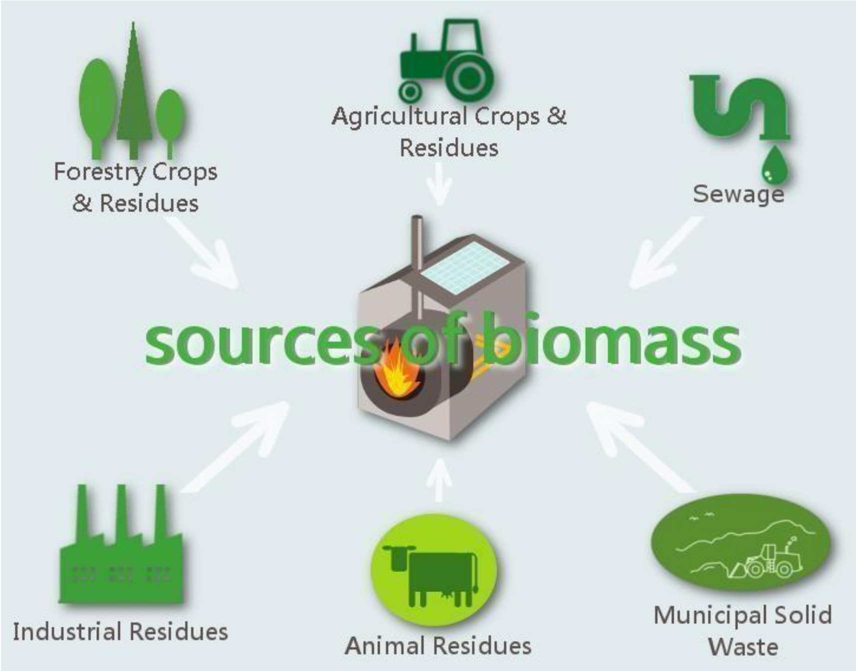


Figure 25 Sources of Biomass

Direct and Indirect uses of Biomass energy

Biomass energy can be used directly or indirectly. Firewood is a common example of direct use by combustion. But biomass energy can be transformed into other forms of fuel. Ethanol from agricultural crops such as sugarcane and methane from manure and sewage are examples of indirect use of biomass as fuel.

Figure 26 Direct Use of Biomass

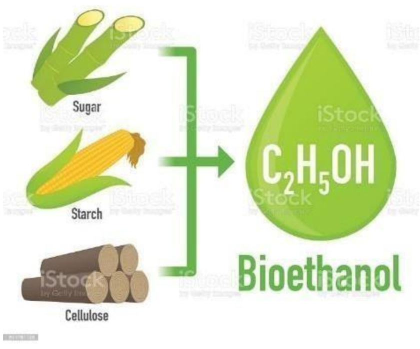


Figure 27 Indirect Use of Biomass

Biomass fuels are defined as any solid, liquid or gaseous product derived from a wide range of organic raw materials, either directly from plants or indirectly from industrial, commercial, domestic, forest or agricultural wastes and produced in a variety of ways.

Biomass Energy – Conversion

Biomass conversion into power, heat, fuels and bio-based products, based on the specific feedstock, is generally categorized into two major conversion pathways—biochemical and thermochemical. The following flowchart presents the different routes of biomass energy conversion.

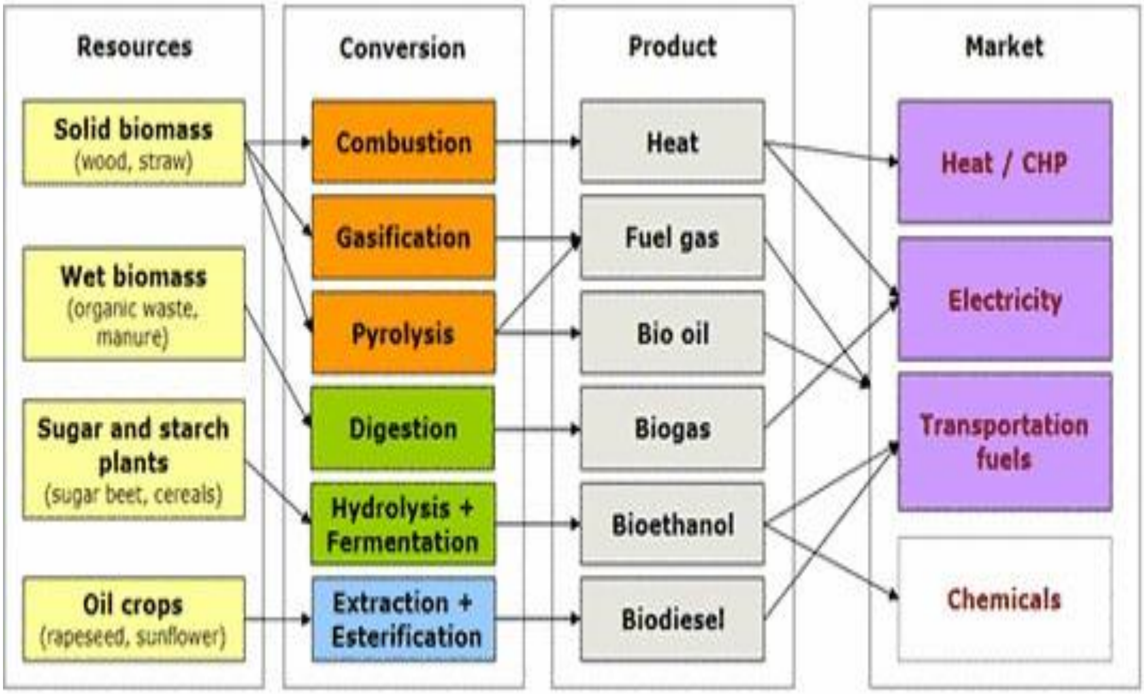


Figure 28 Biomass Energy Conversion Route

Thermochemical Conversion

Thermochemical conversion is an efficient method to convert biomass into biofuels that involves heat application to rupture the main structure of polymers. This can be applied with or without oxygen. It is the controlled heating and/or oxidation of biomass as part of several pathways to produce intermediate energy carriers or heat.

Thermochemical energy conversion can happen in three ways

Combustion (including co-firing - mixed coal/biomass combustion)

Pyrolysis and

Gasification

Combustion

Biomass combustion simply means burning organic materials. Biomass combustion takes place when biomass reacts with the oxygen in air to produce heat. The heat created by the burning of biomass is used in the operation of equipment such as boilers, furnaces, kilns and engines. Along with heat, carbon dioxide and water vapour are created as by-products of the chemical reaction.

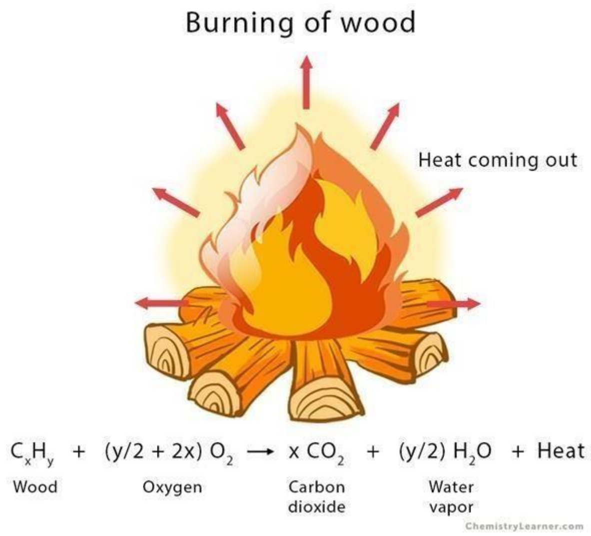


Figure 29 Combustion of Biomass

Farmers and other rural homeowners are increasingly looking to biomass heat as an economical alternative to propane or furnace oil. Biomass burning provides a relatively cheap fuel source, reduces reliance on fossil fuels and provides self-sufficiency, even during blackouts. On the other hand, open field burning of biomass is a major contributor to poor air quality and reduced visibility. Open field burning produces significant amounts of air pollutants that have been linked to numerous health problems. Effective burning of biomass can help reduce our dependence on fossil fuels.

Pyrolysis

Pyrolysis is the heating of an organic material, such as biomass, in the absence of oxygen. Because no oxygen is present the material does not combust but the chemical compounds (i.e. cellulose, hemicellulose and lignin) that make up that material thermally decompose into combustible gases and charcoal. Most of these combustible gases can be condensed into a combustible liquid, called pyrolysis oil

(bio-oil), though there are some permanent gases (CO_2, CO, H_2, light hydrocarbons). Thus pyrolysis of biomass produces three products: one liquid, bio-oil, one solid, biochar and one gaseous (syngas). The proportion of these products depends on several factors including the composition of the feedstock and process parameters.

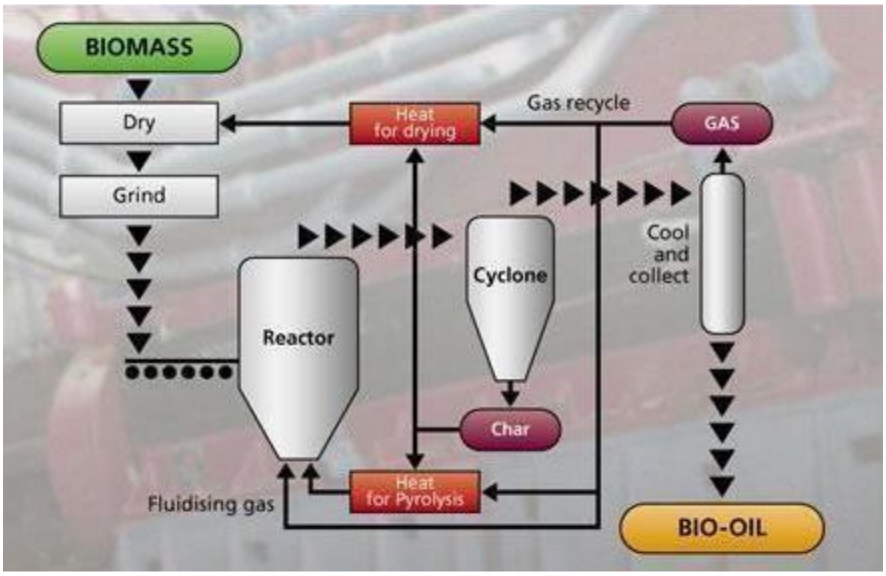


Figure 30 Pyrolysis

However, all things being equal, the yield of bio-oil is optimized when the pyrolysis temperature is around 500 °C and the heating rate is high (i.e. 1000 °C/s) i.e. fast pyrolysis conditions. Under these conditions bio-oil yields of 60-70 wt % of can be achieved from a typical biomass feedstock, with 15-25 wt % yields of bio-char. The remaining 10-15 wt % is syngas. Processes that use slower heating rates are called slow pyrolysis and bio-char is usually the major product of such processes.

Gasification

Biomass gasification means incomplete combustion of biomass with restricted supply of air resulting in production of combustible gases consisting of Carbon monoxide (CO), Hydrogen (H_2) and traces of Methane (CH_4). This mixture is called producer gas.

Producer gas can be used to run internal combustion engines (both compression and spark ignition), can be used as substitute for furnace oil in direct heat applications and can be used to produce, methanol –which is useful both as fuel for heat engines as well as chemical feedstock for industries. Since any biomass material can undergo gasification, this process is much more attractive than ethanol production or biogas where only selected biomass materials can produce the fuel.

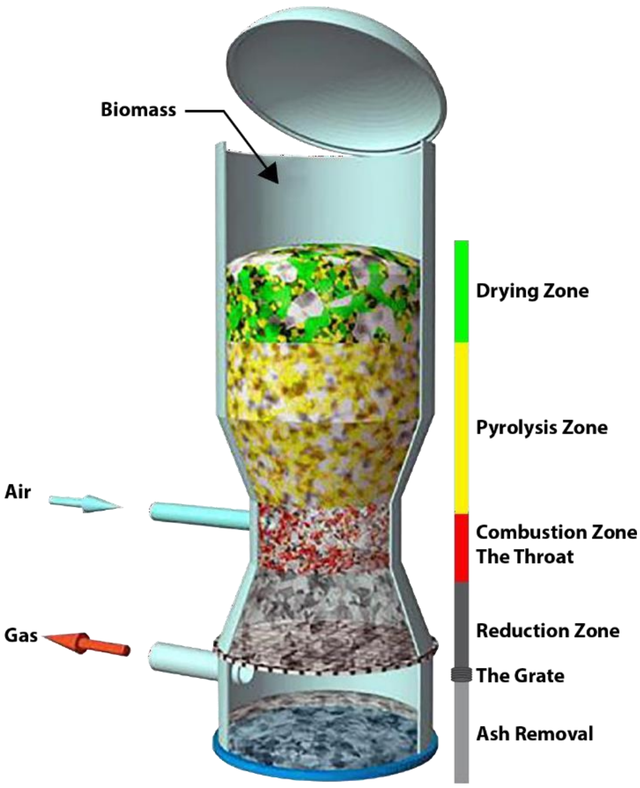


Figure 31 Gasification

Biochemical Conversion

Biochemical conversion involves the use of microorganisms or their enzymes to break down biomass. Widely used biochemical technologies for waste conversion include Anaerobic Digestion and fermentation.

Anaerobic Digestion (AD)

During AD, microbes convert the organic fraction of wastes into biogas [40%–65% methane (CH_4), 35%–55% CO_2, and other gases present in trace amounts like hydrogen (H_2) and H_2S]. A nutrient-rich residue is also produced that can be used as a soil conditioner. The biogas can be mainly produced by anaerobic digestion of municipal/industrial waste waters, municipal solid wastes, and agricultural residues.

Obtained methane gas from this technology can be utilized for electricity generation. The advantages of AD are that it can be applied on a wide range of substrates, even those with high moisture contents and impurities.

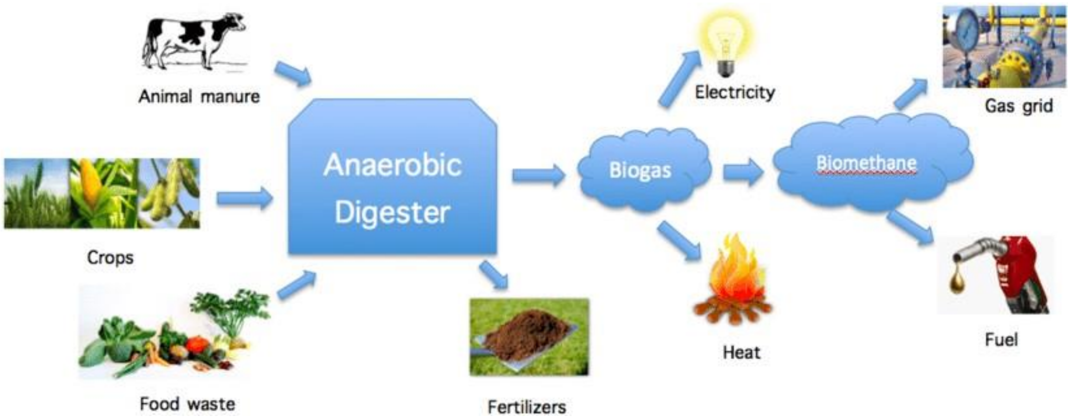


Figure 32 Anaerobic Digestion

Fermentation

In the fermentation, an organic substrate of biomass is chemically changed by the action of enzymes, which is secreted by different microorganisms such as yeasts. Fermentation is a widely adopted technology in different countries to produce ethanol (C_2H_5OH) on a large-scale from sugar crops such as sugarcane and sugar beet, as well as starch crops such as maize and wheat. Molasses is the most common biomass feedstock for ethanol fermentation because its total weight is composed of about 50% sugar and about 50% organic and inorganic compounds.

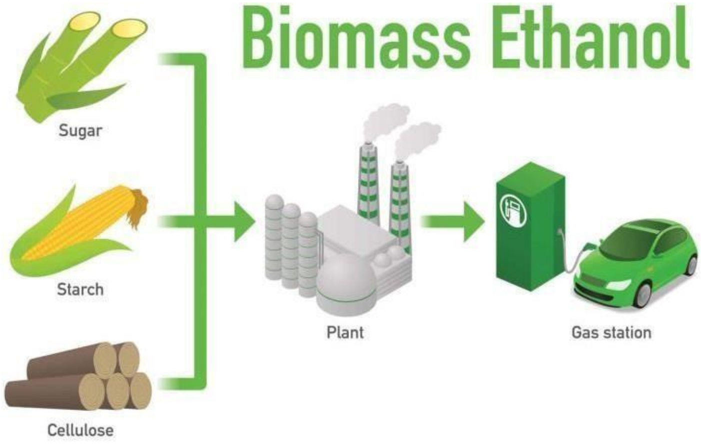


Figure 33 Bioethanol Conversion

The fermentation of sugars for ethanol production has been recognized as one of the greenest technology for liquid fuel production since the generated CO_2 can be used in other applications of a bio-refinery.

In this process, initially, the biomass feedstock is ground down, and the starch is converted to sugars by enzymes, and finally, the sugars are converted to ethanol by yeasts. Hence, the fermentation of starch is more complex than sugar fermentation, because the starch should be converted to sugar first and then to ethanol.

Chemical Conversion

A chemical conversion process known as transesterification is used for converting vegetable oils, animal fats, and greases into fatty acid methyl esters (FAME), which are used to produce biodiesel.

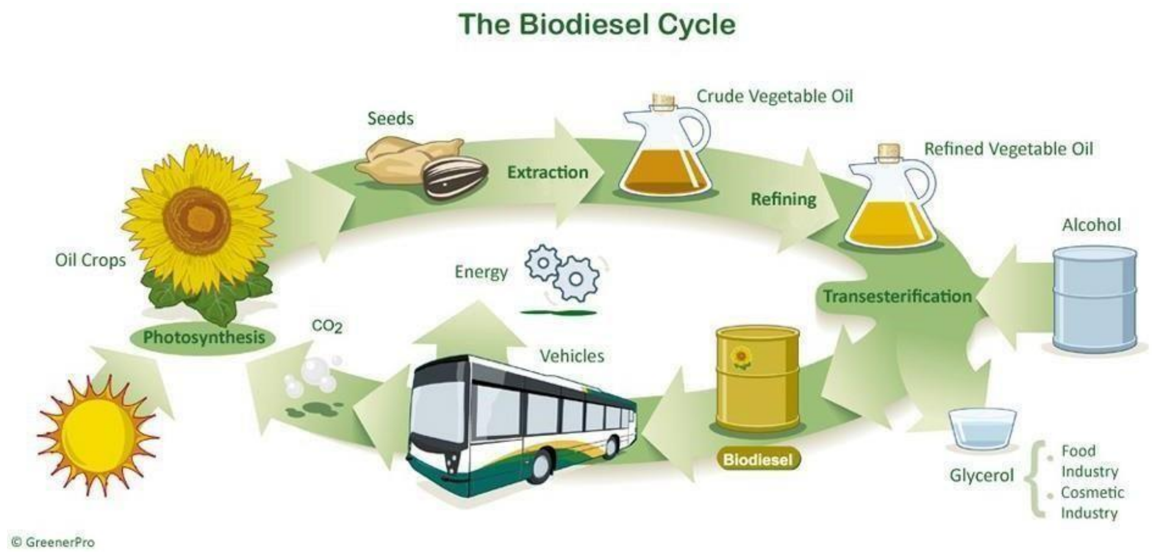


Figure 34 Biodiesel Production Process

Transesterification

Biodiesel is produced from vegetable oils or animal fats and an alcohol, through a transesterification reaction. This chemical reaction converts an ester (vegetable oil or animal fat) into a mixture of esters of the fatty acids that makes up the oil (or fat). Biodiesel is obtained from the purification of the mixture of fatty acid methyl esters (FAME). A catalyst is used to accelerate the reaction and the catalyst may be basic, acidic or enzymatic.

Biodiesel is a liquid biofuel obtained by chemical processes from vegetable oils or animal fats and an alcohol that can be used in diesel engines, alone or blended with diesel oil. It is called biodiesel because it is mostly used in diesel engines.

Biodiesel is most often added (blend) with petroleum distillate/diesel in ratios of 2% (referred to as B2), 5% (B5), or 20% (B20). Pure biodiesel (B100) can also be used in many applications. Petroleum diesel fuel tanks and equipment can also store and transport biodiesel. Biodiesel blends may also be used as heating oil.

Comparison of Biochemical and Thermochemical Processes

Thermochemical	Biochemical
Effectively applied to almost any biomass feedstock	Involves the use of microbes, enzymes, and/or chemicals
No pre-treatment	Pre-treatment is essential
Relatively higher productivity due to completely chemical nature of reaction	Productivity is limited due to biological conversion
Multiple high-value products possible using fractional separation of products	Normally, limited to one or few products and would require additional microbes, enzymes for more products
Independent of climatic conditions	Mostly susceptible to ambient temperature, anaerobic digester
Complete utilization of waste/biomass	Production of secondary wastes such as biomass sludge
Less reaction time	High reaction time

Lecture 3

Biofuels

Topics Covered: **Biofuels – importance – biodiesel and bioethanol production method – flowchart – by products utilization**

Background and Necessity of Biofuels

India is dependent on imports of petroleum, where around 82 per cent of its crude oil requirement derived from the Middle East. The rising number of automobiles has also raised the increase in consumption, where the crude oil import volume amounted to approximately 217 million metric tons during the year 2018. But it was around 203 million metric tons in 2016. This has led to fall in value of foreign reserve and also faces frequent disturbance during the rise in crude prices. In order to contain the rise, the government and other economic experts have been voiced for the biofuel as a replacement for the crude oil.

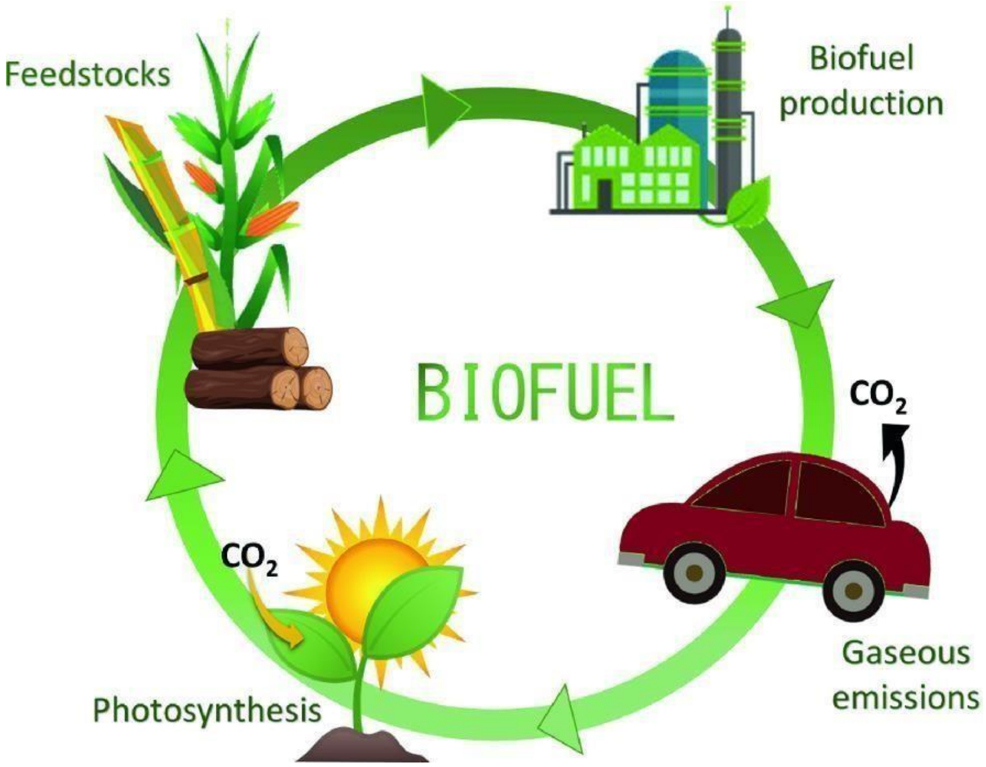


Figure 35 Biofuels

Biofuels

Biofuels are liquid or gaseous components which are used as fuels. They are primarily produced from biomass, and can be used as an alternative or sometimes in addition to diesel, petrol or other fuels. The crops with higher sugar content like sugarcane, sugarbeet, sweet sorghum are most used for production of bio fuel. Even starch (such as maize and tapioca) or oils (such as soybean, rapeseed, coconut, and sunflower) are also used for producing biofuels.

Different categories of biofuels

First generation biofuels – Fuels made from sugar, starch, vegetable oil, or animal fats using conventional technology. Some of the prevalent first-generation biofuels include Bioalcohols, Biodiesel, Vegetable oil, Bioethers, Biogas.

Second generation biofuels – Fuels produced from non-food crops like cellulosic biofuels and waste biomass (stalks of wheat and corn, and wood).

Third generation biofuels – Fuels produced from micro-organisms like algae.

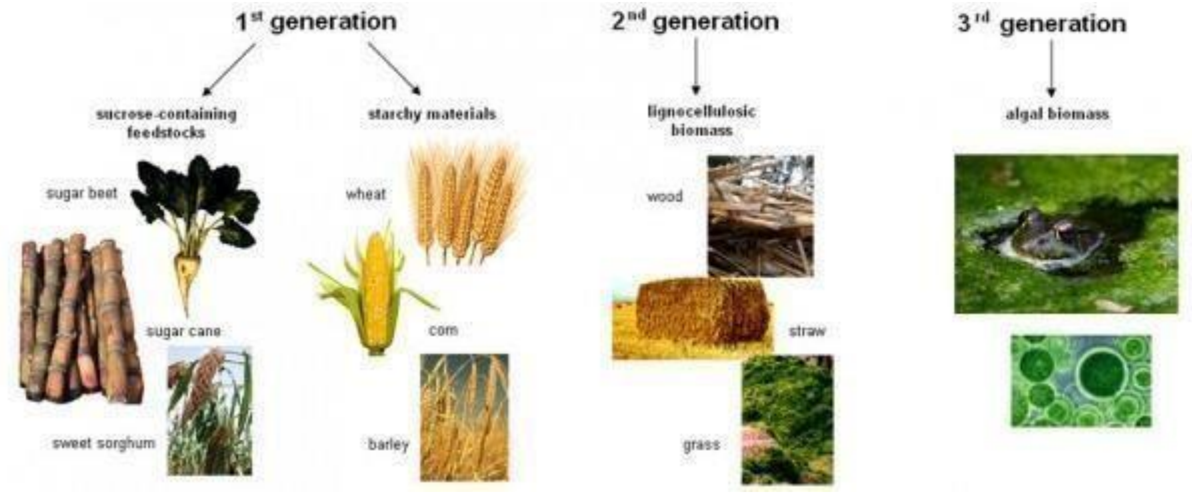


Figure 36 Different Categories of Biofuels

Fourth generation biofuels – The feedstock used in fourth generation is derived from specially engineered plants or biomass that produces higher energy and pose very less barrier to cellulosic material breakdown and are able to grow on non-agricultural lands or water bodies.

Benefits of Biofuels

Biofuels are eco-friendly and can reduce vehicle emission. It is produced from renewable sources and can be prepared easily with dependence on imports. Bio fuels increases the performance of the engines as they contain higher energy boosters as compared to petrol and diesel.

Besides, they offer good lubricity to the vehicle. Since they are from bio component, they are very safe for storage and transport along with the nontoxic.

Furthermore, it helps in reduction of greenhouse gases at least by 3.3 kg CO2 equivalent per kg of biodiesel.

For example, bio-diesel is an alternative diesel fuel prepared from domestic renewable resources from vegetable oils (edible or non- edible oil) and animal fats.

These natural oils and fats are primarily made up of triglycerides which react while mixing with lower alcohols in presence of a catalyst produces fatty acid esters. These esters are very much similar to petroleum derived diesel and are called "Biodiesel". As India is deficient in edible oils, non-edible oil may be a material of choice for producing biodiesel. Examples are *Jatropha curcas*, Pongamia, etc.

Kinds of biofuels

Jatropha

It is a multi-purpose non edible oil yielding plant. This is a hardy and drought tolerant crop can be raised in marginal lands with lesser input. The plant has the capacity to withstand 30 years.

Sugarbeet

It is sugar producing tuber crop, grown in temperate countries. Now, tropical sugarbeet varieties are gaining momentum in tropical and sub-tropical countries, since they are used as a promising alternative energy crop for the production of ethanol.

Sorghum

It is useful as component which adds value to ethanol, syrup and jaggery and bioenriched bagasse as a fodder and as a base material for cogeneration.

Pongamia

It is a non-edible oil yielding tree which can produce biofuel.

Figure 37 Jatropha

Figure 38 Sugarbeet

Figure 39 Sorghum *Figure 40 Pongamia*

Biodiesel

Biodiesel is an alternative fuel for diesel engines that is produced by chemically reacting a vegetable oil or animal fat with an alcohol such as methanol or ethanol. In words, the reaction is:

Oil + alcohol → biodiesel + glycerin

The following image shows a bottle of biodiesel and glycerin (also called glycerol). The biodiesel is the lighter-colored layer at the top. The darker-colored crude glycerin has settled to the bottom.

Figure 41 Bottle of biodiesel (top layer) and glycerol (bottom layer)

Biodiesel Production

The chemical reaction that converts a vegetable oil or animal fat to biodiesel is called "transesterification." This is a long name for a simple process of combining a chemical compound called an "ester" and an alcohol to make another ester and another alcohol.

Oils and fats are included in the ester family. When they react with methanol or ethanol, they make methyl or ethyl esters and a new alcohol called glycerol or, more commonly,
glycerin.

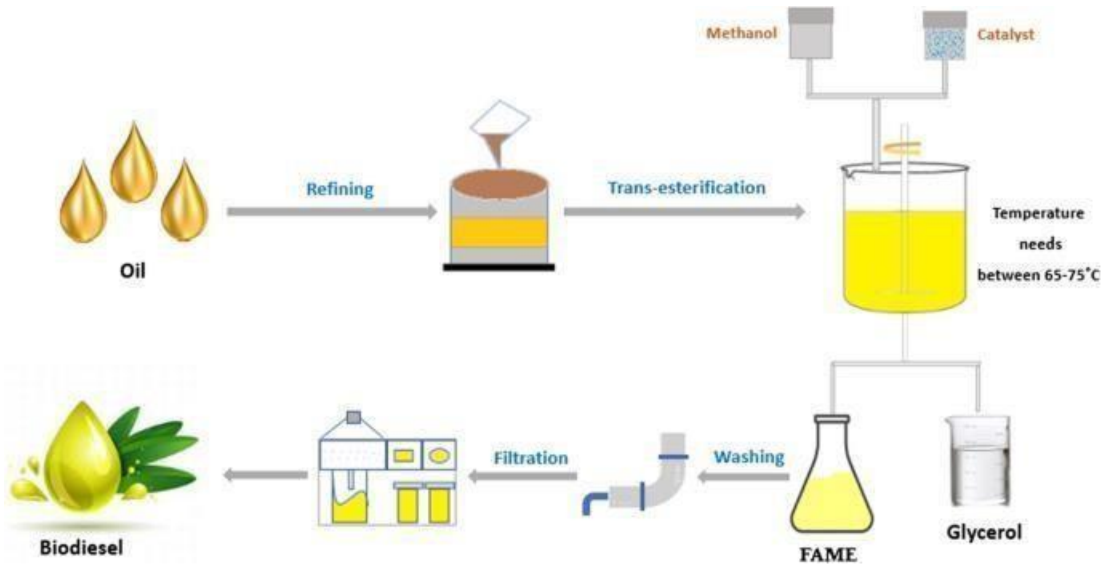


Figure 42 Process of Biodiesel Production

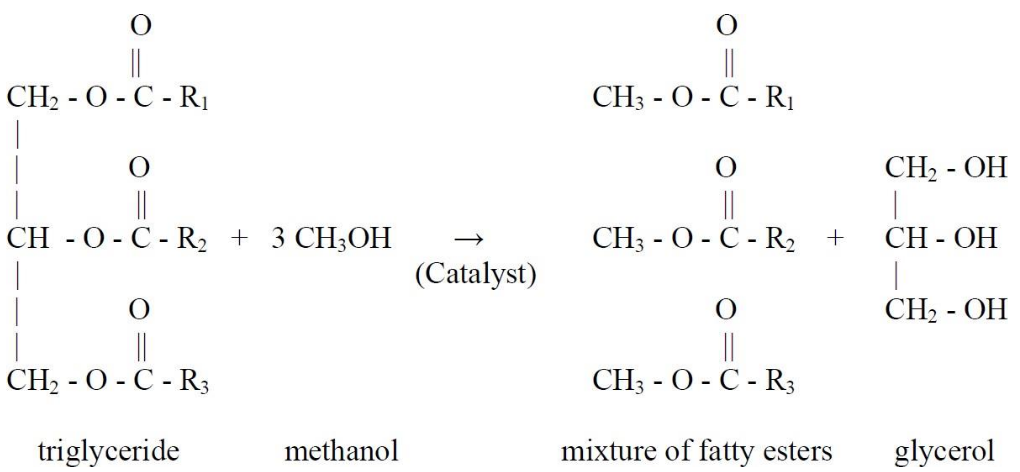


Figure 43 Chemistry of Biodiesel Production

TNAU Biodiesel Pilot Plant

For the esterification of Jatropha oil, alkaline-based catalyst is used TNAU biodiesel pilot plant. The Jatropha oil is blended with alcohol and catalyst mixture. The oil extracted from the seeds of Jatropha is mixed with methanol catalyst mixture at a proportion under a particular temperature. This solution is continuously stirred for two hours. During the above process, glycerol present in the solution separate out, which when settled can be separated out. For settling, three separate tanks are provided in the plant.

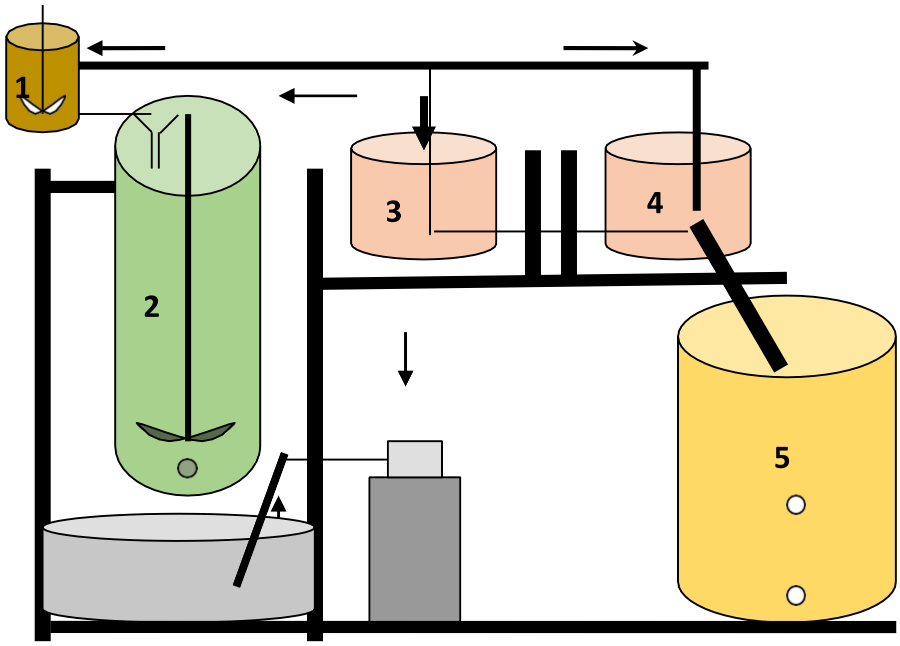


Figure 44 Biodiesel pilot plant diagrammatic sketch

1. Mixing tank for chemical || 2. Main reactor || 3 & 4. Settling tanks || 5. Washing tank

After removing the glycerol, the liquid biodiesel is transferred to washing tank, where the fuel is washed twice and the purified biodiesel is obtained.

By using the above unit, about 250 litres of biodiesel could be produced in a day. The cost of the unit is approximately 1.5 lakhs. This could be reduced by appropriate substitutions in the existing plant. Depending upon the need, the size of the unit can be scaled up to get higher capacity.

Mechanics of the transesterification process

1. Take 50 litres of Jatropha oil in the container and pump oil from inlet tank to biodiesel reactor by using inlet pump (10 minutes)

2. Switch ON for heater of biodiesel reactor
3. Take 20 per cent of methanol and 1 per cent of sodium hydroxide (by weight of oil) in the chemical mixing tank. Ensure that gate valve for chemical tank is in closed position before filling of methanol into tank
4. Switch ON for stirrer of chemical mixing tank (15 minutes) to produce the sodium methoxide solution
5. After reaching reaction temperature 60 ºC, the sodium methoxide is send to biodiesel reactor by opening of gate valve and close the valve.
6. Switch ON for main stirrer of biodiesel reactor and reaction is continued for about 2 hours
7. After reaction time is completed, open the gate valve for glycerol settling tank and the biodiesel and glycerol mixer is send to the glycerol settling tank (by using storage switch)
8. Allow the biodiesel mixture in glycerol settling tanks for 12 hours
9. Before feeding of raw biodiesel, fill 100 litres of water in the washing tank
10. Remove the glycerol from settling tank and biodiesel is sent to washing tank by opening gate
11. Switch ON the aerator for 30 minutes. Allow the sample for 3 hours and remove the biodiesel from washing tank
12. Heat the biodiesel for 20 minutes to remove the moisture.

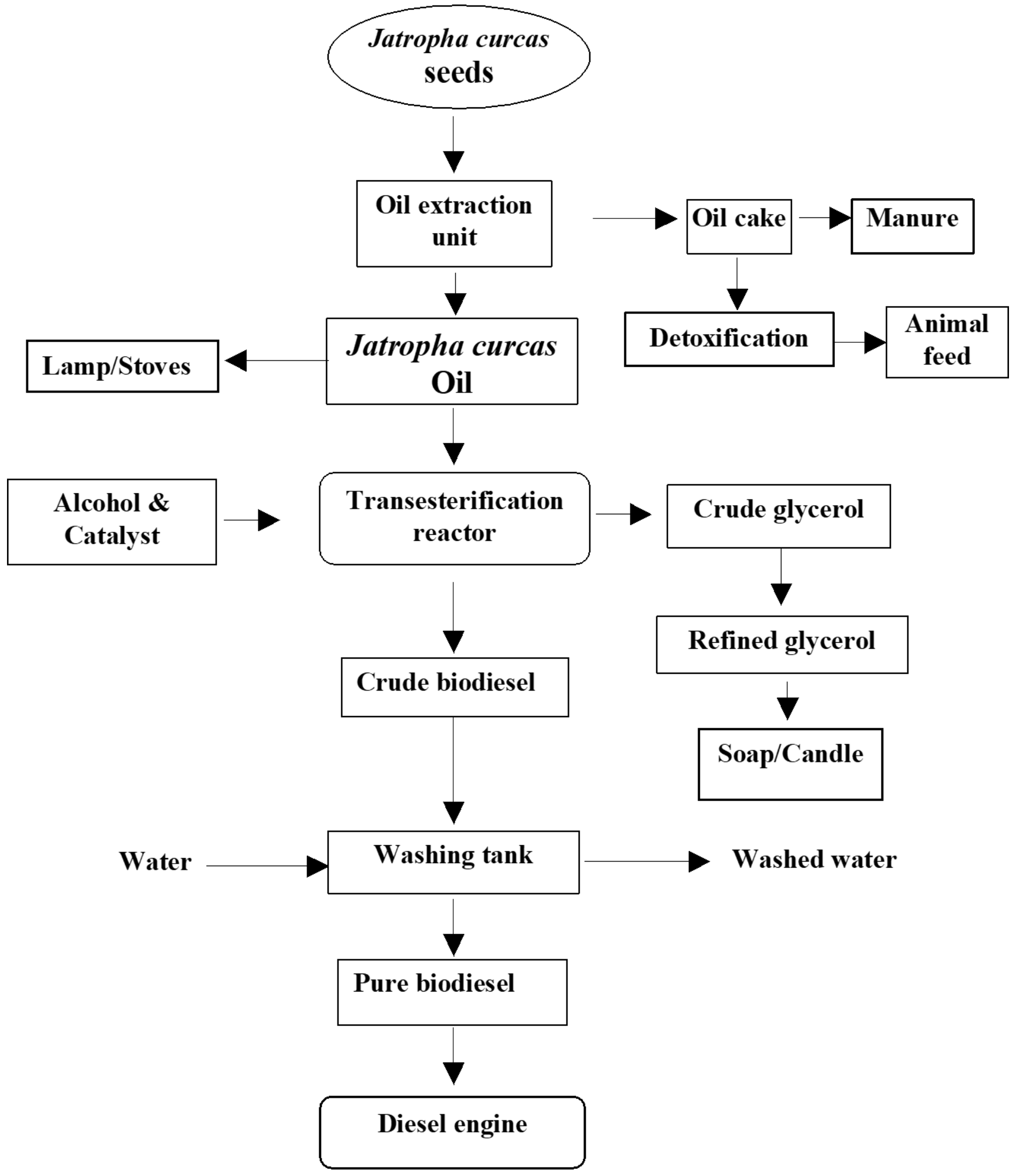


Figure 45 Biodiesel Production – Flowchart

Byproducts from Biodiesel Production

Glycerol (or glycerin; 1,2,3-propanetriol) is produced in addition to FAAE during transesterification of vegetable oils and animal fats. In general, glycerol may be used as a chemical feedstock in the production of polyurethanes, polyesters, polyethers, and other materials. Glycerol may also be found in lubricants, wrapping and packaging materials, foods, drugs, cosmetics, soaps, candles and tobacco products.

Bio-ethanol

Bioethanol (CH_3CH_2OH) is the most popular alcoholic biofuel available in the current world market. Henry Ford has used the term ''fuel of the future'' for the ethanol. Ethanol which is produced by fermentation (biochemical/ microbial/ enzymatic/ biotechnological route) of renewable source (like bioresource) is known as bioethanol.

Like anaerobic fermentation of sugar in the presence of yeast culture results ethyl alcohol (i.e. bioethanol), glucose has the renewable source.

$$C_6H_{12}O_6 + \text{Yeast} \rightarrow 2C_2H_5OH + 2CO_2$$

There are several reasons for being its use as alternative fuel such as

(i) it is produced from the renewable agricultural products like corn, sugar, molasses including other products rather than nonrenewable petroleum products,

(ii) it is less toxic than other alcoholic fuels, and

(iii) byproducts of incomplete oxidation of ethanol (e.g. acetic acid and acetaldehyde) are less toxic than the by-products formed from other fuel alcohols.

Bioethanol is commonly produced from the agricultural raw materials containing sugar. This material can be classified as first generation material (includes sugar and starch) and second generation material (includes lignocellulosic sugar from rice straw, wheat straw, wheat bran, rice husk, banana waste, newspaper, sugarcane bagasse, and grasses). Sugars (e.g., from sugarcanes, molasses, sugar beet, and fruits) can be directly fermented using yeast to produce ethanol.

Bio-ethanol Production

There are following steps in ethanol production:

Milling
Liquefaction
Saccharification
Fermentation
Distillation
Dehydration

1. Milling

The feedstock is passed through a hammer mill which grinds it into a fine powder called a meal.

2. Liquefaction

The meal is mixed with water and alpha-amylase. Then passed through bioreactor where the starch is liquified and heat is applied here to enable liquefaction. Bioreactor with the high-temperature stage (120-150˚C) and lower temperature holding period (95˚C) are used. High temperatures reduce bacteria levels in the mash.

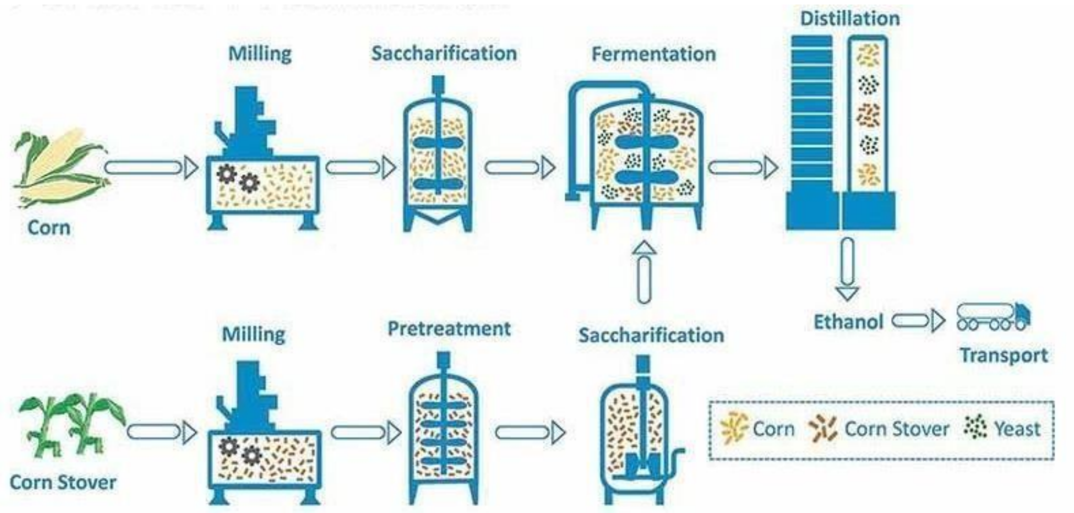


Figure 46 Bioethanol production from Corn and Corn Stover

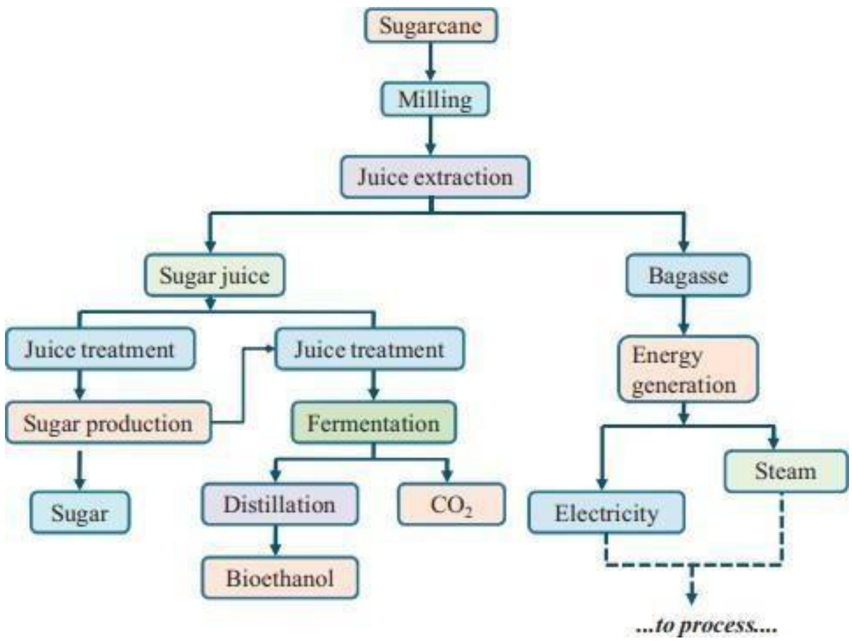


Figure 47 Bioethanol production from Sugarcane

3. Saccharification

The mash from the bioreactor is cooled and secondary enzyme glucoamylase is added. This converts the liquified starch into the fermentable sugars.

4. Fermentation

Yeast is added to ferment the sugars to ethanol and carbon dioxide. In a continuous process, the fermenting mash can flow through several fermenters until it is fully fermented and leaves the final tank. In a batch process, the mash stays in one fermenter for about 48 hours before distillation starts.

Batch fermentation

Yeast reuse results in a decrease in new growth with no more sugar available for ethanol production and an increase in the yield from 2 to 7%. Traditional yield 1-3g/L.

Continuous fermentation:

To ensure system homogeneity and reduce the concentration gradient in the culture broth, Continuously Stirred Tame Reactor (CSTR) are employed. Reduce construction costs of bioreactors. Lower requirements of maintenance and operation. Better control of the process. Higher productivities. Cultivation of yeast under anaerobic conditions for a long time diminish their ability to produce ethanol. Aeration is important which can enhance cell concentration.

5. Distillation

Mash is pumped to continuous flow. Multicolumn distillation system where the alcohol is removed from solid and water. The alcohol leaves the top of the final column at about 96% strength. The residue mash is called stillage which is transferred from the base of the column to the co-product processing area.

6. Dehydration

The alcohol from the top of the column is passed through a dehydration system where the remaining water will be removed. Most ethanol plants use a molecular sieve to capture the last bit of water in the ethanol. The alcohol product at this stage is called anhydrous alcohol.

Byproducts from Bioethanol Production

Carbon dioxide

It is used to carbonate the beverages, manufacture dry ice. It is used to flash freeze meat. It is also used by paper mills and food industries.

Advantages of Bio-ethanol

The overwhelming advantage of bio-ethanol for the environment is its potential to be carbon neutral on a lifecycle basis – meaning the carbon dioxide (CO_2) emitted during its use is offset by the absorption from the atmosphere during its growth.

With emissions of CO_2 and nitrous oxide taken into account, some studies suggest that lifecycle greenhouse gas emissions can be reduced by 90% with bio-ethanol compared to petrol.

Bio-ethanol also has the advantage of lower taxation.

Disadvantages of Bioethanol

There are many concerns over the use of bio-ethanol as a long-term alternative in the fuelling of cars. These include:

Biodiversity – A large amount of arable land is required to grow crops. This could see some natural habitats destroyed including rainforests.

The food Vs fuel debate – There is concern that due to the lucrative prices of bio-ethanol some farmers may sacrifice food crops for biofuel production which will increase food prices around the world.

Carbon emissions – There is debate over the neutrality of bio-ethanol when all elements are taken into consideration including the cost of changing the land use of an area, transportation and the burning of the crop.

There are also concerns over the fuel systems used. Too many older cars are currently unequipped to handle even 10% ethanol while there is concern that using 100% ethanol decreases fuel economy by around 15-30% compared with 100% petroleum.

Limitations of Biofuels

Biofuel is the new requirement of the global community, but the requirements were huge. For example, Jatropha is considered best for biofuel, high investment is required for seed productivity ratio. Besides, if many follow bio fuel yielding crops, it leads to monoculture where farmer produces the same crops year after year, rather than producing various crops over a period of time. Though it could be economically attractive for farmers, they could leave the soil without the nutrients.

Government Initiatives

The Union Cabinet, chaired by the Prime Minister Shri Narendra Modi has approved the National Policy on Biofuels – 2018. Some of the important features include, setting up of supply chain mechanisms for biodiesel production from non-edible oilseeds, Used Cooking Oil, short gestation crops.

It expands the scope of raw material for ethanol production by allowing use of Sugarcane Juice, Sugar containing materials like Sugar Beet, Sweet Sorghum, Starch containing materials like Corn, Cassava, Damaged food grains like wheat, broken rice, Rotten Potatoes, unfit for human consumption for ethanol production.

With a thrust on Advanced Biofuels, the new initiative indicates a viability gap funding scheme for 2G ethanol Bio refineries of Rs 5000 crore in 6 years in addition to additional tax incentives, higher purchase price as compared to 1G biofuels.

Lecture 4

Biogas Technology

Topics Covered: **Biogas technology – classification - types of biogas plants – KVIC and Deenabandhu model biogas plants – factors affecting biogas plants**

Biogas

Most organic materials undergo a natural anaerobic digestion in the presence of moisture and absence of oxygen and produce biogas. It's a mixture of gas produced by the microorganisms during the anaerobic fermentation of biodegradable materials. Anaerobic fermentation is a biochemical process in which particular kinds of bacteria digest biomass in an oxygen-free environment resulting in production of CH_4, CO_2, H_2 and traces of other gases along with decomposed mass.

The production of biogas is of particular significance in India because of its large scale cattle production. The biogas is used for cooking, domestic lighting and heating, run I.C. Engines and generation of electricity for use in agriculture and rural industry.

Properties of Biogas

Biogas is a mixture of different components and the composition varies depending upon the characteristics of feed materials, amount of degradation, etc. Biogas predominantly consists of 50 to 70 per cent methane, 30 to 40 per cent carbon dioxide and low amount of other gases.

Methane is a combustible gas. The energy content of biogas depends on the amount of methane it contains. Methane content varies from about 50 percent to 70 percent. The biogas contains traces of H_2, H_2S and N_2.

The calorific value of biogas ranges from 5000 to 5500 kcal/kg (18.8 to 26.4 MJ/m^3). The biogas can be upgraded to synthetic natural gas (SNG) by removing CO_2 and H_2S.

Table 1 Composition of biogas

Name of the gas	**Composition in biogas (%)**
Methane (CH_4)	50-70
Carbon dioxide (CO_2)	30-40
Hydrogen (H_2)	5-10
Nitrogen (N_2)	1-2
Water vapour (H_2O)	0.3
Hydrogen sulphide (H_2S)	Traces

Table 2 Properties of biogas

Properties	**Range**
Net calorific value (MJ/m^3)	20
Air required for combustion (m^3/m^3)	5.7
Ignition temperature (^0C)	700
Density (kg/m^3)	0.94

Microbiology of biogas production

The production of biogas from organic material under anaerobic condition involves sequence of microbial reactions. During the process complex organic molecule present in the biomass are broken down to sugar, alcohols, pesticides and amino acids by acid producing bacteria. The resultant products are then used to produce methane by another category of bacteria.

The biogas production process involves three stages namely:

- Hydrolysis
- Acid formation and
- Methane formation

The process of degradation of organic material in every step is done by range of bacteria, which are specialized in reduction of intermediate products formed. The efficiency of the digestion depends how far the digestion happens in these three stages. Better the digestion, shorter the retention time and efficient gas production.

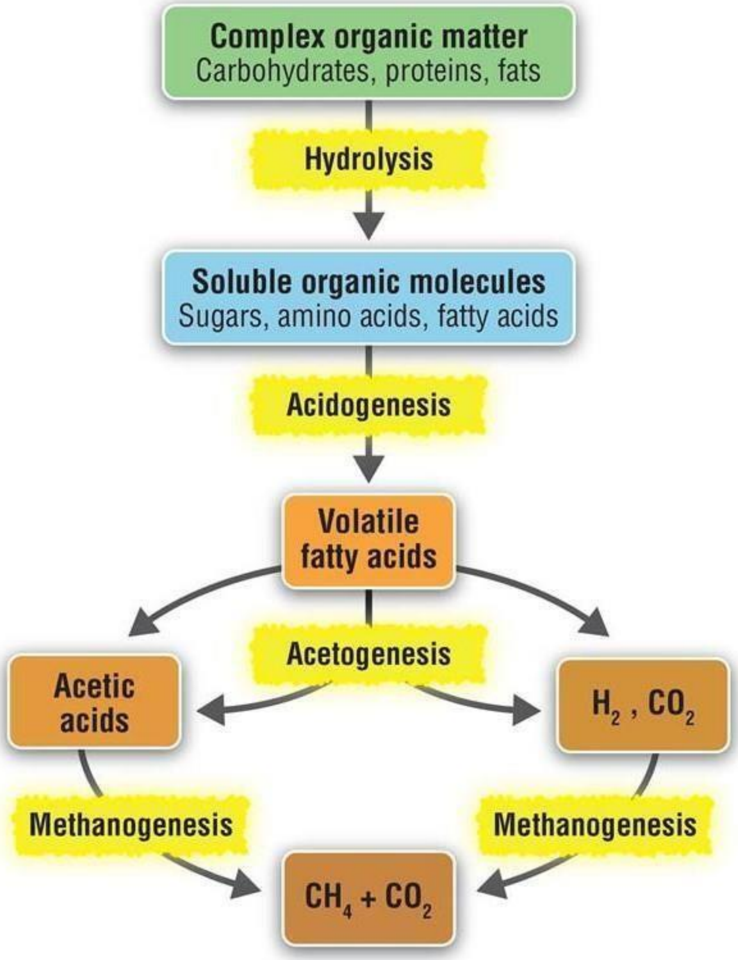


Figure 48 Flow process in Biogas Production

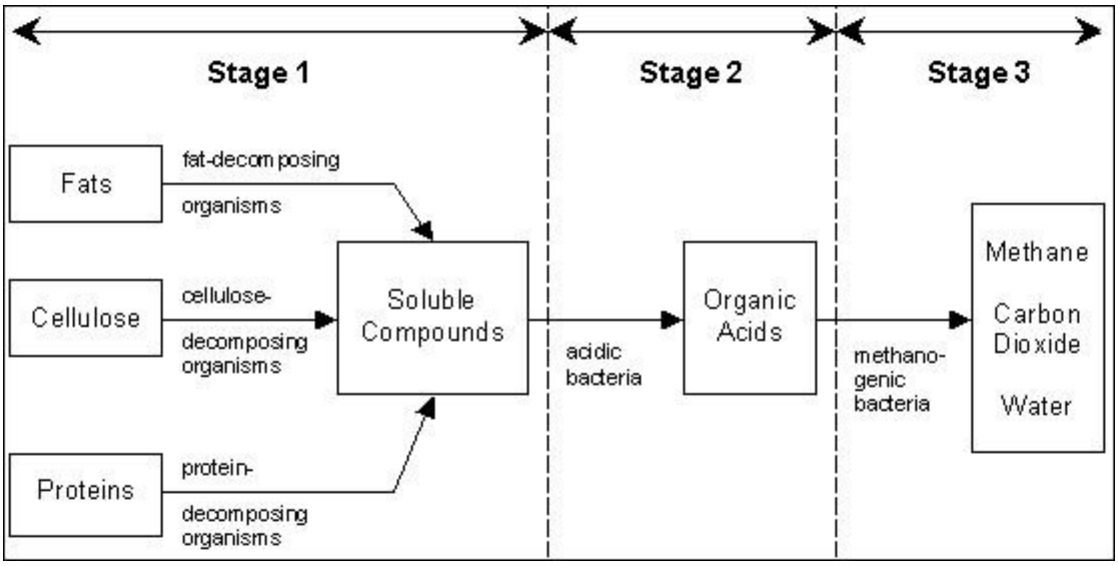


Figure 49 Stages of Biogas Formation

Hydrolysis

The complex organic molecules like fats, starches and proteins which are water insoluble contained in cellulosic biomass are broken down into simple compounds with the help of enzymes secreted by bacteria. This stage is also known as polymer breakdown stage (polymer to monomer). The major end product is glucose which is a simple product.

Acid formation

The resultant product (monomers) obtained in hydrolysis stage serve as input for acid formation stage bacteria. Products produced in previous stage are fermented under anaerobic conditions to form different acids. The major products produced at the end of this stage are acetic acid, propionic acid, butyric acid and ethanol.

Methane formation

The acetic acid produced in the previous stages is converted into methane and carbon dioxide by a group of microorganism called "Methanogens". In other words, it is process of production of methane by methanogens. They are obligatory anaerobic and very sensitive to environmental changes. Methanogens utilise the intermediate products of the preceding stages and convert them into methane, carbon dioxide, and water. Methanogenesis is sensitive to both high and low pH's and occurs between pH 6.5 and 7.5.

Raw materials for biogas generation

Biogas is produced mainly from

- Cow dung
- Sewage
- Crop residues
- Vegetable wastes
- Water hyacinth
- Poultry droppings
- Pig manure

Biogas plant and its components

A physical structure designed to carry out anaerobic digestion of organic materials is called "Biogas plant". Following are the components of biogas plants:

Mixing tank	:	Cow dung is collected from the shed and mixed with the water in equal proportion (1:1) to make a homogenous mixture (slurry) in the mixing tank
Feed inlet pipe/tank	:	The homogenous slurry is let into the digester through this inlet pipe (KVIC biogas plants)/tank (Janatha biogas plants)
Digester	:	The fed slurry is subjected to anaerobic fermentation with the help of microorganisms inside the digester.
Gas holder	:	As a result of anaerobic fermentation, gas produced is stored in gas holder (Drum in the case of KVIC and in dome in the case of fixed dome biogas plants)

Slurry outlet tank/pipe	:	The digested slurry is let out from the digester through slurry outlet pipe (KVIC biogas plants)/tank (Janatha biogas plants)
Gas outlet pipe	:	Stored gas is released and conveyed through the gas outlet pipe present at the top of gas holder.

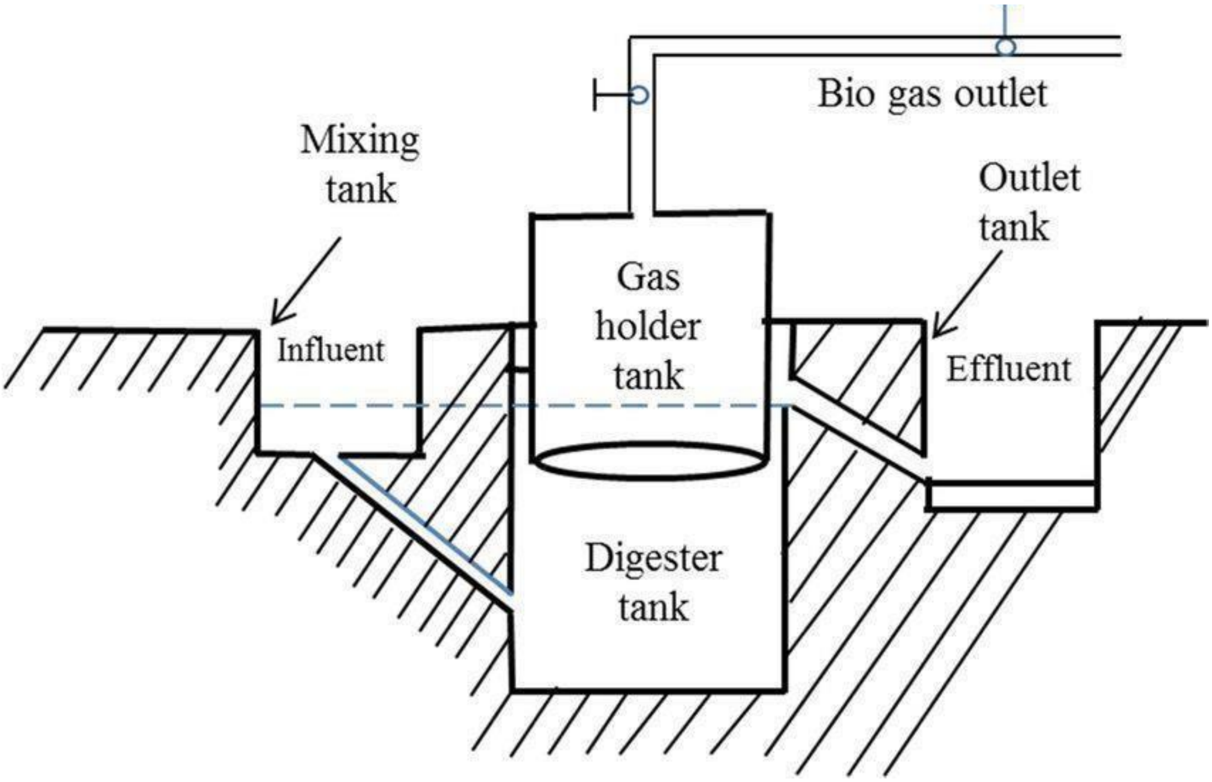


Figure 50 Biogas Plant and its Components

Classification of Biogas Plants

Based on the nature of feeding, biogas plants would be broadly divided into 3 types and they are as follows:

Batch type

The organic waste materials to be digested under anaerobic condition are charged only once into a reactor-digester. The feeding is between intervals, the plant is emptied once the process of digestion is complete. Retention time usually varies from 30 to 50 days. The gas production in it is intermittent. These plants are well suited for fibrous materials. This type of plant needs addition of fermented slurry to start the digestion process and it not economical to maintain which are considered to be the major draw backs.

Semi continuous

A predetermined quantity of feed material mixed with water is charged into the digester from one side at specified interval of time; (say once a day) and the digested material (effluent) equivalent to the volume of the feed, flows out of the digester from the other side (outlet).

Continuous type

The feed material is continuously charged to the digester with simultaneous discharge of the digested material (effluent). The main features of this type of plants are continuous gas production, requires small digestion area, lesser period for digestion, less maintenance, etc.

The biogas plants used in the villages are of semi continuous type employing animal dung and other biomass as the feed stock for biogas production. So the classification of semi-continuous type biogas plant is explained below.

- Floating drum type – Khadi Village and Industrial Commission (KVIC) model
- Fixed dome type model – Deenbandhu model

Figure 51 Floating Drum Type

Figure 52 Fixed Dome Type

Floating drum type (Constant pressure)

In this type of plants digester is made of bricks and is of circular in shape. It is constructed typically underground to lessen the heat loss from the plant. Partition wall is constructed (dividing the digester into two parts) for higher size capacity plants to avoid the short-circuiting of digested slurry with the fresh feed.

Separate gasholder is fabricated and fixed to store the gas produced during digestion besides acting as an anaerobic seal for the process. As the volume of gas production increases drum starts to rise and if the stored gas is withdrawn the level of drum drops to lower level. Scum formed in the digester can be broken with the help of drum rotation both clockwise and anticlockwise.

Central guide frame is provided to hold the gasholder and to allow it to move vertically during gas production. The drum is made up of mild steel and it constitutes around 60 per cent of overall plant costs. Salient features of this type of plants include weight of drum helps to discharge the gas produced at constant pressure, volume of gas storage can be judged visually.

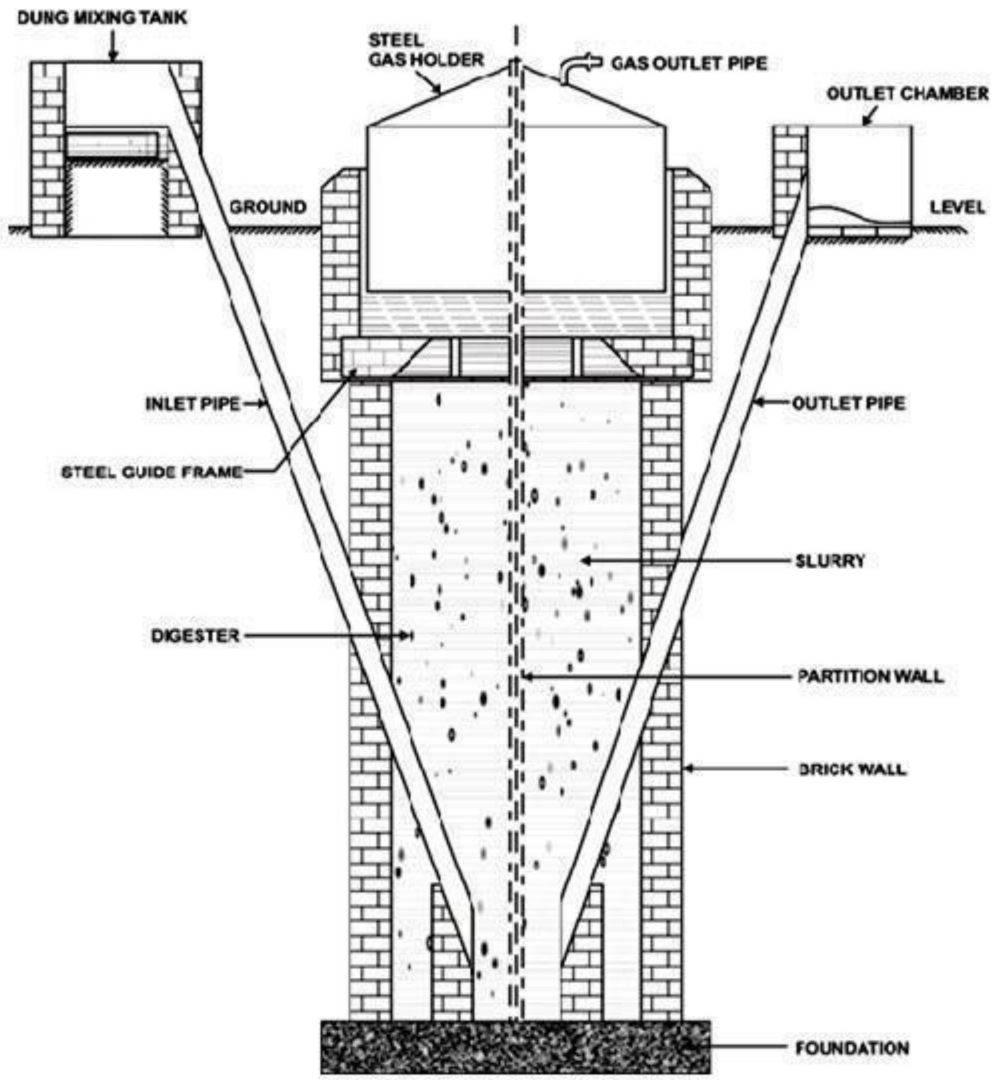


Figure 53 KVIC Biogas Plant Model

Small masonry tanks are constructed for mixing of cow dung, water and to discharge the slurry out of the digester. Concrete pipes are provided to convey the raw and digested slurry in and out of the digester. Gas outlet pipe is provided at top of the drum to let the gas out of drum. KVIC floating drum model is predominantly used in India.

Advantages and disadvantages of floating drum plant

Advantages

- Higher gas production per cum of the digester volume is achieved.
- Floating drum has welded braces, which help in breaking the scum by

rotation.

- No problem of gas leakage.
- Constant gas pressure.

Disadvantages

- It has higher cost, as cost is dependent on steel and cement
- Heat is lost through the metal gasholder.
- Gasholder required painting once or twice a year, depending on the humidity of the location.
- Flexible pipe joining the gasholder to the main gas pipe requires maintenance, as ultraviolet rays in the sun damage it.

Fixed dome biogas plants (Constant volume)

To reduce the cost of biogas plants, researchers has designed fixed dome plants in which dome act as gasholder in place of high cost drum. Gasholder and digester constructed as single unit. The digesters of such plants are completely underground to maintain a perfect environment for anaerobic fermentation to take place besides avoiding cracking of dome due to difference in temperature and moisture.

Janatha Biogas Plants

This is the first fixed-dome biogas plant was introduced in the form of the Janta Model Biogas Plant by Gobar Gas Research Station, Ajitwal in 1978. The main feature of this model is that the digester and the gas holder are integrated parts of brick masonry structure. The digester is made of a shallow well having a dome-shaped roof on it.

Provision of Inlet and outlet of raw and digested slurry is constructed in the form of tank. Slurry fed is allowed to undergo anaerobic fermentation in the digester. Gas produced as a result rises up and gets collected in the dome. As the pressure of gas stored in the dome increases, it pushes up the slurry down and causes the slurry level to increase both in inlet and outlet tanks. These levels drop down when the gas in the dome is used up. This displacement provides necessary pressure to push the gas up to the usage point. The pressure coming out of the dome is of variable type as constant in the case of floating drum type. Volume of gas stored in the plant is equal to the total volume of slurry displaced both in inlet and outlet tanks. The size of these plants is limited to 15 m^3 per day.

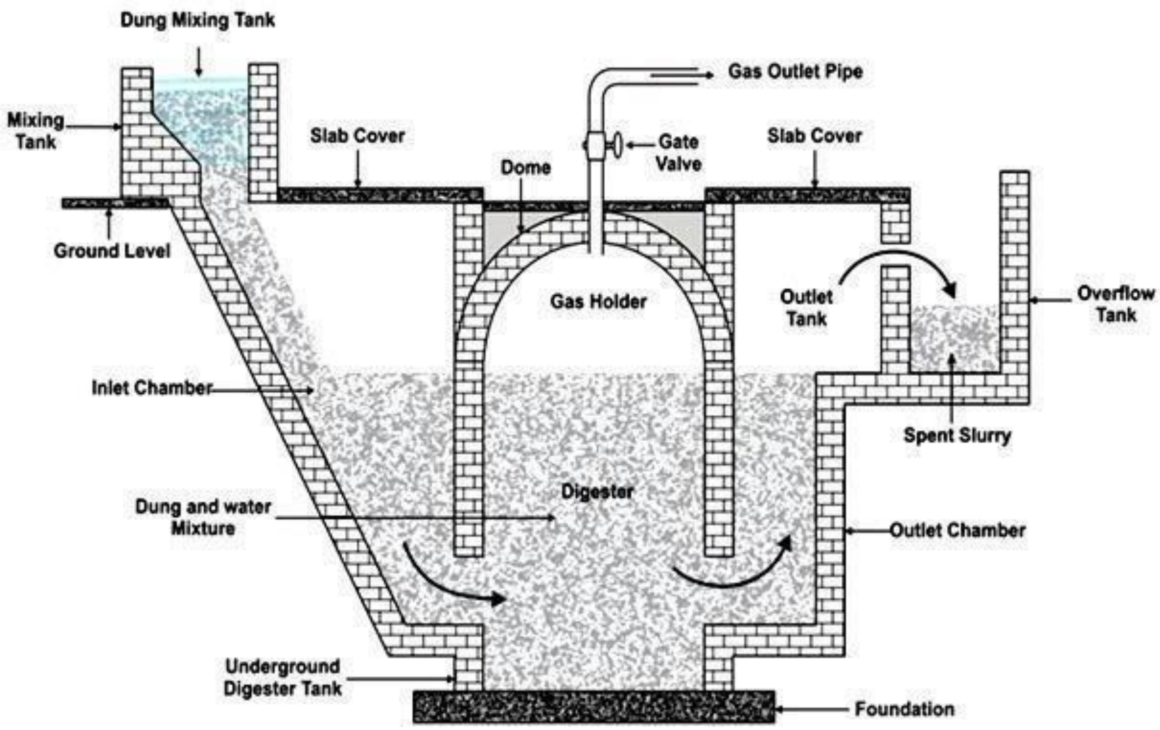


Figure 54 Janata Model Biogas Plant

Deenbandhu Biogas Plants

One of the outstanding designs of biogas plants in Indian biogas development program is Deenbandhu biogas plant design. It is improved version of Janatha biogas plant model. Action for food production (AFPRO), a voluntary organization based in New Delhi, developed this model in 1984. This is constructed with locally available materials and the plant demand skilful manpower for construction. Important considerations for design modification are reduction in the overall construction cost, elimination of the loss of biogas through inlet chamber and maximum utilization of digester volume to make the operational HRT close to the designed HRT.

It is constructed by joining the two spheres of different diameters at their bases, thus reducing the cost of bricks used in construction of digester wall. Bottom part of the plant is a designed as a segment of sphere, whereas the top portion as hemisphere. In this plant feedstock is fed through concrete pipes and the digested slurry is taken out the digester through tank. As a precaution to avoid the entry of slurry through gas outlet pipe, outlet opening is constructed 150 mm lower than the bottom of gas outlet pipe. Gas holding capacity is 33 per cent of total capacity of the plant.

Studies proved that the cost of deenbandhu is 30 and 45 per cent less than that of Janatha and KVIC biogas plants. The size of these plants is recommended up to 6 m^3 per day.

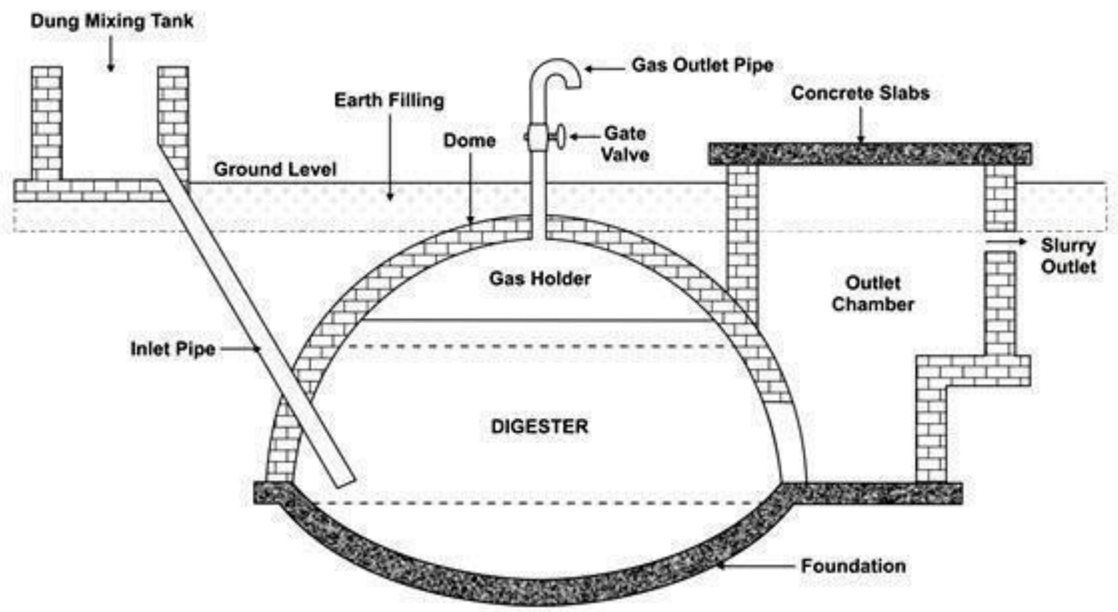


Figure 55 Deenbandhu Model Biogas Plant

Advantages

- It has low cost compare to floating drum type, as it uses only cement and no steel.
- It has non-corrosion trouble.
- It this type heat insulation is better as construction is beneath the ground.

- Temperature will be constant.
- Cattle and human excreta and long fibrous stalks can be fed.
- No maintenance.

Disadvantages

- This type of plant needs the services of skilled masons, who are rather scarce in rural areas.
- Gas production per cum of the digester volume is also less.
- Scum formation is a problem as no stirring arrangement
- It has variable gas pressure

Table 3 Comparison among KVIC, Janta and Deenbandhu biogas plants

S. No.	KVIC	Janata	Deenbandhu
1.	The digester of this plant is a deep well shaped masonry structure. In plants of above $3m^3$ capacity a partition wall is provided in middle of the digester.	Digester of this plant is a shallow well shaped masonry structure, No partition wall is provided.	Digester is made of segments of two spheres: one for the bottom and other for the top.
2.	Gas holder is generally made of mild steel. It is inverted into the digester and goes up and down with formation and utilization of gas.	Gas holder is an integral part of the masonry structure of the plant. Slurry from the gas storage portion is displaced out with the formation of gas and comes back when it is used.	The structure described above includes digester and the gas storage chamber. Gas is stored in the same way as in the case of Janata plants.
3.	The gas is available at a constant pressure of about 10 cm of water column.	Gas pressure varies from 0 to 90 cm of water column.	Gas pressure varies from 0 to 75 cm of water column.
4.	Inlet and outlet connections are provided through A.C pipes	Inlet and outlet tanks are large masonry structures designed to store the slurry displaced out of the digester with the formation of gas.	Inlet connection is through A.C pipe. Outlet tank is a large masonry tank designed to store slurry displaced out of the digester with the formation of gas.

5.	Gas storage capacity of the plant is governed by the volume of gas holder and is 50% of gas produced per day.	It is the combined volume of inlet and outlet displacement chambers and is 50% of gas produced per day.	It is the volume of outlet displacement chamber and is 33% of gas produced per day.
6.	The floating mild steel gas holder needs regular care and maintenance to prevent the gas holder from getting worn out because of corrosion. It also has short life span.	There is no moving part and hence no recurring expenditure. It also has long working life.	There is no moving part and hence no recurring expenditure. It also has a long working life.
7.	Installation cost is very high.	It is cheaper than the KVIC type plants.	It is much cheaper than KVIC and Janata type plants.
8.	Digester can be constructed locally but the gasholder needs sophisticated workshop facilities.	Entire plant can be built by a trained mason using locally available materials.	Entire plant can be built by a trained mason using locally available materials.

Classification of biogas plants

The biogas plants are mainly classified into three classes

- Community biogas plants
- Institutional biogas plants
- Family size biogas plants

Community biogas plants

It is a plant to be used by a group of people as a community. These types of plants are installed by a Village Panchayat/Municipal Committee for any Village/Mohalla/Town/City. The biogas produced from this type of plant is distributed to the people living in that locality. The size of these plants is recommended to be more than 15 m^3 per day.

Institutional biogas plants

These types of biogas plants are installed by an institution such as religious institution like Gurudwara/Mandir/Gowshala or educational institution like School/College. The biogas produced from these plants is used for the respective institution. The size of these plants is recommended also to be more than 15 m^3 per day.

Family size biogas plants

This type of biogas plants are installed at individual family level. The biogas from this type of biogas plants are used by the individual family. The size of these plants is recommended up to 6 m^3 per day.

Factors involved in biogas production

Biogas production involves different physical, chemical and biological process for conversion of biodegradable organic materials to energy rich gas.

C/N ratio

The ratio of carbon to nitrogen present in the feed material is called C:N ratio. It is a crucial factor in maintaining perfect environment for digestion. Carbon is used for energy and nitrogen for building the cell structure. Optimum condition for anaerobic digestion to take place ranges from 20:1 to 30:1. This means the bacteria use up carbon about 20 to 30 times faster than they use up nitrogen.

When there is too much carbon in the raw wastes, nitrogen will be used up first and carbon left over. This will make the digestion slow down and eventually stops. On the other hand if there is too much nitrogen, the carbon soon becomes exhausted and fermentation stops. The nitrogen left over will combine with hydrogen to form ammonia. This can kill or inhibit the growth of bacteria specially the methane producers.

Temperature

Temperature affects the rate of reaction happening inside the digester. Increase in the ambient temperature increases the rate of reaction thus increasing the biogas production as well. Methane bacteria work best at a temperature of 35° – 38 °C. The fall in gas production starts at 20°C and stops at a temperature of 10 °C. Studies showed that 2.25 m^3 of gas was produced from 4.25 m^3 of cattle dung every day when the digester temperature was 25°C. When the temperature rose to 28.3°C the gas production was increased by 50 per cent to 3.75 m^3 per day.

Retention time

It is the theoretical time that particular volume of feedstock remains in the digester. In other words, retention time describes the length of time the material is subjected to the anaerobic reaction. It is calculated as the volume of digester divided by the feedstock added per day and it is expressed in days. Under anaerobic condition, the decomposition of the organic substances is slow and hence need to keep for long time to complete the digestion. In case of Indian digesters, where the feed stock is diluted with equal composition, so demarcation prevails between solid and liquid. In this case, biomass in the form of bacteria is washed out; hence the solid retention time (SRT) is equal to hydraulic retention time (HRT).

Loading rate

Loading rate is defined as the amount of raw material fed to the digester per day per unit volume. If the reactor is overloaded, acid accumulation will be more obviously affecting daily gas production. On the other hand, under loading of digester have negative impact in designed gas production.

Toxicity

Though small quantities of mineral ions like sodium, potassium stimulates the growth of bacteria, the high concentration of heavy metals and detergents have negative impact in gas production rate. Detergents like soap, antibiotics, and organic solvents are toxic to the growth of microbes inside the digester. Addition of these substances along with the feed stock should be avoided.

pH or hydrogen ion concentration

To maintain a constant supply of gas, it is necessary to maintain a suitable pH range in the digester. pH of the slurry changes at various stages of the digestion. In the initial acid formation stage in the fermentation process, the pH is around 6 or less and much of CO_2 is given off. In the latter 2-3 weeks times, the pH increase as the volatile acid and N_2 compounds are digested and CH_4 is produced. The digester is usually buffered if the pH is maintained between 6.5 and 7.5. In this pH range, the micro – organisms will be very active and digestion will be very efficient. If the pH range is between 4 and 6 it is called acidic. If it is between 9 and 10 it is called alkaline.
Both these are detrimental to the methanogenic (Methane production) organisms.

Total solid content

The raw cow dung contains 80-82% of moisture. The balance 18-20% is termed as total solids. The cow dung is mixed usually in the proportion of 1:1 in order to bring the total solid content to 8-10%. This adjustment of total solid content helps in digesting the materials at the faster rate and also in deciding the mixing of the various crop residues as feed stocks in biogas digester.

Feed rate

One of the prerequisites of good digestion is the uniform feeding of the digester so that the micro – organisms are kept in a relatively constant organic solids concentration at all times. Therefore the digester must be fed at the same time every day with a balanced feed on the same quality and quantity.

Diameter to depth ratio

Studies reveal that gas production per unit volume of digester capacity was maximum, when the diameter to depth ratio was in the range of 0.66 to 1.00. One reason may be that because in a simple unstirred single stage digester the temperature varies at different depths. The most activity digesting sludge is in the lower half of the digester and this is less affected by changes in night and day temperature.

Nutrients

The major nutrients required by the bacteria in the digester are, C, H_2, O_2, N_2, P and S, of these nutrients N_2 and P are always in short supply and therefore to maintain proper balance of nutrients an extra raw material rich in phosphorus (night soil, chopped leguminous plants) should be added along with the cow dung to obtain maximum production of gas.

Degree of mixing

Bacteria in the digester have very limited reach to their food, it is necessary that the slurry is properly mixed and bacteria get their food supply. It is found that slight mixing improves the fermentation, however a violent slurry agitation retards the digestion.

Sizing of biogas plant

Sizing of biogas plant follows based on three parameters namely

- Daily feed,
- Retention time and
- Digester volume

The biogas plant size is dependent on the average daily feed stock and expected hydraulic retention time of the material in the biogas system. Capacity of the plant should be designed based on the availability of raw materials. Capacity of the plant indicates the quantity of gas produced in a day. Based on the study, 1 kg of cow dung along with equal quantity of water (1:1) under anaerobic conditions in a day produces 0.04 m^3 or 40 litres of biogas.

Based on the availability of cow dung, the capacity of biogas plant to be constructed can be calculated as follows

Example

i. Cow will yield an average of 10 kg of cow dung in a day.

ii. Assume a house is having 3 cows. iii. Our objective is to calculate the capacity of the plant to be constructed.

iv. 3 cow x 10 kg/cow/day = 30 kg of cow dung/day 1 kg of cow dung will yield 0.04 m^3 or 40 litres of biogas.

v. So 30 kg will produce 30 x 40 = 1200 litres or 1.2 m^3 of gas in a day.

vi. So the capacity of the plant to be constructed will be 1 m^3.

Example

To produce 1 m^3 of gas in a day, quantity of cow dung required can be calculated as

1 m^3 / (0.04 m^3/kg of cow dung) = 25 kg of dung.

When a biogas plant is underfed the gas production will be low; in this case, the pressure of the gas might not be sufficient to fully displace the slurry in the outlet chamber. If too much material is fed into the digester and the volume of gas is consumed, the slurry may enter the gas pipe and to the appliances.

Table: Quantity of cow dung required for different plant capacities.

Volume of Gas Produced (m^3)	Daily dung required/day (kg)	Quantity of water required (litres)
1	25	25
2	50	50
3	75	75
4	100	100
6	150	150
8	200	200

10	250	250

Scaling of the digester

The size of the digester i.e. the digester volume is determined by the length of the retention time and by the amount of fermentation slurry supplied daily. The amount of fermentation slurry consists of the feed material (e.g., cattle dung) and the mixing water.

Example

25 kg of cow dung + 25 l water = 50 l fermentation slurry

The digester volume is calculated by the formula

Digester volume (l) = Daily feed (l/day) x Retention time (days)

Assuming the Retention time to be 40 days, then the digester volume can be calculated by

Digester volume = 50 (l/day) x 40 (days)

= 2000 l or 2 m^3

Approximate rules used for sizing biogas plants

The following are some approximate rules used for sizing biogas plants or for estimating their performance:

1. One kg of dry cattle dung produces approximately 0.1 m^3 of biogas.
2. One kg of fresh cattle dung contains 8% dry biodegradable mass.
3. One kg of fresh cattle dung has a volume of about 0.9 litres.
4. One kg of fresh cattle dung requires an equal volume of water for preparing slurry.
5. Typical retention time of slurry in a biogas plant is 40 days.

Selection of construction site

Selection of construction sites are mainly governed by the following factors:

The site should facilitate easy construction works.

The selected site should be such that the construction cost is minimized

The selected site should ensure easy operation and maintenance activities like feeding of plant, use of main gas valve, composing and use of slurry, checking of gas leakage, draining condensed water from pipeline etc.

The site should guarantee plant safety.

To make plant easier to operate and avoid wastage of raw materials, especially the dung/swine manure, plant must be as close as possible to the cattle shed.

The site should be in slightly higher elevation than the surrounding. This helps in avoiding water logging. This also ensures free flow of slurry from overflow outlet to the composting pit.

For effective functioning of bio-digesters, right temperature (20-35°C) has to be maintained inside the digester. Therefore it is better to avoid damp and cool place – Sunny site is preferable.

To mix dung and water or flush swine manure to the digester, considerable quantity of water is required. If water source is far, the burden of fetching water becomes more.

The well or ground water source should be at least 10 meter away from the biodigester especially the slurry pit to avoid the ground water pollution.

If longer gas pipe is used the cost will be increased as the conveyance system becomes costly. Furthermore, longer pipeline increases the risk of gas leakage. The main gas valve which is fitted just above the gas holder should be opened and closed before and after the use of biogas. Therefore the plant should be as near to the point of application as possible.

The site should be at sufficient distance from trees to avoid damage of bio-digester from roots.

Type of soil should have enough bearing capacity to avoid the possibility of sinking of structure.

Location of biogas plant

A biogas plant should not be located further than 5 meters from the field. The digester chamber must be in an open area and should not be near any water source or natural water as animal excrement may seep into underground water. The plant should also be situated on a slope and not on the low land to avoid the danger of floods. The excess manure from expansion chamber should flow into the farmer's field or the storage tank and not into natural water bodies such as rivers to avoid the risk of pollution.

Lecture 5

Alternate feedstock and Applications of Biogas

Topics Covered: **Alternate feedstock for biogas production – applications of biogas cooking, lighting and engine operations – bio-digested slurry and enrichment.**

Feedstock

The material that is used in anaerobic digestion is called feedstock. The feedstock doesn't have to be waste, any biodegradable non-woody plant or animal matter is a suitable feedstock for a digester.

However, anaerobic micro-organisms cannot break down lignin, the complex polymer that gives plants their strength, which means that wood products, paper and straw will slow the digester.

The yield of biogas from a particular feedstock will vary according to the following criteria:

- Dry matter content
- The energy left in the feedstock, if it has undergone prolonged storage it may already have begun to break down
- Length of time in the digester
- The type of AD plant and the conditions in the digester
- The purity of the feedstock

Alternate feedstock for biogas production

Most easily biodegradable biomass materials are acceptable as feedstock for anaerobic digestion. Common feedstock include livestock manure, food-processing waste, and sewage sludge.

The energy production potential of feedstock varies depending on the type, level of processing/pre-treatment and concentration of biodegradable material. The biogas potential of feedstock is an important factor when considering anaerobic digestion on your farm. But other considerations, such as economics, regulatory issues, feedstock availability on and off the farm, and end use of the biogas, should also be evaluated.

Listed below are feedstock that can be commonly used in anaerobic digesters:

Livestock manures

Waste feed

Food-processing wastes

Slaughterhouse wastes

Corn silage (energy crop)

Ethanol stillage

Milkhouse wash water

Fresh produce wastes   Industrial wastes

Food cafeteria wastes

Sewage sludge

Uses of biogas

Biogas serves as a suitable alternate fuel for satisfying the energy needs of human society. It can be used for production of power, for cooking, lighting, etc.

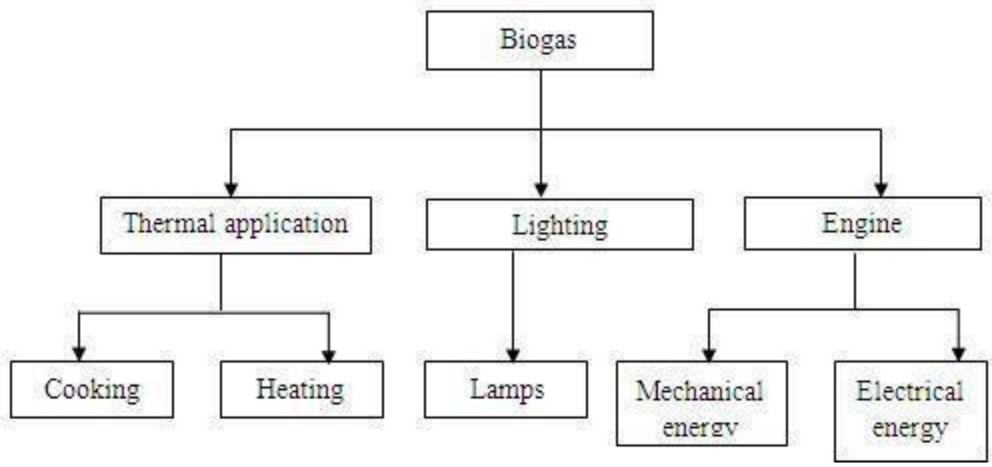


Figure 56 Applications of biogas

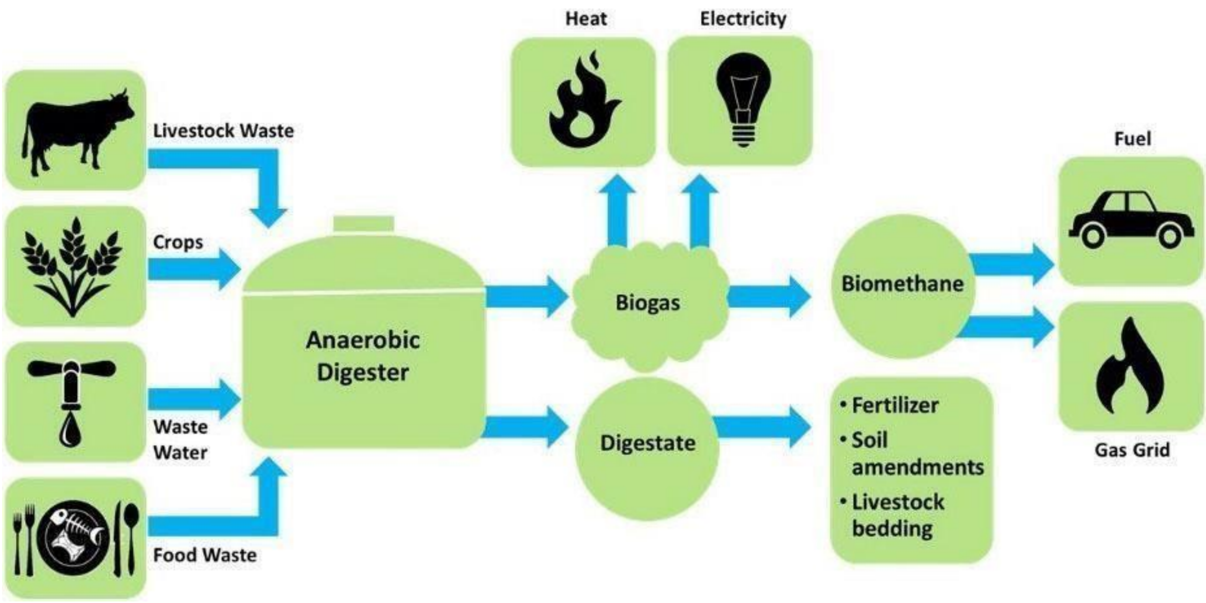


Figure 57 Illustration of Biogas Application

Cooking and lighting

The primary domestic uses of biogas are cooking and lighting. Because biogas has different properties from other commonly used gases, such as propane and butane, and is only available at low pressures (4 - 8 cm water), stoves capable of burning biogas efficiently must be specially designed. Biogas burns with blue flame and without any soot and odour which is considered to be one of the major advantage compared to traditional cooking fuel like firewood and cow dung cake.

Table: Required quantity of biogas for different purposes

S. No.	Purpose	Size	Required quantity of biogas (m_3/hour)
1.	Cooking	5 cm burner	0.30
		10 cm burner	0.50
		15 cm burner	0.64
2.	Lighting	100 candle power lamp	0.13
		1 mantle lamp	0.07-0.08
		2 mantle lamp	0.14
		3 mantle lamp	0.17

Lighting can be provided by means of a gas mantle, or by generating electricity. Biogas mantle lamps consume 2-3 cubic feet per hour having illumination capacity equivalent to 40 W electric bulbs at 220 volts. This application is predominant in rural and unelectrified areas.

Biogas as an Engine Fuel

Biogas can be used as a fuel in stationary and mobile engines, to supply motive power, pump water, drive machinery (e.g., threshers, grinders) or generate electricity. It can be used to operate four stroke diesel and spark ignition engines.

Electricity generation using biogas is a commercially available and proven technology. Typical installations use spark-ignited propane engines that have been modified to operate on biogas. Biogas-fuelled engines could also be used for other on-farm applications.

IC engines (typically used for electricity generation) can be converted to burn treated biogas by modifying carburetion to accommodate the lower volumetric heating value of the biogas into the engine and by adjusting the timing on the spark to accommodate the slower flame velocity of biogas ignition systems.

When biogas is used to fuel such engines, it may be necessary to reduce the hydrogen sulphide content if it is more than 2 percent otherwise the presence will lead to corrosion of engine parts.

In terms of electricity production, small internal combustion engines with generator can be used to produce electricity in the rural areas with clustered dwellings thus promoting decentralized form of electricity avoiding grid losses.

Use of biogas as vehicular fuel

Biogas is suitable as a fuel for most purposes, without processing. If it is to be used to power vehicles, however, the presence of CO_2 is unsatisfactory, for a number of reasons.

It lowers the power output from the engine, takes up space in the storage cylinders (thereby reducing the range of the vehicle), and it can cause problems of freezing at valves and metering points, where the compressed gas expands, during running, refuelling, as well as in the compression and storage procedure.

All, or most, of the CO_2 must therefore be removed from the raw biogas, to prepare it for use as fuel for vehicles, in addition to the compression of the gas into high-pressure cylinders, carried by the vehicle.

Uses of bio-digested slurry

The slurry after the digestion will be washed out of the digester which is rich in various plant nutrients such as nitrogen, phosphorous and potash. Well-fermented biogas slurry improves the physical, chemical and biological properties of the soil resulting qualitative as well as quantitative yield of food crops.

Figure 58 Bio-digested slurry as Fertilizer

Slurry from the biogas plant is more than a soil conditioner, which builds good soil texture, provides and releases plant nutrients. Since there are no more parasites and pathogens in the slurry, it is highly recommended for use in farming. The economic value of the slurry shows that investment can be gained back in three to four years' time if slurry is properly used.

The cow dung slurry after digestion inside the digester comes out with following characteristics and has following advantages:

- When fully digested, effluent is odourless and does not attract insects or flies in the open condition.
- The effluent repels termites whereas raw dung attracts them and they can harm plants fertilised with farmyard manure (FYM).
- Effluent used as fertiliser reduces weed growth with about 50%. When FYM is used the undigested weed seeds cause an increased weed growth.
- It has a greater fertilising value than FYM or fresh dung. The form in which nitrogen available can be easily assimilated by the crops.

Lecture 6

Biomass Briquetting

Topics Covered: **Briquetting – MED – VED – Methods – Need for briquetting - Benefits of biomass briquettes.**

Briquetting

The direct burning of these agro-residues in domestic and industrial applications is inefficient and associated with wide scale air pollution. In order to achieve more efficient usage of agro residues, it is essential to densify them to compact pieces of definite shape and high thermal value.

Briquetting is one of the several compaction technologies in the category of densification. The process of briquetting consists of applying pressure to a mass of particles with or without a binder and converting it into a compact product of high bulk density, low moisture content, uniform size and shape and good burning characteristics.

Figure 59 Saw Dust Briquettes

Briquetting is the process of densification of biomass to produce homogeneous, uniformly sized solid pieces of high bulk density which can be conveniently used as a fuel. In this process, the raw material is pressed together at an elevated temperature and forced through an orifice.

In a pure briquetting process, the pressure and temperature make the material bond with the help of its own lignin which acts as a binder. In some process utilizing a lower pressure or a lignin poor raw material, a separate binding material may be added.

Briquettes can be produced with the density of 1.2 to 1.4 g/cm^3 from loose agro residues with a bulk density of 0.1 to 0.2 g/cm^3.

Need for Densification

The low density of biomass materials poses a challenge for the handling, transportation, storage and combustion processes. These problems may be addressed through densification, a process that produces either liquid or solid fuel with denser and more uniform properties than the raw biomass.

Advantages of briquettes

- Better feed handling characteristics
- Higher calorific value
- Improved combustion characteristics
- Reduced particulate emissions
- More uniform size

Raw materials for briquetting

Almost all agro residues can be briquetted. Agro residues such as saw dust, rice husk, tapioca waste, groundnut shell, cotton stalks, pigeon pea stalks, soybean stalks, coir pith, mustard stalks, sugar cane bagasse, wood chips, tamarind pod, castor husk, coffee husk, dried tapioca stick, coconut shell powder are the commonly used raw materials for briquetting in India. All these residues can be briquetted individually and in combination with or without using binders.

The factors that mainly influence on the selection of raw materials are moisture content, ash content, flow characteristics, flow characteristics, particle size and availability in the locality.

Figure 60 Raw materials for Briquetting

Moisture content in the range of 10-15% is preferred because high moisture content will pose problems in grinding and more energy is required for drying. The ash content of biomass affects its slagging behaviour together with the operating conditions and mineral composition of ash. Biomass feedstock having up to 4% of ash content is preferred for briquetting. The granular homogeneous materials which can flow easily in conveyers, bunkers and storage silos are suitable for briquetting.

Energy density

Energy density is the amount of energy stored in a given system or region of space per unit volume or mass. Densification of biomass increases the mass energy density and volume energy density of biomass. Volume energy density of biomass is increased more than 100 % in spite of its moisture content. It is evident that the mass energy density of raw moist biomass is doubled when it is densified.

Mass energy density (MED)

Mass Energy Density is defined as the heat content of the fuel per unit mass. The unit for mass energy density is kJ/kg.

Volume Energy Density

Volume Energy Density is the heat content of the fuel per unit volume. The unit for volume energy density is kJ/m^3.

Relationship between mass energy density and volume energy density

$$\text{Mass energy density} = \frac{\text{Volume energy density}}{\text{Density of the material}} = \frac{kJ/m^3}{kg/m^3} = kJ/kg$$

Where

Mass energy density is in kJ/kg; Volume energy density is in kJ/m^3;

Density of the material is in kg/m^3.

Briquetting Process

The series of steps involved in the briquetting process are

Collection of raw materials

Preparation of raw materials

Compaction

Cooling and Storage.

Figure 61 Briquetting Process

Collection of raw materials

In general, any material that will burn, but is not in a convenient shape, size or form to be readily usable as fuel is a good candidate for briquetting.

Preparation of raw materials

The preparation of raw materials includes drying, size reduction, mixing of raw materials in correct proportion, mixing of raw materials with binder etc.

Drying

The raw materials are available in higher moisture contents than what required for briquetting. Drying can be done in open air (sun), in solar driers, with a heater or with hot air.

Size reduction

The raw material is first reduced in size by shredding, chopping, crushing, breaking, rolling, hammering, milling, grinding, cutting etc. until it reaches a suitably small and uniform size (1 to 10 mm). For some materials which are available in the size range of 1 to 10mm need not be size reduced. Since the size reduction process consumes a good deal of energy, this should be as short as possible

Raw material mixing

It is desirable to make briquettes of more than one raw material. Mixing will be done in proper proportion in such a way that the product should have good compaction and high calorific value.

Compaction

Compaction process takes place inside the briquetting machine. The process depends on the briquetting technology adopted.

Cooling and Storage of briquettes

Briquettes extruding out of the machines are hot with temperatures exceeding 100 °C. They have to be cooled and stored in dry place.

Briquetting Technologies

Briquetting technologies used in the briquetting of the agro residues are divided into three categories. They are

(i) High pressure or high compaction technology

In high pressure briquetting machines, the pressure reaches the value of 100 MPa. This type is suitable for the residues of high lignin content. At this high pressure the temperature rises to about 200 - 250°C, which is sufficient to fuse the lignin content of the residue, which acts as a binder and so, no need of any additional binding material.

(ii) Medium pressure technology

In medium pressure type of machines, the pressure developed will be in the range of 5 MPa and 100MPa which results in lower heat generation. This type of machines requires additional heating to melt the lignin content of the agro residues which eliminates the use of an additional binder material.

(iii) Low pressure technology

The third type of machine called the low pressure machines works at a pressure less than 5 MPa and room temperature. This type of machines requires addition of binding materials. This type of machines is applicable for the carbonized materials due to the lack of the lignin material.

High pressure or high compaction technology

The high pressure compaction technology for briquetting of agro residues can be differentiated in to two types (i) hydraulic piston press type and (ii) screw press type.

Among these two technologies hydraulic piston press type was predominantly used to produce briquettes in India, particularly in Tamil Nadu all the briquette producing firms' uses hydraulic piston press technology for briquetting. Mostly cylindrical shaped briquettes with 30 mm to 90 mm diameter were produced. All the commercial firms involved in briquette making produces 60 mm and 90 mm diameter briquettes.

Piston press technology

The piston presses are also known as ram and die technology. In this case the biomass is punched into a die by a reciprocating ram with a very high pressure thereby compressing the mass to obtain a briquette. The briquette produced is 60 mm in external diameter. This machine has a 700 kg/hr capacity and the power requirement is 25 kW. The ram moves approximately 270 times per minute in this process. Since the mechanical press is electric driven and not hydraulic driven, energy losses are reduced and throughput efficiency is increased.

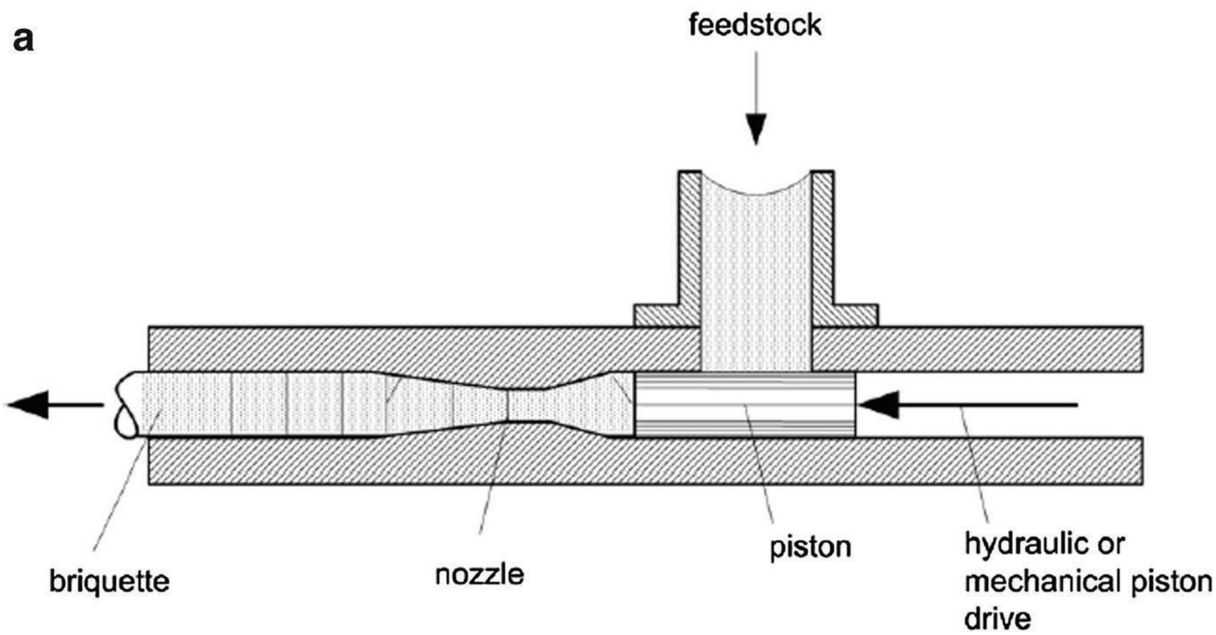


Figure 62 Piston Press Technology

The merits and demerits of piston press briquetting machine are:

There is less relative motion between the ram and the biomass hence, the wear of the ram is considerably reduced.

It is the most cost-effective technology currently offered by the Indian market.

The moisture content of the raw material should be less than 12% for the best results.

The quality of the briquettes goes down with an increase in production for the same power.

Carbonisation of the outer layer is not possible.

Briquettes are somewhat brittle.

Screw technology

In this process, the biomass is extruded continuously by one or more screws through a taper die which is heated externally to reduce the friction. Here also, due to the application of high pressures, the temperature rises fluidizing the lignin present in the biomass which acts as a binder. The outer surface of the briquettes obtained through this process is carbonized and has a hole in the centre which promotes better combustion. Standard size of the briquette is 60 mm diameter.

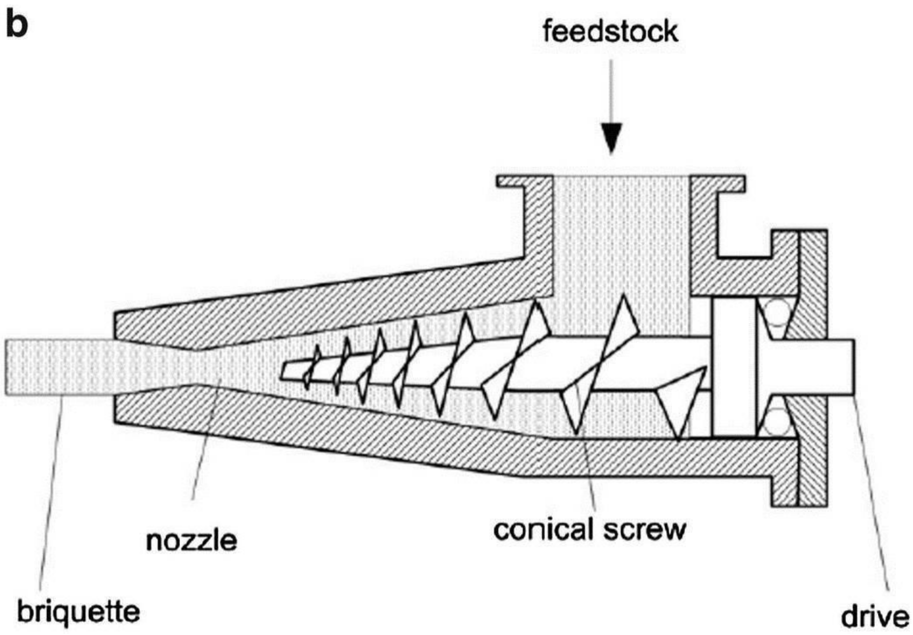


Figure 63 Screw Press Technology

The main merits and demerits of this technology are:

The output from the machine is continuous and not in strokes, and is also uniform in size.

The bulk density is higher (1500 kg/m^3 against 1200 kg/ m^3 for the piston press technology).

The outer surface of the briquette is carbonized facilitating easy ignition and combustion and also provides an impervious layer for protection against moisture ingress.

The central core of the briquette is hollow which provides a passage for supplying the air necessary for combustion.

The machine runs very smoothly with no shock loads.

The machine is very light due to the absence of reciprocating parts and flywheel.

There is no alternate suction and pressurization of machine thereby reducing the possibility of dust collection in the machine.

The power consumed by this equipment is very high.
The wear rate of the screw is very high.

There is a limitation on the raw material that can be compacted.

Comparison of a piston press and a screw extruder

	Piston press	**Screw extruder**
Optimum moisture content of raw material	10–15%	8–9%
Wear of contact parts	Low	High
Output from the machine	In strokes	Continuous
Power consumption	50 kWh/ton	60 kWh/ton
Density of briquette	1–1.2 gm/cm^3	1–1.4 gm/cm^3
Maintenance	High	Low
Combustion performance of briquettes	Not so good	Very good
Carbonization to charcoal	Not possible	Makes good charcoal
Suitability in gasifiers	Not suitable	Suitable

Homogeneity of briquettes	Non-homogeneous	Homogeneous

Necessary requirements to start a briquette production unit

1. Land requirement

Land area of minimum 1 acre is required for starting a briquette production unit to store the raw materials for briquetting and produced briquettes.

2. Raw materials

Continuous availability of raw materials is a major factor for profitable briquette production.

3. Drying facility to dry raw materials

The raw materials which are commonly available are with higher moisture content. So, any of the drying technologies such as solar driers/ heater/ hot air generator system is required to bring down the moisture content to an desirable level for briquetting.

4. Shredding machine

A shredding machine with minimum of 5 hp motor is required to powder the agro residues for briquetting.

5. Briquetting machine

A high pressure hydraulic piston press type briquetting machine powered by minimum of 50 hp motor is required to produce binderless briquettes from agro residues.

Figure 64 Paddy Straw based Briquetting Plant set up in Punjab

Lecture 7

Biomass Combustion

Topics Covered: **Combustion – Improved chulha – single pot – double pot – conventional chulha – biomass gas stove – constructional features – principles and applications**

Biomass Combustion

Biomass combustion simply means burning organic material. For ages, humans have used this basic technology to create heat and, later, to generate power through steam. Direct combustion is the most common method for converting biomass to useful energy.

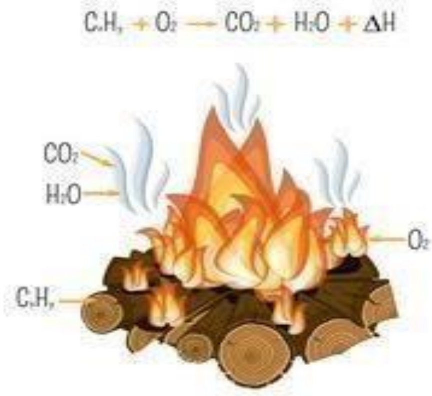


Figure 65 Biomass Combustion - Reaction

While wood is the most commonly used feedstock, a wide range of materials can be burned effectively. These include residuals and by-products such as straw, bark residuals, sawdust and shavings from sawmills, as well as so-called "energy crops" that are grown specifically to create feedstock. Briquettes or Pelletized agricultural and wood residues are also an increasingly popular option because they are very easy to handle.

Farmers and other rural homeowners are increasingly looking to biomass heat as an economical alternative to propane or furnace oil. Stoves and fireplaces can provide direct space heating or be hooked up with a back boiler that feeds heated water to radiators throughout the building.

Wood Burning Stoves

In India, 80 per cent of total population lives in villages. The major energy demand of rural population is for cooking which contributes to about 98 per cent of their total energy consumption. Wood, agricultural waste and biomass are used as fuel in rural kitchen. The cooking appliances which are commonly used in rural houses have very low thermal efficiency (10 to 15 per cent) and hence per capita energy consumption in rural areas is much higher than that in urban areas.

Conventional Stoves

Conventional stoves waste a lot of energy and pose many pollution hazards. Most traditional stoves can utilize only 2 – 10 per cent of the energy generated by the fuel. Black smoke emission consists of particles of sizes up to 5, CO, CO_2, oxides of nitrogen and sulphur, hydrocarbons, aldehydes, ketones etc. These pollutants are detrimental to environment and to the health of rural women. It causes headache, watery eyes, common cold and sneezing. Conventional stoves (chulha) take more time for cooking, more difficult to fire and consume more fuel.

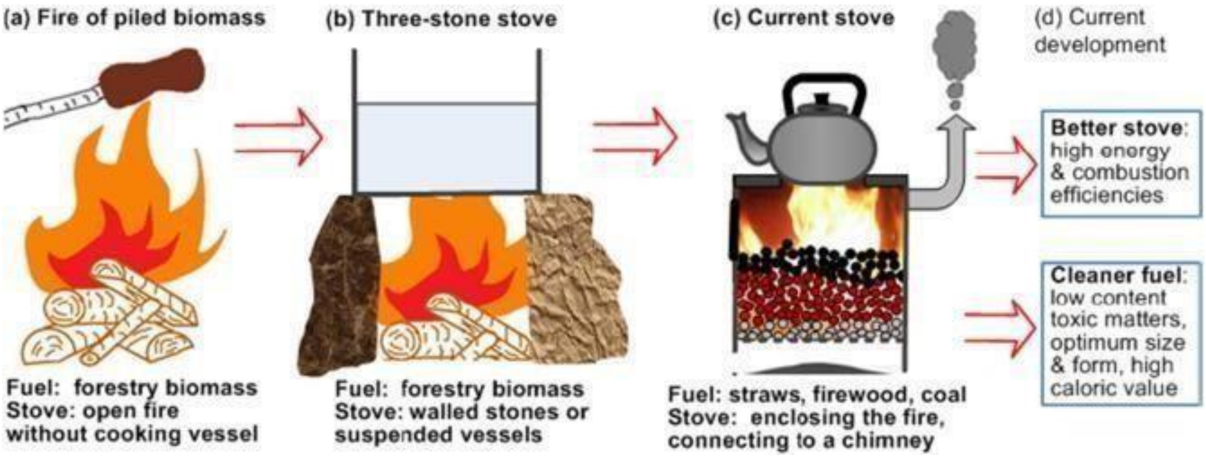


Figure 66 Wood Burning Stoves - Development

The growing gap between availability and demand for fire wood, poor thermal performance and pollution caused by traditional stoves forced the technologists to concentrate their attention on improving the thermal efficiencies of stoves. The adoption and large scale propagation of improved stoves would help in improving the health of rural women and in making a more efficient resource utilisation. This will also stop the large scale denudation of forest cover in the developing countries, and in arresting the large scale climatological changes.

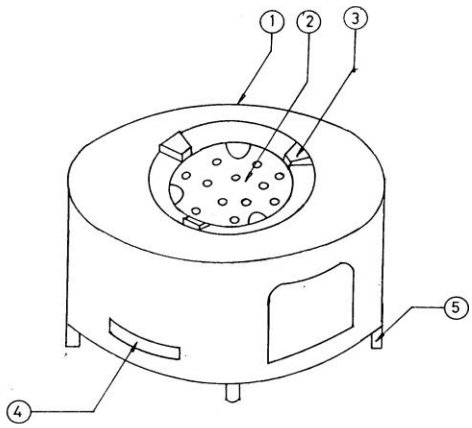
TNAU SINGLE POT CHULHA

The single pot chulha has a double wall with a gap of 2.5 cm. It has a grate at the bottom of the combustion chamber. The ash can be collected below the grate. The outer wall has two rectangular secondary air openings on both sides at the lower portion. The inner wall has 1cm diameter holes which maintain a triangular pitch of approximately 3 cm. Separate mounds are provided for holding bigger and smaller vessels. The secondary air enters through the rectangular opening in the outer wall, gets heated in the annular chamber and distributed through the holes in the combustion chamber. The preheated air helps in proper burning of the fuel.

Figure 67 TNAU Single Pot Chulha

Salient features

Height : 21 cm.
Inner wall diameter : 18 cm.
Outer wall diameter : 24 cm.
Fuel inlet opening : 15.5 x 15 cm.
Leg height : 5 cm.
Cost of the Unit : Rs. 350/-
Efficiency : 24%



1. Outer wall
2. Inner wall
3. Mount
4. Air hole

5. Leg

Figure 68 TNAU Single Pot Stove

TNAU Double Pot Chimneyless Chulha

This double pot portable chulha (Chimneyless) is made with two walls with an air gap of 2.5 cm. There are two secondary air inlets, one on the outer wall with rectangular shape (17 cm x 1 cm) near the combustion chamber and the other circular hole of diameter 5 cm at the bottom of the second pot. A cast iron grate is placed at the bottom of the combustion chamber.

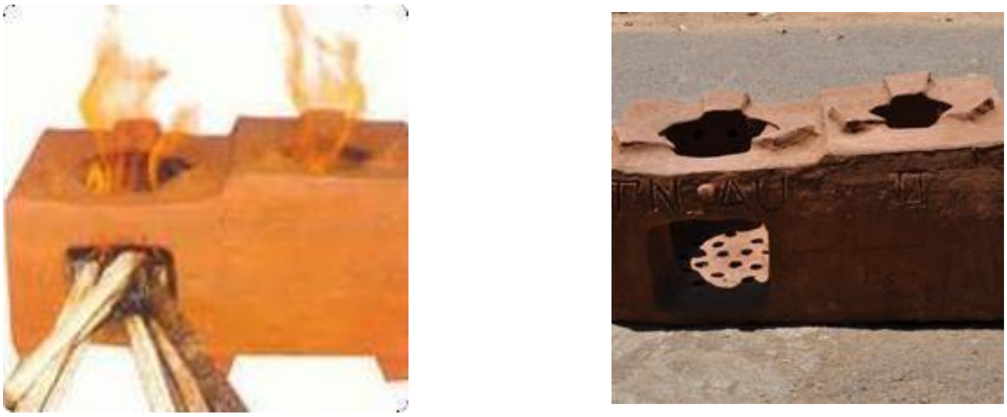
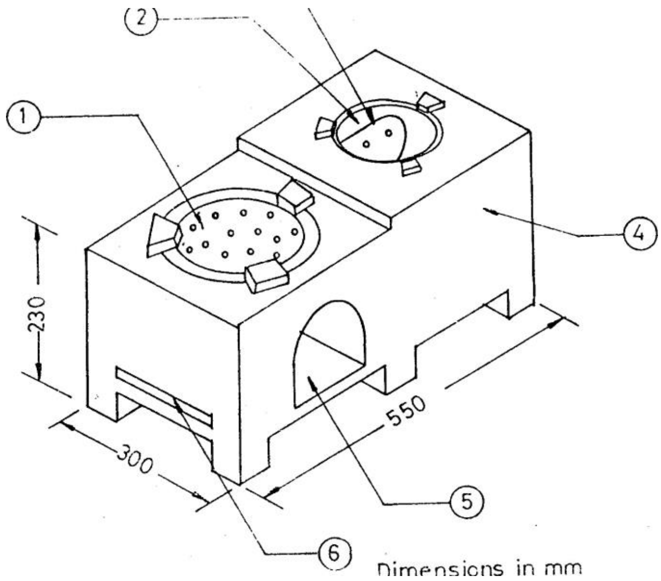


Figure 69 TNAU Double Pot Chimneyless Chulha

Salient features

Overall dimension	: 55 x 30 x 25 cm (L x B x H)
Fuel inlet opening	: 15.5 x 15 cm
Air inlet	: 17x1 cm
Size and No. of legs	: 5x5 cm 6nos
Cost of the Unit	: Rs. 600/-
Efficiency	: 26%



1. First pot hole
2. Second pot hole
3. Tunnel
4. Outer wall
5. Fire box
6. Air hole

Figure 70 TNAU Double Pot Stove

Biomass Gas Stove

The biomass gas stove has been developed for small scale thermal application in Agriculture and allied industries. This stoves widens the market for agro wastes, makes possible a higher efficiency and in some cases reduce the time and investment, all by comparison with combustion.

System Description

The biomass gas stove is a natural convection type updraft gasifier consisting of a cylindrical body made of clay, sand and paddy husk with its top open and bottom closed. The diameters and height of the stove are 290mm and 630mm respectively. This can be reduced depending on the applications.

An iron grate to hold the biomass is fixed at 50 mm from the base of the reactor. The bottom is provided with an air opening cum ash removal door. At the top, provision is made to place vessel for cooking, boiling etc.

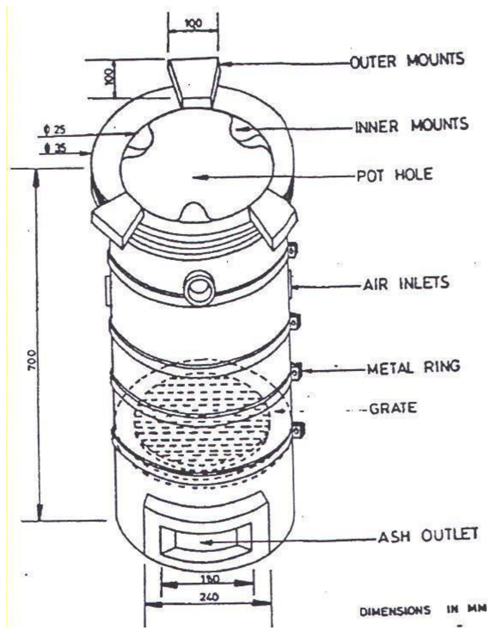


Figure 71 Biomass gas stove

Feedstock

The biomass viz., wood chips, agricultural residues like coconut shell, groundnut shell, arecanut husk, tree barks and leaves can be used in this biomass gas stove. The feedstock materials used should preferably be in the form of small chips, splinters and small logs.

Ignition methods

The stove can be ignited in two methods. One is igniting from bottom and other is from the top. In the first method, a bed of ignited charcoal (½- 1 kg) to a depth of 50mm is placed over the grate. Then the biomass used is dumped over the red hot charcoal. A white gas emanates first and the following the combustible gas is ignited.

Whereas in the second method, it is ignited at the top with diesel soaked waste cotton or by using easily combustible agricultural residues. Initially burning is started in combustion mode and then changes to gasification mode. The stove consumes 4 to 5 kg of biomass per hour. The quantity varies with the type of biomass used.

Efficiency of biomass gas stove

The conventional wood burning stoves give a thermal efficiency of 12-15 percent and the temperature of the flame obtained by direct combustion of biomass in the stove is in the range of 400-500° C only, whereas in the biomass gas stove the efficiency is 25 per cent and the temperature of the flame obtained is in the range of 600-700° C. The saving in fuel and time over the conventional wood stoves are 10 per cent and 40 per cent respectively. The cost of the unit is Rs.1000/-.

Applications of biomass gas stove

The biomass gas stove can be used for thermal applications in farm households, tea shops, jaggery manufacturing, small scale paddy parboiling, arecanut boiling and other agro-industrial applications.

Lecture 8

Biomass Pyrolysis

Topics Covered: **Pyrolysis – methods for charcoal production – biochar production – comparison between slow and fast pyrolysis**

Background and Necessity of Pyrolysis

Pyrolysis is the process, through which organic materials are converted into secondary fuels and chemical products in the absence of oxygen. The products are gases, condensed vapours as liquids, tars and oils and charcoal (solid). Among thermochemical methods, combustion and gasification are now widely in use for energy generation, and also for rural and industrial applications.

Principle

Pyrolysis is the one of the most common methods in thermal conversion technology of biomass. In pyrolysis, biomass is heated to moderate temperatures, 400-600 °C. In the absence of stoichiometric oxygen to produce oil that can be used as a feed stock in existing petroleum refineries. This is a high throughput process that has a potential for requiring relatively low capital investment. In gasification, biomass is heated to high temperatures, >700 °C, to produce a synthesis gas (H_2 and CO), which can be converted in a catalytic step to liquid transportation fuels. The products of biomass pyrolysis include biochar, bio-oil and gases including methane, hydrogen, carbon monoxide, and carbon dioxide.

Biomass Pyrolysis Techniques

Depending on the operating conditions, the pyrolysis process can be divided into three sub classes. Conventional slow pyrolysis, fast pyrolysis and flash pyrolysis.

The range of important operating parameters for pyrolysis processes is given in the following table. At present, the preferred technology is fast or flash pyrolysis at high temperature with very short residence time.

Main Operating Parameters for Pyrolysis Process

Operating parameters	Slow pyrolysis	Fast pyrolysis	Flash pyrolysis
Pyrolysis temperature (°C)	300-700	600-1000	800-1000
Heating Rate(°C/Sec)	0.1-1	10-200	>1000
Particle size (mm)	5-50	<1	<0.2
Solid residence time (Sec)	300-550	0.5-10	<0.5

Pyrolysis Processes

Slow Pyrolysis

Slow pyrolysis is a conventional pyrolysis process whereby the heating rate is kept slow (approximately 0.1-1 °C/s). This slow heating rate leads to higher char yield than the liquid and gaseous products. Slow pyrolysis has been utilized for thousands of years primarily for the production of charcoal. In slow wood pyrolysis, biomass is heated to ~500 °C. The vapour residence time in the reactor, gas-phase products have ample opportunities to continue to react with other products to form char.

Fast Pyrolysis

Fast pyrolysis uses much faster heating rates (about 100-200 °C) and is considered as a better process than slow pyrolysis for producing liquid or gases. In fast pyrolysis the liquid product yield is higher since the fast heating rates allow the conversion of thermally unstable biomass compounds to a liquid product before they form undesired coke. Typically, fast pyrolysis processes produce 60-75 wt% of liquid bio oil, 15-20%wt of solid char and 10-20 %wt of non-condensable gases depending on the feed stock used. Fast pyrolysis occurs on the timescale of a few seconds or less.

Flash Pyrolysis

Flash pyrolysis is an improved version of fast pyrolysis, whereby the heating rates are very high, >1000 °C/s, with reaction times of few to several seconds.

Feedstocks for Pyrolysis

A wide range of biomass feedstocks can be used in pyrolysis processes. The pyrolysis process is very dependent on the moisture content of the feedstock, which should be around 10%. At higher moisture contents, high levels of water are produced and at lower levels there is a risk that the process only produces dust instead of oil. High-moisture waste streams, such as sludge and meat processing wastes, require drying before subjecting to pyrolysis.

Advantages of Pyrolysis

Pyrolysis can be performed at relatively small scale and at remote locations which enhance energy density of the biomass resource and reduce transport and handling costs. Pyrolysis offers a flexible and attractive way of converting solid biomass into an easily stored and transported liquid, which can be successfully used for the production of heat, power and chemicals.

Bio-oil

Bio-oil is a dark brown liquid and has a similar composition to biomass. It has a much higher density than woody materials which reduces storage and transport costs. Bio-oil is not suitable for direct use in standard internal combustion engines. Alternatively, the oil can be upgraded to either a special engine fuel or through gasification processes to a syngas and then biodiesel. Bio-oil is particularly attractive for co-firing because it can be more readily handled and burned than solid fuel and is cheaper to transport and store.

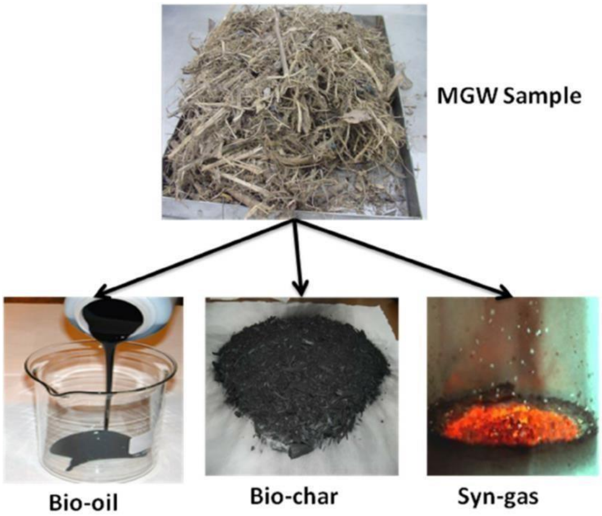


Figure 72 Products of Pyrolysis

Bio-oil can offer major advantages over solid biomass and gaification due to the ease of handling, storage and combustion in an existing power station when special start-up procedures are not necessary. In addition, bio-oil is also a vital source for a wide range of organic compounds and speciality chemicals.

Biochar

The growing concerns about climate change have brought biochar into limelight. Combustion and decomposition of woody biomass and agricultural residues results in the emission of a large amount of carbon dioxide. Biochar can store this CO_2 in the soil leading to reduction in GHGs emission and enhancement of soil fertility. In addition to its potential for carbon sequestration, biochar has several other advantages.

Biochar can increase the available nutrients for plant growth, water retention and reduce the amount of fertilizer by preventing the leaching of nutrients out of the soil.

Biochar reduces methane and nitrous oxide emissions from soil, thus further reducing GHGs emissions.

Biochar can be utilized in many applications as a replacement for other biomass energy systems.

Biochar can be used as a soil amendment to increase plant growth yield.

Lecture 9

Mid Semester Examination

Background and Necessity of Biofuels

India is dependent on imports of petroleum, where around 82 per cent of its crude oil requirement derived from the Middle East. The rising number of automobiles has also raised the increase in consumption, where the crude oil import volume amounted to approximately 217 million metric tons during the year 2018. But it was around 203 million metric tons in 2016.

Lecture 10 & 11

Biomass Gasification

Topics Covered: **Gasification – chemistry – types – updraft gasifier – working principles operations – application - Downdraft gasifier – working principles – operation and applications.**

Background and Necessity of Gasification

Gasification is a partial oxidation process whereby a carbon source such as coal, natural gas or biomass, is broken down into carbon monoxide (CO) and Hydrogen (H_2) plus carbon dioxide (CO_2) and possibly hydrocarbon molecules such as methane (CH_4). This mix of gas is known as producer gas and the precise characteristics of the gas will depend on the gasification parameters such as temperature and also the oxidizer used. The oxidizer may be air, in which case the producer gas will also contain Nitrogen (N_2), or steam or oxygen.

Chemistry of gasification

Gasification is a quite complex thermo-chemical process. Gasification stages viz., drying, pyrolysis, oxidation and reduction occur at the same time in different parts of gasifier.

The generation of gas occurs in two significant steps. The first step involves exothermic reactions of oxygen in air with the pyrolysis gas under fuel-rich conditions. The second step involves the endothermic reaction of these gases largely CO_2 and H_2O with hot char leading to product gases namely, CO, H_2 and CH_4.

Drying

Biomass fuel consists of moisture ranging from 5 to 35%. At the temperature above 100 °C, the water is removed and converted into steam. In the drying stage, fuels do not experience any kind of decomposition.

Pyrolysis

Pyrolysis is the thermal decomposition of biomass fuel in the absence of oxygen. Pyrolysis involves release of three kinds of products: solid, liquid and gases. The ratio of products is influenced by the chemical composition of biomass fuels and the operating conditions. The heating value of gas produced during the pyrolysis process is low (3.5 - 8.9 MJ/m^{3}). It is noted that no matter how gasifier is built, there will always be a low temperature zone, where pyrolysis takes place, generating condensable hydrocarbon.

Oxidation

Air is introduced in the oxidation zone contains oxygen, water vapours and inert gases such as nitrogen and argon. These inert gases are considered to be non-reactive with the fuel constituents. Oxidation takes place at 700-2000°C temperature. Heterogeneous reaction takes place between oxygen in the air and solid carbonized fuel, producing carbon monoxide. Positive and negative symbol indicate the release and supply of heat energy during the process respectively.

$$C + O_2 \rightarrow CO_2 + 406\ MJ/kmol$$

Hydrogen in fuel reacts with oxygen in the air blast, producing steam.

$$H_2 + ½\, O_2 \rightarrow H_2O + 242\ MJ/kmol$$

Reduction

In reduction zone, a number of high temperature chemical reactions take place in the absence of oxygen. The principal reactions that take place in reduction are mentioned below:

Boudouard reaction

$CO_2 + C \rightarrow 2CO - 172.6$ MJ/kmol

Water-gas reaction

$C + H_2O \rightarrow CO + H_2 - 131.4$ MJ/kmol

Water shift reaction

$CO_2 + H_2 \rightarrow CO + H_2O + 41.2$ MJ/kmol

Methane production reaction

$C + 2H_2 \rightarrow CH_4 + 75$ MJ/kmol

Main reactions show that heat is required during the reduction process. Hence, the temperature of gas goes down during this stage. If complete gasification takes place, all the carbon is burned or reduced to carbon monoxide, a combustible gas and some other mineral matter is vaporized. The remains are ash and some char (unburned carbon).

Types of Gasifiers

Gasifiers are basically divided into two major types namely fixed bed and fluidized bed.

Fixed Beds

Fixed bed gasifiers typically have a grate to support the feed material and maintain a stationary reaction zone. They are relatively easy to design and operate, and are therefore useful for small and medium scale power and thermal energy uses. It is difficult, however, to maintain uniform operating temperatures and ensure adequate gas mixing in the reaction zone. As a result, gas yields can be unpredictable and are not optimal for large-scale power purposes (i.e. over 1 MW).

Fluidized Beds

In a fluidized bed boiler, inert material and solid fuel are fluidized by means of air distributed below the bed. A stream of gas (typically air or steam) is passed upward through a bed of solid fuel and material (such as coarse sand or limestone). The gas acts as the fluidizing medium and also provides the oxidant for combustion and tar cracking. The fluidized bed behaves like a boiling liquid and has some of the physical characteristics of a fluid. Waste is introduced either on top of the bed through a feed chute or into the bed through an auger.

Fluidized-beds have the advantage of extremely good mixing and high heat transfer, resulting in very uniform bed conditions and efficient reactions. Fluidized bed technology is more suitable for generators with capacities greater than 10 MW because it can be used with different fuels, requires relatively compact combustion chambers and allows for good operational control. Fluidized beds offer the best vessel design for the gasification of MSW. Fluidized bed gasifiers have been the focus of appreciable research and development and there have been several commercialization projects over the last ten years. The two main types of fluidized beds for power generation are bubbling and circulating fluidized beds.

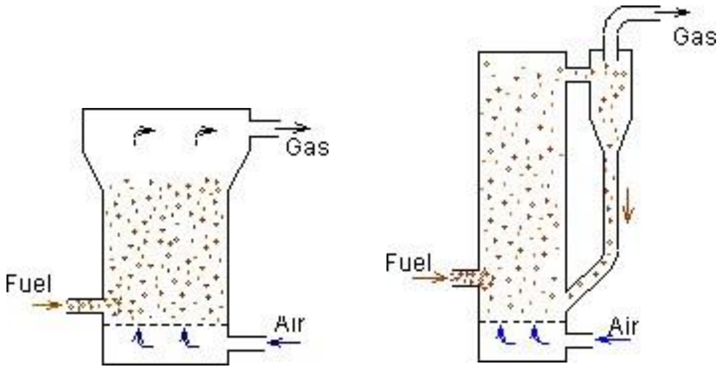


Figure 73 Fluidized bed gasifier

Classification of Fixed Bed Gasifiers

The primary types of fixed bed gasifiers are updraft, downdraft and crossdraft.

Updraft Gasifier

The air intake is at the bottom and the gas leaves at the top. Near the grate at the bottom the combustion reactions occur, which are followed by reduction reactions somewhat higher up in the gasifier. In the upper part of the gasifier, heating and pyrolysis of the feedstock occur as a result of heat transfer by forced convection and radiation from the lower zones. The tars and volatiles produced during this process will be carried in the gas stream. Ashes are removed from the bottom of the gasifier.

The major advantages of this type of gasifier are its simplicity, high charcoal burn-out and internal heat exchange leading to low gas exit temperatures and high equipment efficiency, as well as the possibility of operation with many types of feedstock (sawdust, cereal hulls, etc.).

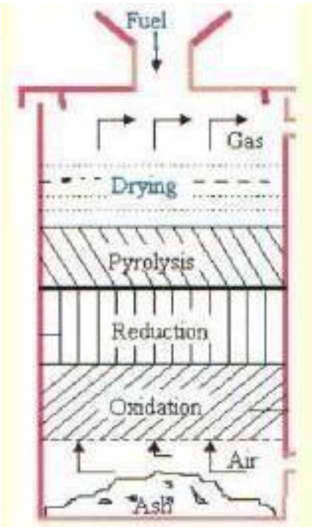


Figure 74 Updraft Gasifier

Down draft gasifier

The primary gasification air is introduced at or above the oxidation zone in the gasifier. The producer gas is removed at the bottom of the apparatus, so that fuel and gas move in the same direction.

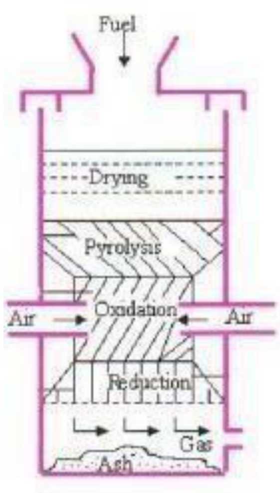


Figure 75 Downdraft Gasifier

The main advantage of down draft gasifiers lies in the possibility of producing a tar-free gas suitable for engine applications. A major drawback of down draft equipment lies in its inability to operate on a number of unprocessed fuels. Minor drawbacks of the down draft system, as compared to up draft, are somewhat lower efficiency resulting from the lack of internal heat exchange as well as the lower heating value of the gas. Besides this, the necessity to maintain uniform high temperatures over a given cross-sectional area makes impractical the use of down draft gasifiers in a power range above about 350 kW (shaft power).

Cross Draft Gasifier

In cross draft gasifier, the ash bin, fire and reduction zone are separated. The design characteristics limit the type of fuel for operation to low ash fuels such as wood, charcoal and coke. The load following ability of cross draft gasifier is quite good due to concentrated partial zones which operate at temperature up to 2000°C. Start up time (5 -10 minutes) is much faster than that of downdraft and updraft units. The relatively higher temperature in cross draft gasifier has an obvious effect on gas composition such as high carbon monoxide and low hydrogen and methane content when dry fuel such as charcoal is used. Cross draft gasifier operates well on dry blast and dry fuel.

The disadvantages such as high exit gas temperature, poor CO_2 reduction and high velocity are the consequence of the design.

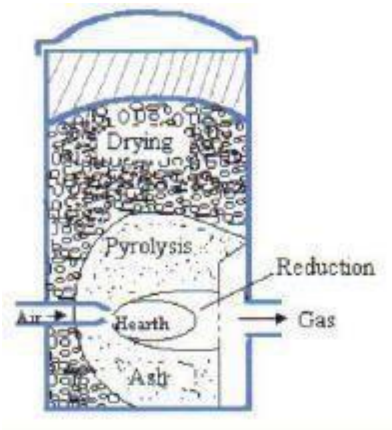


Figure 76 Crossdraft Gasifier

Applications of Gasifiers

For thermal applications, gasifiers are a good option as a gasifier can be retrofitted with existing devices such as ovens, furnaces, boilers, etc. Thermal energy of the order of 4.5 to 5.0 MJ is released by burning 1 m^3 of producer gas in the burner. Flame temperatures as high as 1200° C can be obtained by optimal air preheating and pre-mixing of air with gas. Producer gas can thus replace fossil fuels in a wide range of devices. A few of the devices which could be retrofitted with gasifiers are furnaces for melting non-ferrous metals and for heat treatment, tea dryers, ceramic kilns, boilers for process steam and thermal fluid heaters.

A diesel engine can be operated on dual fuel mode using producer gas. Diesel substitution of over 80% at high loads and 70 - 80% under normal load variations can be achieved. The mechanical energy thus derived can be used either for driving water pumps for irrigation or for coupling with an alternator for electrical power generation.

Alternatively, a gas engine can be operated with producer gas on 100% gas mode with suitably modified air / fuel mixing and control system.

Lecture 12

Solar Energy

Topics Covered: **Solar energy – characteristics of solar radiation - types of radiation – solar constant**

Background and Necessity of Solar Energy

Sun is the primary source of energy and all forms of energy on the earth are derived from it. The solar energy option has been identified as one of the promising alternative energy sources for the future.

Solar energy has the greatest potential of all the sources of renewable energy and if only a small amount of this form of energy could be used. Solar energy is a very large, inexhaustible source of energy. The power from the sun intercepted by the earth is approximately 1.8 x 10^{11} MW which is many thousands of times larger than the present consumption rate on the earth of all commercial energy sources. Thus, in principle, solar energy could supply all the present and future needs of the world on a continuing basis. This makes it one of the most promising of the unconventional energy sources.

Solar energy utilization in India

India has a total land area of 3.28 x 10^{11} m^2. On an average 5 kW/m^2 per day solar energy is falling on this land for over 300 days per annum. In certain areas the bright sunny days may be more. Even if 1 % of this land is used to harness solar energy for electricity generation at an overall efficiency of 10%, 492 x 10^9 kWh/year electricity can be generated.

Applications of solar energy

- Heating and cooling of buildings
- Solar water heating
- Solar air heating
- Salt production by evaporation of seawater
- Solar distillation
- Solar drying of agricultural products
- Solar cookers
- Solar water pumping
- Solar refrigeration
- Electricity generation through Photo voltaic cells
- Solar furnaces

Classification of methods for solar energy utilization

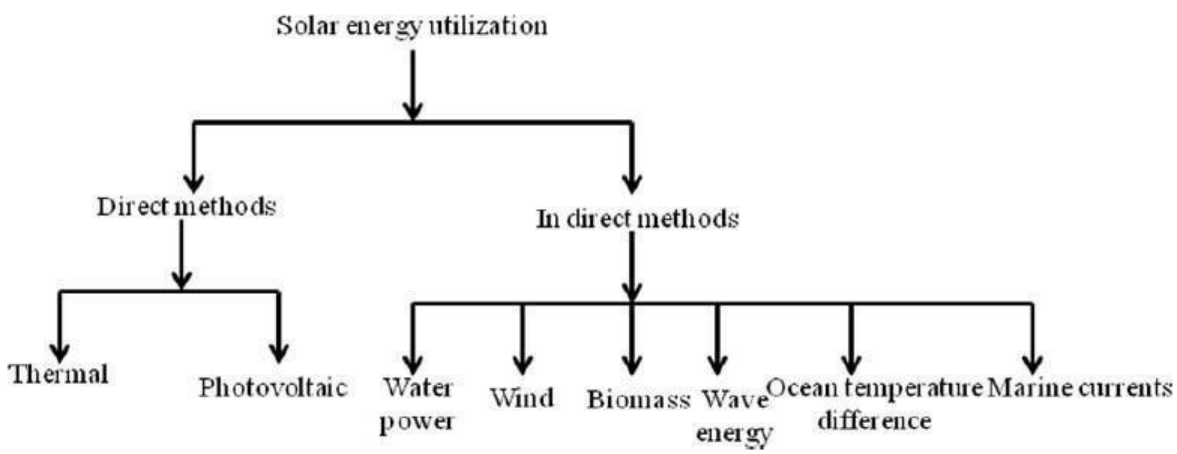


Figure 77 Solar Energy Utilization

Types of Solar Energy

The five common type of solar energy are as follow

Passive solar energy is refers to the harnessing of the sun's energy without using any mechanical devices. Using south-facing windows in home to provide natural lighting and heat are examples of passive solar energy.

Active solar energy is that type of solar energy which uses different mechanical devices in the collecting, storing, and distributing of solar energy.

Solar thermal energy is that form of solar energy which is created by converting solar energy into heat.

Photovoltaic solar power is that type of solar energy which is created by converting solar energy into electricity by the help of photovoltaic solar cells.

Concentrating solar power or CSP is a well-known type of solar thermal energy that is used to generate solar power electricity. Nowadays scientist and researches are aimed to large-scale energy production by the help of CSP.

Key Advantages & Disadvantages of Solar Power system

Advantages of Solar Power

Solar energy is free source of power but cost will be incurred in the building of 'collectors' and other required equipment to convert sunlight into electricity or hot water.

Solar energy does not cause any pollution so this is consider environment friendly. However, solar collectors and other related equipment are manufactured in factories that cause some pollution.

Solar energy can be used in such remote areas where it is highly expensive to extend the electricity power grid.

Disadvantages of Solar Power

Solar energy cannot be harnessed in cloudy weather or during night, it can only be harnessed during daytime and sunny.

Solar collectors, equipment, panels and cells are expensive to manufacture although the prices of all solar equipment are falling rapidly. Solar power stations are also very expensive. They can be built but there power output is less than the similar sized conventional power stations.

In countries like the UK, the unreliable climatic conditions means that solar energy is also unreliable as a source of energy. Cloudy skies reduce effectiveness of solar power in such areas.

A very large areas of land is required to capture the sunlight to convert in electricity. Collectors are arranged together to producing electricity for using in the same location.

Radiation

Heat transfers occur mainly by three mechanisms. The first is by conduction through solid materials is the presence of temperature difference. The second mechanism is radiation in which energy moves in space by electromagnetic waves. In a moving fluid, the fluid molecules gain the heat or lose it by conduction or radiation and carry its mechanism is called as convection.

Solar radiation is electromagnetic in nature and is the radiant energy emitted from the sun. The total frequency spectrum of this electromagnetic solar radiation covers visible light and near visible radiation (UV Rays, Infrared Rays, X-Rays, etc.). The visible light and heat supports life on earth while much of the near visible harmful radiation is deflected away by the earth's atmosphere.

Solar radiation is currently being used to generate electricity via two technologies photovoltaics and solar thermal. Photovoltic systems generate electricity directly by solar cells made from semiconductor materials.

Types of radiation

The solar radiation that penetrates the earth's atmosphere and reaches the surface differs in both amount and character of the radiation at the top of the atmosphere.

In the first place, part of the radiation is reflected back into the space, especially by clouds. Furthermore, the radiation entering the atmosphere is partially absorbed by molecules in the air. Oxygen and Ozone (O_3), formed from oxygen, absorb nearly all the ultraviolet radiation, and water vapour and carbon dioxide absorb some of the energy in the infrared range.

In addition, part of the solar radiation is scattered (i.e. its direction has been changed) by droplets in clouds by atmospheric molecules, and dust particles.

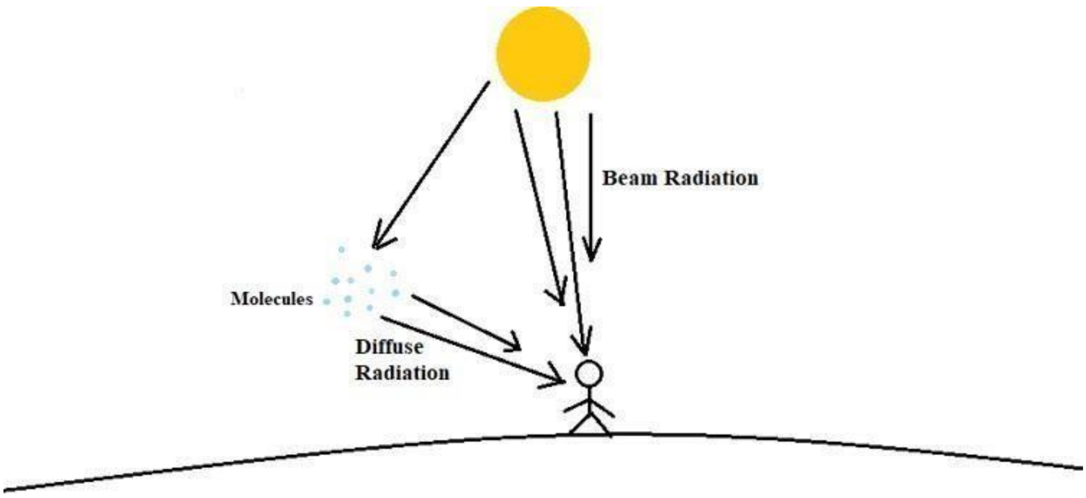


Figure 78 Direct and diffused sunlight

Solar radiation that has not been absorbed or scattered and reaches the ground directly from the sun is called direct radiation or beam radiation. It is the radiation, which produces a shadow when interrupted by an opaque object.

Diffuse radiation is that solar radiation received from the sun after its direction has been changed by reflection and scattering by the atmosphere. Because of the solar radiation is scattered in all directions in the atmosphere, diffuse radiation comes to the earth from all parts of the sky.

Solar Insolation

The total solar radiation received at any point on the earth's surface is the sum of the direct and diffuse radiation. This is referred to in a general sense as the insolation at the point. More specifically, the insolation defined as the total solar radiation energy received on a horizontal surface of unit area (e.g., 1 sq.m) on the ground in unit time (e.g., 1 day).

Solar insolation is the amount of electromagnetic energy (solar radiation) incident on the surface of the earth. This refers to the amount of sunlight shining down on the area under consideration. The values are generally expressed in $kWh/m^2/day$. This is the amount of solar energy that strikes a square meter of the earth's surface in a single day. This value is averaged to account for differences in the day's length.

The insolation at a given location on the earth's surface depends, among other factors, on the altitude of the sun in the sky (the altitude is the angle between the sun's direction and the horizontal). Since the sun's altitude changes with the date and time of the day and with the geographic latitude at which the observations are made, the rate of arrival of solar radiation on the ground is a variable quantity even in the time.

Instruments for measuring solar radiation and sunshine

Measurements of solar radiation are important because of the increasing number of solar heating and cooling applications, and the need for accurate solar irradiation data to predict performance. Two basic types of instruments are employed for solar radiation measurement

Pyrheliometer

A pyrheliometer is an instrument which measures beam or direct radiation.

Pyranometer

A pyranometer is an instrument which measures total or global radiation. The duration of bright sunshine in a day is measured by means of a sunshine recorder. India lies between latitude 7° and 37° N, and receives an annual average intensity of solar radiation 16700 - 29260 $kJ/m^2/day$, (400 $cal/cm^2/day$).

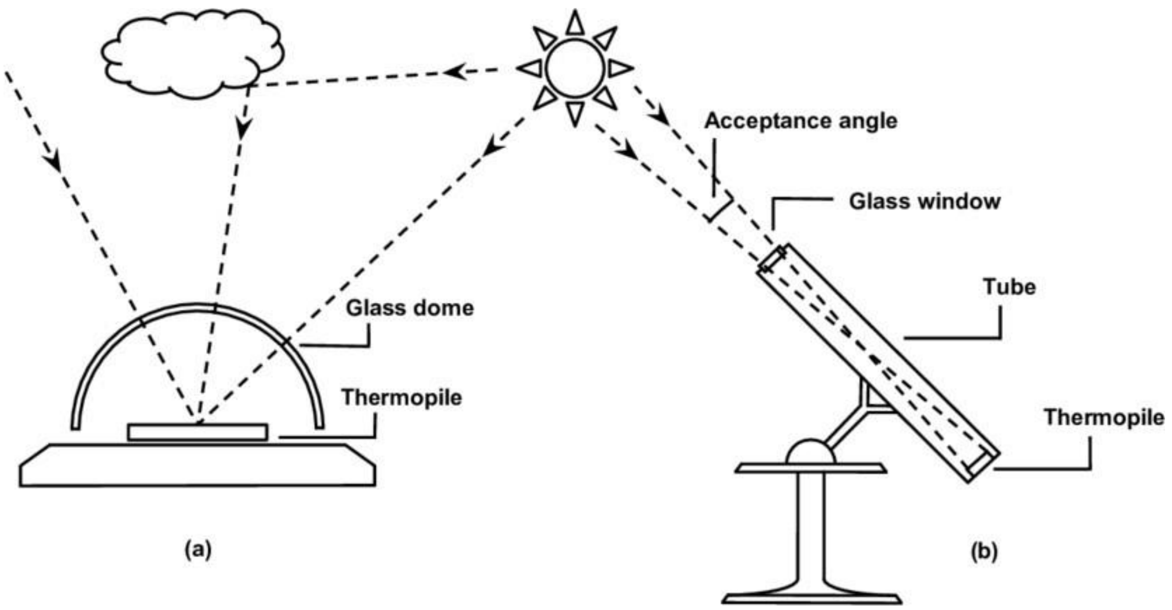


Figure 79 A schematic illustration of a pyranometer (a) and a pyrheliometer (b)

Solar constant - availability of solar radiation

The rate at which solar energy arrives at the top of the atmosphere is called the solar constant ISC. This is the amount of energy received in unit time on a unit area perpendicular to the sun's direction at the mean distance of the earth from the sun. Because of the sun's distance and activity vary throughout the year, the rate of arrival of solar radiation varies accordingly. The so called solar constant is thus an average from which the actual values vary up to about 3 percent in either direction. This variation is not important, however, for most practical purposes.

The National Aeronautics and Space Administration's (NASA) standard value for the solar constant, expressed in three common units.

1.353 kilowatts per square meter or 1353 watt per square metre.

116.5 langleys (calories per square cm) per hour, or 1165 kcal per sq. m per hour (1 Langley being equal to 1 cal/cm^2 of solar radiation received in one day).

Lecture 13

Solar Thermal Devices

Topics Covered: **Solar thermal devices – solar water heater – solar cooker – solar pond – solar distillation – working principles and applications.**

Solar Thermal Energy

Solar thermal energy is a form of energy and a technology for harnessing solar energy to generate thermal energy or electrical energy for use in industry, and in the residential and commercial sectors.

Solar collector

A solar collector is a device for collecting solar radiation and transfer the energy to a fluid passing in contact with it. The utilization of solar energy requires solar collectors. These are generally of two types

- Non - concentrating or flat plate type solar collector
- Concentrating (focussing) type solar collector

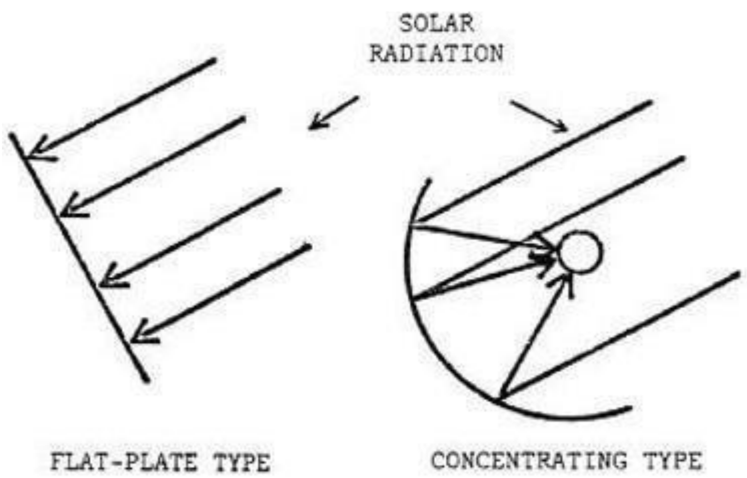


Figure 80 Flat plate and Concentrated Type Solar Collector

The solar energy collector, with its associated absorber, is the essential component of any system for the conversion of solar radiation energy into a more usable form (e.g. heat or electricity). In the non-concentration type the collector area (i.e. the area that intercepts the solar radiation) is the same as the absorber area (i.e. the area absorbing the radiation). On the other hand, in concentrating collectors, the area intercepting the solar radiation is greater, sometimes hundreds of times greater than the absorber area.

Physical Principles of the Conversion of Solar Radiation

The fundamental process now in general use for heat conversion is the greenhouse effect. Most of the energy we receive from the sun comes in the form of light, a shortwave radiation, not all of which is visible to the human eye. When this radiation strikes a solid or liquid, it is absorbed and transformed into heat energy; the material becomes warm and stores the heat, conducts it to surrounding materials (air, water, other solids or liquids) or reradiates it to other materials of lower temperature. This re-radiation is a long wave radiation.

Glass easily transmits short - wave radiation, which means that it poses little interference to incoming solar energy, but it is a very poor transmitter of long wave – radiation. Once the sun's energy has passed through the glass windows and has been absorbed by some material inside, the heat will not be radiated back outside. Glass therefore; act as a heat trap, a phenomenon which has been recognized for some time in the construction of greenhouses, which can get quite warm on sunny days, even in the middle of winter; this has come to be known in fact, as the 'greenhouse effect'. Solar collectors for home heating usually called flat plate collectors; almost have one or more glass covers, although various plastics and other transparent materials are often used instead of glass.

SOLAR WATER HEATERS

A solar water heater is a system that utilizes solar energy (or the energy from sunlight) to heat water. It has a system that is installed on a terrace or open space where it can get sunlight and the energy from the sun is then used to heat water and store it in an insulated tank.

The system is not connected to electricity supply and thus does not have an on-off switch, but it uses the sunlight throughout the day to heat the water and store it in the storage tank. Most of the solar water heater on a sunny day can provide heater water at about 68° ±5° C temperature. Water from the storage tank can then be used for any application as desired.

Components of Solar Water Heaters

The solar water heater consists of the following parts,

The solar collector, in which water is heated by solar radiation.

An insulated storage tank, in which the heated water from the collector is stored. The storage tank must be put higher than the top of the collector.

An insulated pipe connecting the lower part of the collector and the upper part of the storage tank.

An insulated pipe connecting the lower part of the storage tank and the bottom of the collector.

A cold water inlet connecting an existing water supply system to the storage tank. Usually the cold water inlet runs via a buffer tank with a floating gauge.

An insulated hot water outlet running from the storage tank to the tap.

A vent (air escape pipe) to prevent overpressure, caused by air or steam.

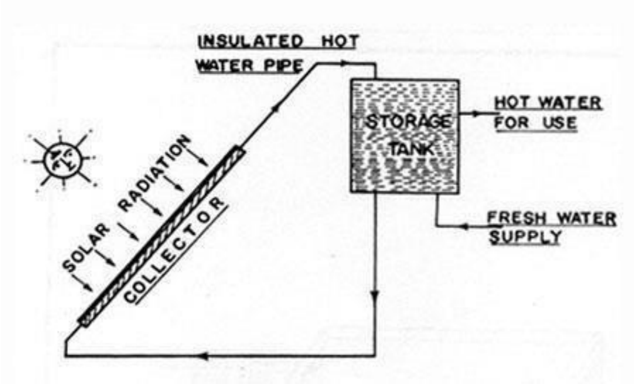


Figure 81 Thermo syphon Solar Water Heater

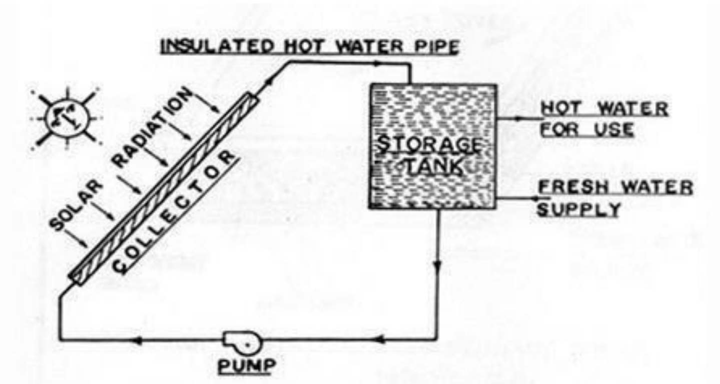


Figure 82 Forced Flow Solar Water Heater

TYPES AND BENEFITS

There are 2 types of solar water heaters that are available in the Indian market:

FLAT PLATE COLLECTORS SYSTEM

Flat Plate Collector Systems are metallic systems. They contain an insulated metallic box covered with a toughened glass. The metallic box has a layer of a copper sheet which is good for absorbing heat. The copper sheet is further coated with a black coating which improves heat absorption.

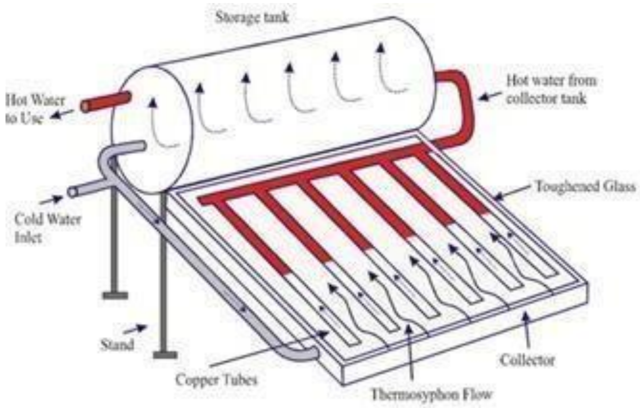


Figure 83 Flat plate Collectors

The metallic box contains copper tubes arranged vertically and connected at the top and bottom by two horizontal copper pipes called headers. The cold water enters the collector (the metallic box) from the bottom pipe and rises up into the vertical pipes. It gets heated up in the vertical pipes. As it gets heated the water becomes lighter (hot water is lighter than cold water) and it rises up and gets collected in the storage tank via the top horizontal pipe (or header). This water now gets available for use.

These are metallic type systems and have a longer life.

EVACUATED TUBE COLLECTORS SYSTEM

Evacuated Tube Collector systems are made of Glass. It has vertical tubes that are made out of two co-axial glass tubes. The air between the two coaxial tubes is removed to create a vacuum which improves insulation. Additionally, the surface of the inner tube is coated to provide better heat absorption and insulation. Coldwater is filled up in these glass tubes and it gets heated up due to the sunlight. Hot water is lighter than cold water, and so it rises up and gets collected in the storage tank from where it is available for use.

These systems are made up of glass and are fragile.

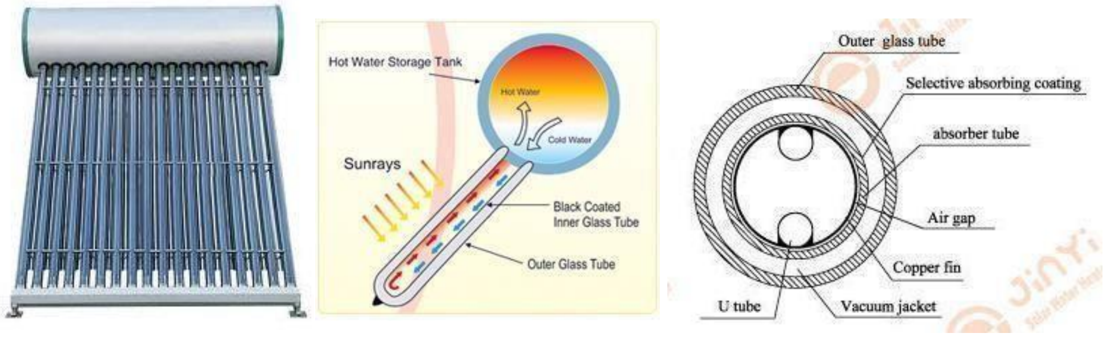


Figure 84 Evacuated Tube Collector

Both these type of water heaters come with or without a pump. The pump is used to move water from collectors to the storage tank. Those without pump use the thermosiphon principle to move water from collectors to storage tank automatically.

SOLAR COOKER

A device that utilizes solar energy for cooking purposes is called a solar cooker. The most commonly used form of solar cooker is known as box-type solar cooker.

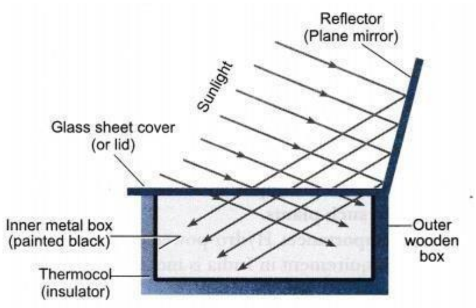


Figure 85 Box-type solar cooker

CONSTRUCTION OF A BOX-TYPE SOLAR COOKER

A box-type solar cooker consists of the following components:

Box (B): This is an insulated metal or a wooden box. It is painted black from inside because black surface absorbs more heat. The box may be provided with four roll-wheels.

Glass cover (G): A cover made of two sheets of toughened glass held together in an aluminum frame is used as a cover of the box B.

Plane mirror reflector: A plane mirror reflector fixed in a frame is fixed to the box B with the help of hinges. The mirror reflector can be positioned at any desired angle to the box. The mirror is positioned so as to allow the reflected sunlight fall on the glass cover of the box.

Cooking containers: A set of containers made of aluminum and blackened from outside are kept in the box B. These containers are also painted black because black surface absorbs more heat.

WORKING

The food is cooked in a shallow vessel of the container. The box has a transparent covering of glass sheet over it. The solar cooker is placed in sunlight and reflector (plane mirror) is adjusted in such a way that a strong beam of sunlight enters the box through the glass sheet. The blackened metal surfaces in the wooden box absorb infra-red radiations from the beam of sunlight and heat produced raises the temperature of blackened metal surface to about 100°C.

The food absorbs heat from the black surface and gets cooked. The thick glass sheet does not allow the heat produced to escape and thus, helps in raising the temperature in the box to a sufficiently high degree to cook the food.

PARABOLIC SOLAR COOKERS

Parabolic solar cookers use a parabolic-shaped reflector to direct sunlight to a small area in order to generate heat for cooking. They are able to reach high temperatures, 350 °C (662 °F) or higher, which allows them to be used for grilling and frying. Parabolic Solar
Cookers are also known as Concentrating Solar Cookers or solar dish cookers.

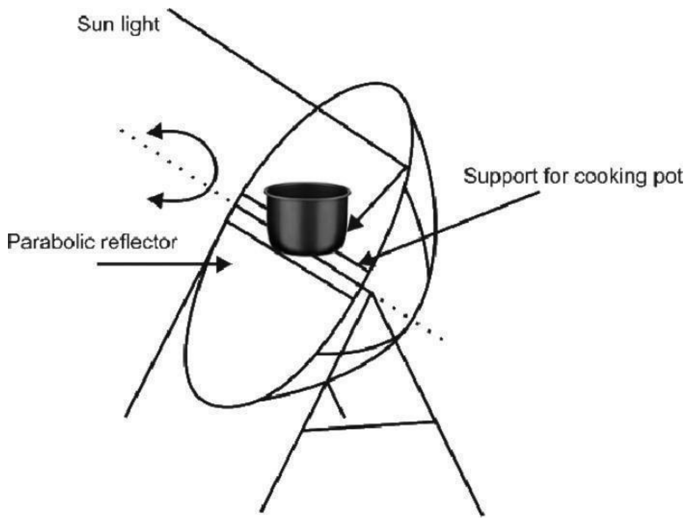


Figure 86 Parabolic Solar Cooker

PARTS OF CONCENTRATING SOLAR COOKERS

Reflecting Structure: Mainly all concentrating solar cookers are made with parabolic shape in circular or rectangular profile. Reflecting material can be anodized aluminum sheet, reflecting mirror or any other reflecting media with reflectivity more than or equal to 90. This will reflect all the sun rays to one focal point known as focus of the parabola.

Cooking Pot: At the focus of the parabola the heat is maximum due to concentration of the sun rays. The cooking pot is kept at the focal point so that maximum heat can be utilized. In this type of cookers the temperature can go beyond the 250 ºC. Due to this it can be used for frying also which is not possible in the box cooker or in panel cooker. The proper pot holder is provided at the focus of parabola.

Support Structure: This is the structure on which the complete parabolic cooker rest and perform its operation. It must have Rigid structure to withstand the higher wind velocity and also it should be protected with the corrosion resistance paint/ Coating.

Castor Wheel or Tracking Mechanism: This type of solar cookers require continuous tracking along with the rotation of the sun. So there is automatic tracking or the wheel is provided for the manual tracking.

WORKING

It concentrates all the sun ray at one focal point due to this the temperature is higher at the focal point where the cooking pot is kept. This can boil one liter of water in just 9-10 minutes.

ADVANTAGES

>>The cooking is very fast compared to Box Cookers and Panel Cookers.

>>The frying and making Chapattis is also possible.

>>Other commercial use like melting of wax, boiling of fruit juice etc. also possible.

>>Due to folding design it can be easily transport.

>>Smaller version with 1 m Diameter can cook for family of 10.

DISADVANTAGE

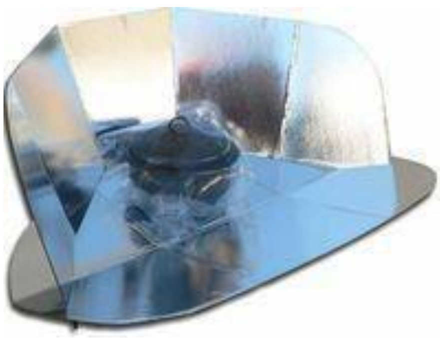
>> Due to higher temperature the burning of food can be possible.

>> Loss of food value compare to box cooker and panel cooker is higher in this type.

>> Attention is must for tracking and to check for over burning,

PANEL COOKERS

Panel cookers incorporate elements of box and parabolic cookers. They often have a large reflector area and the cook pot has some form of clear enclosure to retain heat. Panel cookers are capable of cooking at approximately 150 °C (302 °F). They are the easiest style to make and relatively inexpensive to buy.



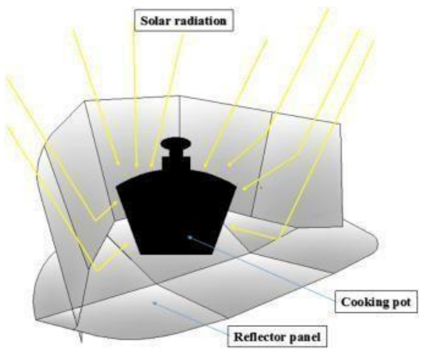


Figure 87 Panel Type Solar Cooker

SOLAR DISTILLATION

"Solar distillation" is a technology for producing potable water from brackish and underground water of low-quality at low cost. It can reduce water-scarcity problems together with other water purification technologies. Solar distillation is analogous to natural hydrological cycle. It uses an apparatus called a solar still in which water is evaporated using solar energy, a form of renewable energy, and collected as distillate after condensation of the vapor. It effectively produces distilled water after removal of impurities.

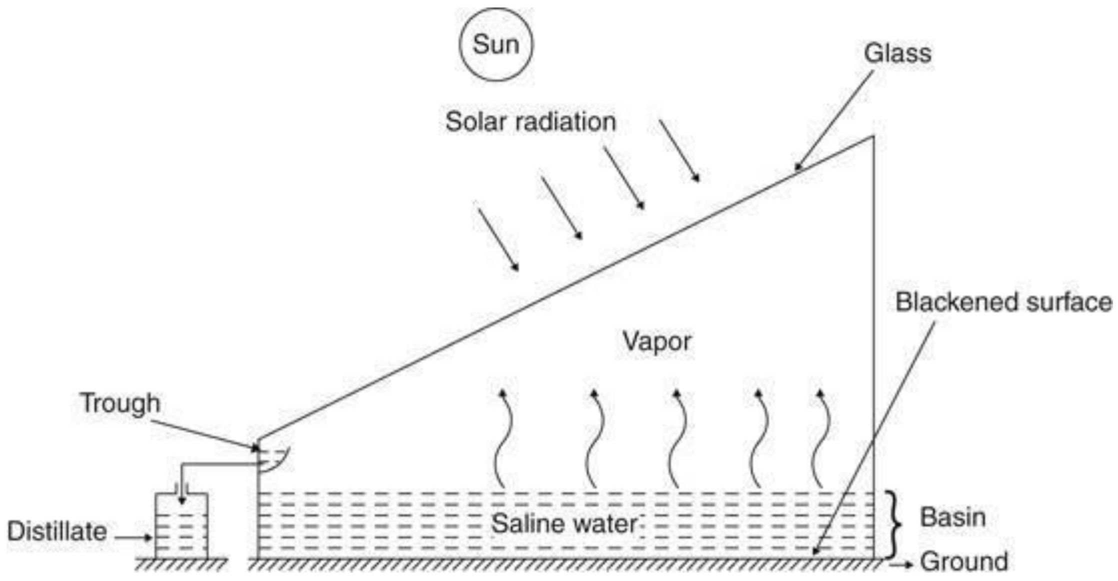


Figure 88 Solar Still

WORKING

The incident solar radiation is transmitted through the glass cover and is absorbed as heat by a black surface in contact with the water to be distilled. The water is thus heated and gives off water vapour. The vapour condenses on the glass cover, which is at a lower temperature because it is in contact with the ambient air, and runs down into a gutter from where it is fed to a storage tank.

SOLAR POND

A solar pond is a body of water that collects and stores solar energy. Solar energy will warm a body of water (that is exposed to the sun), but the water loses its heat unless some method is used to trap it. Water warmed by the sun expands and rises as it becomes less dense. Once it reaches the surface, the water loses its heat to the air through convection, or evaporates, taking heat with it. The colder water, which is heavier, moves down to replace the warm water, creating a natural convective circulation that mixes the water and dissipates the heat.

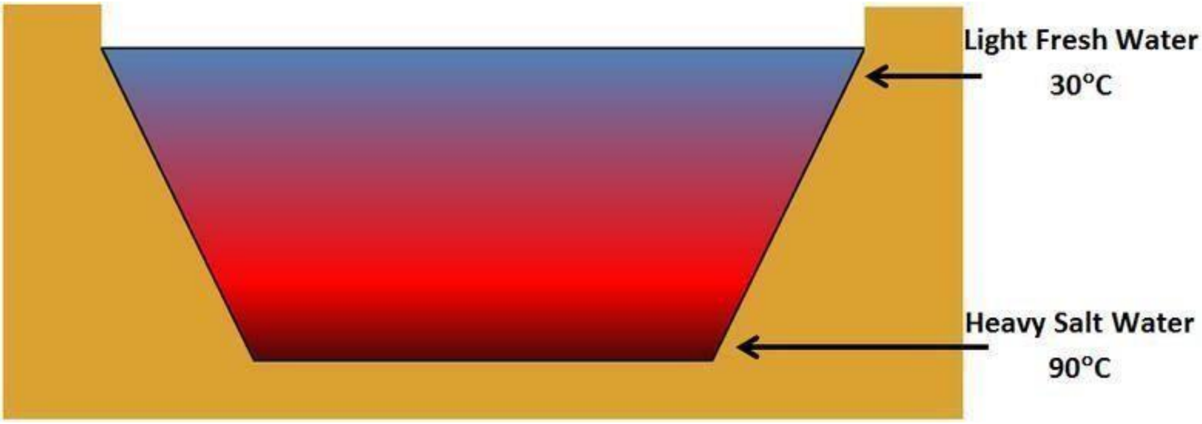


Figure 89 Solar Pond

The design of solar ponds reduces either convection or evaporation in order to store the heat collected by the pond. They can operate in almost any climate.

A solar pond can store solar heat much more efficiently than a body of water of the same size because the salinity gradient prevents convection currents. Solar radiation entering the pond penetrates through to the lower layer, which contains concentrated salt solution. The temperature in this layer rises since the heat it absorbs from the sunlight is unable to move upwards to the surface by convection. Solar heat is thus stored in the lower layer of the pond.

WORKING PRINCIPLE

The solar pond works on a very simple principle. It is well-known that water or air is heated they become lighter and rise upward. Similarly, in an ordinary pond, the sun’s rays heat the water and the heated water from within the pond rises and reaches the top but loses the heat into the atmosphere. The net result is that the pond water remains at the atmospheric temperature. The solar pond restricts this tendency by dissolving salt in the bottom layer of the pond making it too heavy to rise.

A solar pond is an artificially constructed water pond in which significant temperature rises are caused in the lower regions by preventing the occurrence of convection currents. The more specific terms salt-gradient solar pond or non-convecting solar pond are also used. The solar pond, which is actually a large area solar collector is a simple technology that uses a pond between one to four meters deep as a working material.

The solar pond possesses a thermal storage capacity spanning the seasons. The surface area of the pond affects the amount of solar energy it can collect. The dark surface at the bottom of the pond increases the absorption of solar radiation. Salts like magnesium chloride, sodium chloride or sodium nitrate are dissolved in the water, the concentration being densest at the bottom (20% to 30%) and gradually decreasing to almost zero at the top.

Zones of Solar Pond

Typically, a salt gradient solar pond consists of three zones.

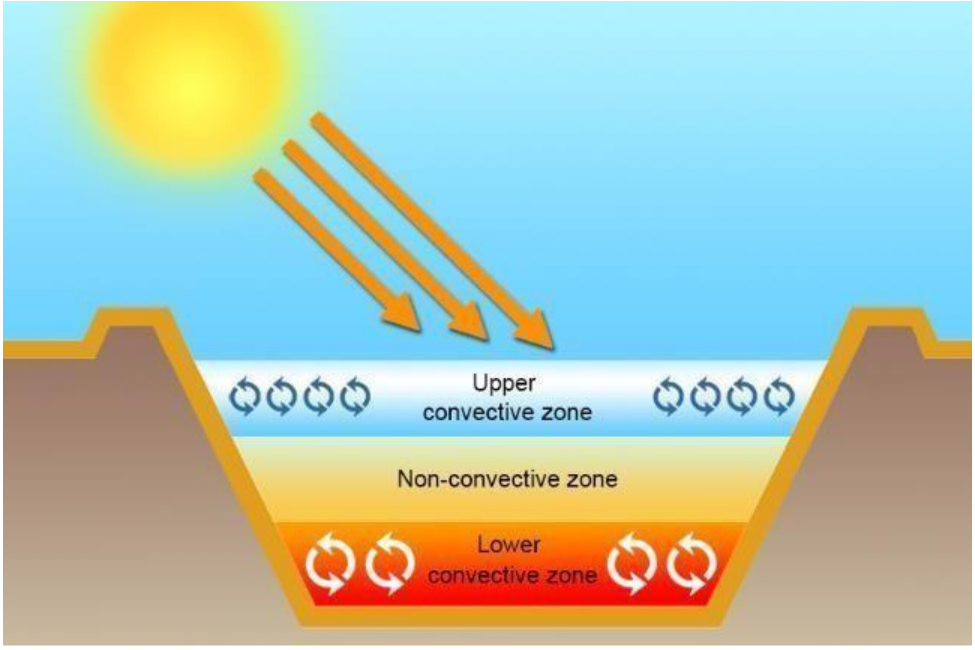


Figure 90 Diagram of the different layers of a Solar Pond

An upper convective zone of clear fresh water that acts as solar collector/receiver and which is relatively the shallowest in depth and is generally close to ambient temperature.

A gradient which serves as the non-convective zone which is much thicker and occupies more than half the depth of the pond. Salt concentration and temperature increase with depth.

A lower convective zone with the densest salt concentration, serving as the heat storage zone. Almost as thick as the middle non-convective zone, salt concentration and temperatures are nearly constant in this zone.

When solar radiation strikes the pond, most of it is absorbed by the surface at the bottom of the pond. The temperature of the dense salt layer therefore increases. But the salt density difference keeps the 'layers' of the solar pond separate. The denser salt water at the bottom prevents the heat being transferred to the top layer of fresh water by natural convection, due to which the temperature of the lower layer may rise to as much as 95°C.

TYPES OF SOLAR PONDS

CONVECTING SOLAR PONDS

A well-researched example of a convecting pond is the shallow solar pond. This pond consists of pure water enclosed in a large bag that allows convection but hinders evaporation. The bag has a blackened bottom, has foam insulation below, and two types of glazing (sheets of plastic or glass) on top. The sun heats the water in the bag during the day. At night the hot water is pumped into a large heat storage tank to minimize heat loss. Excessive heat loss when pumping the hot water to the storage tank has limited the development of shallow solar ponds.

NON-CONVECTING SOLAR PONDS

The main types of non-convecting ponds is salt gradient ponds. A salt gradient pond has three distinct layers of brine (a mixture of salt and water) of varying concentrations. Because the density of the brine increases with salt concentration, the most concentrated layer forms at the bottom. The least concentrated layer is at the surface. The salts commonly used are sodium chloride and magnesium chloride. A dark-colored material usually butyl rubber lines the pond. As sunlight enters the pond, the water and the lining absorb the solar radiation. As a result, the water near the bottom of the pond becomes warm up to 93.3°C. Even when it becomes warm, the bottom layer remains denser than the upper layers, thus inhibiting convection. Pumping the brine through an external heat exchanger or an evaporator removes the heat from this bottom layer. Another method of heat removal is to extract heat with a heat transfer fluid as it is pumped through a heat exchanger placed on the bottom of the pond.

APPLICATIONS

Process heat Studies have indicated that there is excellent scope for process heat applications (i.e. water heated to 80 to 90° C.), when a large quantity of hot water is required, such as textile processing and dairy industries. Hot air for industrial uses such as drying agricultural produce, timber, fish and chemicals and space heating are other possible applications a visual Demonstration of how a Solar Pond is used to Generate Electricity.

Drinking water is a chronic problem for many villages in India. In remote coastal villages where seawater is available, solar ponds can provide a cost-effective solution to the potable drinking water problem. Desalination costs in these places work out to be 7.5paise per litre, which compares favourably with the current costs incurred in the reverse osmosis or electrodialysis/desalination process.

Refrigeration applications have a tremendous scope in a tropical country like India. Perishable products like agricultural produce and lifesaving drugs like vaccines can be preserved for long stretches of time in cold storage using solar pond technology in conjunction with ammonia based absorption refrigeration system.

ADVANTAGES

Low investment costs per installed collection area.

Thermal storage is incorporated into the collector and is of very low cost.

Diffuse radiation (cloudy days) is fully used.

Very large surfaces can be built thus large scale energy generation is possible.

Expensive cleaning of large collector surfaces in dusty areas is avoided.

Lecture 14

Solar Photovoltaic (PV) Systems

Topics Covered: **Solar PV systems – principle – solar lantern - water pumping applications**

Solar Photovoltaic System

Electricity can be produced from sunlight through a process called the PV effect, where "photo" refers to light and "voltaic" to voltage.

The device used in photovoltaic conversion is called solar cells. When solar radiation falls on these devices, it is converted into DC electricity. The principle advantages associated with solar cells are that they have no moving parts, require little maintenance, and work quite satisfactorily with beam or diffuse radiation.

Photovoltaic Effect

The working principle of solar cells is based on the photovoltaic effect, i.e. the generation of a potential difference at the junction of two different materials in response to electromagnetic radiation. The photovoltaic effect is closely related to the photoelectric effect, where electrons are emitted from a material that has absorbed light with a frequency above a material-dependent threshold frequency.

Solar Cell

The solar energy conversion into electricity takes place in a semiconductor device that is called a solar cell. A solar cell is a unit that delivers only a certain amount of electrical power. In order to use solar electricity for practical devices, which require a particular voltage or current for their operation, a number of solar cells have to be connected together to form a solar panel, also called a PV module. For large-scale generation of solar electricity the solar panels are connected together in a solar array.

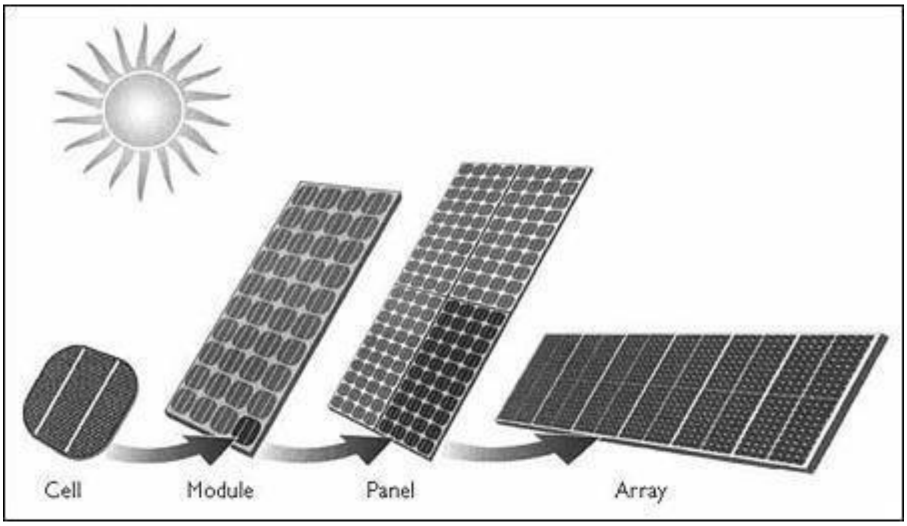


Figure 91 Photovoltaic array nomenclature

A PV cell can be either circular in construction or square. Cells are arranged in a frame to form a module. Modules put together form a panel. Panels from an array. Each PV cell is rated for 0.5 - 0.7 volt and a current of 30 mA/cm^2.

The solar cell is composed of a P-type semiconductor and an N- type semiconductor. Solar light hitting the cell produces two types of electrons, negatively and positively charged electrons in the semiconductors.

When sunlight strikes a PV cell, the photons of the absorbed sunlight dislodge the electrons from the atoms of the cell. The free electrons then move through the cell, creating and filling in holes in the cell. It is this movement of electrons and holes that generates electricity. The physical process in which a PV cell converts sunlight into electricity is known as the photovoltaic effect. One single PV cell produces up to 2 watts of power, too small even for powering pocket calculators or wristwatches.

To increase power output, many PV cells are connected together to form modules, which are further assembled into larger units called arrays. This modular nature of Fundamentals of Photovoltaic Materials. The efficiency is the power developed per unit area of the array divided by the solar energy flux in the free space (1.367kW/m^2). The amount of current generated by a PV cell depends on its efficiency, its size (surface area) and the intensity of sunlight striking the surface.

The heart of the solar energy generation system is the Solar cell. It consists of three major elements, namely:

- The semiconductor material which absorbs light and converts it into electron-hole pairs.
- The junction formed within the semiconductor, which separates the photo-generated carriers (electrons and holes)
- The contacts on the front and back of the cell that allow the current to flow to the external circuit.

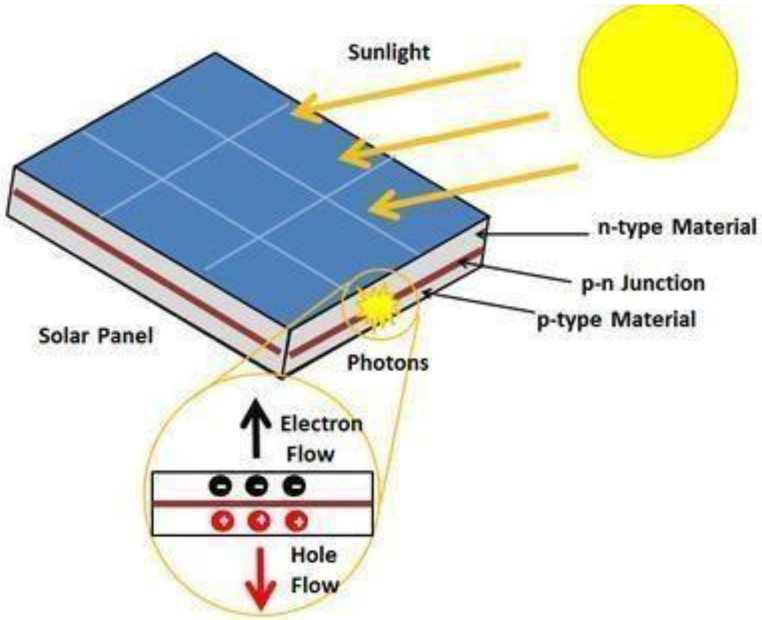


Figure 92 Solar Cell

The main types of solar cells are (i) monocrystalline silicon cells, (ii) Poly crystalline silicon cells, (iii) Amorphous silicon cells (iv) Gallium arsenide (GaAs), and (v) Copper indium diselenide (CID) cells. At present, silicon solar cells occupy 60% of the world market.

Basic types of silicon solar cells are: (i) Mono crystalline silicon solar cells, (ii) poly crystalline silicon solar cells, and (iii) thin film or Amorphous silicon solar cells.

Mono crystalline silicon solar cells

These modulus possess high efficiency between 15 and 18% and are used in medium and large size plants.

Poly crystalline silicon solar cells

The high efficiency of solar cell is 12 to 14%.

Thin-film solar cells

The efficiency is 5 to 8%.

Components of solar photovoltaic system

The solar photovoltaic system comprises of three main sub-systems, viz., solar panel, control unit and battery. The solar panel contains solar cells, which produce electricity when exposed to sunlight. The electricity generated charges the battery / batteries and the power stored can be used at a later time. The control unit regulates the charging and discharging of the battery. There are more than five PV applications in practice. Thus are the solar lantern, solar water pumping system, solar street light, solar sprayer, solar insect trap and solar powered tricycle.

One square meter of fixed array kept facing south yields nearly 0.5 kWh of electrical energy on a normal sunny day. In full sunlight, the solar energy may reach the ground at a rate of roughly 1kW/ sq.m.

The maximum power of a silicon cell occurs at an output voltage of approximately 0.45 volt. In full sunlight, the current from a commercial cell is thus about 0.45 x 270 = 120 watts (or 0.12 kW) per sq.m.

Solar electric power generation

The direct conversion of solar energy into electrical energy by means of the photovoltaic effect, that is, the conversion of light (or other electromagnetic radiation) into electricity.

The advantages of photovoltaic solar energy conversion

- Absence of moving parts

- Direct conversion of light to electricity at room temperature
- Can function unattended for a long time
- Low maintenance cost
- No environmental pollution
- Very long life
- Highly reliable
- Solar energy is free and no fuel required
- Can be started easily as no starting time is involved
- Easy to fabricate
- These have high power-to-weight ratio, therefore very useful for space application
- Decentralized or dispersed power generation at the point of power consumption can save power transmission and distribution costs
- These can be used with or without sun tracking

The limitations of photovoltaic solar energy conversion

- Manufacture of silicon crystals is labour and energy intensive
- The principle limitation is high cost
- The insolation is unreliable and therefore storage batteries are needed
- Solar power plants require very large land areas
- Electrical generation cost is very high.
- The energy spent on the manufacture of solar cells is very high
- The initial cost of the plant is very high and still requires a long gasification period.

SOLAR PUMPING SYSTEM

A solar water pump system is essentially an electrical pump system in which the electricity is provided by one or several Photovoltaic (PV) panels. A typical solar powered pumping system consists of a solar panel array that powers an electric motor, which in turn powers a bore or surface pump.

The whole system of solar pumping includes the panels, support structure with tracking mechanism, electronic parts for regulation, cables, pipes and the pump itself.

- Solar panels or modules
- Solar pump
- Support structure and tracking mechanism
- Foundations (array and pump)
- Electrical interconnections
- Earthing kit
- Plumbing

COMPONENTS OF SOLAR PUMPING SYSTEM

SOLAR PANELS OR MODULES

- Solar panels are the main components used for driving the solar pump.
- Several solar panels connected together in arrays produce DC electricity, interconnections are made using series or parallel combinations to achieve desired voltage and power for the pump.

SOLAR PUMP

- Centrifugal or submersible pumps are connected directly to the solar array using DC power produced by the solar panels.
- Solar pumps are available in several capacities depending upon the requirement of water.

SUPPORT STRUCTURE AND TRACKING MECHANISM:

- Support structure provides stability to the mounted solar panels and protects them from theft or natural calamities.

- To obtain maximum output of water, a manual tracking device is fixed to the support structure.
- Tracking increases the output of water by allowing the panels to face the sun as it moves across the sky.

FOUNDATIONS (ARRAY AND PUMP)

- Foundations are provided for support structures and pump.

ELECTRICAL INTERCONNECTIONS

- A set of cables of appropriate size, junction boxes, connectors and switches are provided along with the installation.

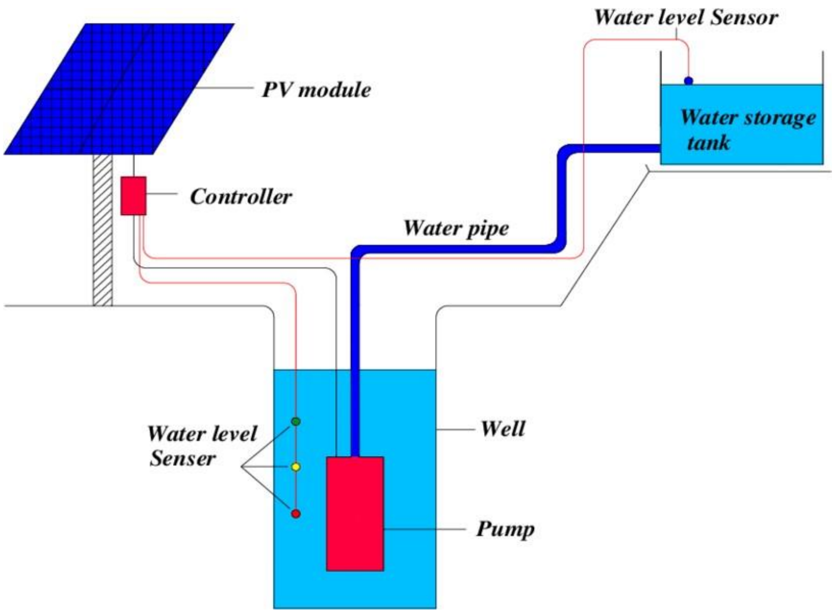


Figure 93 Components of Solar Water Pumping System

EARTHING KIT

- Earthing kit is provided for safety in case of lightning or short circuit.

PLUMBING

- Pipes and fittings required to connect the pump come as part of the installation.

WORKING OF SOLAR PUMP SYSTEM

When the solar energy drops sun rays on the PV panels then the solar panel converts the rays into electrical energy with the help of Si wafers fixed within the PV panels. Then the solar energy supplies to the electrical motor to operate the pumping system using cables. By the revolution of the shaft which is fixed to the pump, then the pump begins to pick up the soil water and supplies to the fields.

TYPES OF SOLAR PUMPS

Solar water pumps are classified into different types based on the application however there are two types of solar pumps that are used mostly due to its success rate such as submersible solar pump & surface pump. These pumps are available in both AC & DC technology.

1) SOLAR SURFACE PUMP

The solar surface pump is mainly recommended for where the deepness of water is below 15 meters and you wish to lift above ground level. These pumps are used in the irrigation field, communities for supplying clean water while supplying water from ponds, lakes, rivers or canals.

2) SOLAR SUBMERSIBLE PUMP

A solar submersible pump is mainly recommended for where the deepness of water is above 15 meters and you wish to lift above ground level. These pumps are arranged in the underground water. These pumps are the most selling ones in India because the deepness of the water level is extremely low in the utmost areas. The solar pump applications mainly involve in the irrigation field, communities for supplying clean water while supplying water from sumps or bore-wells.

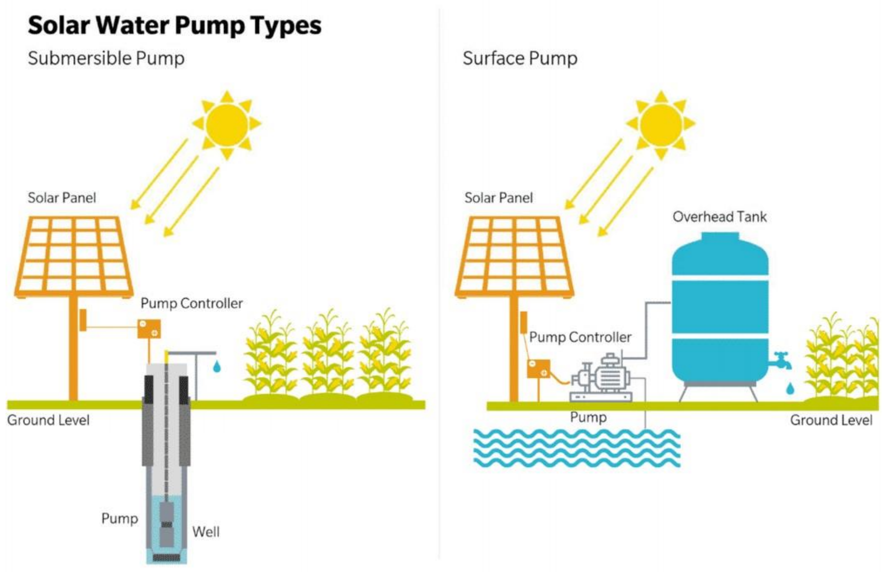


Figure 94 Types of Solar Pumps

ADVANTAGES

- Low operating cost
- Low maintenance
- Harmonious with nature
- Flexibility

LIMITATIONS

- Low yield
- Variable yield
- Theft

SOLAR LANTERN

A Solar lantern is a simple application of solar photovoltaic technology, which has found good acceptance in rural regions where the power supply is irregular and scarce. Even in the urban areas people prefer a solar lantern as an alternative during power cuts because of its simple mechanism.

Solar Lantern is made of three main components - the solar PV panel, the storage battery and the lamp. The lamp, battery and electronics all placed in a suitable housing made of metal, plastic or fibre glass. The operation is very simple. The solar energy is converted to electrical energy by the SPV panel and stored in a sealed maintenance-free battery for later use during the night hours.

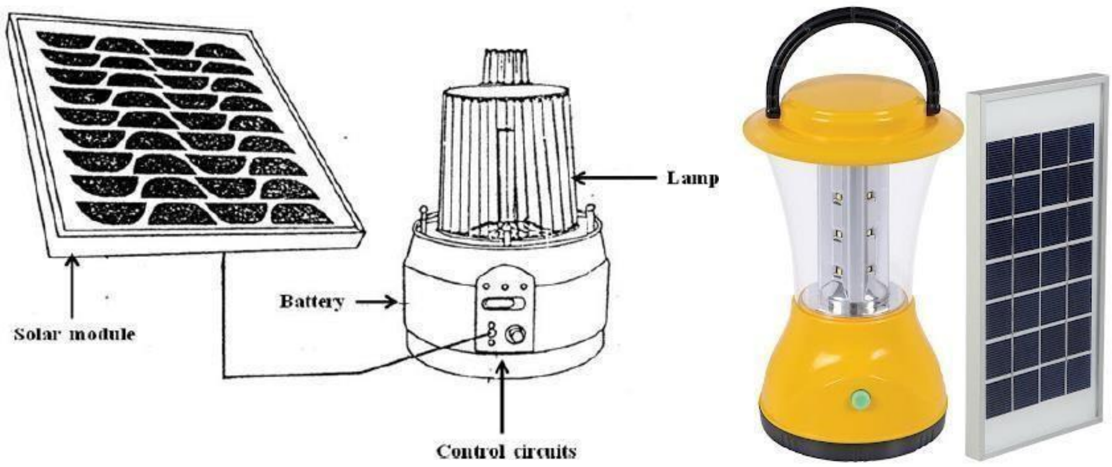


Figure 95 Solar Lantern

The lantern is basically a portable lighting device suitable for either indoor or outdoor lighting, covering a full range of 360 degrees. The solar lantern is a portable solar photovoltaic lighting system which provides about 2-3 hours of light per night based on the day's charge. The lantern is designed to be similar to a hurricane lantern in its shape and about a hundred times brighter. The system consists of 5 watt tube which is driven at a specially designed frequency choke / inverter operating at a frequency above 30 kHz. As these lanterns are portable, it can be carried by a person as per his requirements and convenience. As the battery is a sealed maintenance free type, no special maintenance is required except for daily charging.

Lecture 15

Solar Dryers

Topics Covered: **Solar dryers – natural and forced convection types – solar tunnel drier – working principles and operation.**

Solar Dryers

Solar dryers are devices that use solar energy to dry substances, especially food. Sometimes solar dryers are used to generate hot air and subsequently the hot air can be used for various applications viz. space heating, drying of various commodities such as grains, vegetables, fruits etc. The performance such as quantity of hot air generation, hot air temperature, system efficiency etc. can be assessed.

TYPES OF SOLAR DRYER

There are two types of the solar dryer.

1) Direct solar dryer

2) Indirect solar dryer

Sometimes, dryers works by direct and indirect drying method and called combined or mixed type dryers.

DIRECT SOLAR DRYERS

In these types of dryers, food or clothing is exposed to the sunlight directly. The sunlight removes the moisture from the substance.

INDIRECT SOLAR DRYERS

In these types of dryers, the material is dried by circulating hot air over it without directly exposing the material to the sun.

Two methods of indirect type solar dryer are (a) natural circulation type and (b) forced circulation type

Natural circulation type: It is also recognized as passive solar dryer because of the natural circulation of air due to thermo-syphon effect. Food is heated because of hot air and then the moisture contained in the product is eliminated to outside air through the chimney which is placed at the top of the drying chamber by natural air circulation.

Figure 96 Natural Convection Type Dryer

Forced circulation type (Active mode) – Here, as electric fan or blower is used to force the air, into or out of the dryer. So controlling the drying rate is possible in this type of dryer. It is also categorized in the same way as natural circulation type with the addition of a fan or blower. Some other types of solar dryers are: solar dryer with greenhouse collector and tunnel type dryer with integral collector.

COMBINED DRYERS

The product is dried both by direct radiation and by heated moving air. It has the advantages of both direct type and indirect type dryer. Heat energy is absorbed by the product directly from the sun as well as indirectly by supply of hot air.

BENIFITS OF SOLAR DRYER

Solar dryer use solar energy to dry food and sometimes clothes.

Solar energy is non-conventional source of energy. So it can use unlimited source of energy from the sun to dry foods and clothes.

LIMITATIONS OF SOLAR DRYER

Drying can be performed only during sunny days, unless the system is integrated with a conventional energy-based system.

Due to limitations is solar energy collection, the solar drying process is slow in comparison with dryers that use conventional fuels.

Normally, solar dryers can be utilized only for drying at 40−50 ^oC.

CONSTRUCTION AND WORKING OF SOLAR DRYER

The solar dryer is a relatively simple concept. The basic principles employed in a solar dryer are:

Converting light to heat: Any black on the inside of a solar dryer will improve the effectiveness of turning light into heat.

Trapping heat: Isolating the air inside the dryer from the air outside the dryer makes an important difference. Using a clear solid, like a plastic bag or a glass cover, will allow light to enter, but once the light is absorbed and converted to heat, a plastic bag or glass cover will trap the heat inside. This makes it possible to reach similar temperatures on cold and windy days as on hot days.

Moving the heat to the food: Both the natural convection dryer and the forced convection dryer use the convection of the heated air to move the heat to the food.

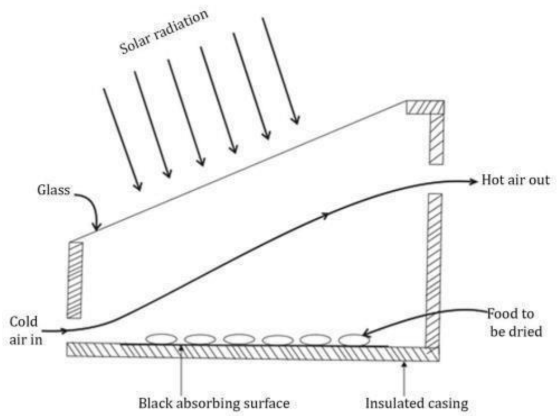


Figure 97 Direct type Solar Dryer

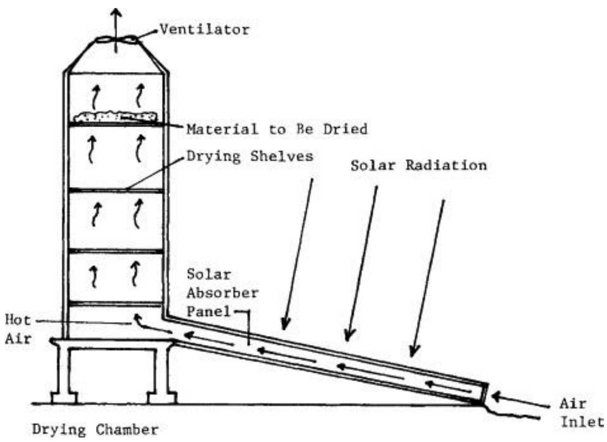


Figure 98 Indirect type Solar Dryer

Solar tunnel dryers

Solar tunnel dryers collect solar energy, i.e. energy from Sun rays and air from atmosphere to dry food products, food colour, agricultural material like Tomato, Onion, Agro waste leaves and Bagasse from sugar factory and chilly or any other similar products preparing them for proper storage, processing and export, etc…

The material to be dried is spread in an even layer on trays on the racks inside the tunnel. The air below the semi-transparent collector is heated by the sun and spreads throughout the tunnel. It increases the temperature inside the tunnel to 65-70 degC. The increased temperature inside the tunnel dryer decreases the relative humidity of the air, thereby allowing the air to more efficiently dry the material inside.

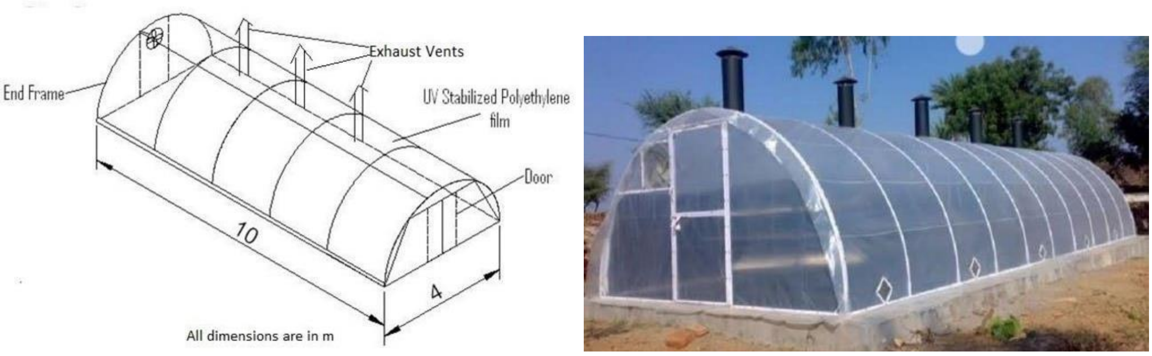


Figure 99 Solar Tunnel Dryer

Figure 100 Trays inside solar tunnel dryer

Direct Sun drying vs Solar Tunnel Drying

- Drying in the direct sunlight has the risk of damaging the product quality whereas conventional open sun drying tends to contaminate product with dust, pests and airborne microbes, etc.
- Food products under direct sun drying are not protected against humidity changes or drizzle
- Solar tunnel dryer can be a time saving and cost effective alternative to direct sun drying
- Solar tunnel dried products have better colour, flavour and taste than direct sun dried products

Lecture 16

Wind Mills

Topics Covered: **Wind mills – types – horizontal and vertical axis – components – working principles – applications.**

Background and Necessity of Wind Energy

Air in motion is called wind. The winds on the earth's surface are caused primarily by the unequal heating of the land and water by the sun. The differences in temperature gradients induce the circulation of air from one zone to another. Wind energy uses the high wind velocity available in certain areas. Wind energy is used for pumping the water or power generation.

About 0.7 million wind pumps are in operation in different countries. A minimum wind speed or 3 m/s is needed. This is considered to have a high efficiency. Coastal, hilly and valley areas are suitable for this process. Potential in India estimated between 20,000 and 25,000 MW. Coastal areas of Gujarat, Maharashtra and Tamil Nadu are considered as favourable. The maximum power generated from any single unit is about 1MW.

The potential of wind energy as a source of power is large. The energy available in the winds over the earth's surface is estimated to be 1.6 x 10^7 MW, which is of the same order of magnitude as the present energy consumption of the earth.

Conversion of the kinetic energy (i.e., the energy of motion) of the wind into mechanical energy that can be utilized to perform useful work, or to generate electricity. Wind energy conversion devices are commonly known as wind turbine because they convert the energy of the wind stream into energy of rotation. India wind speed value lies between 5 to 12 - 20 km/h.

Wind turbines harness the wind—a clean, free, and widely available renewable energy source—to generate electric power.

The power in the wind

Wind possesses energy by virtue of its motion. Any device capable of slowing down the mass of moving air, like a sail or propeller can extract part of the energy and convert it into useful work. The power in the wind can be computed by using the concept of kinetics. The windmill works on the principle of converting kinetic of the wind to mechanical energy.

The maximum power available from the wind varies according to the square of the diameter of the interception area (or square of the rotor diameter), normally taken to be swept area of the aeroturbine. Thus doubling the diameter of the rotor will result in a four – fold increase in the available wind power.

The fraction of the free - flow wind power that can be extracted by a rotor is called the power – coefficient.

$$\text{Power coefficient} = \frac{\text{Power of the wind rotor}}{\text{Power available in the wind}}$$

Where power available is calculated from the air density, rotor diameter, and free wind speed as shown above. The maximum theoretical power coefficient is equal to 16/27 or 0.593. This value cannot be exceeded by a rotor in a free - flow wind stream.

As an ideal rotor, with propeller - type blades of proper aerodynamic design, would have a power coefficient approaching 0.59. But such a rotor would not be able strong enough to withstand the stresses which it is subjected when rotating at a high rate in a high speed wind stream. For the best practical rotors, the power coefficient is about 0.4 to 0.45, so that the rotors cannot use more than 40 to 45 percent of the available wind power. The power available in the wind increases as the cube of the wind speed, doubling the wind speed increases the power available by eight - fold.

Maximum power

The total power cannot be converted to mechanical power. Consider a horizontal - axis, propeller - type wind mill, henceforth to be called a wind turbine, which is the most common type used today.

$$P_{max} = 0.595\ P_{total}$$

The ideal, or maximum, the theoretical efficiency (also called the power coefficient) of a wind turbine is the ratio of the maximum power obtained from the wind, to the total power available in the wind. The factor 0.593 is known as the Betz coefficient. It is the maximum fraction of the power in a wind stream that can be extracted. Thus Cp cannot exceed 0.593 for a horizontal axis wind machine.

Lift and drag force

The extraction of power, and hence energy, from the wind depend on creating certain forces and applying them to rotate (or to translate) a mechanism. There are two primary mechanisms for producing forces from the wind lift and drag.

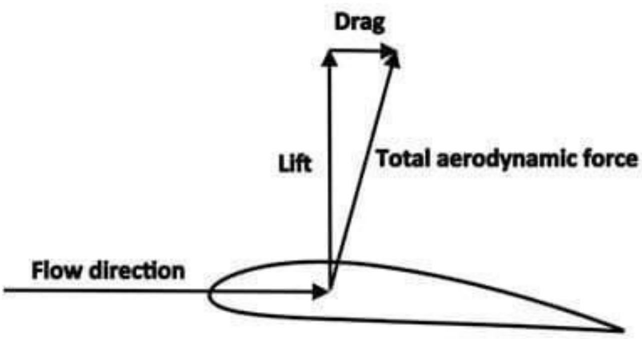


Figure 101 Lift and Drag Force

Windmill

A windmill is defined as a machine that converts the kinetic energy of the wind into mechanical energy. All the blades of windmill always rotate in a clockwise direction. The first windmill was designed in the year 1854 by Daniel Halladay from the United States.

Types of Windmills

There are two basic types of windmills based on their axis of rotation, and they are:

Horizontal Axis Wind Turbine (HAWT)

HAWT, short for Horizontal Axis Wind Turbine, is the most commonly used design configuration in wind turbines with rotors similar to that of aircraft rotors. When the rotating axis of the blades is parallel to the wind stream, the turbine is called horizontal axis wind turbine (HAWT). HAWTs are available in many sizes ranging from a few hundred watts up to hundred kilowatts. These types of wind turbines are typically used under streamline wind conditions where a constant stream and direction of wind is available in order to capture the maximum wind energy. HAWTs are not effective where the wind is turbulent, so they are generally located in areas where there is a constant directional airflow.

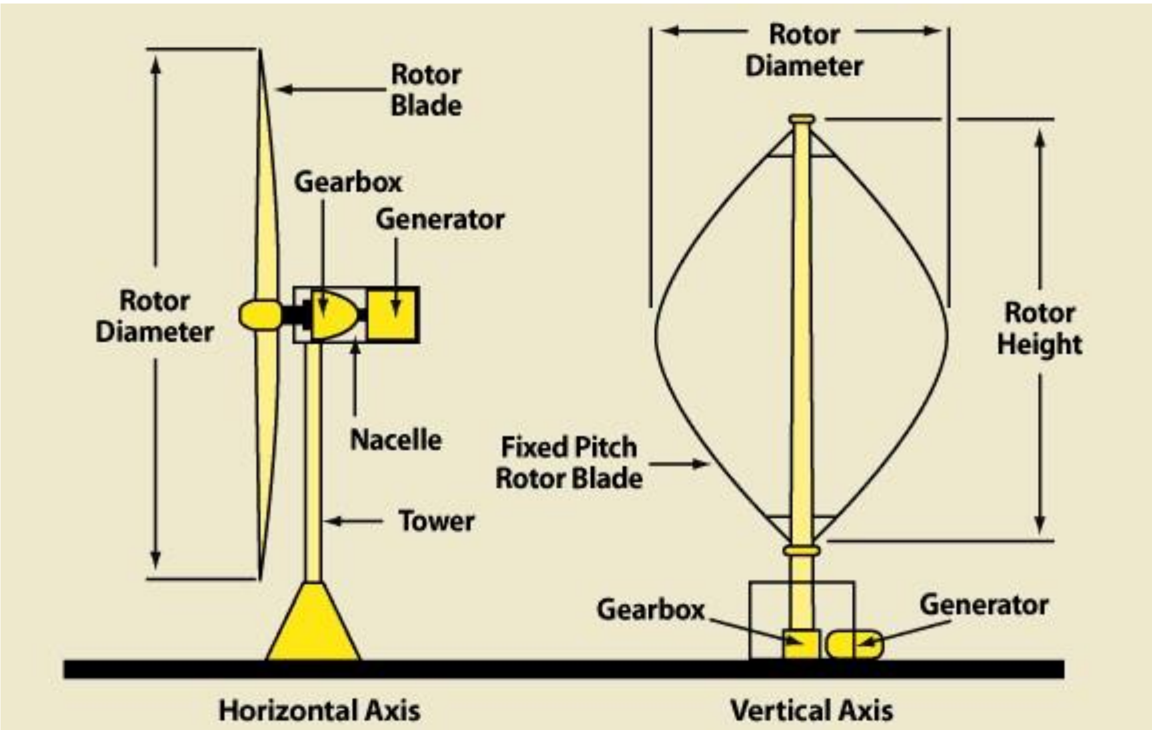


Figure 102 Horizontal and Vertical Axis Wind Turbine

Vertical Axis Wind Turbine (VAWT)

Vertical Axis Wind Turbine, or VAWT, is probably the oldest type of windmills in which the axis of the drive shaft is perpendicular to the ground. It is a type of windmill where the main rotor shaft runs vertically, as opposed to the horizontal axis wind turbine. The blades of the VAWTs rotate with respect to their vertical axes that are perpendicular to the ground. VAWT designs are sometimes loosely categorized as lift or drag based designs. They can capture wind from any direction and their heavy machinery is at ground level. Since the machinery is set on the ground, it simplifies the wind tower design and construction and reduces the turbine cost consequently. Unlike HAWTs, VAWTs are typically used in areas with turbulent wind flow such as coastlines, rooftops, cityscapes, etc. Vertical axis wind mills includes Savonius or S type wind mill (low wind velocity) and Darrius wind mill (high wind velocity).

Description of the main components of Windmill

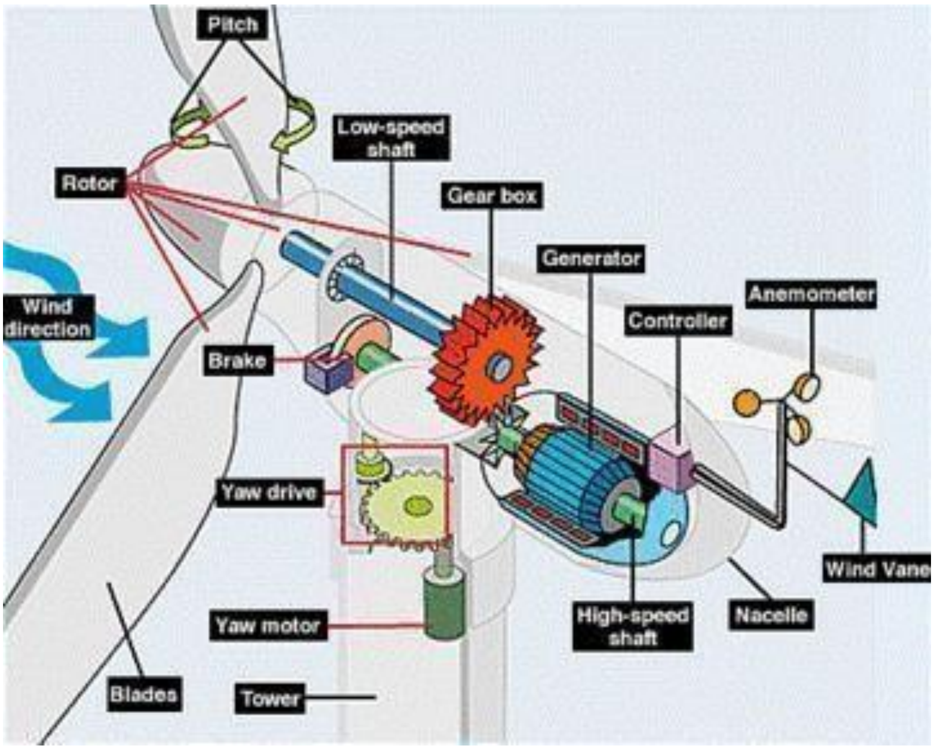


Figure 103 Components of Windmill

The **tower** is the physical structure that holds the wind turbine. It supports the rotor, nacelle, blades, and other wind turbine equipment. Typical commercial wind towers are usually 50–120 m long and they are constructed from concrete or reinforced steel.

Blades are physical structures, which are aerodynamically optimized to help capture the maximum power from the wind in normal operation with a wind speed in the range of about 3–15 m/s. Each blade is usually 20 m or more in length, depending on the power level.

The **nacelle** is the enclosure of the wind turbine generator, gearbox, and internal equipment. It protects the turbine's internal components from the surrounding environment.

The **rotor** is the rotating part of the wind turbine. It transfers the energy in the wind to the shaft. The rotor hub holds the wind turbine blades while connected to the gearbox via the low-speed shaft.

Pitch is the mechanism of adjusting the angle of attack of the rotor blades. Blades are turned in their longitudinal axis to change the angle of attack according to the wind directions.

The **shaft** is divided into two types: low and high speed. The low-speed shaft transfers mechanical energy from the rotor to the gearbox, while the high-speed shaft transfers mechanical energy from gearbox to generator.

Yaw is the horizontal moving part of the turbine. It turns clockwise or anticlockwise to face the wind. The yaw has two main parts: the yaw motor and the yaw drive. The yaw drive keeps the rotor facing the wind when the wind direction varies. The yaw motor is used to move the yaw.

The **brake** is a mechanical part connected to the high-speed shaft in order to reduce the rotational speed or stop the wind turbine over speeding or during emergency conditions.

Gearbox is a mechanical component that is used to increase or decrease the rotational speed. In wind turbines, the gearbox is used to control the rotational speed of the generator.

The **generator** is the component that converts the mechanical energy from the rotor to electrical energy. The most common electrical generators used in wind turbines are induction generators (IGs), doubly fed induction generators (DFIGs), and permanent magnet synchronous generators (PMSGs).

The **controller** is the brain of the wind turbine. It monitors constantly the condition of the wind turbine and controls the pitch and yaw systems to extract optimum power from the wind.

Anemometer is a type of sensor that is used to measure the wind speed. The wind speed information may be necessary for maximum power tracking and protection in emergency cases.

The **wind vane** is a type of sensor that is used to measure the wind direction. The wind direction information is important for the yaw control system to operate.

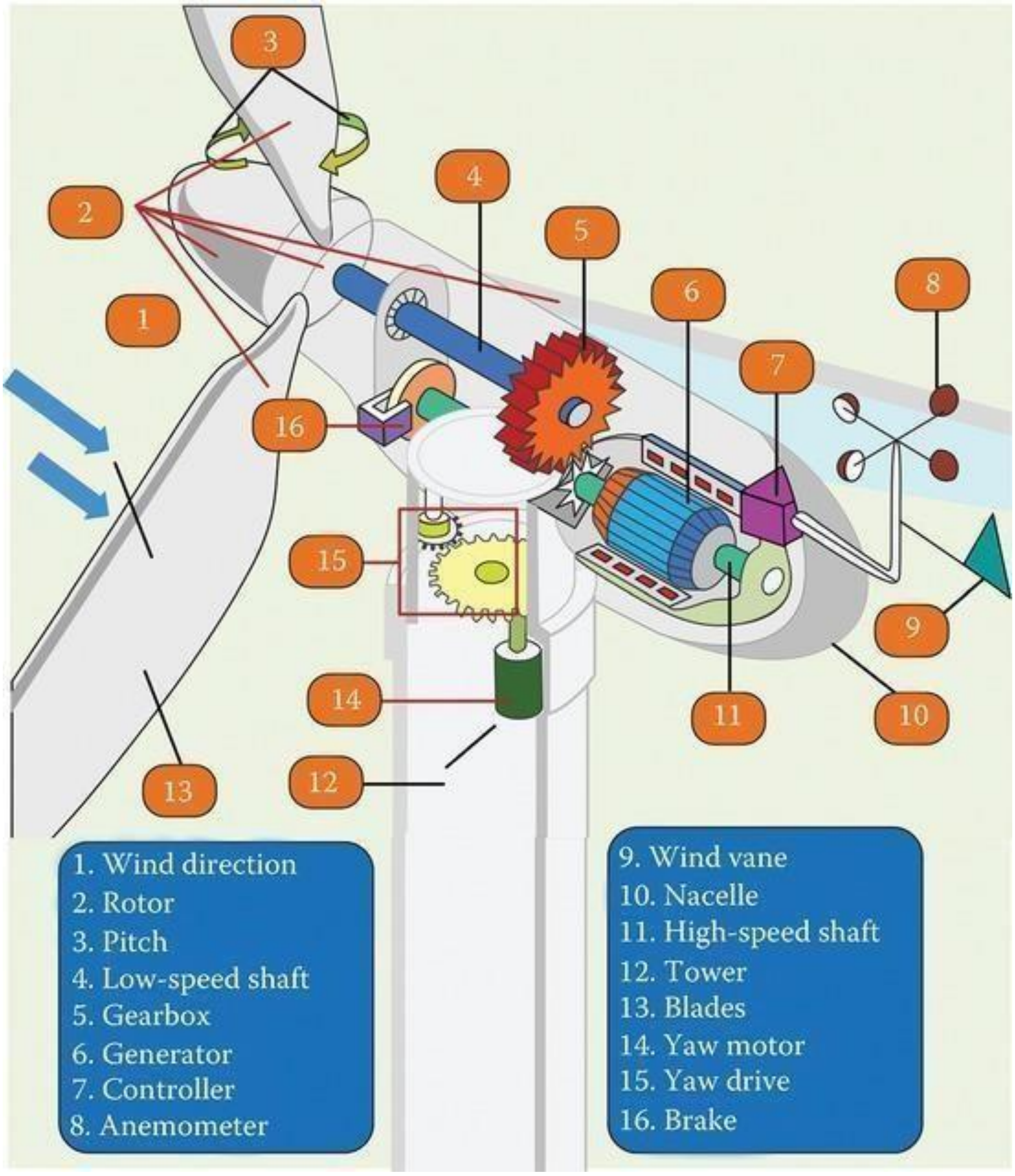


Figure 104 Components of Wind mill (2)

Working of Wind Turbines

A wind turbine turns wind energy into electricity using the aerodynamic force from the rotor blades, which work like an airplane wing or helicopter rotor blade. When wind flows across the blade, the air pressure on one side of the blade decreases. The difference in air pressure across the two sides of the blade creates both lift and drag.

The force of the lift is stronger than the drag and this causes the rotor to spin. The rotor connects to the generator, either directly (if it's a direct drive turbine) or through a shaft and a series of gears (a gearbox) that speed up the rotation and allow for a physically smaller generator. This translation of aerodynamic force to rotation of a generator creates electricity.

Uses of Windmill

The main purpose of windmill is to convert wind energy into electrical energy, and when electrical energy is obtained, the following are the ways it is used:

For pumping of groundwater.

Extraction of oil from the seeds.

Milling of the grains

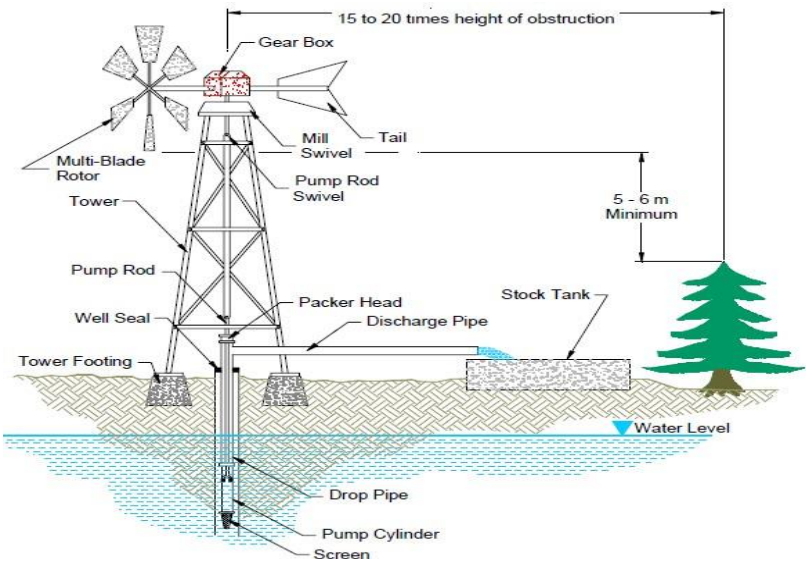


Figure 105 Windmill Pumping System

Lecture 17

Ocean and Geothermal Energy

Topics Covered: **Energy from ocean, waves, tides – Geothermal energy sources – principles and operation**

Ocean Energy

Oceans cover more than 70% of Earth’s surface, making them the world’s largest solar collectors. The ocean can produce two types of energy: thermal energy from the sun’s heat, and mechanical energy from the tides and waves.

Ocean Thermal Energy Conversion (OTEC)

OTEC, or ocean thermal energy conversion, is an energy technology that converts solar radiation to electric power. The sun’s heat warms the surface water a lot more than the deep ocean water, and this temperature difference creates thermal energy. OTEC systems use the ocean's natural thermal gradient—the fact that the ocean's layers of water have different temperatures—to drive a power-producing cycle. As long as the temperature between the warm surface water and the cold deep water differs by about 20°C (36°F), an OTEC system can produce a significant amount of power. Ocean thermal energy is used for many applications, including electricity generation.

Ocean Closed-cycle systems

Ocean Closed-cycle systems use the ocean’s warm surface water to vaporize a working fluid, which has a low-boiling point, such as ammonia. The vapor expands and turns a turbine. The turbine then activates a generator to produce electricity.

Ocean Open-cycle systems

Open-cycle systems actually boil the seawater by operating at low pressures. This produces steam that passes through a turbine/generator.

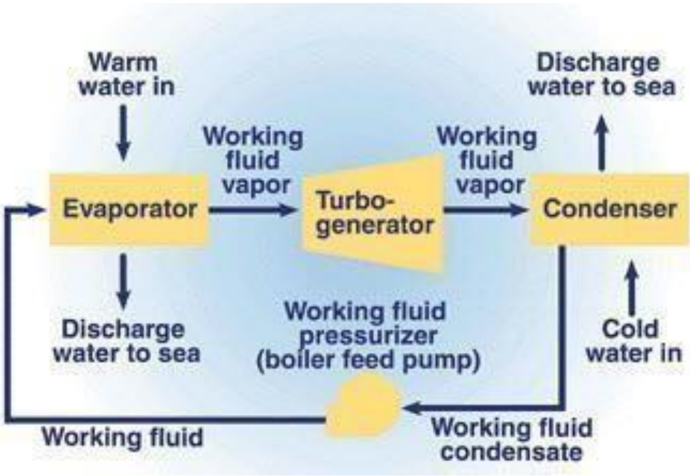


Figure 106 Ocean Closed System

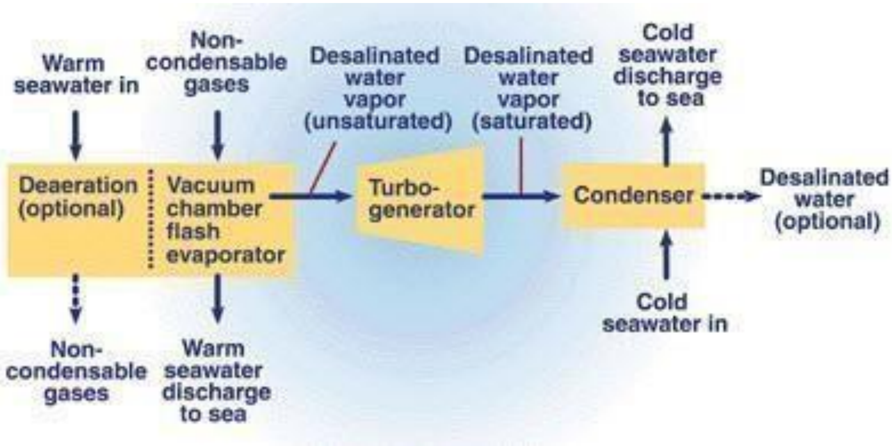


Figure 107 Ocean Open System

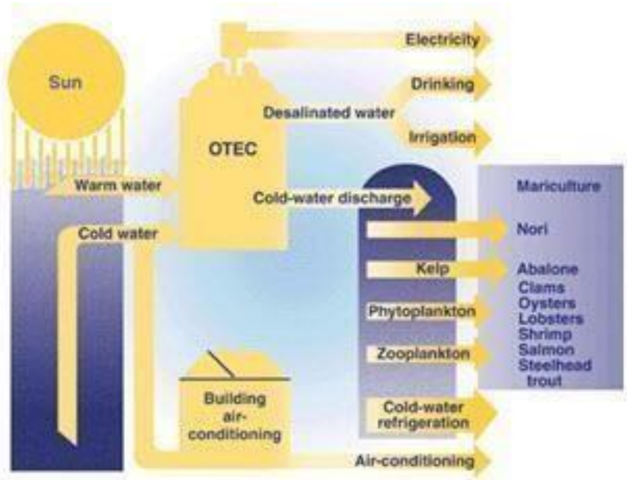


Figure 108 OTEC Applications

Applications

OTEC can be used to generate electricity, desalinate water, support deep-water mariculture, and provide refrigeration and air-conditioning as well as aid in crop growth and mineral extraction. These complementary products make OTEC systems attractive to industry and island communities.

Ocean mechanical energy

Ocean mechanical energy is quite different from ocean thermal energy. Even though the sun affects all ocean activity, tides are driven primarily by the gravitational pull of the moon, and waves are driven primarily by the winds. As a result, tides and waves are intermittent sources of energy, while ocean thermal energy is fairly constant. Also, unlike thermal energy, the electricity conversion of both tidal and wave energy usually involves mechanical devices.

Tide Energy

Tides are the alternating rise and fall of the surface of the seas and oceans. Generating electricity from tides is very similar to hydroelectric generation, except the tides flow in two directions rather than one. The mechanical power created from these systems either directly activates a generator or transfers to a working fluid, water, or air, which then drives a turbine/generator.

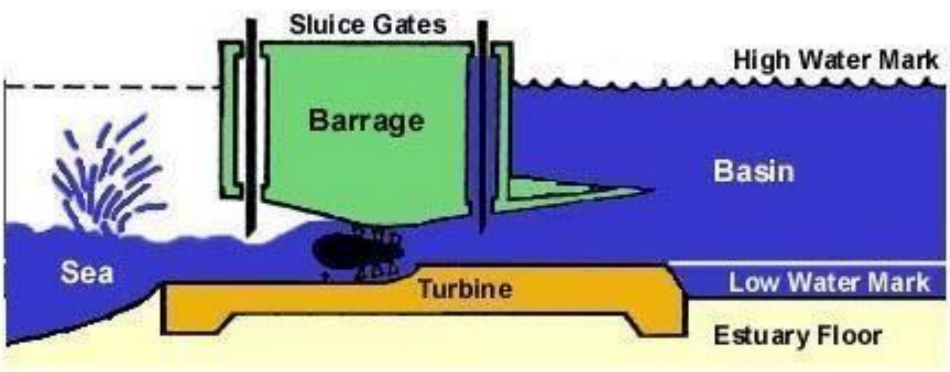


Figure 109 Tidal Energy

A barrage (dam) is typically used to convert tidal energy into electricity by forcing the water through turbines, activating a generator. It is constructed across an estuary. The tidal basin is allowed to fill when the sluice gates are opened and high tide is in. The gates are then closed when the tide turns trapping the water behind the gates. Once low tide is reached, the gates are opened the water flows through the turbines located underneath the water generating electricity.

Benefits

It is environment-friendly because the devices generating power don't emit harmful gases.

The energy produced from these waves goes directly into the electricity-generating devices and is used to power generators and power plants nearby.

Geothermal energy

Geothermal energy is heat within the earth. The word geothermal comes from the Greek words geo (earth) and therme (heat). Geothermal energy is a renewable energy source because heat is continuously produced inside the earth. People use geothermal heat for bathing, to heat buildings, and to generate electricity.

Molten rocks formed in the Earth's crust are pushed upward where they get trapped in certain regions called 'hot spots'. When underground water comes in contact with the hot spot, steam is generated. Sometimes this hot water formed region finds outlets at the surface. When this hot water gushes out of one of these outlets, it is called hot springs. This steam is used to run turbines and produce electricity.

Working

In order to harness the geothermal energy, a hydrothermal convection system is used. In this process, a hole is drilled deep under the earth, through which a pipe is inserted. The steam trapped in the rocks is routed through this pipe to the surface of the earth. This steam is then used to turn the blades of a turbine of an electric generator.

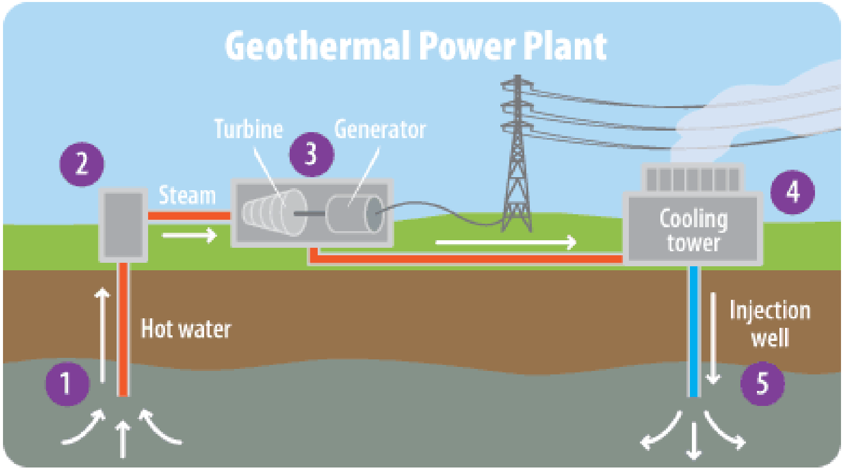


Figure 110 Working of Geothermal Power Plants

Applications

Farming: In cold countries, geothermal energy is used to heat greenhouses or to heat water that is used for irrigation.

Industry: Geothermal energy is used in industries for the purpose of food dehydration, milk pasteurizing, gold mining, etc.

Heating: Geothermal energy is used to heat buildings through district heating systems in which hot water through springs is directly transported to the buildings through pipelines.

Advantages

Renewable resource

Green energy

Generation of employment

Can be used directly

Disadvantages

- Transportation and transmission
- High installation cost
- Intensive research required

- Limited to particular regions
- Impact on the environment