BULE HORA UNIVERSITY
COLLEGE OF AGRICULTURE
DEPARTMENT OF AGROFORESTRY

Well come !



Course :- **Biomass Energy Production and Management**

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Chapter One

Introduction to Biomass Energy Resources

1. Introduction

- **Biomass** is any **organic** matter that can be used as an energy source. Wood, crops, and yard and animal waste are examples of biomass.
- Biomass is organic matter produced directly (in producer organisms) from solar energy through photosynthesis and indirectly by consumers feeding

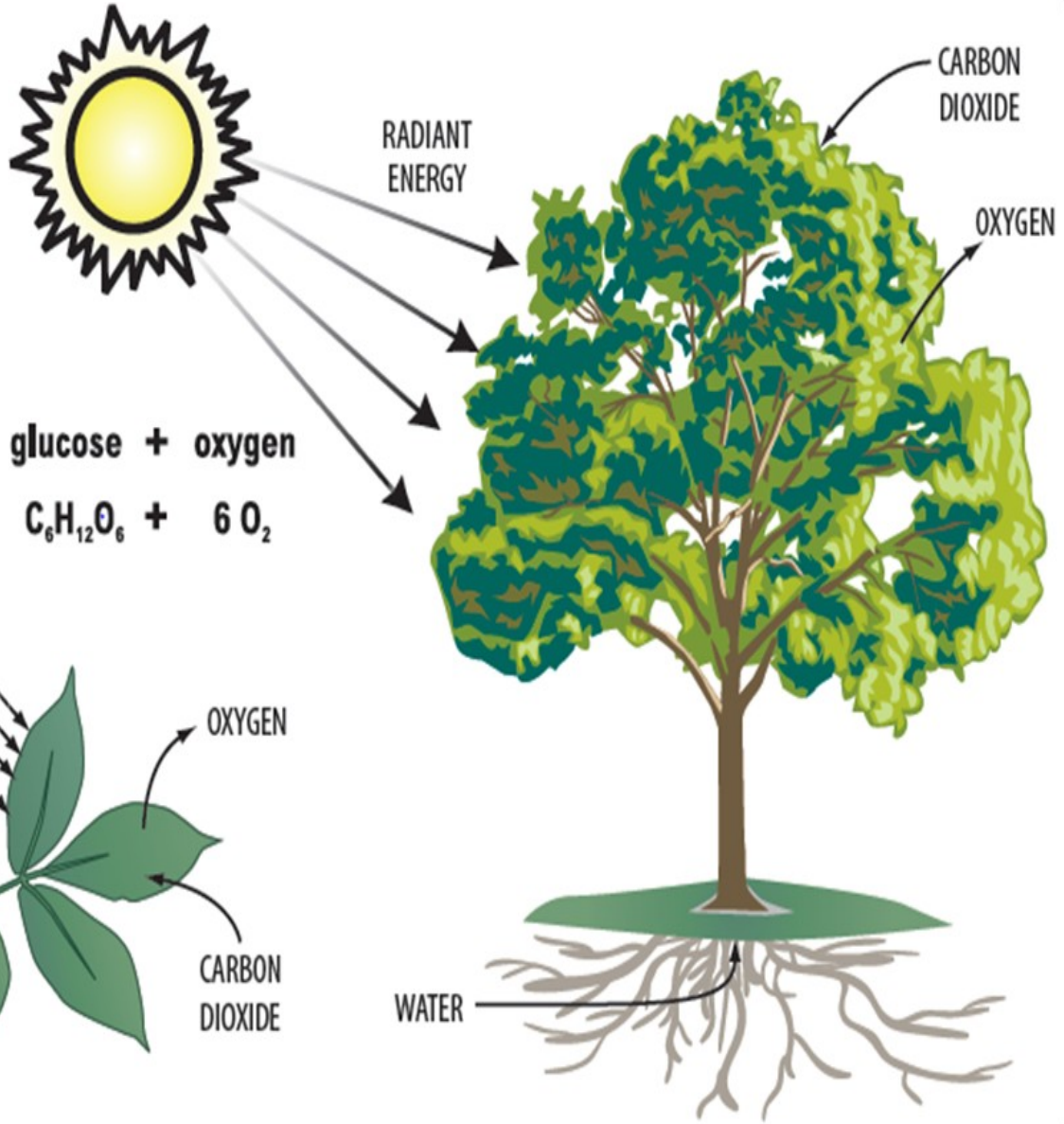
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- ✓People have used biomass longer than any other energy source.
- ✓ For thousands of years, people have burned wood to heat their *homes* and *cook their food.*
- ✓Various types of biomass fuels can be used for heating space and water, producing electricity, and propelling vehicles.

Solar Energy Restoration

Photosynthesis

In the process of photosynthesis, plants convert radiant energy from the sun into chemical energy in the form of glucose (or sugar).



water + carbon dioxide + sunlight ⟶ glucose + oxygen

$6\ H_2O$ + $6\ CO_2$ + radiant energy ⟶ $C_6H_{12}O_6$ + $6\ O_2$

Data: Energy Information Administration

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- Biomass was the first form of energy that was harnessed by humans in the form of wood being burned.
- Biomass is not only used by humans, but all other animals use biomass to get their energy for living.
- Herbivores eat the plants (biomass), omnivores eat the plants as well as some animals, and carnivores eat other animals to get energy needed for everyday activities.

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- Biomass gets its energy from the sun.
- Plants absorb sunlight in a process called **photosynthesis.**
- With sunlight, air, water, and nutrients from the soil, plants make sugars called **carbohydrates.**
- Foods that are rich in carbohydrates (like spaghetti) are good sources of energy for the human body.
- Biomass is called a **renewable** energy source because it can grow more in a short period of time.

1.2 The potential sources of Biomass energy

- Biomass resources include primary, secondary, and tertiary sources of biomass. Primary biomass resources are produced directly by photosynthesis and are taken directly from the land.
- They include perennial short-rotation woody crops and herbaceous crops, the seeds of oil crops, and residues resulting from the harvesting of agricultural crops and forest trees (e.g., wheat straw, corn stover, and the tops, limbs, and bark from trees).

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- Secondary biomass resources result from the processing of primary biomass resources either physically (e.g., the production of sawdust in mills), chemically (e.g., black liquor from pulping processes), or biologically (e.g., manure production by animals).
- Tertiary biomass resources are post-consumer residue streams including animal fats and greases, used vegetable oils, packaging wastes, and construction and demolition debris.

1.3 Composition of biomass

- Photosynthesis results in the production of structural and non-structural carbohydrates comprising the plant tissues.
- The components of biomass include cellulose, hemicelluloses, lignin, lipids, proteins, simple sugars, starches, water, HC, ash, and other compounds.

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- The concentrations of each class of compound varies depending on species, type of plant tissue, stage of growth, and growing conditions.
- Cellulose is a linear polysaccharide of b-D glucopyranose units linked with 1–4. glycosidic bonds.
- Hemicelluloses are polysaccharides of variable composition including both five and six carbon monosaccharide units.

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- **The lignin** is an irregular polymer of phenylpropane units w8–12x.
- Plants producing large amounts of free sugars, such as sugar cane and sweet sorghum, are attractive as feedstocks for fermentation, as are starch crops such as maize, corn and other grains.
- Lignins are not yet generally considered fermentable, and thermochemical means are usually proposed for their conversion.

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- Due to the carbohydrate structure, biomass is highly oxygenated with respect to conventional fossil fuels including HC liquids and coals. Typically, 30 to 40 wt.% of the dry matter in biomass is oxygen.
- The principal constituent of biomass is carbon, making up from 30 to 60 wt.% of dry matter depending on ash content.
- Of the organic component, hydrogen is the third major constituent, comprising typically 5 to 6% dry matter.

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- Nitrogen, sulfur, and chlorine can also be found in quantity, usually less than 1% dry matter but occasionally well above this.
- The latter are important in the formation of pollutant emissions and sulfur and chlorine in certain ash reactions leading to fouling and slagging.
- Nitrogen is a macronutrient for plants, and critical to their growth. Certain inorganic elements can be found in high concentration as well

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- In annual growth tissues, concentrations of the macronutrient potassium frequently exceed 1% dry matter.
- In some of the gramineae grasses and straws., silica is the third largest component in rice straw, silica is 10–15% of dry matter.

Heating Value:

- The heat value, or amount of heat available in a fuel (kJ/kg), is one of the most important characteristics of a fuel because it indicates the total ***amount of energy*** that is available in the fuel.
- The heat value in a given fuel type is mostly a function of the fuel's chemical composition.
- The heat value can be expressed in one of two ways: the **higher heating value** or the **lower heating value.**

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- **The higher heating value (HHV)** is the total amount of heat energy that is available in the fuel, including the energy contained in the water vapor in the exhaust gases.
- **The lower heating value (LHV)** does not include the energy embodied in the water vapor.
- Generally, the HHV is the appropriate value to use for *biomass combustors*, although some manufacturers may utilize the LHV instead, which can lead to confusion.
- **(GHV), also know as the available potential heat.**
- RHE = recoverable heat energy is the amount of heat that can be utilized after combustion

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- Some **species** of biomass tend to have more energy per unit of mass than others.
- However, the variation between species is often no greater than the natural variations found within one species or another.
- The heat content of a fuel type can vary significantly depending on the **climate and soil** in which the fuel is grown, as well as other conditions.
- As a result, the energy content of a biomass fuel should be thought of as a range rather than a fixed value.

Moisture and dry matter content

- Most forms of biomass contain water to varying degrees and this affects the energy content of the material.
- Measuring the moisture content is critical for solid biomass assessment and also when purchasing it to determine a fair value.

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- It can be achieved by taking samples weighing them, oven drying at around 90^{o}c until constant weight, then reweighing the remaining dry matter to calculate the moisture that has been driven off.
- Using electronic instruments such as conductivity probes pushed into a pile of straw or wood chips is more rapid though their accuracy can vary.

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- The atmospheric ambient conditions, (mainly temperature, air movement and humidity), together with the structure of the tissues of the specific biomass, determine the natural release of moisture from the biomass by transpiration and evaporation, and hence the drying rate.

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- A branch or tree with leaves left on after felling results in faster transpirational drying taking place to bring down the moisture content of the stem wood.
- The interactions between **moisture contents, dry matter losses in storage over time, heating values and biomass bulk densities** need to be understood as they affect the overall costs of transport, storage and conversion of the biomass.

Calculating the MC of solid biomass

- The moisture content in a fuel can be calculated by one of two methods: wet basis or dry basis.
- In the case of wet-basis calculations, the moisture content is equal to the mass of water in the fuel divided by the total mass of the fuel.
- In the case of dry-basis calculations, the moisture content is equal to the mass of water in the fuel divided by the mass of the dry portion of the fuel.

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- It is important to know which type of calculation is being used, as the two values can be quite different in magnitude.
- *100
- *100
- ..\Wood is mainly composed of.docx

Chapter Two

Production and Management of Bioenergy crops

2.1 Energy crops

- Bioenergy is the energy retrieved from biomass sources.
- Bioenergy crops are defined as any plant material used to produce bioenergy.
- These crops have the capacity to produce large volume of biomass, high energy potential, and can be grown in marginal soils.
- Bioenergy can contribute to reducing the overall consumption of fossil fuels.
- Energy may be generated through direct combustion or gasification of the crops to create electricity and heat, or by converting them to liquid fuels such as ethanol, biodiseal, methanol for use in vehicles.

2.2 Types of Energy Crops

- Energy crops are generally divided into two types: herbaceous and woody.

I). Herbaceous Crops

- Herbaceous energy crops are mostly types of grasses, which are harvested like hay.

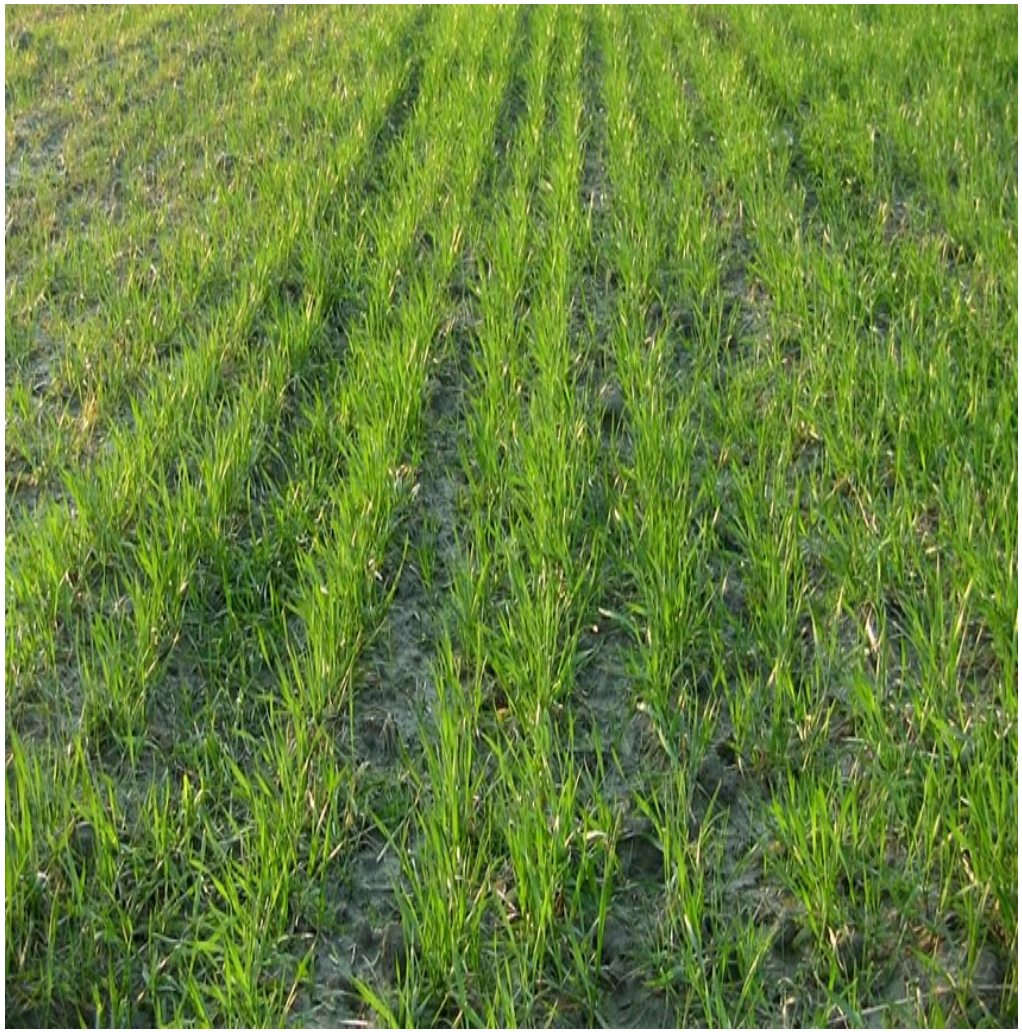
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- Perennial grasses, such as switchgrass, miscanthus, bluestem, elephant grass, and wheatgrass could all potentially be grown as energy crops.
- These grasses regrow from their roots and therefore do not require replanting for long periods of time (15 years or more).

Switchgrass:

- Switchgrass has become a main focus for research over other types of energy crops because yields are higher and production costs lower.
- One reason switchgrass has lower production costs is that standard farming equipment can be used for cutting and baling.
- Another benefit of switchgrass over other types of energy crops is its drought tolerance and adaptability to many types of soils and climates.

Switch grass





- Unlike many traditional crops, switchgrass is a perennial so it doesn't need to be planted each year.
- Once established it can be harvested up to twice a season.
- Switchgrass reaches full yield capacity after 3 years.
- Its permanent root system can extend over 10 feet into the ground and coupled with its large temporary root system it can improve soil quality through increased water infiltration and "nutrient-holding capacity".



Swithchgrass harvest



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- One problem with switchgrass is that it’s susceptible to be overtaken by weeds until it establishes itself.
- However, this can be overcome with proper weed control by mow weeds to 4-5 inches, or through burning in late winter or early spring before new switchgrass has started to grow.

ii) Short Rotation Woody Crops

- The other type of energy crops are Short Rotation Woody Crops (SRWC).

- This includes many types of trees such as cottonwood, silver maple, black locust, bamboo and poplar.
- SRWCs can be grown for a primary purpose such as paper production and the by-products can be utilized for energy.

Short rotation woody crops

Cottonwood



Silver Maple



Black locust



Bamboo



Poplar



2.3 Growing energy crops

- Another way to produce more biomass is to grow it as special energy crops.

a) These can be *vegetative perennial grasses* cut annually or even 2 or 3 times each year,

b) Short rotation forests harvested every 5 to 10 years and either replanted or allowed to regrow from the cut stump (coppicing),

c) *Annual crops* grown for their energy components such as oil, or sugar or straw.

Growing the Energy crops

- The three major elements that need to be considered when growing energy crops are:
  i. Assessing whether the selected crop will be economically viable to grow, harvest and store under the specific circumstances of the market at that time;
  ii. Selecting the most appropriate species and provenance to best match the soil types and climatic conditions; and
  iii. Crop management to maximize environmental benefits, minimize any negative impacts and to fit in with existing crop rotations , machine and labour availability.

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- A grower will select a suitable site for producing an energy crop once a *reliable market* has been identified and the *economic viability* confirmed.
- Site selection will depend on such factors as landscape, road access, proximity to a bioenergy processing plant, soil type, water availability, disease and pest history, archaeological history, competition for growing other crops and public access.
- Where a popular view is likely to be blocked or modified, or access to a public right of way reduced, then public resistance to the project will be increased.

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- Landscapes of specific quality and with conservation values may be under special protection and local policies may apply that inhibit new crop production.
- Tree crops can also affect visibility of paths and views and impact on people's visual amenity.
- Straight rows and boundaries for tree plantations for example can have a greater visual impact than planting around the contours.
- Conversely, some plantations may contribute positively to variations in landscape and biodiversity, provide shelter and wind breaks and provide recreational value.

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- Where a heat demand exists on a farm or for local industry it could make sense to use straw or other crop residues from existing crops.
- Where no other suitable biomass resource is available, a crop could be grown to meet that purpose.
- The sale of any *surplus biomass* by a landowner could generate additional income if there is a market, and also make better use of any under-utilised land.

2.4 Categories of Energy Crops

- There are five broad categories of bioenergy crops; these include:
  - **a) Traditional Bioenergy Crops,**
  - **b) First Generation Bioenergy Crops,**
  - **c) Second Generation Bioenergy Crops,,**
  - **d) Third Generation Bioenergy Crops and**
  - **e) Dedicated Bioenergy crops**

a).Traditional Bioenergy crops

- Traditional biofuels derived from *natural vegetation or from crop residues.*
- Such biofuels still are the main energy source in number of countries, but they are *not sustainable,* their exploitation may contribute to *land degradation and desertification* and are unable to mitigate the impact of Global Climate change.

b). First generation bioenergy crops (FGECs)

- The vast majority of current *liquid biofuels* production is based on FGECs.
- It can also used for ***food*** therefore; their raw materials compete with food for fertile land and inputs. For example **corn, sugarcane, oil palm and rapeseed.**
- Biofuels derived from FGECs rely on *fermentation* of sugars to produce *ethanol* or on *trans-esterfication* of plant oils to produce *biodiesel*.

Corn



Oil Palm



Rape seed plant



Sugar cane



c). Second generation bioenergy crops (SGECs):

- The SGECs are expected to be ***more efficient*** than FGECs and to provide fuel made from cellulose and non-oxygenated, pure hydrocarbon fuels such as biomass-to-liquid fuel.
- Biofuels produced biochemically or thermo-chemically from lingo-cellulosic SGECs, have more energy content (GJ/ha/yr) than most FGECs biofuels.

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- They avoid many of the environmental concerns, and may offer greater cost reduction potential.
- Early SGECs include **perennial forage crops** such as *Switchgrass., Phalaris arundinacea L., Medicago sativa L., Pennisetum purpureum Schumach., and Cynodon spp* (Oliver et al., 2009).

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- The capacity of *Miscanthus* to fix CO2 ranges from 5.2 to7.2tC/ha/yr, which results in a negative C balance (Boe and Beck, 2008; Jakob et al.,2009).
- The contribution of non-edible plant oils (e.g., from *Jatropha curcas* L., Euphorbiacea; 30-50% oil) and soapnut (*Sapindus mukorossi* and *S. trifoliatus*; 52% oil), as new sources for *biodiesel production* have the advantage of not competing with edible oils produced from crop plants (Ram et al., 2008).

d). Third generation bioenergy crops (TGECs):

- The TGECs include *boreal plants, CAM plants, Eucalyptus spp. and micro-algae*.
- The boreal and CAM plants are potential sources of feed stocks for *direct cellulose fermentation* and ***Eucalyptus*** for bioenergy production through thermo-conversion whereas, *algae* is a potential source of *biodiesel*.

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- A number of TGECs oleaginous crops being tested for biodiesel production include: African palm (22% oil), coconut (55-60% oil), and grain of castor bean (45-48% oil), and peanut (40-43% oil).
- They can help to reduce GHG emissions by capturing CO2 released from power plants or by generating biomass through photosynthesis.

e). Dedicated bioenergy crops (DECs)

- DEC have been proposed as a strategy to produce energy without impacting *food security* or the *environment.*
- Their Genetic resources requirements for biological, chemical or physical pretreatment are more environmentally friendly and will contribute more to GCC mitigation (Petersen, 2008).
- They are beneficial in providing certain ecosystem services, including *C sequestration, biodiversity enhancement, salinity mitigation, and enhancement of soil and water quality.*

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The Dedicated Crops include:

i. Crops including short rotation trees and shrubs such as eucalyptus (*Eucalyptus* spp.), poplar (*Populus* spp.), willow (*Salix* spp.), and birch (*Betula* spp.);

ii. Perennial grasses such as giant reed (*Arundo donax*), reed canary grass (*Phalaris arundinacea*), switchgrass (*Panicum virgatum*), elephant grass (*Miscanthus gigantus*), Johnson grass (*Sorghum halepense*) and sweet sorghum (*Sorghum bicolor*);

iii. Non-edible oil crops such as castor bean (*Racinus communis*), physic nut (*Jatropha curcas*), oil radish (*Raphanus sativus*), and pongamia (*Pongamia* spp).

2.5 Energy crop production in Ethiopia

- ✓The Ethiopian Government plans to allocate areas with low agricultural potentials or degraded areas for the production of biofuel crops.
- ✓ 2,300ha of land is ready for biofuel production.

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- These areas are often recognized as food insecure areas.
- For example in the northern region of the country Kola Temben; one company has planted perennial crop trees for biofeul feedstock on 15,000ha. This is an area known with a large population living under extreme poverty and food insecurity.
- In southern region of Ethiopia, Wolayta and Gamo Gofa districts which are known to be heavily food insecure.
- Castor production in the southern region started in 2008 with castor seed distribution to more than 10,000 farm households in wolayta and Gamo Gofa.

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- The Ethiopian *Biofuel Development and Utilization Strategy*" is targeted to supply fuels from locally produced biofuel (*Jatropha*, Castor bean, Palm oil and sugar cane)

- The objective of the strategy is to ensure the production of biofuel without affecting food self sufficiency, to improve balance of payment and to reduce environmental impacts.

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- Bio-ethanol can be made of sugar cane.
- 8millionLitter of ethanol is currently produced annually from sugar cane in Ethiopia and bio-ethanol has been starting to be

Castor bean





Jatropha carcus





Chapter Three

Environmental impacts of energy crops production

3.1 Introduction

- For developing countries, the development of bioenergy presents both *opportunities* and *challenges* for economic development and the environment.
- Like any crop and plantation, the environmental impacts of planting feedstock for biofuels will depend on the *bioclimatic conditions* of the site used, the *biofuel crop characteristics* and the *agriculture practices applied*, including *socio-economic factors, the scale of production and the previous use of the land.*

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- The main crops currently used as feedstock in liquid biofuel production require *high quality agricultural land and major inputs* in terms of *fertilizers, pesticides* and *water* to generate economically viable yields.

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- On the other hand, Jatropha, like other bioenergy crops (*willow or grasses*), has the potential to grow in *marginal land* with *little rainfall* requirements and can help revive certain areas.

3.2 Environmental Impacts of Bioenergy crops

- Bioenergy crops may have a wide range of effects on **soils, water, air, habitat, and greenhouse gas emissions.**
- The net effect will depend on the particular *type of energy crop and the previous use of the land, the cultivation methods practiced, the overall effort to integrate the crop with the regional landscape ecology,* and other factors.

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- The anticipated large increase in energy crop production will require **large land areas** (UNEP, 2009).
- As high quality land for agricultural production is limited, or at least unevenly distributed, biomass crops will most likely ***compete with food and feed production, urban development, forestry and nature conservation or high nature value farming*** (Sala et al., 2009).
- Regardless of the total land area required for energy crops, the actual pattern of spatial distribution and habitat configuration of biomass crop plantations will determine their impact.

i) Impact of monoculture plantations

- Large biofuel plantations are grown usually under monoculture cropping systems.
- Over time, continuous intensive monoculture cropping systems may lead to pest and pathogen buildup, declining soil fertility, loss of biodiversity and ultimately, land and natural resource degradation.

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- Before the introduction of **synthetic fertilisers and pesticides**, farmers used to maintain nitrogen supply in the soil for crop uptake by cultivating *nitrogen fixing crops* and pests were often controlled biologically by changing or *diversifying the crops* cultivated on the farm.
- This was generally achieved through the application of **multiple cropping systems** and **crop rotation** (FAO 2012).

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- A number of farming practices aim at limiting the damages of monoculture.
- These include: **Multiple cropping, Sequential cropping, Intercropping and Crop rotation.**
- A full discussion about the benefits and drawbacks of each of these practices applicable to bioenergy feedstock production can be found in (FAO, 2012).

ii) Clearance of forest and use of new land for biofuels production

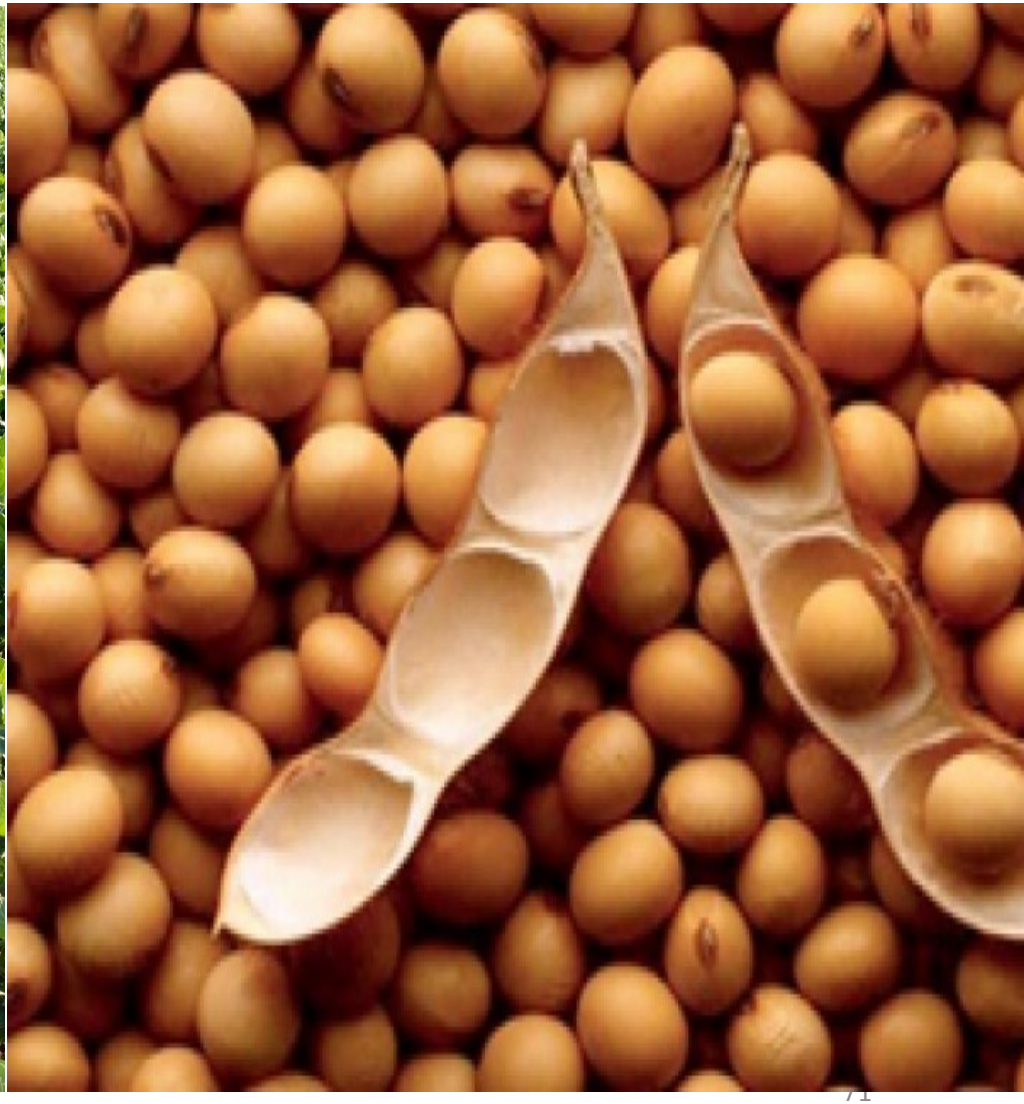
- feedstock used in Latin America.
- The impacts of biofuels on **deforestation** depend on the particular a, *sugarcane* is generally expanding on lands cleared for agriculture a long time ago and is unlikely to cause direct deforestation; it may nevertheless cause indirect land use change by displacing crops or livestock into forests or grasslands.

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- This can create potential *conflict over land use* as a result of feedstock production.
- Soya is in general a pioneer crop, frequently produced on the agricultural frontier in forestlands, cleared for this purpose or in areas cleared for pasture and beef production.

Soya bean





iii) Water pollution by intensive use of agrochemicals

- It is not possible to accurately classify the damage to the environment and particularly to water and soils from feedstocks cultivated for biofuel as the effects depends on many factors such as **climate and location, soil type, farm size, types of feedstock, mode of operation and practices, irrigated or rained.**

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- The fertilisation of the soils consists in an important addition of nutrients (mainly nitrogen and phosphorus).
- When wrongly used, these products degrade the **quality of groundwater and surface waters.**

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- This also generates significant additional costs in the treatment of freshwater.
- An excess of these products causes especially ***eutrophication*** *of rivers, natural water storages and even marine environment: the production of algae and other aquatic species is accelerated with an overall reduction of the biodiversity*.
- Large coastal areas and estuaries are dramatically affected, called "***dead zones***".

iv) Impacts on biodiversity

- Biofuel production can affect wild and agricultural biodiversity in some positive ways, such as through the **restoration of degraded lands**, but many of its impacts will be negative, for example when **natural landscapes are converted into energy crop plantations or peat lands are drained** (CBD, 2008).

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- In general, wild biodiversity is threatened by **loss of habitat** when the area under crop production is expanded,
- Whereas agricultural biodiversity is vulnerable in the case of large-scale *monocropping,* which is based on a *narrow pool of genetic material* and can also lead to **reduced use of traditional varieties.**
- The first pathway for biodiversity loss is *habitat loss* following *land conversion* for crop production, for example from **forest or grassland.**

v). Impacts on water resources

- Water, rather than land, scarcity may prove to be the key limiting factor for biofuel feedstock production in many contexts.
- About 70 percent of *freshwater* withdrawn worldwide is used for agricultural purposes (Comprehensive Assessment of Water Management in Agriculture, 2007).

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- Water resources for agriculture are becoming increasingly scarce in many countries as a result of increased competition with *domestic* or *industrial uses.*
- Moreover, the expected impacts of *climate change in terms of reduced rainfall and runoff* in some key producer regions (including the Near East, North Africa and South Asia) will place further pressure on already scarce resources.

Chapter Four

Thermo-chemical conversion of biomass in to useful energy

4. Introduction

- Conversion of biomass to energy is undertaken using three main process technologies:

1. Thermo-chemical
2. Bio-chemical/biological
3. Mechanical Densificatoin of Biomass.

- Three main processes are used for the thermo-chemical conversion of biomass i.e. combustion, gasification, Carbonization and pyrolysis.

4.1.1 Combustion

- Combustion is the burning of biomass in air, and it is used to convert the **chemical energy** stored in biomass into **heat energy, mechanical power** and also into **electricity** by different process and devices e.g. furnaces,

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- **Combustion** is also the process by which more than 90% of the world's primary energy supply is realizing in order to provide heat and energy services such as materials processing including food preparation, space heating , ventilation and cooling ;electricity and transportation.

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- It is possible to burn any type of biomass but in practice combustion is feasible only for biomass with a moisture content less than 50%, unless the biomass is pre-dried.
- High moisture content biomass is better suited to biological conversion processes.

4.1.2 Significance of Biomass Combustion

- Use of biomass for energy causes no net increase in carbon dioxide emissions to the atmosphere and does not contribute to the risk of global climate change.
- •Growing plants remove carbon from the atmosphere through photosynthesis.

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- If the amount of new biomass growth balances the biomass used for energy, bioenergy is **carbon dioxide "neutral"**
- Globally, biomass meets about 14 percent of the world's energy

a). Direct combustion

- Combustion technologies convert biomass fuels into several forms of useful energy for commercial or industrial uses: hot air, hot water, steam and electricity.

i). A furnace:

- Is the simplest combustion technology:
- Biomass fuels burns in a combustion chamber converting biomass into heat energy (hot gases contains 85 % of the fuel's potential energy).
- Either direct or indirect use of heat exchanger to use the hot gases in the form of hot air or hot water.

A furnace for biomass combustion



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Combustion of wood can be divided into four phases:

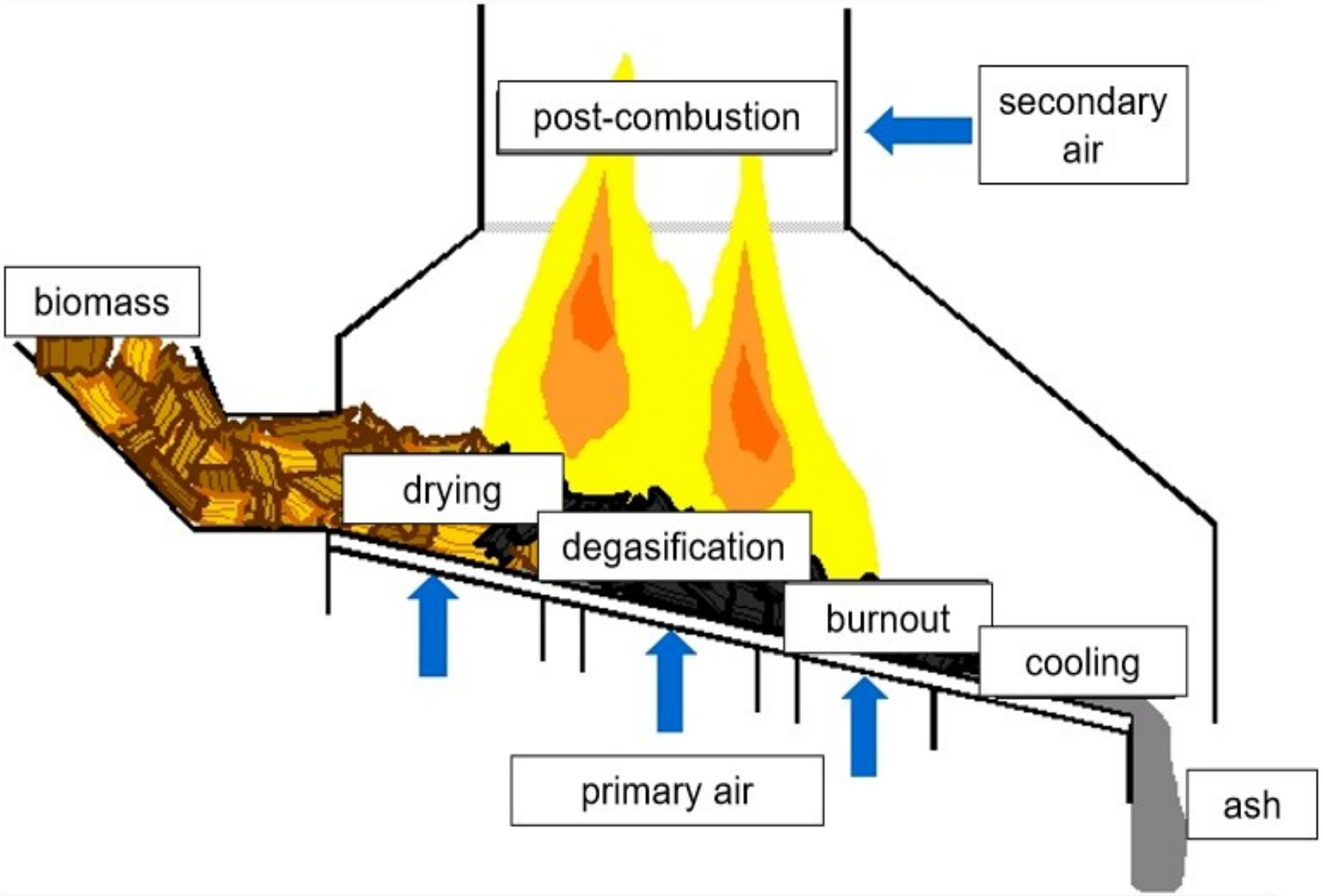
i. **Drying:** water inside the wood boils off.

ii. Degasification: gas content is freed from the wood.

iii. **Gasification:** the gases emitted mix with atmospheric air and burn at a high temperature.

iv. **Combustion:** the rest of the wood (mostly carbon) burns

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post-combustion
secondary air
biomass
drying
degasification
burnout
cooling
primary air
ash

ii) A biomass-fired boiler:

- It is a more adaptable direct combustion technology because a boiler transfers the heat of combustion into steam.
- Steam can be used for electricity, mechanical energy and heat.
- Boiler's steam output contains 60 to 85 % of the potential energy in biomass fuel.
- Major types of biomass combustion boilers: pile burners, stationary or travelling grate combustors, fluidized-bed combustors.

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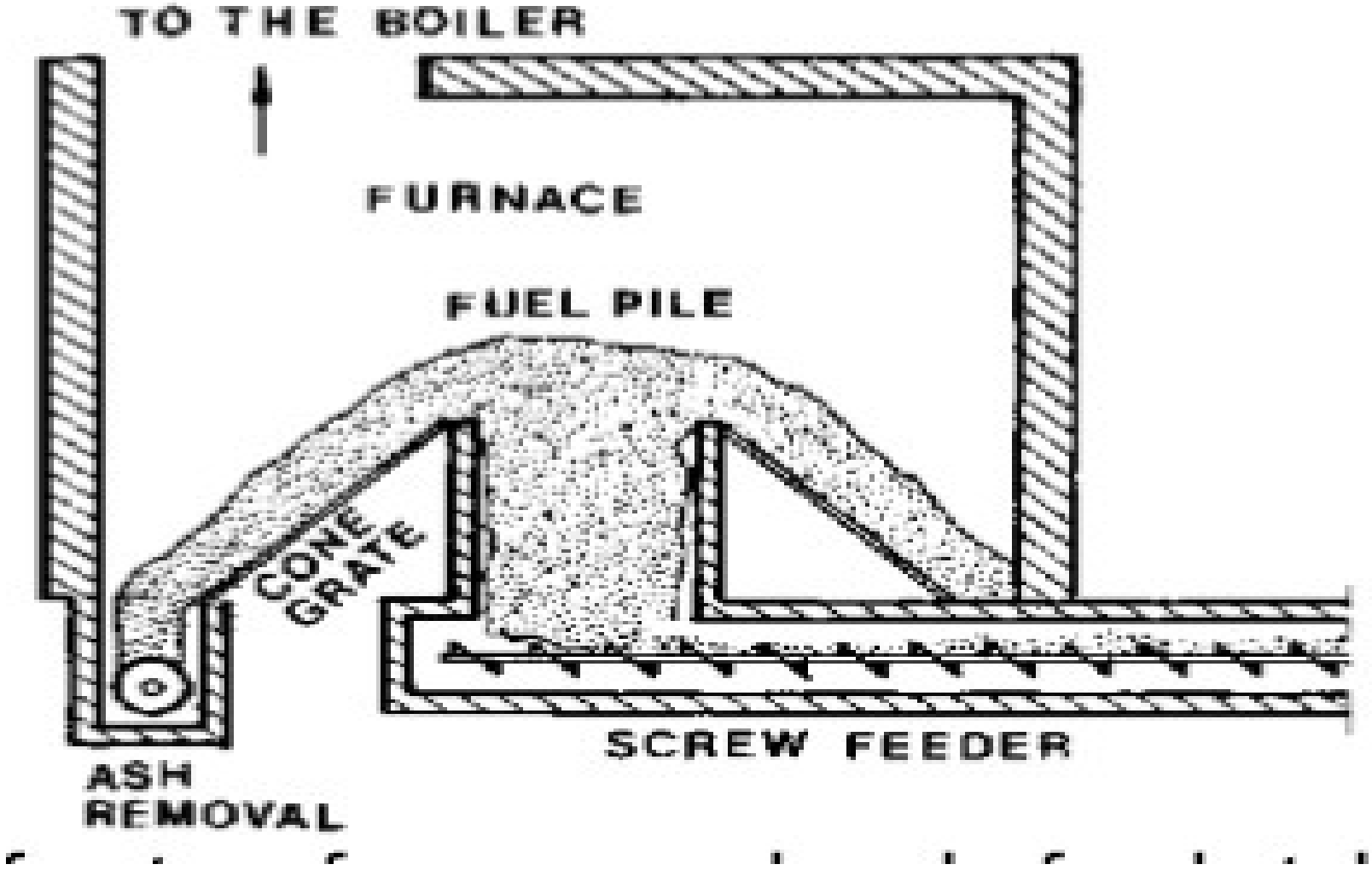
- **Pile burners:** - consist of cells, each having an upper and a lower combustion chamber

  - biomass fuel burns on a grate in the lower chamber, releasing volatile gases

  - the gases burn in the upper combustion chamber

  - operator must shut down pile burners periodically to remove ash.

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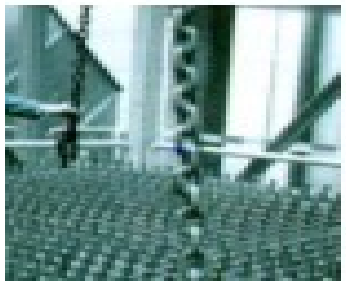

TO THE BOILER
FURNACE
FUEL PILE
CONE GRATE
SCREW FEEDER
ASH REMOVAL

Cont'd

Fluidized-bed combustors:

- Burn biomass fuel in a hot bed of granular material, such as sand.
- Injection of air into the bed creates turbulences resembling a boiling liquid -the turbulences distributes and suspends the fuel.
- The design of a fluidized-bed reactor increases heat transfer and allows for operating temperatures below 950 °C, reducing nitrogen oxide emissions.
- Fluidized-bed combustors can handle high-ash fuels, agricultural residues and sewage sludge.

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flue gas
secondary air
secondary air
fuel
ash
air
combustion bed ash

4.2 Heat Transfer

- Thermal energy is related to the temperature of matter.
- For a given material and mass, the higher the temperature, the greater its thermal energy.
- **Heat transfer** is a study of the exchange of thermal energy through a body or between bodies which occurs when there is a temperature difference.
- When two bodies are at different temperatures, thermal energy transfers from the one with higher temperature to the one with lower temperature.

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- Heat always transfers from hot to cold.
- Heat is typically given the symbol **Q,** and is expressed in joules (J) in SI units.
- The rate of heat transfer is measured in watts (W), equal to joules per second, and is denoted by q.
- **The heat flux,** or the rate of heat transfer per unit area, is measured in watts per area (W/m²), and uses q" for the symbol
- There are three types of heat transfer mechanisms in a system.

4.2.1 Conduction

- ✓Conduction involves the transfer of heat by the interaction between adjacent molecules of a material.
- ✓Heat transfer by conduction is dependent upon the driving "force" of temperature difference and the resistance to heat transfer.

Cont'd

- ✓The resistance to heat transfer is dependent upon the nature and dimensions of the heat transfer medium.
- ✓All heat transfer problems involve the temperature difference, the geometry, and the physical properties of the object being studied.

4.2.2 Convection

- Convection involves the transfer of heat by the motion and mixing of "macroscopic" portions of a fluid (that is, the flow of a fluid past a solid boundary).
- The term natural convection is used if this motion and mixing is caused by density variations resulting from temperature differences within the fluid.

Cont'd

- ✓The term forced convection is used if this motion and mixing is caused by an outside force, such as a pump.
- ✓The transfer of heat from a hot water radiator to a room is an example of heat transfer by natural convection.
- ✓The transfer of heat from the surface of a heat exchanger to the bulk of a fluid being pumped through the heat exchanger is an example of forced convection.

4.2.3 Thermal Radiation

- Radiant heat transfer involves the transfer of heat by electromagnetic radiation that arises due to the temperature of a body.
- Most energy of this type is in the infra-red region of the electromagnetic spectrum although some of it is in the visible region.
- The term thermal radiation is frequently used to distinguish this form of electromagnetic radiation from other forms, such as radio waves, x-rays, or gamma rays.

Cont'd

- The transfer of heat from a fireplace across a room in the line of sight is an example of radiant heat transfer.
- Radiant heat transfer does not need a medium, such as air or metal, to take place.
- Any material that has a temperature above absolute zero gives off some radiant energy.
- When a cloud covers the sun, both its heat and light diminish.
- This is one of the most familiar examples of heat transfer by thermal radiation.

4.3 Gasification

- **Gasification** is the conversion of biomass into a combustible gas mixture by the partial oxidation of biomass at high temperatures, typically in the range 800–900 oC.
- The low calorific value (CV) gas produced can be burnt directly or used as a fuel for gas engines and gas turbines.
- The application of this produced gas can be used as a feedstock (syngas) for the production of chemicals like methanol.

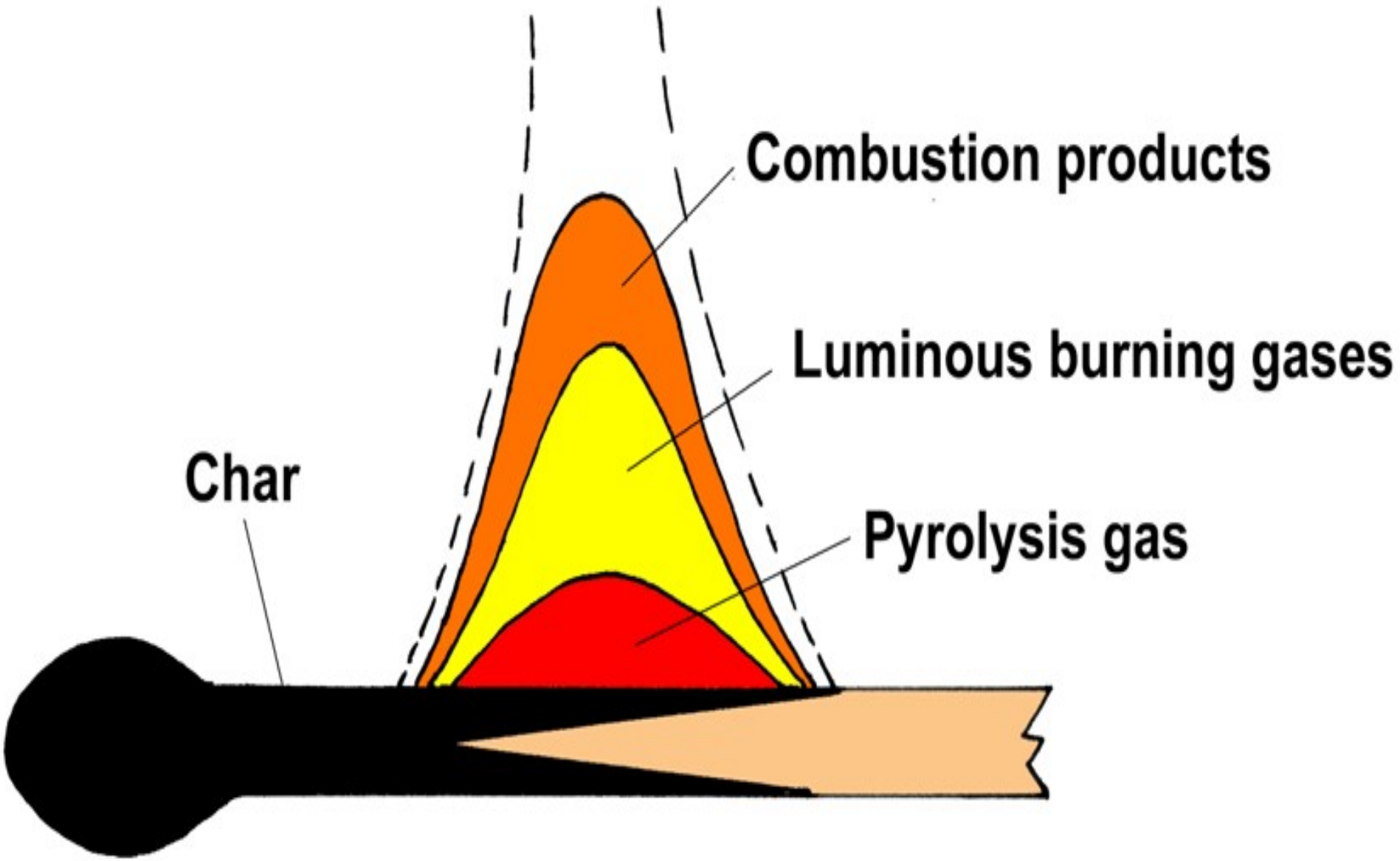
4.4 Pyrolysis

- The word is coined from the Greek-derived elements *“pyro* "fire" and *“lysis”* "separating".
- Thermochemical decomposition of organic material at elevated temperatures in the absence of oxygen (or any halogen)
- It involves the simultaneous change of chemical composition and physical phase, and is **irreversible**

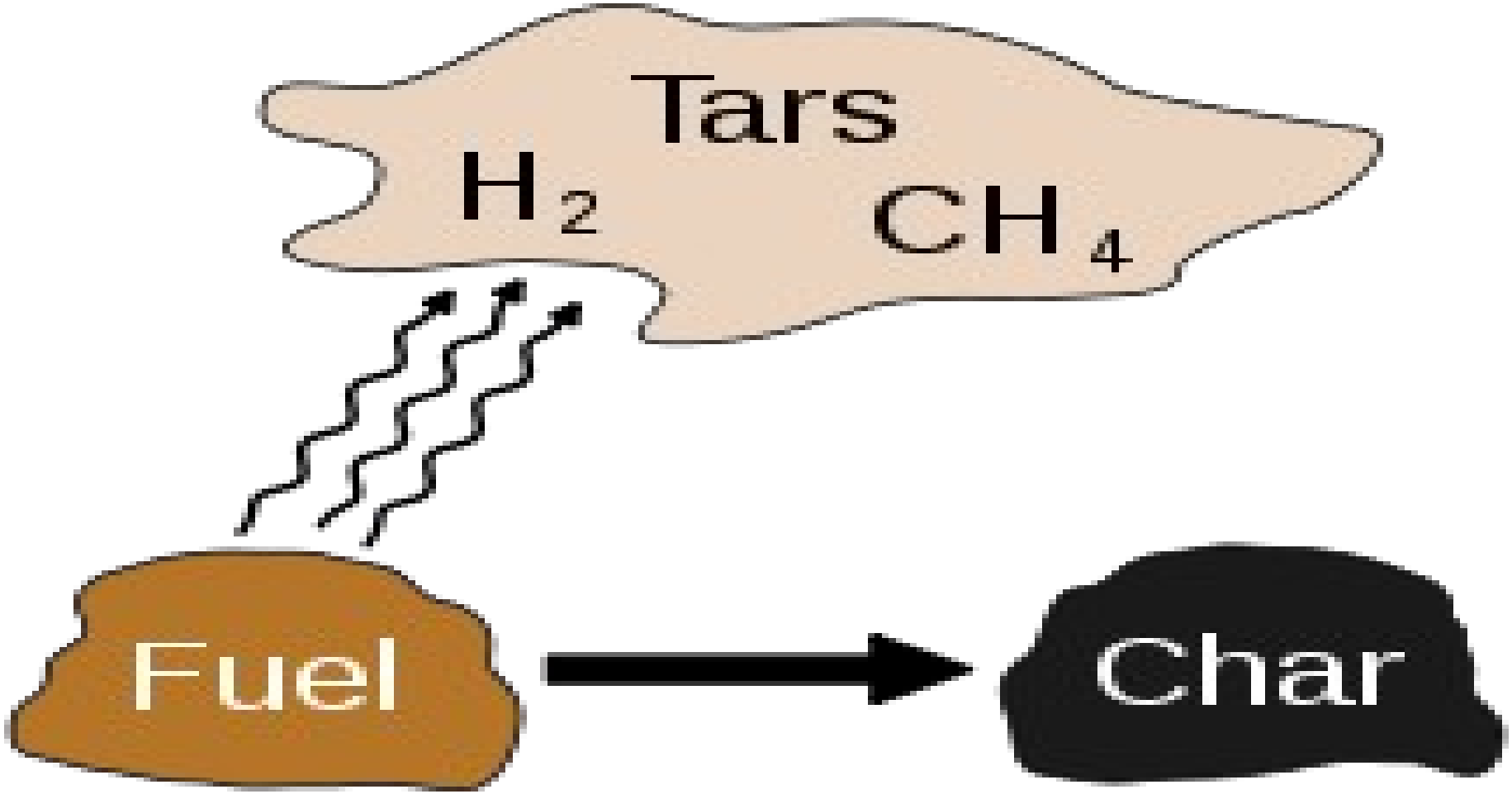
Cont’d

- It is one of the processes involved in charring wood, starting at 200–300 °C
- It also occurs in fires where solid fuels are burning
- In general, pyrolysis of organic substances produces gas and liquid products and leaves a solid residue richer in carbon content, char
- Extreme pyrolysis, which leaves mostly carbon as the residue, is called **carbonization**

Cont’d


Combustion products
Luminous burning gases
Char
Pyrolysis gas

Product of pyrolysis



Pyrolysis System

- Pyrolysis systems use kilns and reactorts and other specialized equipment to contain the baking biomass while excluding oxygen.
- The reaction vessel is vented, to allow pyrolysis gases, often called "syngas", to escape.
- The process becomes *self-sustaining* as the syngas produced is combusted, and heat is released.

Technologies for biomass pyrolysis

- **Fixed beds:** used for the traditional production of charcoal - Poor, slow heat transfer result in very low liquid yields
- **Ablative processes**: Biomass particles are moved at high speed against a hot metal surface. This can be achieved by using a metal surface

Cont’d

- As an alternative, the particles may be suspended in a carrier gas and introduced at high speed through a cyclone whose wall is heated
- A problem shared with all ablative processes is that scale-up is made difficult, since the ratio of the wall surface to the reactor volume decreases as the reactor

Cont’d

- **Rotating cone**:

✓ Pre-heated hot sand and biomass particles are introduced into a rotating cone. Due to the rotation of the cone, the mixture of sand and biomass is transported across the cone surface by centrifugal force

- **Fluidized beds**:

✓ Biomass particles are introduced into a bed of hot sand fluidized by a gas, which is usually a re-circulated product gas.

✓ High heat transfer rates from fluidized sand result in rapid heating of biomass

Cont’d

- **Circulating fluidized beds**: Biomass particles are introduced into a circulating fluidized bed of hot sand.
- Gas, sand, and biomass particles move together, with the transport gas usually being a re-circulated product gas, although it may also be a combustion gas.
- High heat transfer rates from sand ensure rapid heating of biomass particles and ablation stronger than with regular fluidized beds.

Cont’d

- A fast separator separates the product gases and vapors from the sand and char particles. The sand particles are reheated in a fluidized burner vessel and recycled to the reactor
- Although this process can be easily scaled up, it is rather complex and the products are much diluted

Sources of feedstock for pyrolysis

- **Plant materials** such as sawdust, waste wood, woody weeds
- **Agricultural sources** including nut shells, straw, cotton trash, rice hulls, switch grass (*Panicum virgatum* L.) and bred versions of other grasses such as *Miscantheus giganteus*
- **Animal waste** including poultry litter, dairy manure, and other manures
- **Industrial by-products** including paper sludge and distillers grain

Use of pyrolysis

- Pyrolysis is used as a form of thermal treatment to reduce waste volumes of domestic refuse
- Pyrolysis has been used since ancient times for turning wood into charcoal on an industrial scale.
- Pyrolysis is the basis of several methods being developed for producing fuel from biomass, including crops grown for the purpose and biological waste products from other industries.

Cont'd

- Pyrolysis of scrap or waste tires (WT) can separate solids in the tire, such as steel and carbon black, from volatile liquid and gaseous compounds that can be used as fuel.
- Although the pyrolysis of WT has been widely developed throughout the world, there are legislative, economic, and marketing obstacles to widespread adoption.

4.5 Carbonization

- Carbonization of dry distillation takes place when any organic matter is raised to a high temperature (i.e. above 180°C) under strict exclusion of oxygen or under controlled minimal air intake.
- Essentially the process of carbonization follows a general temperature scheme:
- **Between 100°C and 170°C** - all loosely bound water evaporated from the raw materials.

Cont'd

- **Between l70°C and 270 °C** gases develop (off-gas), containing carbon monoxide (CO),carbon dioxide (CO2) , and condensable vapours, which form pyrolysis oil after scrubbing and chilling.
- **Between 270°C and 280°C** an exothermic reaction starts, which can be detected by the spontaneous generation of heat and the rising temperature.
- At the same time, the development of CO and CO2 ceases but the quantity of condensable vapours rises.

4.5.1 Charcoal Making

- Charcoal making is just the simplest and oldest form of pyrolysis.
- Charcoal is already a market product and plays an important role in the *energy consumption structures* of most developing countries.

Cont'd

- ***Charcoal*** is the residue of solid non agglomerating organic matter, of vegetable or animal origin, that results from carbonization by heat in the absence of air at a temperature above 300 degrees Celsius.

Cont'd

- If charcoal is heated to 900oC under confined conditions, it will lose weight because hydrocarbons and nitrogen are driven out.
- This weight loss is extremely important to industrial charcoal consumers when defining the utilization properties.

4.5.2 Charcoal making techniques

A) Traditional charcoal pit:

- Much of the charcoal in the world has been made by families or small businesses run using simple technology and low capital investment.
- Although the technology is simple, it is nevertheless precise and skillful.

Cont’d

- Virtually, there are numerous ways to build a charcoal pit and all need very little skill.
- *The basic principle is to lead the air from one end of the chamber to the other flowing on the bottom.*
- Therefore, before charging the charcoal pit with the fuelwood bedlogs are laid forming some kind of a crib on which the charge will be placed.
- The crib is made from logs, cut to the width of the Pit' and they are laid evenly spaced along the entire length.

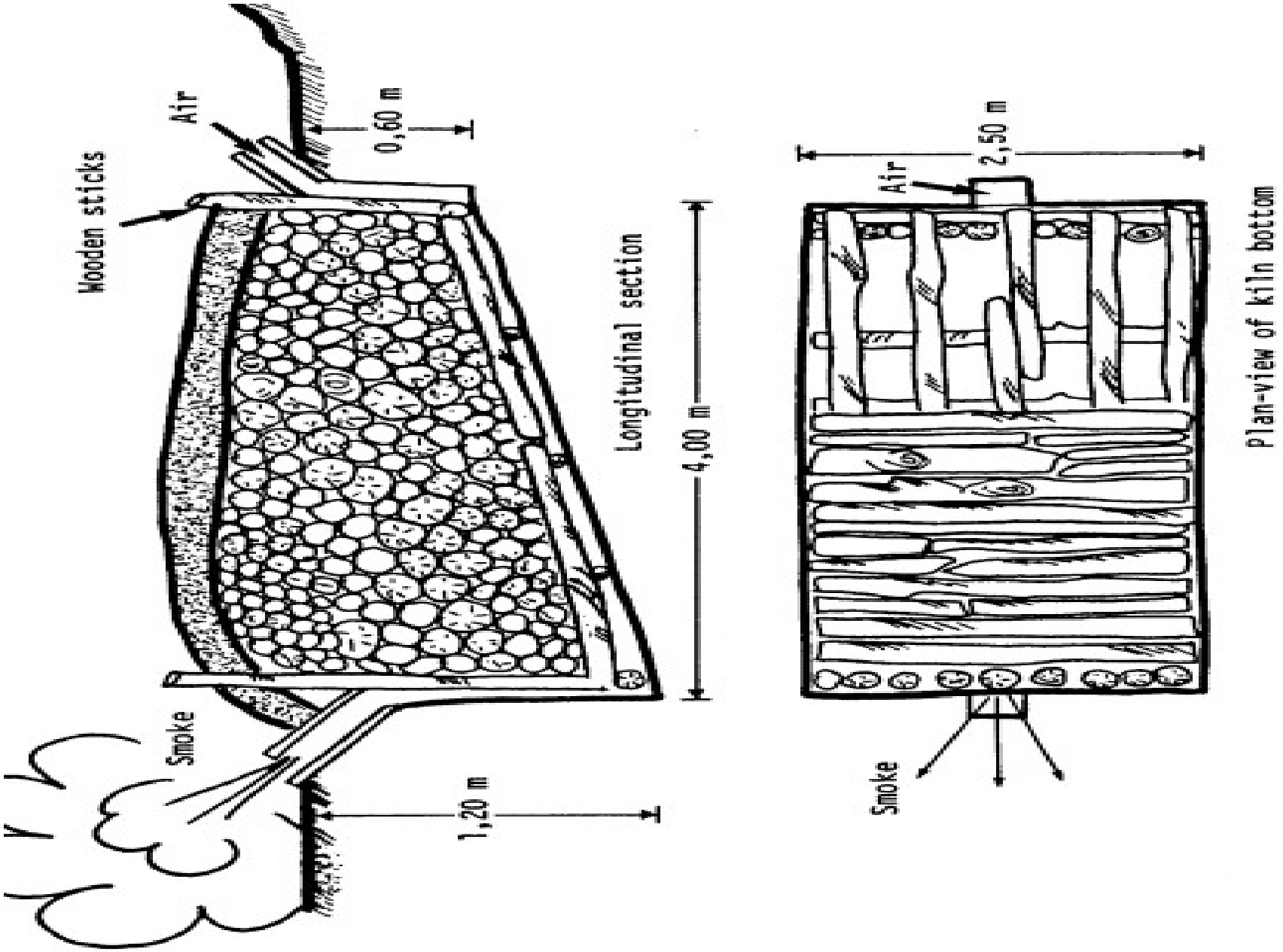
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- The first layer a number of logs will be placed each equal to the length of the charcoal pit.
- Later when the charge has been lighted the incoming air, mixed with the hot gases, will travel beneath the charge and heat it up to carbonization temperature, until they leave the chamber through the flue on the opposite side.
- After loading the pit is covered with a layer of leaves normally 20 cm thick and on top with a layer of soil of the same thickness.

Cont'd

- In a typical pit operation burning takes place progressively from one end to the other.
- The produced charcoal of larger pits is not very uniform, because the burn is difficult to control.
- Smaller pits are more efficient, because they have a better airflow.

Plate 1. A Pit chamber



B/. Earth Mound Kiln

- The typical smallholder charcoal maker builds a kiln of about 2m in diameter at the base and approximately I.5m high.
- Approximately six to ten air inlets are installed at the base.
- The smoke and the gases developing during the carbonization are drawn-off at the top through an opening of 20 cm in diameter.
- This describes roughly a round earth mound kiln. However, can find other shaped kilns like rectangular mounds in as well.

Cont'd

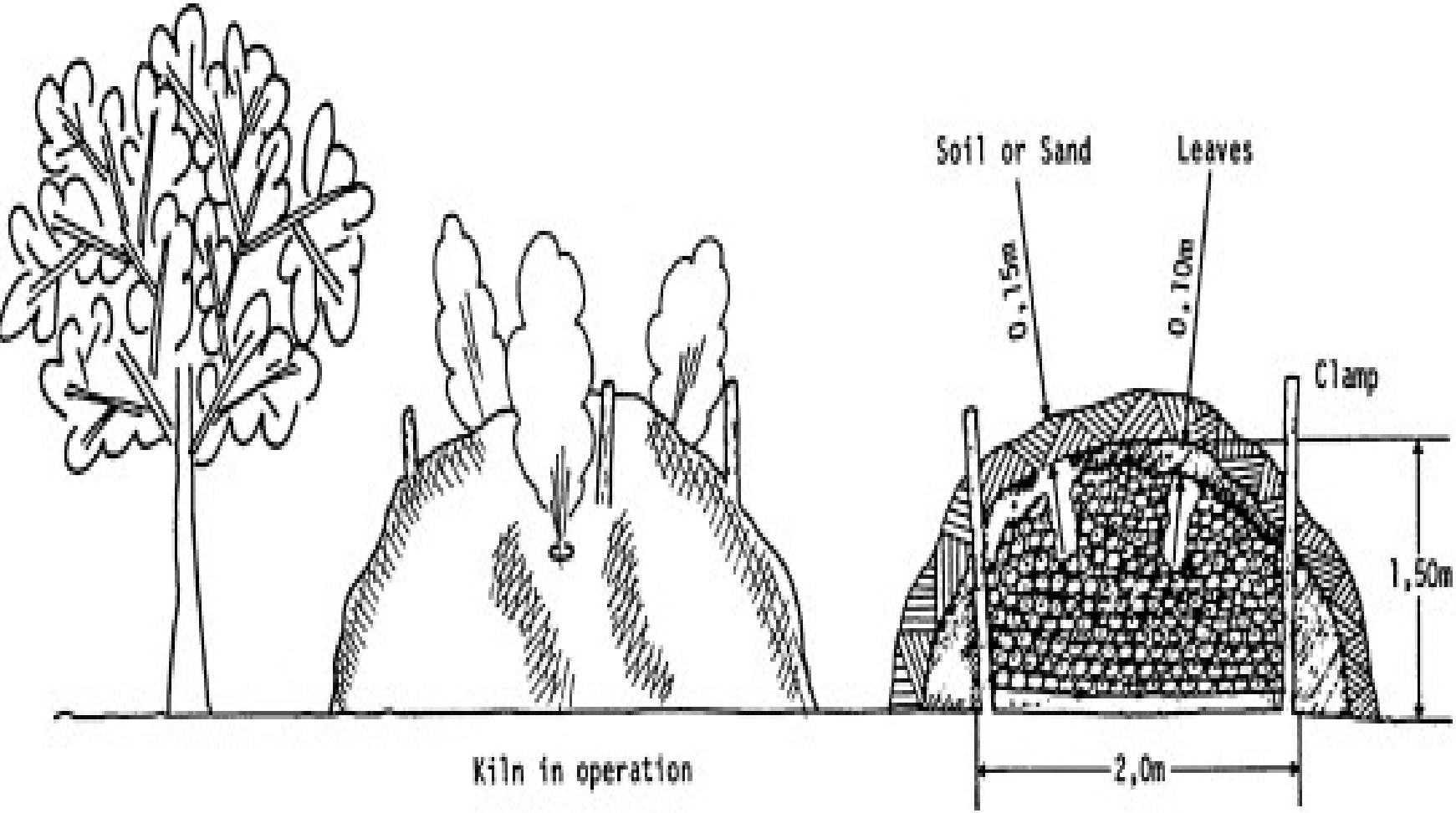
- For the preparation of the kiln site sufficient space has to be cleared, levelled and if necessary compacted also.
- In the case of rectangular or square shaped mounds it becomes necessary to erect posts several on each side, which give stability to the wood pile and provide a support for the operator when covering the kiln with leaves, soil or metal sheets.

Cont'd

- Again, as with the charcoal pit, it is most important to provide a good air and gas flow within the mound after lighting.
- This will be achieved by forming a grid of crossed small- logs (maximum diameter 10 cm) which are first laid out and arranged on the ground.
- On this platform the fuel-wood will be stacked.

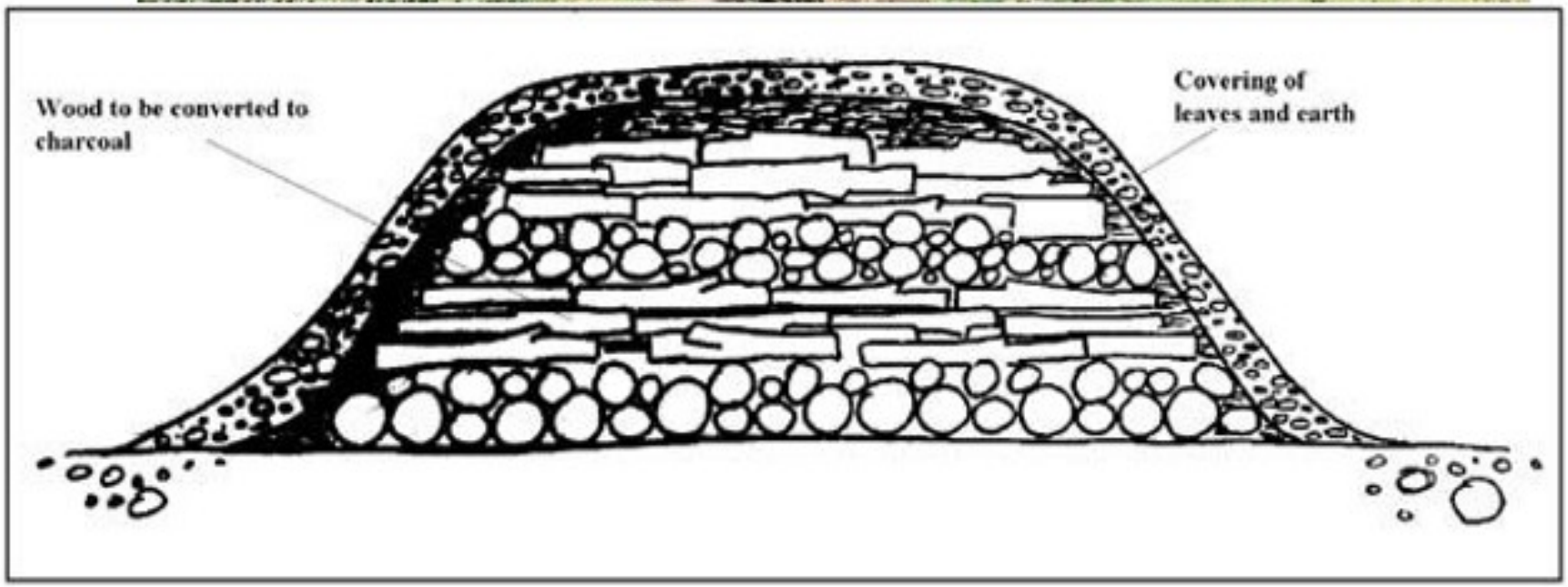
A small Earth Mound kiln

Plate-2



Earth mound kiln





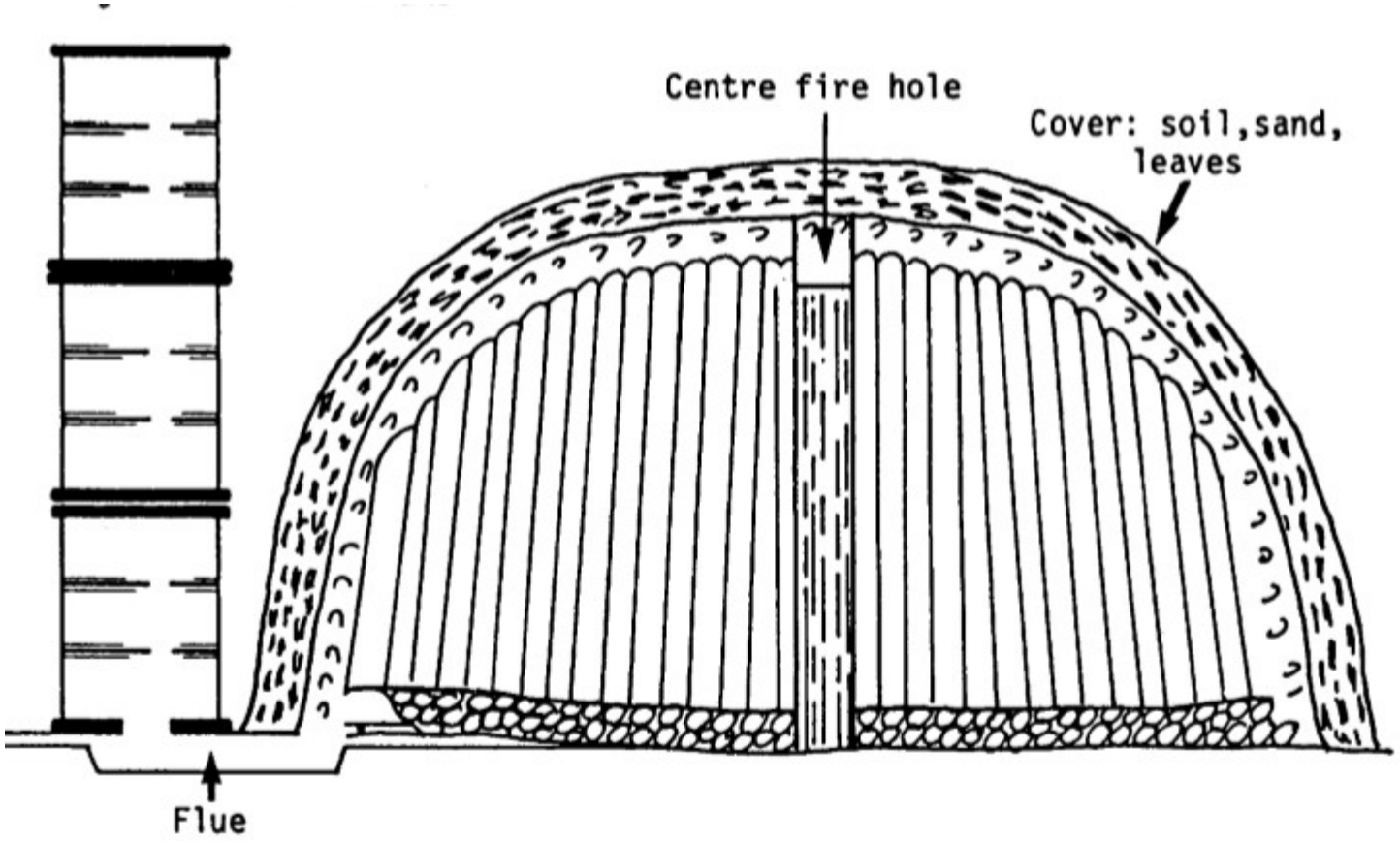
C/. Earth-mound kiln with chimney

- These modified kilns represent the more advanced than the above mentioned the kilns.
- Very large amounts of charcoal- had been produced with these kilns for the growing iron smelting industry.

Con’d

- The elements used for the kiln construction are basically the same as described in the previous section; the grate formed with woodlogs on the bottom, the fuelwood pile (stacked vertically) and the centre hole for firing.
- However, in addition a chimney is attached (normally only one) which is connected to the pile by an *underground flue.*

Earth-mound kiln with chimney



D/. Earth-mound kiln with Tar recovery

- It is only a small step from the chimney-kiln to the charcoal operation with tar recovery.
- A few but important modifications within in the chimney section are necessary.

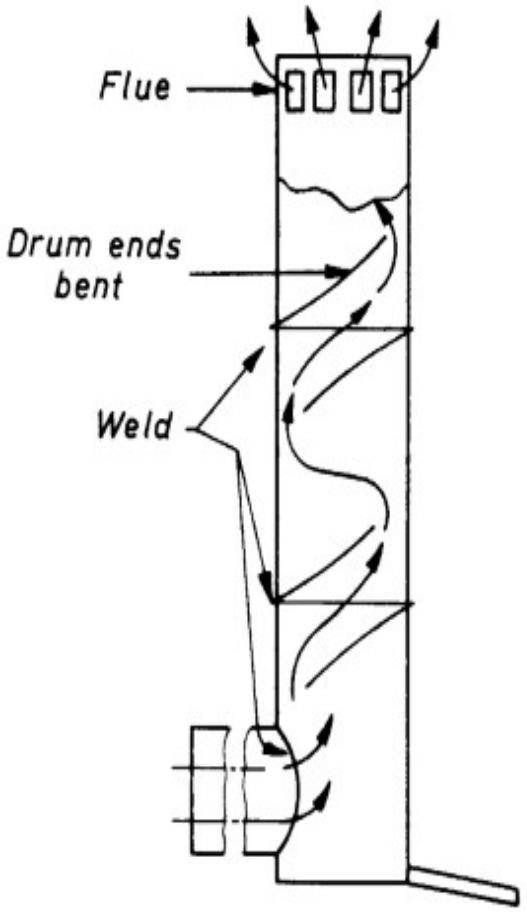
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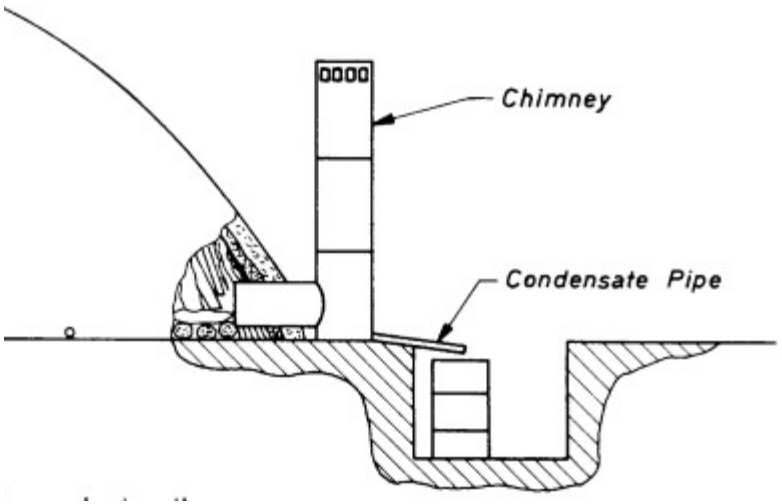
- In the first circumstance the chimney is designed to expel all gases generated during the carbonization process into the ambient atmosphere.
- In the latter case the chimney serves two purposes:
  - ❖ Condensing part of the gases
  - ❖ Guiding the uncondensable portions to the outside.

Cont'd

- Since the investment cost would not allow the installation of chiller and scrubber systems the earth-mound operator has to limit themselves to the collection of only part of the charcoal by products.
- In this case it will be mainly wood tar(charcoal).

Earth-mound kiln with Tar recovery





Chapter five

Bio-chemical conversion of biomass in to useful energy

Biomass fermentation

- Biomass fermentation involves breaking down glucose inside organic material to produce ethanol.
- The end goal is the production of ethanol with *sufficient alcohol concentration* to fuel automobiles, while also finding uses for the solid byproducts.
- Biomass fermentation is one strategy designed to power vehicles without using fossil fuels.

Cont'd

- In the case of biomass fermentation, technicians add **bacteria or yeast** to the biomass, allowing them to turn the sugars into carbon dioxide and ethanol.
- They then distill the ethanol, dehydrating it to achieve a greater concentration, as the purity requirements for vehicle fuel are high.
- Biomass fermentation also creates solid byproducts that are useful in the production of cattle feed.

Cont'd

- Fermentation is used commercially on a large scale in various countries to produce ethanol from sugar crops (e.g. sugar cane, sugar beet) and starch crops (e.g. maize, wheat).
- The biomass is ground down and the starch converted by enzymes to sugars, with yeast then converting the sugars to ethanol.

Cont’d

- Purification of ethanol by distillation is an energy-concentrated step, with about 450 liters of ethanol being produced by 1000 kg of dry corn.
- Solid residue obtained from this process can be given to cattle to feed and bagasse which is obtained from sugar cane can be used for next gasification or as a fuel for boilers .

Cont'd

- The conversion of lignocellulosic biomass (such as wood and grasses) is more complex, due to the presence of longer-chain polysaccharide molecules and requires acid or enzymatic hydrolysis before the resulting sugars can be fermented to ethanol.
- Such hydrolysis techniques are currently at the pre-pilot stage.

Ethanol (C_2H_5OH)

- Ethanol is a liquid alcohol and renewable fuel that can be mass-produced through **fermentation** from any plant (feedstock) that contains a large amount of sugar or components that can be converted into sugar, such as starch or cellulose.

Cont'd

- Ethanol is a clear, colorless liquid.
- It is also known as **ethyl alcohol** and **grain alcohol,**
- Ethanol has the same chemical formula regardless of whether it is produced from starch- and sugar-based feedstocks

First Generation Ethanol Production

- The traditional production of ethanol follows these general steps:

1. **Milling of biomass** to break it down to finer parts, a substance called the **meal**; (This stage can be done either wet or dry; dry processing in some cases can save nearly 50 percent of the total energy used to produce the ethanol.)
2. **Cooking and liquefaction,** in which the meal is mixed with water and enzymes and cooked into a mash
3. **Saccharification**, - a secondary enzyme is used to produce sugars that can be fermented.

Cont'd

4. **Fermentation** of sugars with yeast to form CO_2 and watery ethanol (about 10 percent pure);
5. **Distillation** of the wet ethanol to concentrate the ethanol up to 95 percent;
6. **Dehydration** of the remaining 5 percent water to make fuel-grade ethanol; and
7. **Denaturing**, usually with gasoline to make the ethanol undrinkable.

Cont'd

- The **main inputs** of ethanol production are **feedstock, enzymes, yeast, energy, water, and denaturant**.
- The **main outputs** are ethanol, CO_2 and co-products, which are used as animal feed called distillers' grain.
- The CO_2 is often captured and purified to be sold to other industries.

Second Generation Technology

- Second-generation ethanol, also called cellulosic ethanol, is produced in almost the same way as first-generation ethanol.
- The pre-treatment needed to access the fermentable sugars in the ligno-cellulosic plant materials, however, is much more difficult and may, depending on the feedstock, require acid, pressurized steam, special enzymes or a combination.

Feedstocks

- For the production of ethanol, the most productive biomass has a **high sugar** content.
- Corn, sweet potatoes and sugarcane are some of the most commonly used plants, although can be used.
- Agricultural wastes, wheat, rice, barley, oats and even agricultural wastes contain lignin, which does not ferment but is useful in producing heat and electricity.
- The use of biomass with lignin takes longer because of the increased complexity of converting it into sugars

Cont’d

- Bioethanol is usually made by fermenting sugar contained in various kinds of biomass:
  i. **Sugar-rich biomass**, mainly sugar beet and sugar cane;
  ii. **Starch-rich biomass**, grain (e.g., barley, wheat, co rn, rice),potatoes, sorghum, cassava; and
  iii. **Cellulose-rich biomass**, straw, wood (residues), corn cobsand stalks, grass, paper and more

About half the world’s bioethanol production uses sugar crops as feedstock, mostly **sugarcanes** but also beets.

Cont'd

- The majority of the remaining ethanol is produced from starch crops, mainly grains such as corn and wheat.
- Practically no ethanol is produced from cellulose-rich biomass commercially, but commercial plants are planned.
- Not surprisingly, the most efficient way to produce ethanol today (in terms of cost and CO_2 mitigation) is via Brazilian sugarcane.

Ethanol For Transportation

- Most ethanol used for fuel is being blended into gasoline at concentrations of 5 to 10 percent.
- In fact, Ethanol has a lower energy content than gasoline which means that about one-third more ethanol is required to travel the same distance as on gasoline.
- But ethanol fuel has a characteristics of a high octane rating, result in increased engine efficiency and performance.

Cont’d

- Using ethanol, which is currently mixed with petroleum and represents around 10% of the gas sold for most cars in the Unite States of America., provides only “marginal benefit” over petroleum in terms of greenhouse gas emissions,

Advantages of Ethanol

- Ethanol has both economical and environmental benefits.
- It moderates the price of gasoline to consumers because it takes some of the work away from the petroleum refining industry.
- It creates many jobs because there are many steps in producing it.
- For example, many farmers are needed to grow the crops, and taxi drivers use the fuel to run their taxis.

Advantages of ethanol...

- It improves rural development because farmers must grow crops to make the fuel.
- Being a natural product, it reduces air pollution - fewer toxins are released into the air
- Smog problems in major cities can be eliminated.
- Although ethanol can form explosive vapours in fuel tanks, it is safer than gasoline because its slow evaporation speed keeps alcohol concentration low and therefore non-explosive.

Disadvantages of Ethanol

- Several hectares of cropland are needed to produce ethanol, and this makes it more expensive than gasoline.
- This can also be costly to the environment if the crops aren't replaced.
- Ethanol also gets less miles per gallon than the same amount of gasoline.

- Biochemical Conversion of Biomass to energy

Biodiesel

Biodiesel

- Biodiesel is an alternative fuel similar to conventional or ‘fossil’ diesel.
- Biodiesel can be produced from straight vegetable oil, animal oil/fats, tallow and waste cooking oil.
- The process used to convert these oils to Biodiesel is called transesterification.

Cont’d

- All these processes require an energy input either in the form of electricity or from a fuel, both of which will generally result in the release of green house gases.
- To properly assess the impact of all these sources; it requires use of a technique called life cycle analysis.
- Biodiesel is rapidly biodegradable and completely non-toxic, meaning spillages represent far less of a risk than fossil diesel spillages.
- Biodiesel has a higher flash point than fossil diesel and so is safer in the event of a crash.

Methanol

- In nature MeOH is produced via anaerobic metabolism by many bacteria.
- It is also formed as a by-product during the ethanol fermentation process.
- MeOH also occurs naturally in many plants, especially in fruits.

Cont’d

- Methanol (sometimes called wood alcohol) can be made from various biomass resources like wood), as well as from coal.
- However, today nearly all methanol is made from natural gas, because it is cheaper.
- Methanol is also very poisonous and very harmful if swallowed.
- Methanol must not be confused with ethanol.
- As with gasoline, it is also wise to avoid skin contact with methanol, as it can pass through the skin.

Cont’d

- As an engine fuel, methanol has chemical and physical fuel properties similar to ethanol.
- Methanol use in vehicles has declined dramatically since the early 1990s, and automakers no longer manufacture methanol vehicles in the United States.

Biodiesel Production

- As mentioned above biodiesel can be produced from straight vegetable oil, animal oil/fats, tallow and waste oils.
- There are three basic routes to biodiesel production from oils and fats:

1 Base catalyzed transesterification of the oil.

2 Direct acid catalyzed transesterification of the oil.

3 Conversion of the oil to its fatty acids and then to biodiesel.

Cont’d

- Almost all biodiesel is produced using base catalyzed transesterification as it is the most economical process requiring only low temperatures and pressures and producing a 98% conversion yield.

Cont'd

- The Transesterification process is the reaction of a triglyceride (fat/oil) with an alcohol to form esters and glycerol.
- A triglyceride has a glycerine molecule as its base with three long chain fatty acids attached.
- The characteristics of the fat are determined by the nature of the fatty acids attached to the glycerine.
- The nature of the fatty acids can in turn affect the characteristics of the biodiesel.

Cont’d

- During the transesterification process, the triglyceride is reacted with alcohol in the presence of a catalyst, usually a strong alkaline like sodium hydroxide.
- The alcohol reacts with the fatty acids to form the mono-alkyl ester, or biodiesel and crude glycerol.

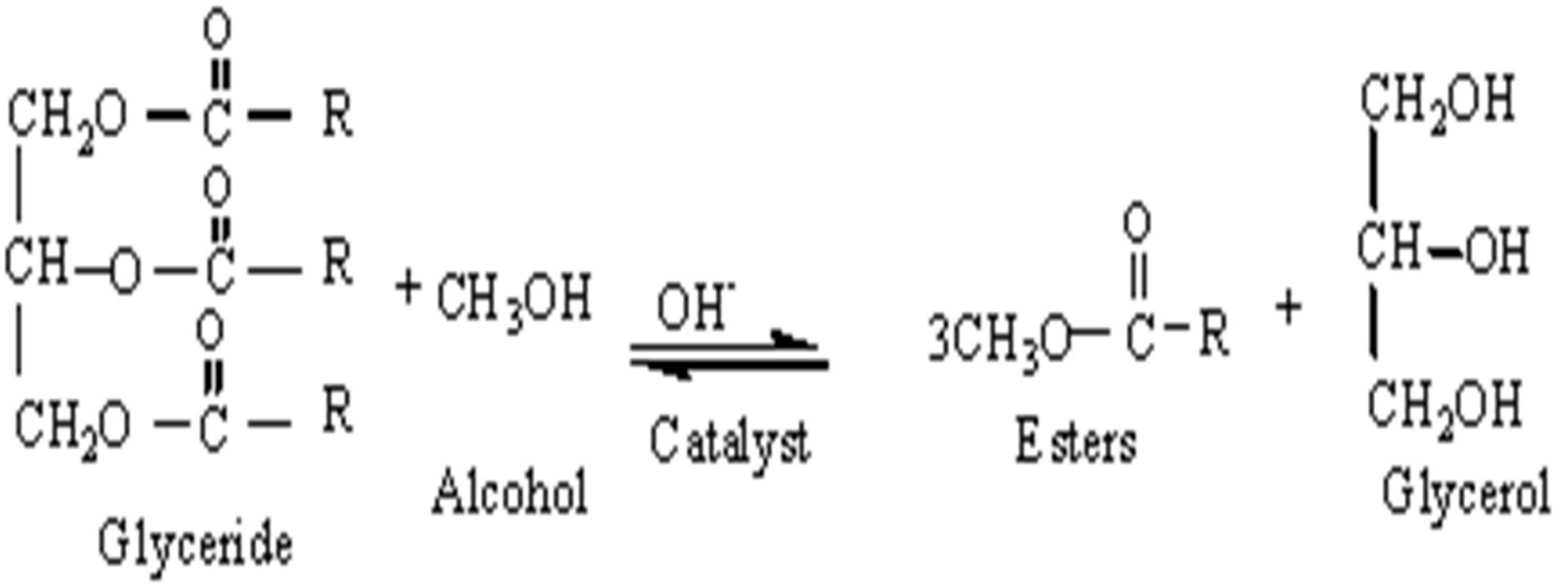
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- In most production methanol or ethanol is the alcohol used (methanol produces methyl esters, ethanol produces ethyl esters) and is base catalysed by either potassium or sodium hydroxide.
- Potassium hydroxide has been found to be more suitable for the ethyl ester biodiesel production, either base can be used for the methyl ester.

Cont'd

- A common product of the transesterification process is Rape Methyl Ester (RME) produced from raw rapeseed oil reacted with methanol.
- The reaction between the fat or oil and the alcohol is a reversible reaction and so the alcohol must be added in excess to drive the reaction towards the right and ensure complete conversion.

Cont'd



Shows the chemical process for ester/ biodiesel

Cont’d

- A successful transesterification reaction is signified by the separation of the ester and glycerol layers after the reaction time.
- The heavier, co-product, glycerol settles out and may be sold as it is or it may be purified for use in other industries, e.g. the pharmaceutical, cosmetics etc.

Feedstock of Biodiesel

- The raw materials for biodiesel production are vegetable oils, animal fats and short chain alcohols.
- The oils most used for worldwide biodiesel production are rapeseed (mainly in the European Union countries), soybean (Argentina and the United States of America), palm (Asian and Central American countries) and sunflower, although other oils are also used, including peanut, linseed, safflower, used vegetable oils, and also animal fats.

Rape seed


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Feed stocks…

- Methanol is the most frequently used alcohol although ethanol can also be used.
- Since cost is the main concern in biodiesel production and trading (mainly due to oil prices), the use of non-edible vegetable oils has been studied for several years with good results.

Feed stocks …

- The non edible crops are produced with low cost and also no food stuffs spent for the production of biodiesel fuel.
- These and other reasons have led to medium- and large-scale biodiesel production trials in several countries, using non-edible oils such as castor oil, tung, cotton, jojoba and jatropha.

Feed stocks …

- Animal fats are also an interesting option, especially in countries with plenty of livestock resources, although it is necessary to carry out preliminary treatment since they are solid; furthermore, highly acidic grease from cattle, pork, poultry, and fish can be used.

Feed stocks …

- Microalgae appear to be a very important alternative for future biodiesel production due to their very high oil yield; however, it must be taken into account that only some species are useful for biofuel production.
- Although the properties of oils and fats used as raw materials may differ, the properties of biodiesel must be the same, complying with the requirements set by international standards.

Advantages of Biodiesel

- Renewable fuel, obtained from vegetable oils or animal fats.
- Low toxicity, in comparison with diesel fuel.
- Degrades more rapidly than diesel fuel, minimizing the environmental consequences of biofuel spills.
- Lower emissions of contaminants: carbon monoxide, particulate matter, polycyclic aromatic hydrocarbons, aldehydes.

Advantages of Biodiesel

- Lower health risk, due to reduced emissions of carcinogenic substances.
- No sulfur dioxide (SO2) emissions.
- Higher flash point (100C minimum). (A flash point indicates how easy a chemical may ignite and burn)
- May be blended with diesel fuel at any proportion; both fuels may be mixed during the fuel supply to vehicles.
- Excellent properties as a lubricant.
- It is the only alternative fuel that can be used in a conventional diesel engine, without modifications.

Advantages of biodiesel…

- Biodiesel has many environmentally beneficial properties. The main benefit of biodiesel is that it can be described as ‘carbon neutral’.
- This means that the fuel produces no net output of carbon in the form of carbon dioxide (CO2).
- This effect occurs because when the oil crop grows it absorbs the same amount of CO2 as is released when the fuel is combusted.
- In fact this is not completely accurate as CO2 is released during the production of the fertilizer required to fertilize the fields in which the oil crops are grown.

Disadvantages of Biodiesel

- Slightly higher fuel consumption due to the lower calorific value of biodiesel.
- Slightly higher nitrous oxide (NOx) emissions than diesel fuel.
- Higher freezing point than diesel fuel. This may be inconvenient in cold climates.
- It is less stable than diesel fuel, and therefore long-term storage (more than six months) of biodiesel is not

Disadvantages of Biodiesel…

- May degrade plastic and natural rubber gaskets and hoses when used in pure form, in which case replacement with Teflon components is recommended.
- It dissolves the deposits of sediments and other contaminants from diesel fuel in storage tanks and fuel lines, which then are flushed away by the biofuel into the engine, where they can cause problems in the valves and injection systems.
- In consequence, the cleaning of tanks prior to filling with biodiesel is recommended.

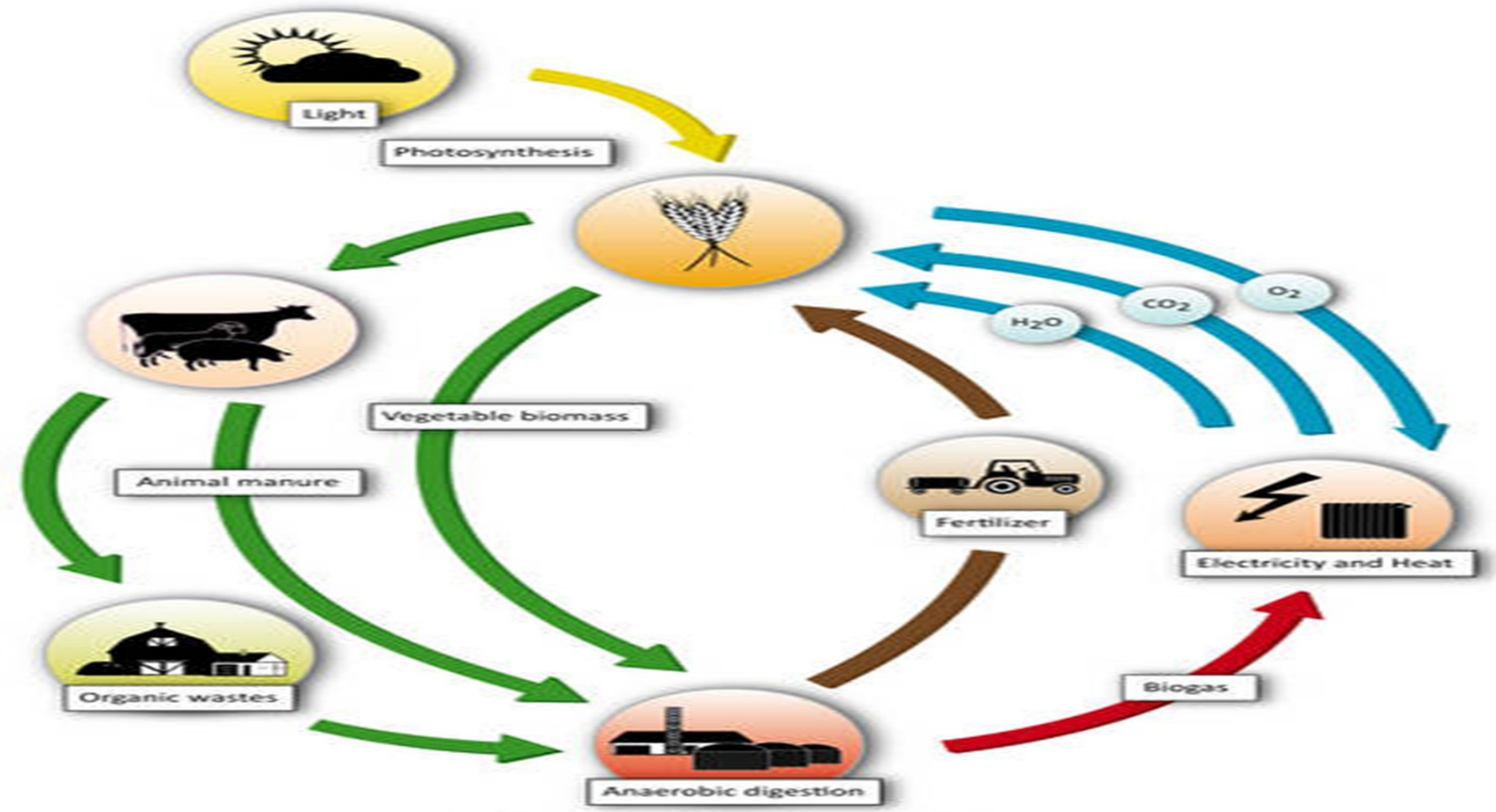
- Biochemical Conversion of Biomass to energy

Biogas

Anaerobic digestion

- One of the most common biochemical processes in nature.
- Anaerobic means the decay or breakdown in the absence of air or more specifically oxygen.
- The process is similar to fermentation as the transformation is brought about by micro-organisms (bacteria) called anaerobes.

Cont’d


Light
Photosynthesis
H_2O
CO_2
O_2
Vegetable biomass
Animal manure
Fertilizer
Electricity and Heat
Organic wastes
Biogas
Anaerobic digestion

Anaerobic digestion...

- Digestion takes place in two stages. First, in the medium of digestion certain micro-organisms break-down the materials into simple sugars, alcohol, glycerol and peptides.
- When these components are present in the correct amounts and the conditions are correct, a second group of micro-organisms converts these simpler molecules into methane gas.

Anaerobic digestion...

- The micro-organisms are particularly sensitive to environmental conditions including temperature, moisture and acidity.
- Carbon and nitrogen are also required for the micro-organisms to live.
- However, the bacteria consume the carbon at about 30 times faster than the nitrogen.
- This 30:1 ratio produces the maximum amount of gas. If the ratio is not correct the bacteria will usually compensate creating the right balance within the digester.

Discovery of Biogas

- Anecdotal evidence indicates that biogas was used for heating bath water in a Syria during the 10th century BC and in Persia during the 16th century.
- Jan Baptita Van Helmont first determined in 17th century that flammable gases could evolve from decaying organic matter.

Discovery of Biogas...

- Count Alessandro Volta concluded in 1776 that there was a direct correlation between the amount of decaying organic matter and the amount of flammable gas produced.
- In 1808, Sir Humphry Davy determined that methane was present in the gases produced during the anaerobic digestion of cattle manure.

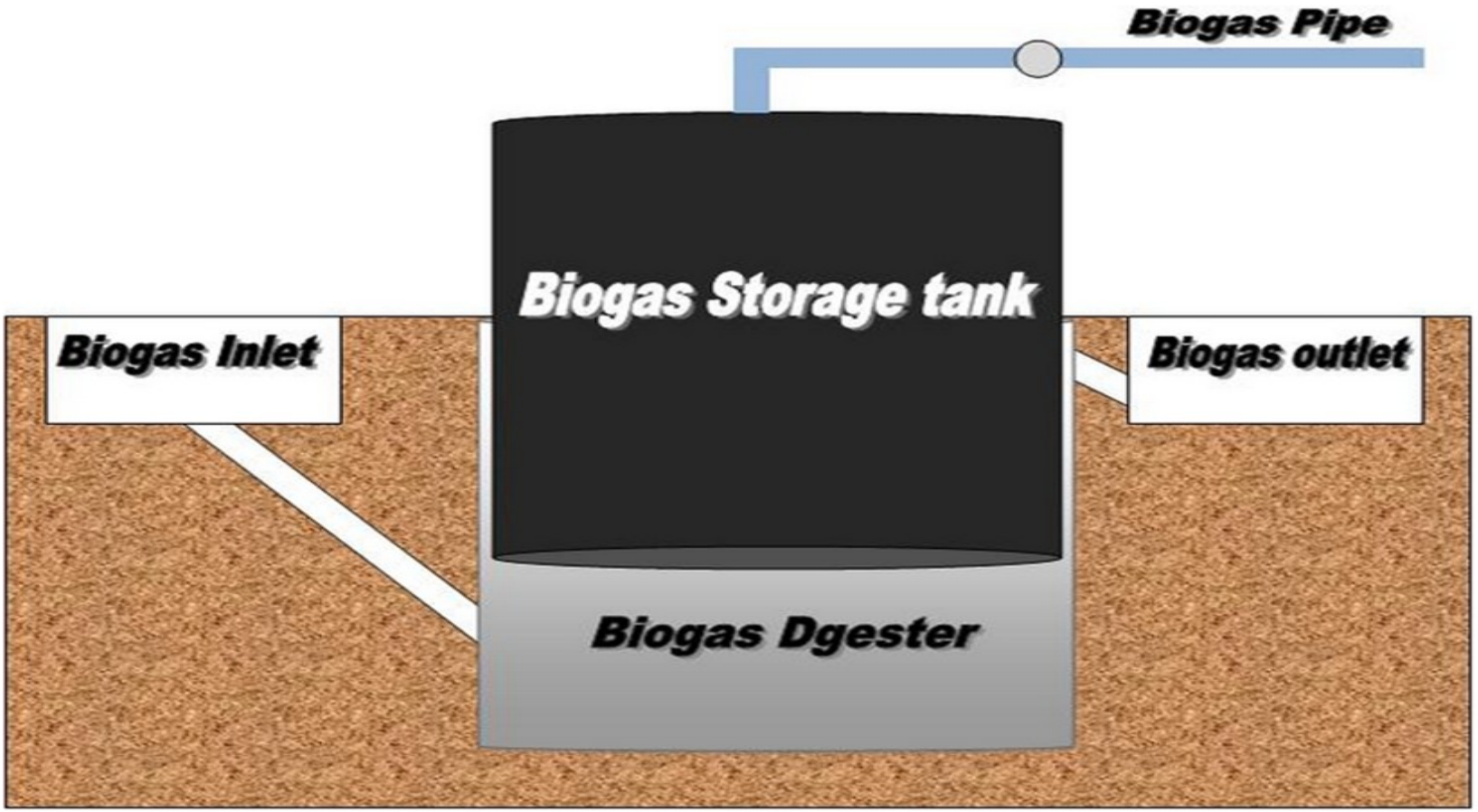
Discovery of Biogas...

- The first anaerobic digestion plant was built at a leper colony in Bombay, India in 1859.
- Research on anaerobic digestion began in earliest in the 1930s.
- The development of microbiology as a science led to research in the 1930s to identify anaerobic bacteria and the conditions that promote methane production.

Biogas Generator Systems

- Digester: an airtight container in which the organic waste - animal, human and other organic wastes - is dumped, usually as a slurry with water, to decompose.
- Storage container: a tank that is used to hold the gas emitted by the slurry from where it is piped for burning as a fuel.

Biogas plant



Above Ground vs. Below Ground Biodigesters

- Biogas production can be achieved in above or below ground plants, though both models have advantages and disadvantages.
- An above ground biogas plant is easier to maintain and able to benefit from solar heating, but needs more care in construction.
- A below ground biogas plant is cheaper to construct and easier to feed, but more difficult to maintain.

Biogas composition

- The methane fraction produced in the biogas varies with the input material;
- ✓ Carbohydrates: approx. 50 vol.-% methane
- ✓ Fats: approx. 70 vol.-% methane
- ✓ Proteins: approx. 84 vol.-% methane

Composition of biogas…

Compound	Vol %
Methane	50-75
Carbon dioxide	25-50
Nitrogen	< 7
Oxygen	< 2
Hydrogen sulfide	< 1
Ammonia	< 1

Properties of Methane

- Methane is a colourless, odourless, flammable gas.
- Depending on the digestion process, the methane content of biogas is generally between 55%-80%.
- The remaining composition is primarily carbon dioxide, with trace quantities (0-15,000 ppm) of corrosive hydrogen sulfide and water.

Cont’d

- Methane will not ignite and burn without the presence of oxygen.
- Lightning could ignite this gas.
- Methane has a calorific value of 10 kWh/Nm3 or 35,900 kJ/Nm3
- Hence, biogas with 65% methane has a calorific value 6.5kWh/m3 (23,300 kJ/m)

Phases of anaerobic digestion

- In the first phase anaerobic bacteria use enzymes to decompose high molecular organic substances such as proteins, carbohydrates, cellulose and fats into low molecular compounds such as amino acids, fatty acids and sugars. This process is called Hydrolysis.
- During the second phase acid forming bacteria continue the decomposition process into organic acids, carbon dioxide, hydrogen sulphide and ammonia. This phase is known as acidification.

Cont’d

- In the third phase, Acid bacteria form acetate, carbon dioxide and hydrogen this process is called acetogenesis.
- The fourth phase, involves methane forming bacteria producing methane, carbon dioxide and alkaline water. This process is called methanogenesis.
- The bacteria can digest any kind of biological material execpt solid biofuels with a high quantity of lignin, such as wood.

Phases of indigestion…

Phase 0	Phase 1	Phase 2	Phase 3	Phase 4
Input	Hydrolysis	Acidification	Acetofication	Methanogenesis
Carbohydrates	>Sugars	>Carbonic acids	>Acetic acid	>Methane
Fats	>Fatty acids	>Alcohols	>Hydrogen	>CO2
Proteins	>Amino acids	>Hydrogen	>CO2	
		>CO2		
		>Ammonia		

Types of biogas digesters

- Biogas plant is a combination of digester and storage tank(gas holder) either a single chamber or separate chambers depending upon the design of the plant.
- There should be an inlet portion in the digester for the input of organic matter and an outlet portion for discharging the treated organic materials from the digester.
- The decomposition process takes place in the digester portion of the plant.
- The biogas produced will be collected in the gas collector portion (gas holder) of the plant.

Types of biogas digesters....

- Commonly there are three common biogas digester plants. These are:
  - i Fixed dome plant
  - ii Floating drum pant
  - iii Balloon Plant

i Fixed-dome plant

- A fixed-dome plant consists of a digester with a fixed, non-movable gas holder, which sits on top of the digester.
- When gas production starts, the slurry is displaced into the compensation tank.
- Gas pressure increases with the volume of gas stored and the height difference between the slurry level in the digester and the slurry level in the compensation tank.
- The costs of a fixed-dome biogas plant are relatively low.

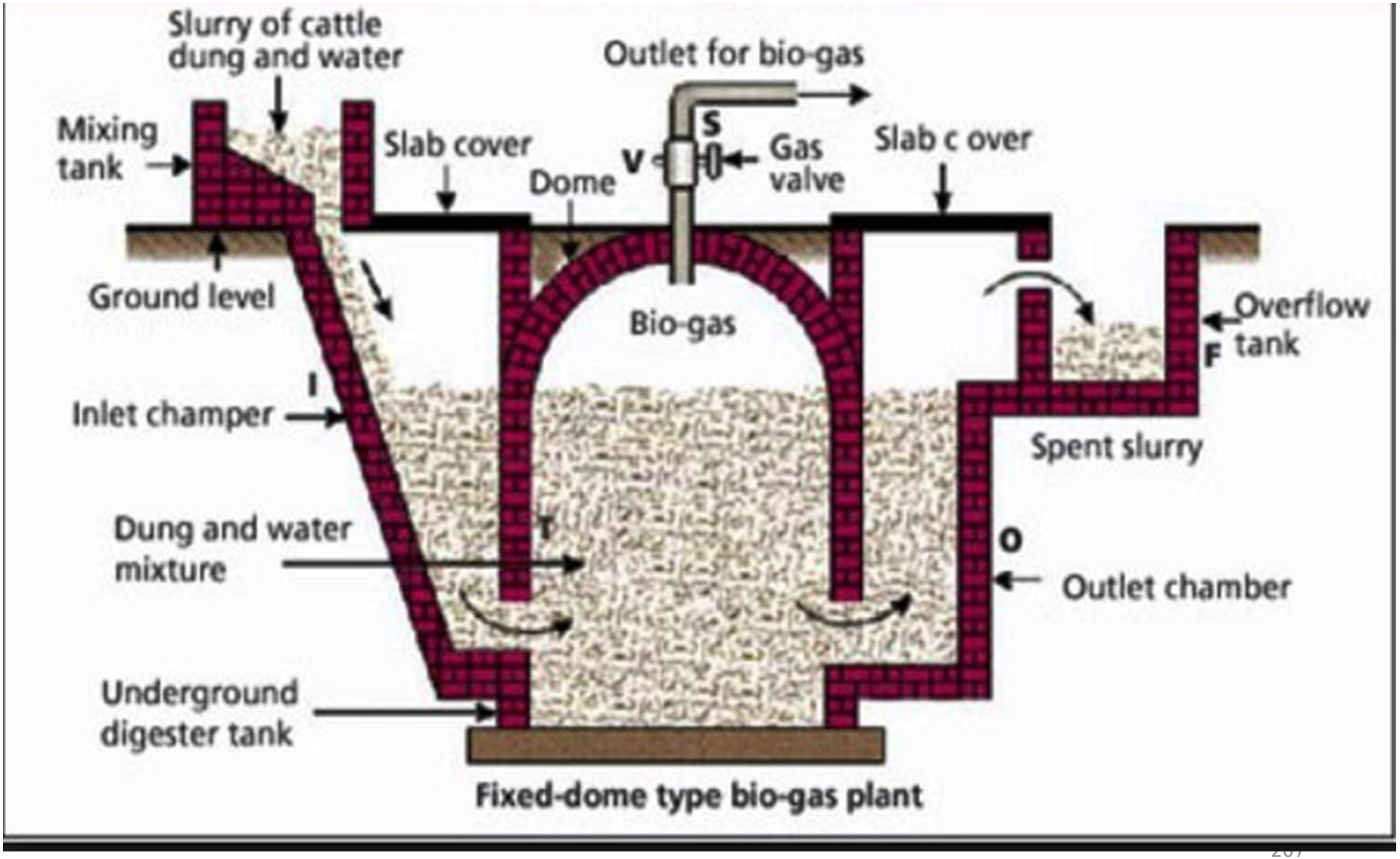
Cont’d

- It is simple as no moving parts exist.
- There are also no rusting steel parts and hence a long life of the plant (20 years or more) can be expected.
- The plant is constructed underground, protecting it from physical damage and saving space. While the underground digester is protected from low temperatures at night and during cold seasons, sunshine and warm seasons take longer to heat up the digester.
- No day/night fluctuations of temperature in the digester positively influence the bacteriological processes

Cont’d

- The construction of fixed dome plants is labor-intensive, thus creating local employment.
- Fixed-dome plants are not easy to build.
- They should only be built where construction can be supervised by experienced biogas technicians.
- Otherwise plants may not be gas-tight (porosity and cracks).

Fixed dome plant



ii. Floating Drum Plants

- Floating-drum plants consist of an underground digester and a moving gas-holder.
- The gas-holder floats either directly on the decomposition slurry or in a water jacket of its own.
- The gas is collected in the gas drum, which rises or moves down, according to the amount of gas stored.
- The gas drum is prevented from tilting by a guiding frame. If the drum floats in a water jacket, it cannot get stuck, even

Cont’d

- Size - Floating-drum plants are used chiefly for digesting animal and human feces on a continuous feed mode of operation, i.e. with daily input.
- They are used most frequently by small- to middle-sized farms (digester size: 5-15m3) or in institutions and larger agro-industrial estates (digester size: 20- 100m3).

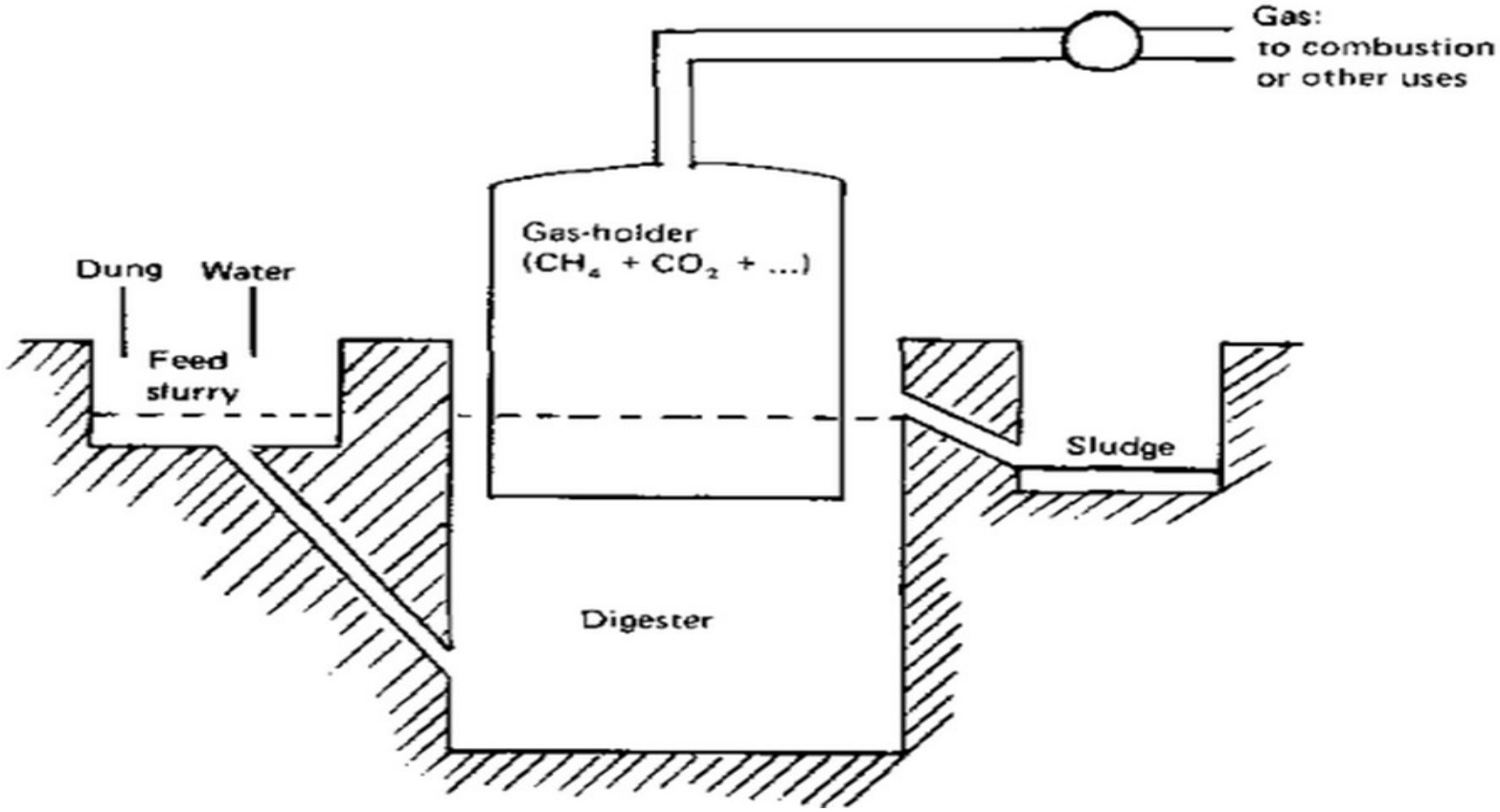
Advantages

- Floating drum plant are the simple, easily understood operation –
- The volume of stored gas is directly visible.
- The gas pressure is constant, determined by the weight of the gas holder.
- The construction is relatively easy, construction mistakes do not lead to major problems in operation and gas yield.

Disadvantages

- Disadvantages are high material costs of the steel drum, the susceptibility of steel parts to corrosion.
- Because of this, floating drum plants have a shorter life span than fixed-dome
- plants and regular maintenance costs for the painting of the drum

Floating drum plant



iii. Baloon Plants

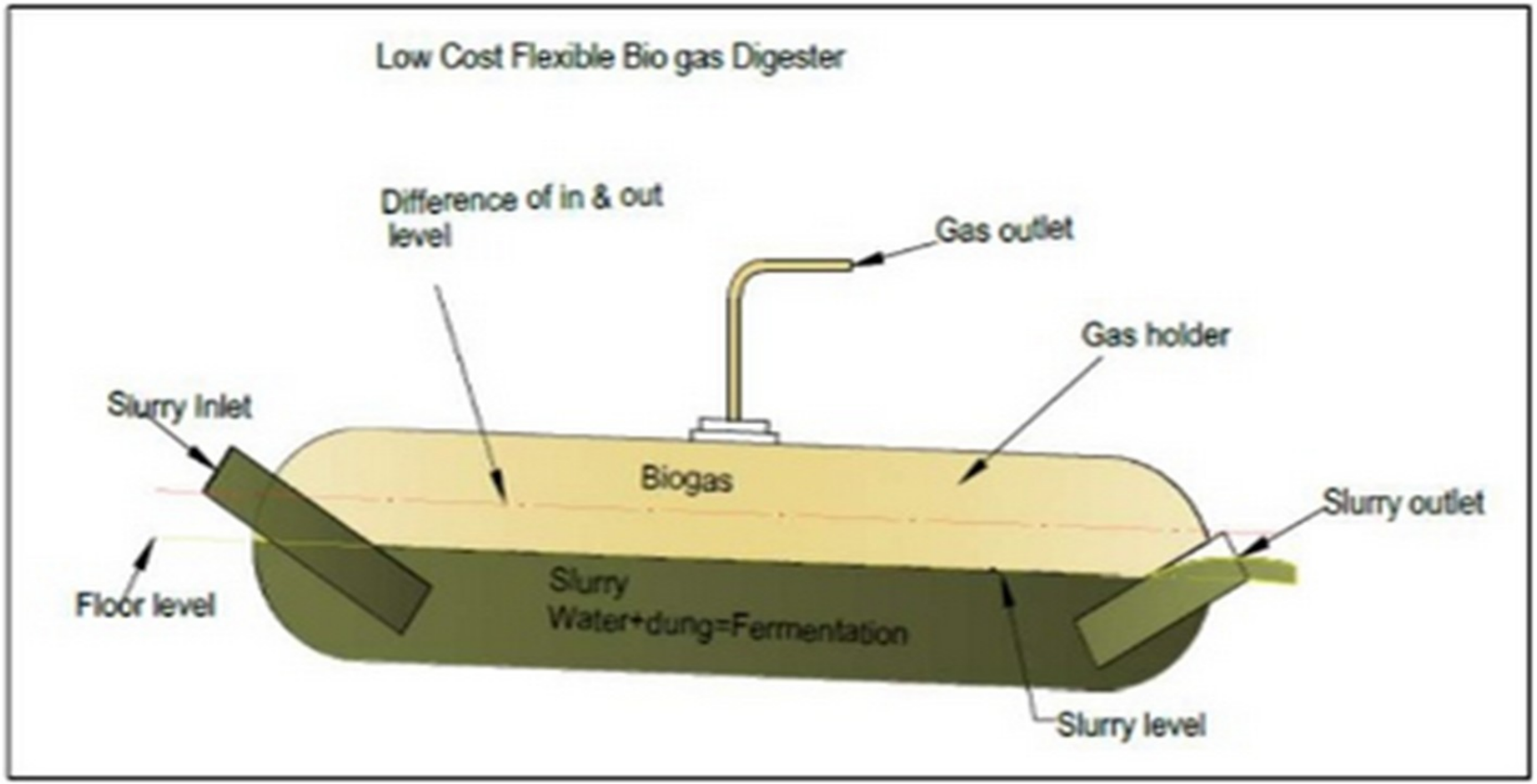
- A balloon plant consists of a heat-sealed plastic or rubber bag (balloon), combining digester and gas-holder.
- The gas is stored in the upper part of the balloon.
- The inlet and outlet are attached directly to the skin of the balloon.
- Gas pressure can be increased by placing weights on the balloon.
- If the gas pressure exceeds a limit that the balloon can withstand, it may damage the skin.

Cont’d

- Therefore, safety valves are required.
- If higher gas pressures are needed, a gas pump is required.
- Since the material has to be weather- and UV resistant, specially stabilized, reinforced plastic or synthetic caoutchouc is given preference.
- Other materials which have been used successfully include RMP (red mud plastic), Trevira and butyl.
- The useful life-span does usually not exceed 2-5 years.

Cont’d

Flexible balloon



Advantages:

- Standardized prefabrication at low cost, low construction sophistication, ease of transportation, shallow installation suitable for use in areas with a high groundwater table;
- High digester temperatures in warm climates; uncomplicated cleaning, emptying and maintenance;
- Difficult substrates like water hyacinths can be used.
- Balloon biogas plants are recommended, if local repair is or can be made possible and the cost advantage is substantial.

Disadvantages:

- Low gas pressure may require gas pumps; scum cannot be removed during operation;
- The plastic balloon has a relatively short useful life-span and is susceptible to mechanical damage and usually not available locally.
- In addition, local craftsmen are rarely in a position to repair a damaged balloon.
- There is only little scope for the creation of local employment and, therefore, limited self help potential.

Biogas Feed stocks

- Almost any organic material can be processed with anaerobic digestion.
- However, the level of putrescibility is the key factor in its successful application.
- The more putrescible (digestible) the material, the higher the gas yields possible from the system.
- Woody wastes are the exception, because they are largely unaffected by digestion, as most anaerobes are unable to degrade lignin.

Biogas feedstocks…

- Domestic (communal) organic waste:
- Organic waste means separate collected fruit and vegetable wastes, flower soil, flowers, eggshells, coffee and tee filters and other organic leftovers. The percentage of dry matter varies between 10 and 30 %.
- Green and plant wastes:
- Lopping and leftovers from cutting

Cont’d

- **Communal sewage sludge:**
- The leftover from communal waste water treatment is sludge, which must be decontaminated to be used for biogas production.
- This sewage sludge can contain phosphorus, nitrate and heavy metals.

Cont’d

- Experience shows that sludge from waste water treatment is suitable in biogas plants, but is not considered as a high quality substrate.
- It is illegal to use sludge from non-public sources because of the higher content of heavy metals or genetically modified organisms or hormones.
- The percentage of dry matter varies between 20 and 30 %.

Cont’d

Liquid or solid manure

- Liquid or solid manure from animal farming is one of the main substrates for the digestion process.
- Cow manure is best, whereas chicken manure for example has a high output, but might contain sand.
- The dry matter of solid manure varies between 15 and 30% and of liquid manure between 5 and 7 %.

Cont’d

- **Energy crops**
- Energy crops are primarily cultivated on otherwise disused fields, such as corn, Sudan grass, millet, white sweet-clover.
- **Industrial food waste**
- Industrial food wastes come from food and meat production sites or processes such as whey, potato mash, vegetable leftovers, brewer grains, apple marc.

Cont’d

- These kinds of substrates are usually very suitable and do not contain harmful substances.
- Substrates from meat production, like slaughterhouse waste, are good organic materials but need special treatment to reduce health risks and odour.

Ideal Temperatures for Biogas Production

- While anaerobic digestion occurs between 0°C and 65°C, the optimum temperature range for methane generating microbial activity is 29°C to 35°C.
- Little gas production occurs below 16°C.
- In colder climates placing the digester in a greenhouse, and perhaps using some of the

Methane Production Time

- The time in starting the digester and producing gas can be as long as 4weeks – but sometimes as short as 2weeks.
- This is because the bacteria will first need time to breakdown the slurry into alcohols and sugars, before the second group of bacteria, the gas producing ones, can adjust the carbon/nitrogen mix and the acidity level for reasonable amounts of gas to be produced.

Biogas vs. Fossil Fuels

- Biogas production is often preferred to fossil fuel energy sources, such as oil or coal, for environmental and economic reasons.
- Though both biogas and fossil fuels emit carbon, fossil fuels release carbon buried for many years in ancient biomass and effectually removed from the carbon cycle.
- Carbon released during biogas production is stored in the form of organic matter only recently and is still part of the cycle.
- Therefore, it does not cause as much of an upset in the carbon concentration in the atmosphere.

Biogas vs. Fossil Fuels…

- Proponents of biogas production also prefer biogas to fossil fuels because it is a low cost, renewable source of energy, and it uses otherwise wasted materials.
- Biogas production may also occur in small-scale sites, making it a viable option for regions in developing nations.

Biogas vs. Fossil Fuels…

- With the re-use of waste as a resource and new technological approaches which have lowered capital costs, anaerobic digestion has in recent years received increased attention among governments in a number of countries, including the United Kingdom, Germany and Denmark

Biogas vs. Natural Gas

- Methane produced by anaerobic digestion is quite similar to natural gas.
- However, natural gas contains hydrocarbons other than methane, such as ethane, propane, and butane.
- Hence, natural gas will always have a higher calorific value than pure methane.

Biogas vs. Natural Gas...

- The average expected energy content of pure methane is 896-1069 Btu/ft3.
- Natural gas has an energy content about 10% higher because of added gas liquids like butane.
- However, the particular characteristics of methane, the simplest of the hydrocarbons, make it an excellent fuel for certain uses.

Biogas vs. Natural Gas...

- With some equipment modifications to account for its lower energy content and other constituent components, biogas can be used in all energy consuming applications designed for natural gas.

Advantages of Biogas

- Biogas is a green energy source in form of electricity and heat for the local grid.
- Considerable environmental advantages - less emission of the greenhouse gasses methane, CO_2 and nitrous oxide.
- Environmentally friendly recirculation of organic

Advantages of Biogas…

- Less odour inconveniences when spreading slurry on the fields - fermented slurry smells considerably less than normal slurry and the smell decreases faster.
- Plants absorb fermented slurry better, increasing the yield on the fields.
- Protection of subsoil water - improved nitrogen exploitation reduces leaching and thereby drinking water contamination.
- Reduced costs for artificial fertilizer.

Disadvantages

- One potentially negative environmental impact of anaerobic digesters that combust the biogas is the creation of nitrogen oxides (NOx), which are regulated air pollutants and an ozone precursor.
- Nitrogen oxides are created by combustion of fuel with air.
- Combustion of dairy biogas or any other methane containing gas (whether in a flare, reciprocating or gas turbine engine, or a boiler) will emit Nox.


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