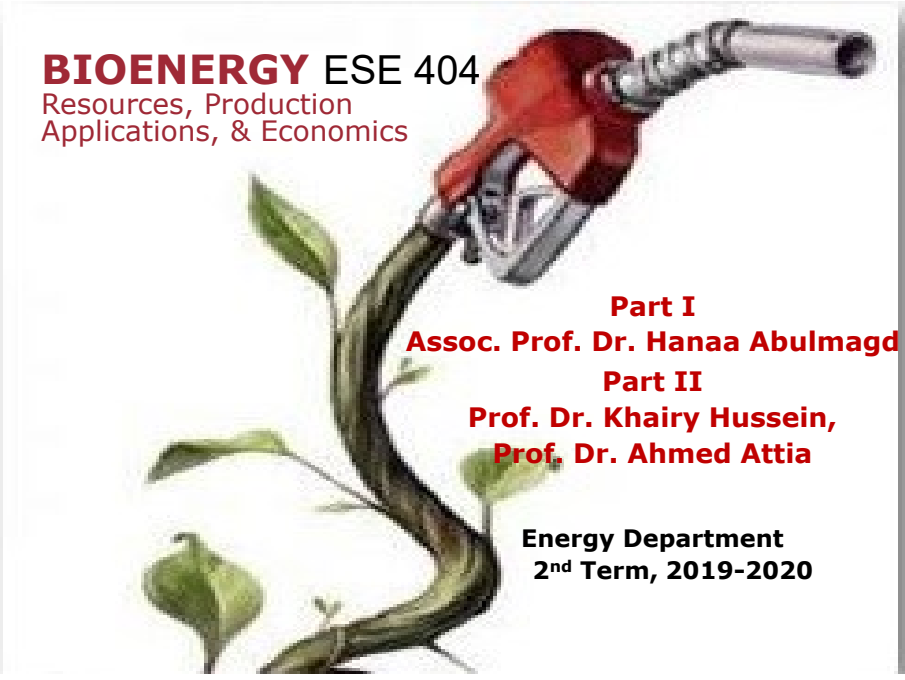
BIOENERGY ESE 404

Resources, Production
Applications, & Economics



Part I
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Energy Department
2nd Term, 2019-2020

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Course Overview

- ✓ Course code: ESE404
- ✓ Pre-requisite: EMP301
- ✓ Credit hours: 3 hrs
- ✓ Contact hours: Wednesday 9:00 am-11:00 am
- ✓ Tutorial : Wednesday from 11:00 am-1:00 pm
- ✓ Marks: 100 (60+40)
- ✓ Marks distribution: 30% mid 1 (7th week)

+ 20% (assignments) + 10% attendance + 40 % final

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Course Topics

- Bio-energy: Origin – Types- characteristics- technology of production and cost.
- Biomass resources: agriculture energy crops, woody crops (trees) – crops residues – forest residues – animal wastes
- Advantages and disadvantages of different biomass resources
- Thermal, chemical and biochemical conversion
- Uses and markets of biofuels
- Technology for producing Bio-power: combustion and gasification – steam or gas turbines, fuel cells, anaerobic digestion of manures to produce methane

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Course Objectives

- To understand the basic principles of Bioenergy.
- To differentiate between non-renewable and renewable energy recourses.
- To differentiate between the different biomass resources.
- To learn how to produce biofuels from biomass.
- To compare between the characteristics of each biofuel.
- To be familiar with Thermal, chemical and biochemical conversion taken place in the biofuels production.
- To understand the basics of combustion and gasification
- To relate the cost of biofuel production to its benefits.

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Four Main Parts to be Covered

Bioenergy Resources

Production of Biofuels

Applications of Bioenergy

Bioenergy Economics Concerns

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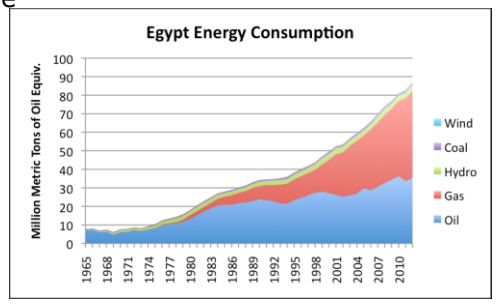
World Energy Picture

Our Needs: electricity, transport, heat

Requirements: coal, oil, gas

Challenges and Concerns:

- Pollution & Climate Change .
- Resource Depletion, Security.
- Rapid increase in population, increase in energy demand.
- Price: people can't afford the energy they want.



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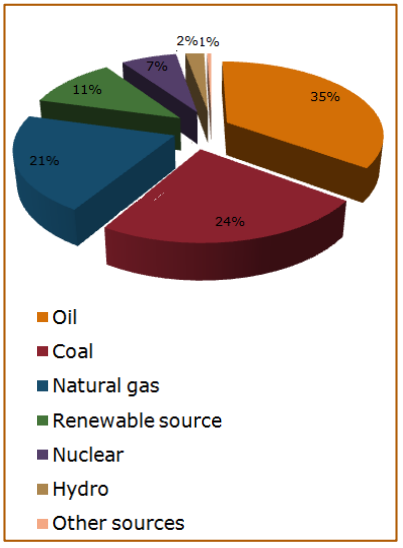
Types of Energy Resources



Sources

- Renewable
  - Solar energy
  - Hydro power
  - **Biofuel**
  - **Biomass**
  - Tidal energy
  - Wind energy
  - Nuclear energy
- Non-renewable
  - Oil
  - Natural gas
  - Coal

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WHY RENEWABLE ENERGY?

- The fast-growing population, and industrialization have increased the demand of energy in developing countries.
- The current demand of energy depend on sources are non-renewable in nature such as fossil fuels.
- Up to 2040, all the resources of fossil fuels will be finished.
- So, for this reason scientists are focus their view on the alternative renewable energy resource such as solar energy, biogas, biodiesel, wind power, tidal energy etc.

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Fuels

Types, Resources, Uses and applications

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What is fuel?, Can you imagine life without it?

- **Fuels** are any material that stores potential energy in forms that can be released and used as heat.
- They are required for a variety of purposes such as:

1) **Transportation**: it accounts for 25% of energy demand and nearly 62% of oil consumed.

2) **Electricity Generation**:

- The generation of electricity is the single largest use of fuel in the world.
- More than 60 % of electricity generated comes from fossil fuels.

3) **Heating**:

any heating purpose, such as cooking, water boilers.

4) **In industry**:

production of petrochemicals such as plastics, lubricants, pesticides, etc.

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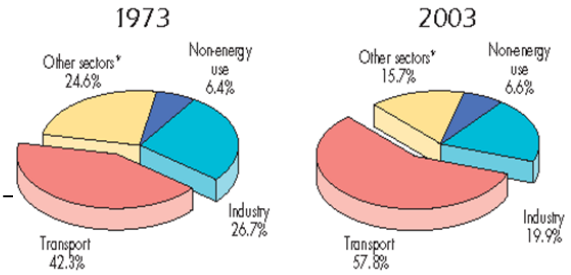
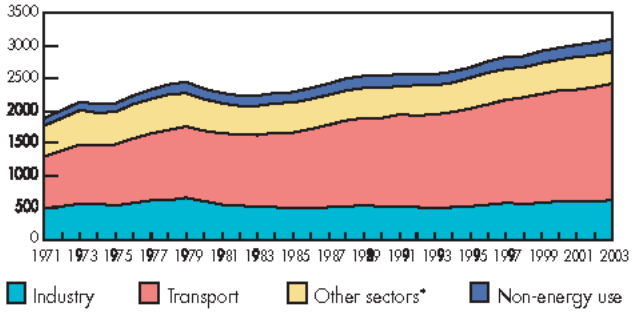
Use of Oil

Mainly in transportation – industry – power production – synthesis of plastics



*Other sectors comprises agriculture, commercial & public service, residential and non-specified.



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Chemical composition of fuel

- Petroleum (black gold) is a complex, naturally occurring liquid, and in usages it includes crude oil and natural gas also.
- It is a mixture of hydrocarbons, and some compounds of oxygen, nitrogen and sulfur.
- It contains four different forms of hydrocarbons with different molecular weights, chemical properties, and organic structures.
- Most of the world's petroleum is to be found in the Middle East.

- Natural gas contains hydrocarbons in gaseous forms, and methane (CH_4) is the major component.

Element	Wt. %	Hydrocarbons	Wt. %
Carbon	83-87	Alkane	30
Hydrogen	10-14	Naphthalene	49
Nitrogen	0.1-2	Aromatics	15
Oxygen	0.1-1.5	Asphaltic	6
Sulfur	0.5-6		
Metals	< 0.1		

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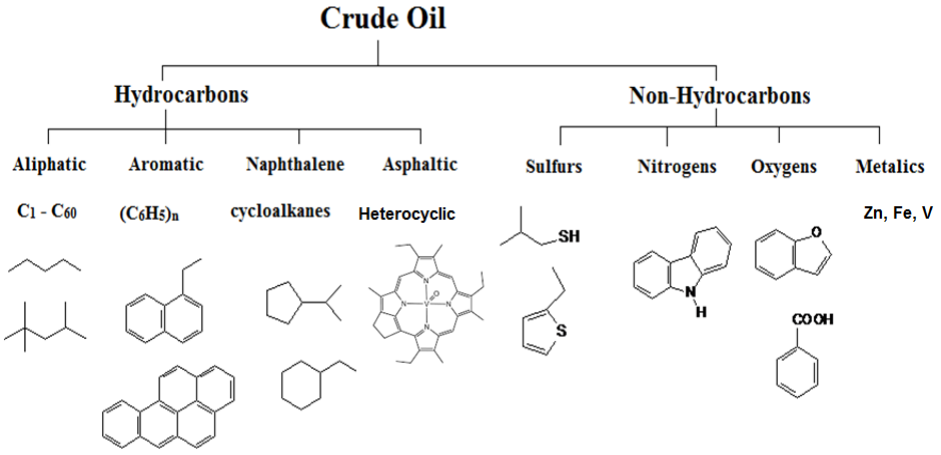
Composition of Crude Oil



Any compound in petroleum contains from 1 to about 60 carbon atoms. They consist of straight chains or cyclic chains of carbon atoms.

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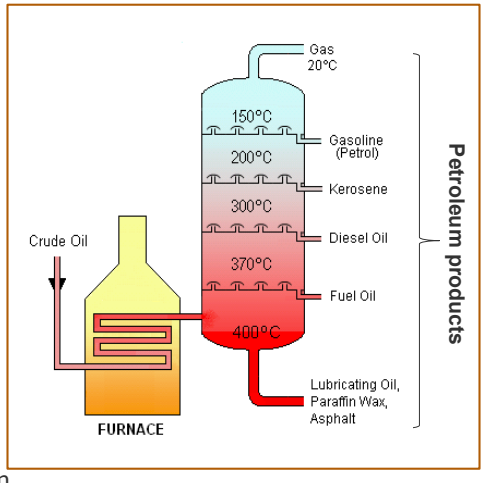
Refining of Crude Oil

During refining of crude oil, the lighter hydrocarbons (gases) move up in the distillation tower.

- **CRUDE** — Petroleum delivered from well field
- **DESALTING** — Water washing to remove impurities
- **REFINING** — Distillation to separate by boiling point ranges
- **REFORMING** — Conversion reactions to alter molecular structures
- **BLENDING** — Mixing to obtain maximum commercial characteristics



Schematic representation of distillation towers

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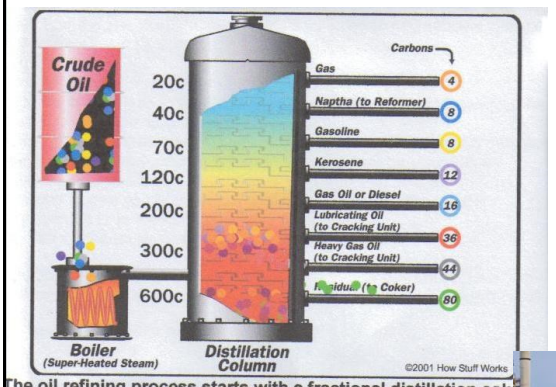

The oil refining process starts with a fractional distillation colu

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Important Chemical Reactions in Petroleum

- Cracking processes take place in petroleum refining to break down heavy hydrocarbons into lighter products. The catalyst used is often silica or alumina

$$C_{22}H_{46} + \text{heat} + \text{catalyst} \rightarrow C_{12}H_{26} + C_6H_{12} + C_4H_8$$

- **Combustion of some petroleum products**

1- Combustion of clean products such as natural gas and gasoline:

$$CH_4 + 2\,O_2 \rightarrow 2\,H_2O + CO_2 + \text{Energy}$$

$$\mathbf{2C_8H_{18} + 25O_2 \rightarrow 16CO_2 + 18H_2O + Energy}$$

2- Combustion of Petroleum Contaminants:

Acid rains

$$CH_4 + 2\,O_2 + N_2 + H_2S \rightarrow$$
$$2\,H_2O + CO_2 + CO + NO + NO_2 + SO_2 + \text{Energy}$$

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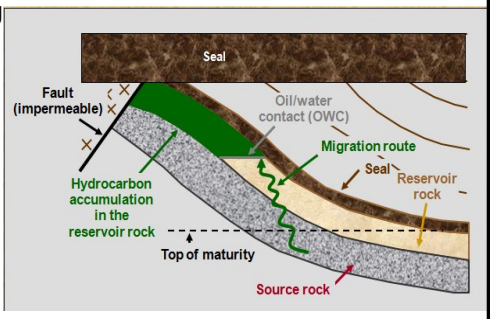
Problems and disadvantages of fossil fuel

Fossil fuels: They are hydrocarbon fuels that take millions years to be formed.

- They are nonrenewable (once used it is no longer available)
- They are very hazardous and cause environmental pollution because their burning releases CO_2 or CO.
- Their prices are always in rising
- Power stations consume lots of fuel and effort to generate electricity, they will be stopped if there is reduction in fuel.



What is the solution !!!!

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Alternative energy – Bioenergy

Bioenergy: energy produced from recently living organic matters called biomass

These matters can be :

burned directly for heat (traditional biomass) or

converted to **biofuels** such as **biodiesel** or **bio-ethanol**.

- **Sources of bioenergy :**
- **Biofuels**
  - Liquids: Methanol, Ethanol, Butanol, Biodiesel
  - Gases: Methane, Hydrogen

- **Bioheat**
  - Wood burning
- **Bioelectricity**
  - Combustion in Boiler to Turbine
  - Microbial Fuel Cells (MFCs)

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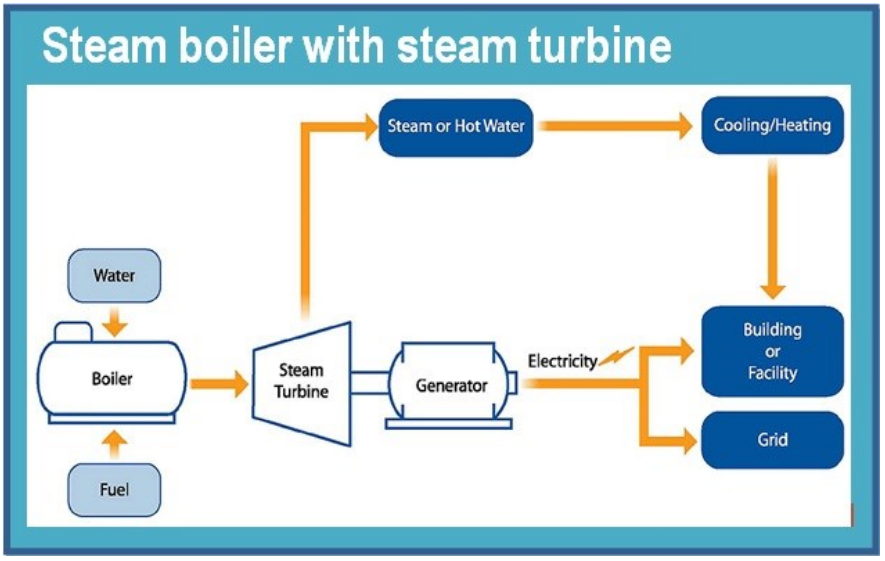

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History of Bioenergy

Bioenergy is not new!!!!!

- Biomass such as wood & crops are used to burn for heat and lightning long time ago.
- 1850s: Ethanol used for lighting.
  - 1896: 1st ethanol-fueled automobile, the Ford Quadricycle.
  - 1908: 1st Ford Model T working with ethanol

  - WWI and WWII: Ethanol used due to high oil costs.
- 1990s: Ethanol was the most recent biofuel popularity

Increased in response to high emissions standards & increasing demands for enhanced fuel economy.

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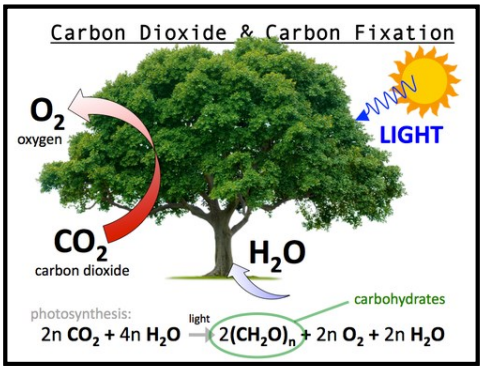
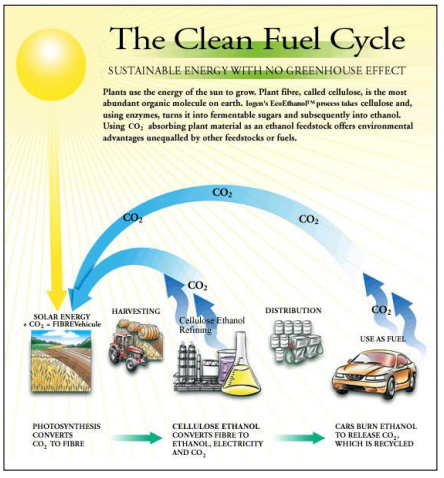
Bioenergy cycles

Lessons from Nature





Photosynthesis is a biological carbon fixation process utilized by plants to obtain energy in the form of carbohydrates.

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Biomass Resources
and
Biofuel Production

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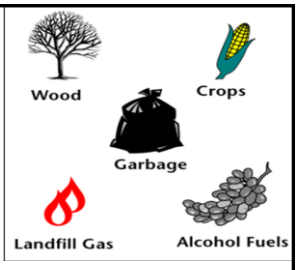
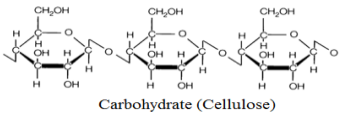
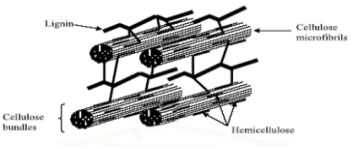
Origin of Biomass

- They are all living or recently living organisms, animal/plant waste, industrial and municipal waste
- The main components of biomass are: carbohydrates & lignin (+proteins, lipids)




Carbohydrate (Cellulose)



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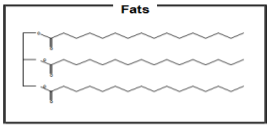

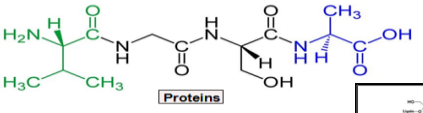

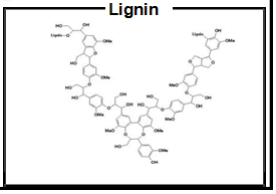

- Biomass can be classified into two categories: Woody and non-woody Biomass.

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Woody Biomass

- **Coconut** - In areas common with coconut trees. Their hulls burn efficiently with very little residue. They are used for cooking and heating specifically in undeveloped countries.

- **Oil Palm** - The oil palm provides biomass in two ways: direct and indirect biomass. The fruit produces oil, which can be chemically converted to biodiesel. The hulls can be burned directly.

Uses of woody biomass:

- Generally burned to heat space or to heat water (direct biomass).
- To produce steam in order to generate electricity via a turbine generator

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Non-Woody Biomass

- Such as corn, sugar cane, soybeans, grass, algae.
- It is used as indirect biomass, or to produce different liquid biofuels.
- The most commonly used non-woody biomass is Switchgrass.
- It becomes more attractive to generate ethanol from cellulosic.

The benefits of switch grass over other biomass include:

- It has high cellulose content that makes it an ideal direct biomass.
- It is also mechanically converted into pellets for easy transportation.
  - Perennial (lowers costs) محصول معمر
  - Improved soil quality from not plowing each year
  - Relatively high yield even in bad lands انتاجية عالية
  - Drought and pest resistant مقاوم للافات و الجفاف
  - Low water and fertilizer needs لا يحتاج لماء و سماد بكمية كبيرة

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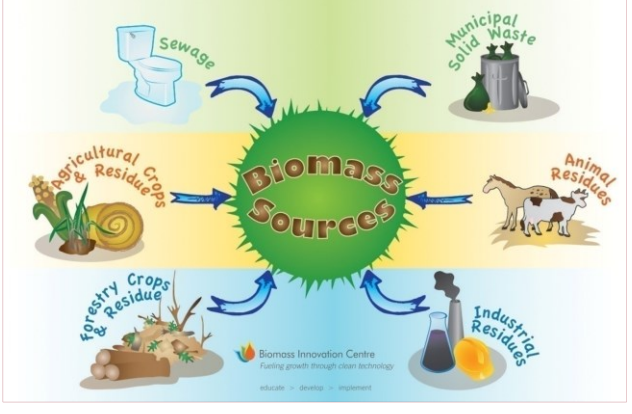
Other agricultural wastes and biomass

- Animal manure, food processing waste, yard waste, municipal wastes, sewage, industrial waste.
- Wood processing mill residues
- Paper & pulping waste slurries



Biomass is an eco-friendly power source

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Energy contents of Biomass

Average heat energy content of fuels

Fuel	Energy content		Fuel	Energy content	
	GJ t^{-1}	GJ m^{-3}		GJ t^{-1}	GJ m^{-3}
Wood (green, 60% moisture)	6	7	Straw (as harvested, baled)	15	1.5
Wood (air-dried, 20% moisture)	15	9	Sugar cane residues	17	10
Wood (oven-dried, 0% moisture)	18	9	Domestic refuse (as collected)	9	1.5
Charcoal	30	*	Commercial wastes (UK average)	16	*
Paper (stacked newspapers)	17	9	Oil (petroleum)	42	34
Dung (dried)	16	4	Coal (UK average)	28	50
Grass (fresh-cut)	4	3	Natural gas (at supply pressure)	55	0.04

Note that the composition of coal and most biofuels is variable and the energy content per kg can differ significantly from the above averages. The energy *per cubic metre* depends on the density and can vary even more widely. (* Indicates dependence on specific types of material.)

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Uses of Biomass

Many important non-energy uses

- Food for humans
- Animal feed (a major and growing use)
- Lumber & other construction materials
- Clothing (cotton, wool, linen, leather)
- Paper, packaging, etc.

Energy uses:

- To produce heat or electricity
- Convert to Gas (CH_4 or CO/H_2)
- Convert to Liquid Fuels to be used in transportation.

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Alternative and renewable fuel

Biofuels:

- Any hydrocarbon fuel that is produced from living organic matter in a short period of time (days, weeks, or months).
- They are alternative of fossil fuels, so they are ways of energy security.
- They burn cleaner than fossil fuels, resulting in fewer emissions of greenhouse gases or substances that cause acid rain such as sulfur.
- They are biodegradable, so when spill, less harm is done compared to when fossil fuels spill.

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Why biofuels?

There are many reasons forced us to use biofuels:

1. To reduce our dependence on fossil fuels
2. To reduce reliance on foreign oil
3. To lower emissions of green house gases
4. To bring business to rural economics

Advantages of biofuels

1. Locally available in every region of the world.
2. Friendly with the environment: do not cause global warming – do not emit any hazardous gas
3. Highly energetic: the energy release per unit mass of biofuel is greater than that of fossil fuels.

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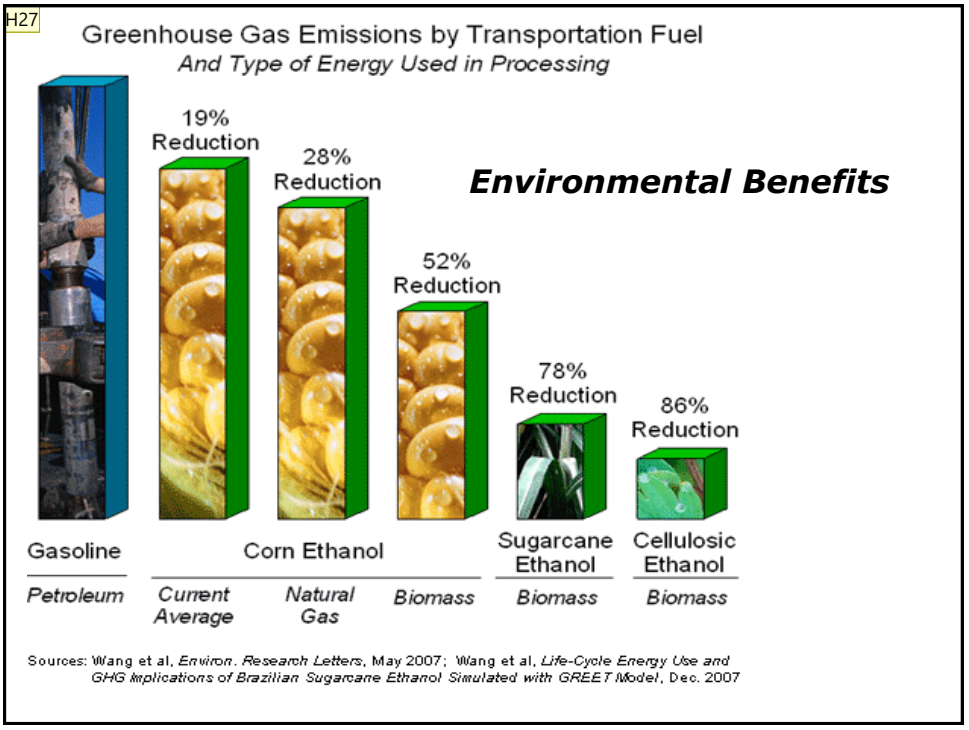

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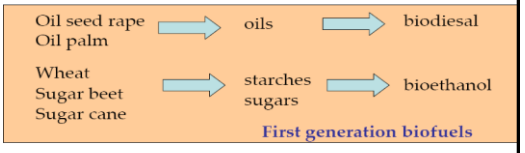
Converting Biomass to biofuels

According to the production method, there are three Generations of biofuels:

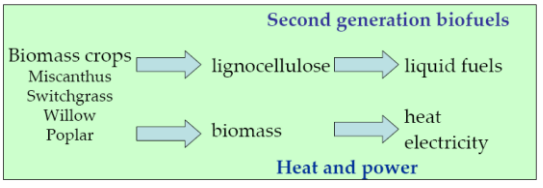
1- First generation: called Conventional Biofuels, made from sugar, starch, and vegetable oil.

i.e produced from edible Stuffs, this will affect the feed security ☹👎



2- Second generation Biofuel: called advanced biofuels, made from non edible plants.

Feed Security 👍☺



3- Third generation Biofuel: made from algae and microbes.

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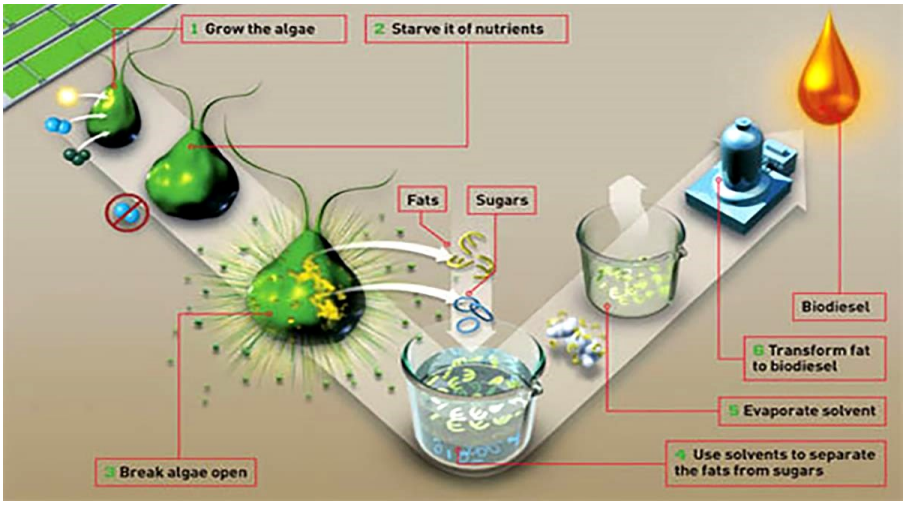
Converting Biomass to biofuels



Production of biofuel from algae

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Types of Biofuels

I) Liquid biofuel

- Biodiesel
- Bioalcohol
  - ✓ Methanol
  - ✓ Ethanol
  - ✓ Butanol

II) Gas biofuel

- Biogas
- Syngas

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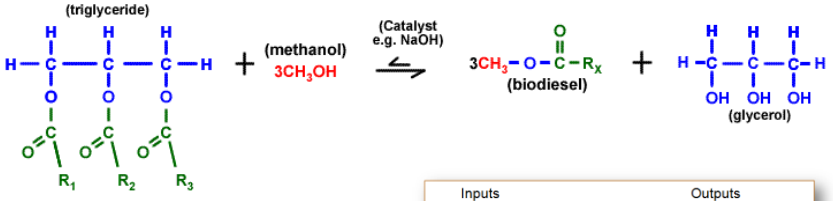
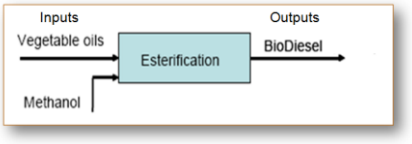
Liquid Biofuels

Types of Biofuels
1) Biodiesel

- It is a famous biofuel in Europe. It contains a reduced amount of carbon and higher hydrogen and oxygen content than fossil diesel.
- **Synthesis**: Produced from trans-esterification of oils or fats mixing with methanol and sodium hydroxide.





- **Applications:**

1- car diesel engine
2- effective solvent
3- oxygenated fuel

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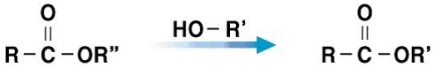
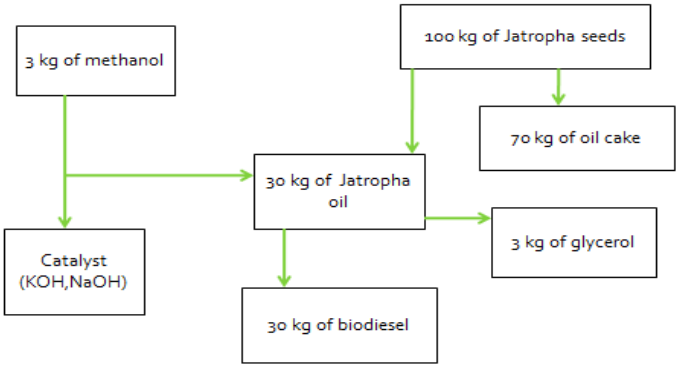
Trans-esterification

- It is base catalyzed reaction of oil with alcohol to form fatty acids and then to form alkyl esters (biodiesel).
- The formed biodiesel can replace the petroleum or mix with it.
- Oils used in synthesis are: vegetable oil, animal fat, or grease.



Ex. Synthesis of biodiesel from Jatropha seeds



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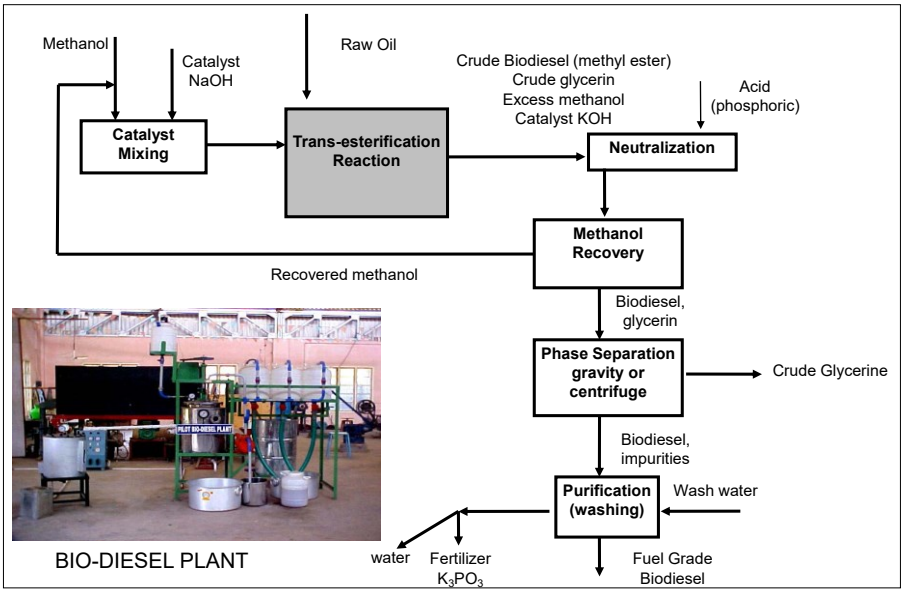
General Biodiesel Production scheme



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Feedstock choices


Soy bean

The main feedstock for biodiesel fuel are:

1. **Virgin oil feedstock:**

Rapeseed - soybean – jatropha - mustard, flax, sunflower, palm oil, coconut


Rapeseed


Palm oil


Jatropha Curcas

2. **Algae:**
Algae can be grown using waste materials such as sewage and without making use of land used for food production.

3. **Animal fats:**
Yellow grease, chicken fat, and the by-products of the production of Omega-3 fatty acids from fish oil are increasingly used as biodiesel fuel feedstocks.

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Advantages & Disadvantages of biodiesel

Advantages:

1. Clean fuel as it does not contain carcinogens, has lower sulphur content than the mineral diesel.
2. Biodiesel reduces carbon dioxide exhaust emissions by up to 80%.
1. The smell of the biodiesel exhaust is far more pleasant.
3. It possesses high lubricating property so engines last longer.
4. Improves engine efficiency and operating life cycle.
5. Readily mixes with petroleum diesel fuel in any ratio.
6. Has higher flash point, so it is safer in transport and storage.

Disadvantages:

1. Higher production cost.
2. Biodiesel attracts moisture more likely than petroleum diesel.

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Lab work for biofuel synthesis
Synthesis of biodiesel from cooking oil waste

100 mL oil
87 g

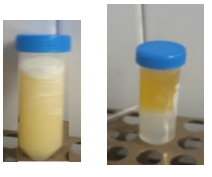
0.8 g NaOH in 10 mL ethanol (0.5% catalyst & 10% alcohol of the oil mass)

Heating the oil at 130 °C

Adding the catalyzed alcohol to oil and keep stirring for 2 hours at 130 °C

After stirring, keep it for 12 hours till cooling and the glycerol settle down

Separating the oil (upper layer) from the glycerol (lower layer



Adding some water to wash the oil from any residue, keep it two hours for separation

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Lab work for biofuel synthesis
Synthesis of biodiesel from cooking oil waste

Separate the oil (upper layer) from the glycerol (lower layer

Repeat the washing two more times or until the pH of the oil become 7 (neutral)

Now, you have biodiesel, keep it for testing

The glycerol part is ready for forming soap

Add some water and stir, soap foam is formed

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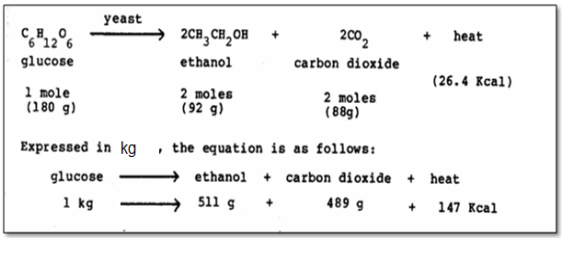
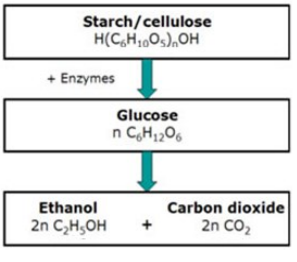
Liquid Biofuels

Types of Biofuels
2) Bioalcohols

- Biologically produced alcohols, most commonly ethanol, and less commonly propanol and butanol.
- **Synthesis**: They are produced by the action of micro-organisms and enzymes through the fermentation of sugars or starches (easiest), or cellulose (which is more difficult because it requires pretreatment and burning of lignin).

Fermentation: a form of anaerobic respiration used primarily by yeasts when oxygen is not present in sufficient quantity.





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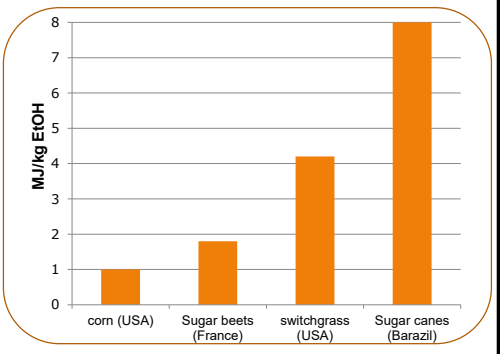
- **Different feedstock:**

  Corn – sugar beets - sugar canes – switch grass



- **Benefits of bio-alcohols**

1. Renewable energy source.
2. Burns more cleanly because of its complete combustion.
3. Reduces greenhouse gases.
4. Fuel spills are more easily biodegraded or diluted to non-toxic materials.
5. Any plant can be used as feedstock provided that it contains sugar and starch.

- **Applications:** Bio-ethanol is the most commonly used bio-fuel in the world and particularly in Brazil. It is used as:

1- Petrol engines as a replacement for gasoline
2- Fuel for vehicles

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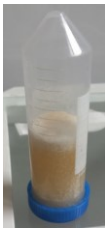
Lab work for biofuel synthesis
Synthesis of bioethanol from sugar and yeast

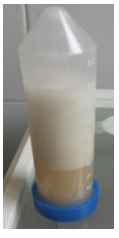
3 g sugar & 0.5 g yeast

Making sugar solution, and dissolving the yeast in some water

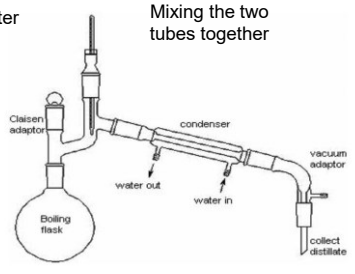
Mixing the two tubes together



Keeping for few hours



Ethanol is formed and should be distilled from the mixture



System used fro distillation

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Comparison of different liquid biofuels

Biofuels are counterparts to traditional fossil fuels, see table

- The energy content of biodiesel is about 90% that of petroleum diesel.
- The energy content of ethanol is about 50% that of gasoline.
- The energy content of butanol is about 80% that of gasoline.
- Biodiesel is sulfur free and it has fewer polycyclic aromatic hydrocarbons which cause cancer.

Biofuel	Fossil Fuel
Ethanol	Gasoline/Ethane
Biodiesel	Diesel
Methanol	Methane
Biobutanol	Gasoline/Butane

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Types of Biofuels
3) Biogas

Gas Biofuels

Biogas is a clean and efficient alternative fuel. It is a mixture of: CH_4 (major constituent 65%)–CO_2–H_2–H_2S – NH_3.

- **Synthesis**: it is produced by a process called (**digestion**) which is an anaerobic breakdown of biodegradable materials such as manure, sewage, green waste, plants with bacteria (**methanogens**) in the absence of oxygen.
- It is produced in a closed system called digester.
- The heating value of biogas is about 60% of natural gas and about 25% of propane.

$$\text{Organic Matter} + H_2O + \text{Bacteria} \xrightarrow[\text{7-21 days}]{\text{digester}} CH_4 + CO_2 + \text{other gases}$$

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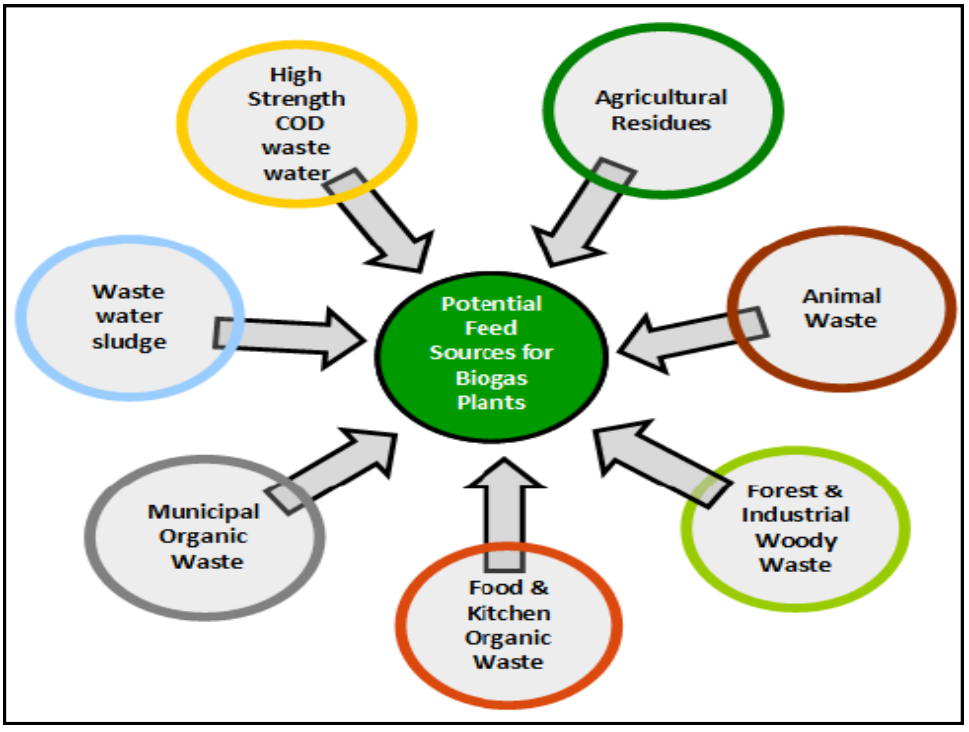

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Overview on Anaerobic Digestions

- **Processes taken place:**
  - Liquefaction
  - Acid Production
  - Acetate Production
  - Methane Production

- **Their Benefits:**
  - Reduce: Smell - Greenhouse gas - Pathogen level
  - Produce biogas
  - Improve fertilizer value of manure
  - Protect water resources

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Production steps of biogas

- The anaerobic decomposition of organic matter occurs in a four-step process:-

1- **Hydrolysis (liquification)**: the slowest step in which the hydraulic bacteria convert complex organic materials into simple liquid materials.

2- **Acidogenesis**: acidogenic bacteria convert the sugars and amino acids to alcohol and fatty acids.

3- **Acetogenesis**: acetogenic bacteria convert fatty acids and alcohols into H_2, CO_2 and acetic acid.

4- **Methanogenesis**: methanogenic bacteria convert the H_2 and acetic acid to methane gas and CO_2.

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Types of digesters:

- **Mesophilic digester:** is a kind of bio-digester that operates in temperatures between 20°C – 40°C, typically 37 °C. It is the most used kind of bio-digesters in the world (90%).

- **Thermophilic digester:** is a kind of bio-digester that operates in temperatures above 50 °C. It does not need agitation- faster in fermentation than a mesophilic digester.

Factors affecting the biogas production:

- Composition of the raw materials – load - digester type - mixing way - quality of methanogens – temperature.

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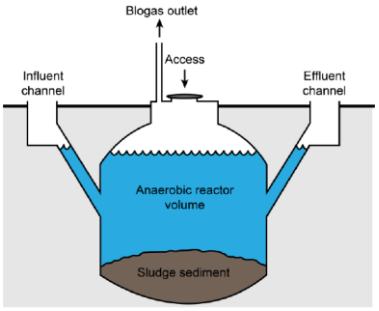
Design of Biogas digesters



Bag digester

To know how to design digester for biogas synthesis, visit this link:
http://www.instructables.com/id/Biogas-Digester/

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Advantages of Biogas

- The technology of biogas production is widely used in farm area, thus:
- It reduces the bad smell and protects water resources.
- It improves fertilizer value of manure.
- It reduces global climate change because if the manure is left to decompose it releases two main gases that changes the climate:

NO_2 (warms the atmosphere 310 times more than CO_2),
CH_4 (warms atmosphere 21 times more than carbon dioxide.

- **Disadvantages:** Biogas has corrosive nature and its storage is not practical

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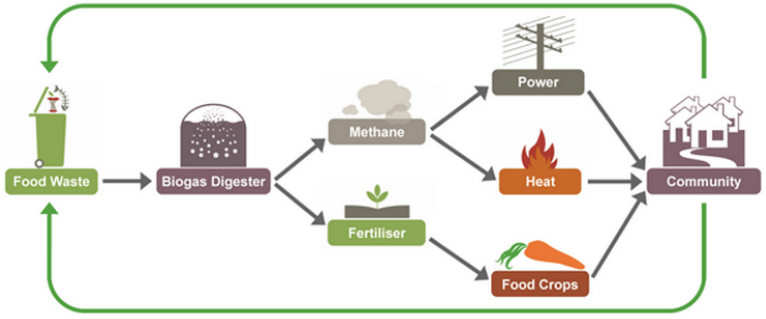
Applications of Biogas



1- To produce Electricity 2- Heating purposes

3- Methane can be combusted directly or converted to bioalcohols.

4- Millions of cows able to produce one hundred billion kilowatt hours of electricity, enough to power millions of homes.

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Biogas for better life

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Diagram showing Anaerobic Septic Tank linked with toilet and biogas plant

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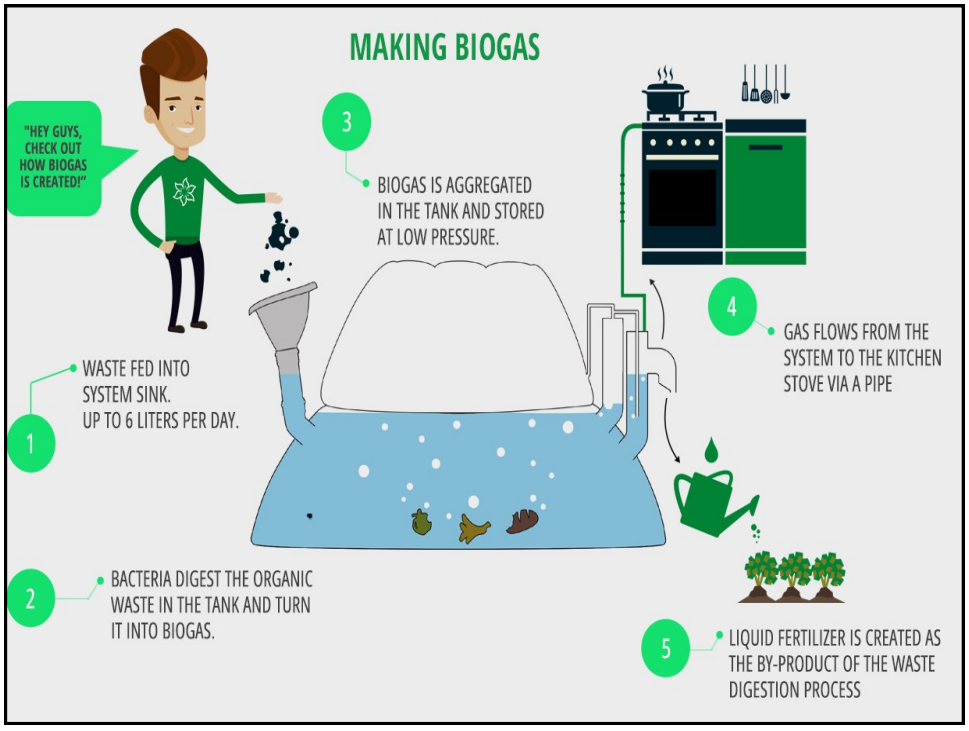
MAKING BIOGAS
"HEY GUYS, CHECK OUT HOW BIOGAS IS CREATED!"
1
WASTE FED INTO SYSTEM SINK. UP TO 6 LITERS PER DAY.
2
BACTERIA DIGEST THE ORGANIC WASTE IN THE TANK AND TURN IT INTO BIOGAS.
3
BIOGAS IS AGGREGATED IN THE TANK AND STORED AT LOW PRESSURE.
4
GAS FLOWS FROM THE SYSTEM TO THE KITCHEN STOVE VIA A PIPE
5
LIQUID FERTILIZER IS CREATED AS THE BY-PRODUCT OF THE WASTE DIGESTION PROCESS

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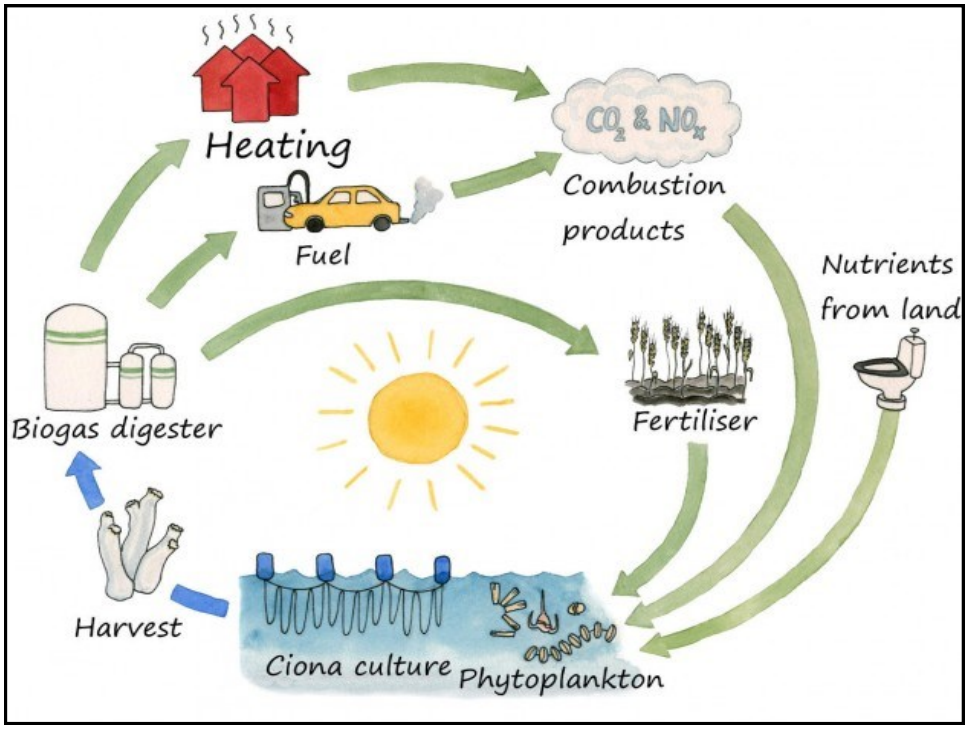

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Types of Biofuels
4) Syngas

Gas Biofuels

- Short name for synthetic gas that made up mainly of H_2 and CO. It contains also small quantity of CO_2 and other gases.
- **Synthesis**: produced by partial combustion of natural gas or biomass, and its production is a combination of two main processes:

A) pyrolysis, B) gasification

- **Pyrolysis**: decomposition of organic material by burning in absence of oxygen. It is used when the feedstock is solid biomass.

$$\underbrace{CH_{1.5}O_{0.67}}_{\text{wood}} + 0.33\ \underbrace{H_2O}_{\text{steam}} \rightarrow \underbrace{CO + 1.08\ H_2}_{\text{syngas}} \qquad \Delta H_r = +101\ \text{kJ/mol}$$

700-900°C, 1 atm

- **Gasification:** partial combustion of the biomass in a low oxygen environment, then passing of hot steam:

$$CH_4 + H_2O \rightarrow 3H_2 + CO$$

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❑ **Benifits of syngas:**

✓Generation of renewable power

✓Conversion of problematic wastes to useful fuels

✓Reduction in carbon emissions

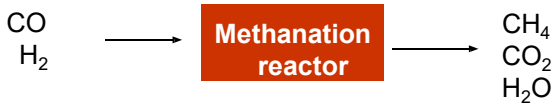
❑**Applications :**

Syngas is an intermediate compound that holds many valuable uses:

1- to produce methanol.

2- hydrogen can be used in fuel cells for generating electricity.

3- provided efficient production of other chemicals



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Thermal Gas Generation in Dakahlia Plant

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General Conversion Processes in Biofuel Production

To obtain biofuel from biomass, there are three types of conversion:

1) **Biological conversion**

- Fermentation: (production of bioalcohol)
- Anaerobic digestion (biogas such as methane)
- Anaerobic respiration (bio-battery)

2) Chemical conversion

- Trans-esterification (biodiesel)

3) Thermal conversion (syngas)

- Combustion
- Gasification
- Pyrolysis

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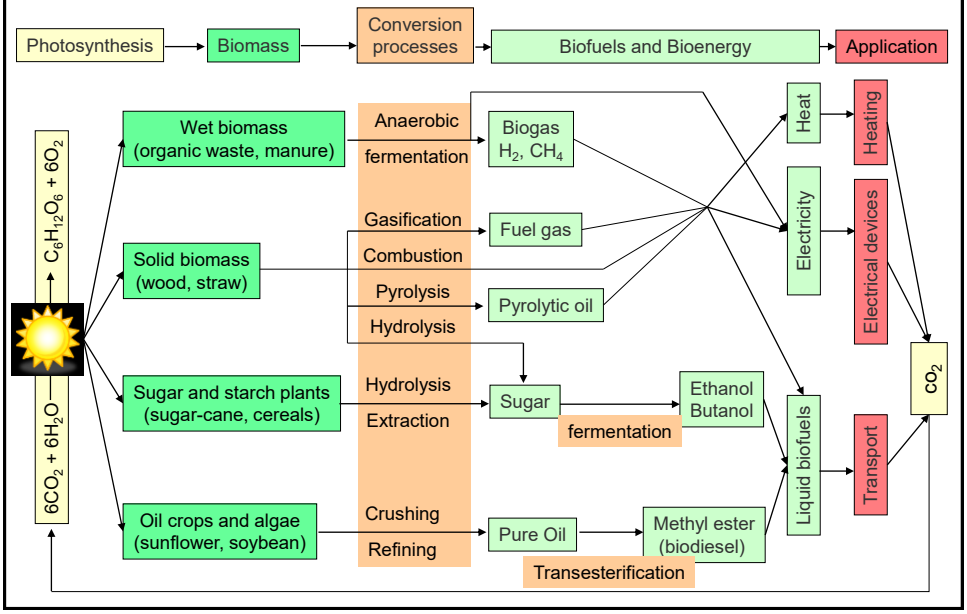
Biomass-to-Bioenergy Routes



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End of 1st part

Dr. Hanaa Abulmagd

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