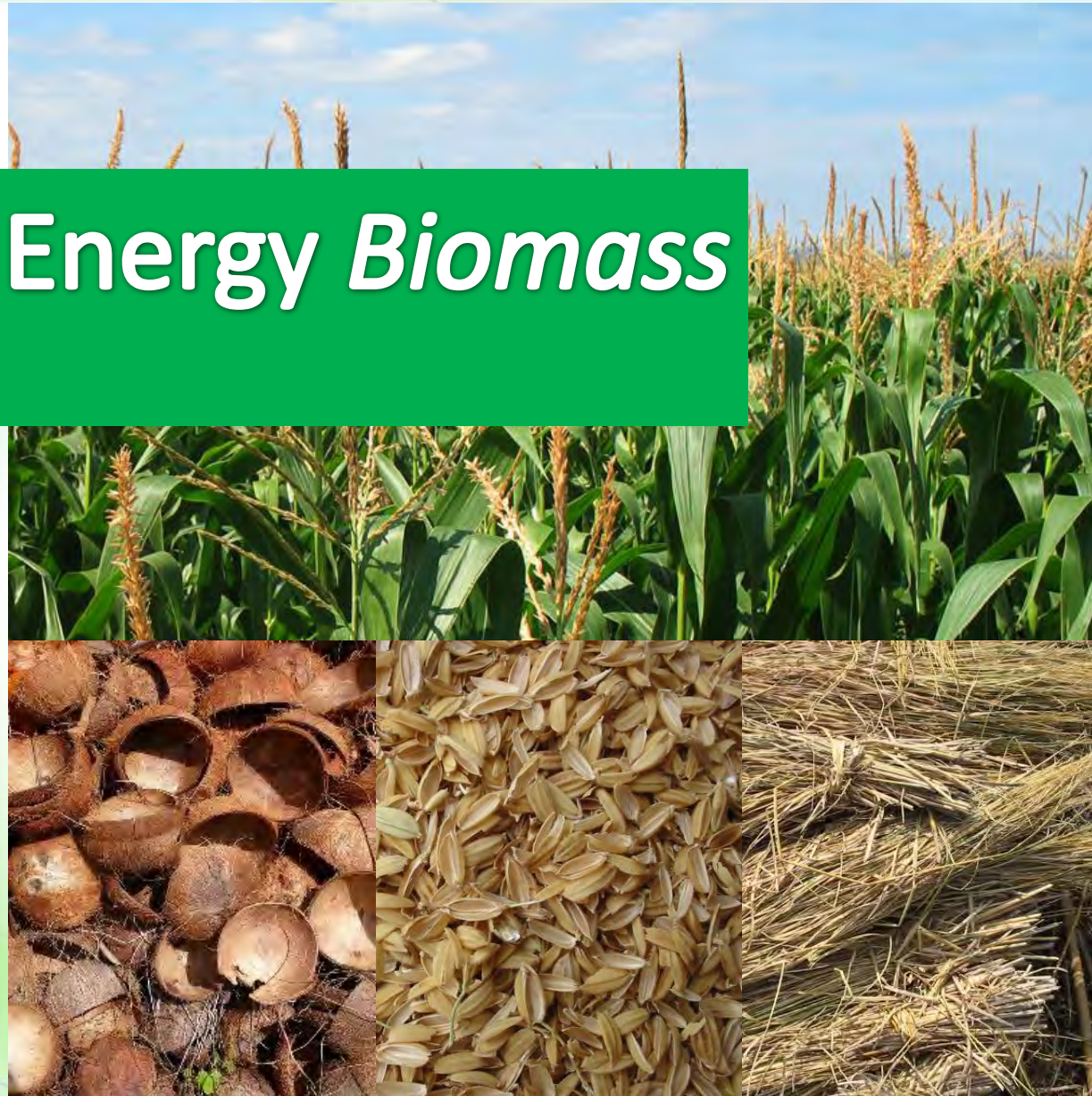


# Renewable Energy *Biomass*

*Dr. Kuok Fidero*



# **INTRODUCTION TO BIOMASS**

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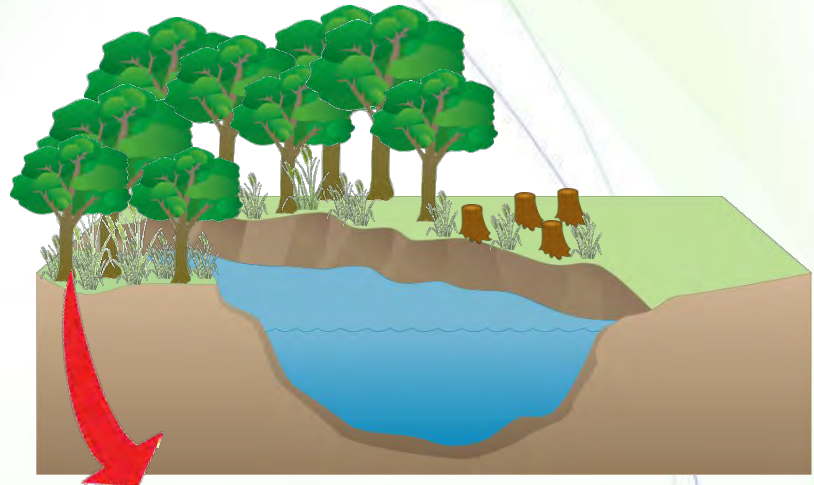
**BY DR. KUOK FIDERO**



# Definition of biomass

- Biomass includes a wide class of materials of vegetable and animal origin as well as rubbish. This could be derived from a number of sources viz [1]:

a) *Forest and Agro-forest compartment: forest-cultural or agro-forest activities and operations residues, use of the coppice, etc.*



# Definition of biomass

*b) Agricultural compartment:  
farming residues, e.g., rice  
stalks, rice husk, coconut  
shells, etc.*



# Definition of biomass

- c) *Livestock wastes compartment: cow, buffalo, and wine manure, etc., for the production of biogas.*



# Definition of biomass

- d) *Industrial compartment: coming from wood or wood product industries and paper industries, as well as agricultural and food industry residues.*



# Definition of biomass

- e) *Solid wastes compartment: the public green and municipal/urban solid wastes.*



# Nature of biomass

- Forest and Agro-forest
  - Forest residues, resulting from the different kinds of forest-cultural intervention, are commonly indicated as forest biomasses.
  - The physical characteristics of the wooden biomasses which are relevant on the energy production depend on the degree of humidity and the density which, with the material's chemical composition, affect the calorific power of the wood.



*The calorific power expresses the quantity of heat that is released during the complete combustion of the weight unit or in fuel volume.*

# Nature of biomass

- Forest and Agro-forest

The main polymers which make up the wooden biomass are:

- Lignin, which gives rigidity to the plant (reinforces the cellular wall), is present in percentages that vary from 20% to 30% of the dry weight and has a high calorific power (6000 kcal/kg approximately).
- Cellulose, which is the main wood component (constitutes 50% of the weight) and has a calorific weight of approximately 3900 kcal/kg.
- Hemicelluloses, which are present in the cellular wall of the plants, in the free spaces left from cellulose. It constitutes from 10% to 30% of the wood and it has a more contained calorific power.

# Nature of biomass

- Forest and Agro-forest
  - The humidity is considerably importance due to its influences on the chemical characteristics of the wood and its specific weight.
  - The humidity expresses the quantity of water that is present in the wood; it is expressed as a percentage in terms of both the dry weight and the fresh wood weight as follows:

$$MC (\%) = [(M_i - M_o)/M_i] \times 100$$

Where  $M_i$  is the exact wood mass and  $M_o$  is the mass of dry wood obtained by drying sample at 105 °C to a constant weight.

# Nature of biomass

- Forest and Agro-forest

Table 1. Main wooden biomass chemical-physical characteristics (DS, dry substance) [1]

Description	Unit
<b><i>Composition</i></b>	
Cellulose	50% of DS
Hemicellulose	10 – 30% of DS
Lignin	20 – 30% of DS
<b><i>Physical and energetic characteristics</i></b>	
Humidity	25 – 60%
Mass density	800 – 1120 kg/m <sup>3</sup>
Calorific power (with a humidity of 12 — 15%)	3600 – 3800 kcal/kg

# Nature of biomass

- **Agricultural residues**
  - The agricultural residues include the set of by-products which are derived from the cultivation.

Table 2. Main chemical-physical agricultural-residues characteristics (DS, dry substance) [1]

<b>Agricultural sub-product</b>	<b>Humidity (%)</b>	<b>Medium production (t/ha)</b>	<b>C/N ratio</b>	<b>Calorific power (kcal/kg DS)</b>
Soft wheat straw	14 – 20	3 – 6	120 – 130	4100 – 4200
Hard wheat	14 – 20	3 – 5	110 – 130	4100 – 4200
Rice straw	20 – 30	3 – 5	60 – 65	3700 – 3800
Maize stocks	40 – 60	4.5 – 6	40 – 60	4000 – 4300
Corncobs and vine shoots	30 – 55	1.5 – 2.5	70 – 80	4000 – 4300

# Nature of biomass

- Dedicated cultures
  - The term “dedicated cultures”, or “energetic cultures”, refers to the cultures prepared with the aim of producing biomass destined for preparing electric and/or thermal energy.



Sorghum



Miscanthus

# Nature of biomass

- Dedicated cultures

Table 3. Productive and energetic parameters of the biomass from dedicated cultures (DS, dry substance) [1]

	<b>Fresh substance production (t/ha year)</b>	<b>Humidity (%)</b>	<b>Dry substance production (t/ha year)</b>	<b>Calorific power (kcal/kg DS)</b>
Fiber sorghum	50 – 100	25 – 40	20 – 30	4000 – 4050
Kenaf	70 – 100	25 – 35	10 – 20	3700 – 3900
Miscanthus	40 – 70	35 – 45	15 – 30	4200 – 4250
Common reed	45 – 110	35 – 40	15 – 35	3950 – 4150
Measly	25 – 60	35 – 45	10 – 25	4100 – 4200
Poplar	20 – 30	50	10 – 15	4100 – 4200

# Nature of biomass

- Livestock wastes

- The energy content of the livestock wastes is in direct relation with the organic substance content presented in the wastes.
- In fact, it is the organic substance which, through a fermentable or anaerobic digestion process, results in the formation of the bio-gas, a high calorific power fuel.



*The organic matter or organic material is matter comes from a recently living organisms and capable of decay, or the product of decay, or composed of organic compounds.*

# Nature of biomass

- Livestock wastes

Table 4. Swine and bovine liquid manure yields in bio-gas (DS, dry substance) [1]

Material	Dry substance (DS, %)	Organic substance (volatile solids-VS, % on DS)	Biogas yield (m <sup>3</sup> /kg VS)
Swine liquid manure	3 – 8	70 – 80	0.25 – 0.50
Bovine liquid manure	5 – 12	75 – 85	0.20 – 0.30

# Nature of biomass

- Municipal solid wastes (MSW)
  - MSW defined as biomass, can be considered as renewable energy sources include all the green biodegradable fractions, which can be divided into those made of lignocellulose wastes component and an humid organic component.
  - Although the MSW is generally used for composting, it can be applied after an appropriate conditioning for heat and/or electricity production through combustion.

# Nature of biomass

- Municipal solid wastes (MSW)

Table 5. Per capita MSW generation and its composition in various countries [2]

Country	MSW generation (kg day <sup>-1</sup> capita <sup>-1</sup> )	Major waste component [%]						Reference
		Food	Plastics	Paper	Metals	Glass	Other	
United States	2.09	12.5	12.1	32.7	8.2	5.3	29.2	[3]
European Union	1.51	27.5	7.0	26.0	4.0	6.0	29.5	[4]
Japan (Tokyo)	1.08	31.3	7.8	44.5	1.2	1.1	14.1	[5]
Vietnam (Hanoi)	1.0	49.1	15.6	1.9	6.0	7.2	20.2	[6]
Singapore	0.96	38.8	5.8	20.6	3.2	1.1	30.5	[7]
Mexico	0.917	52.4	4.4	14.1	2.9	5.9	20.3	[8]
China (Beijing)	0.85	63.4	12.7	11.1	0.3	1.8	10.8	[9]
Iran (Rasht)	0.8	80.2	9.0	8.7	0.7	0.2	1.2	[10]
Cambodia	0.74	63.3	15.5	6.4	0.6	1.2	13.0	[11]
Nepal (Kathmandu Valley)	0.565	70.0	9.5	8.5	–	2.5	9.5	[12]
India (Delhi)	0.5	38.6	6.0	5.6	0.2	1.0	48.6	[13]
Sri Lanka	0.26	66.0	8.0	13.0	3.0	2.0	8.0	[14]
England	–	20.2	10.2	33.2	7.3	9.3	19.8	[15]

# Nature of biomass

- Municipal solid wastes (MSW)

Table 6. Typical composition of MSW in Phnom Penh [2]

Composition [%]	1999 <sup>a</sup>	2002 <sup>b</sup>	2003 <sup>c</sup>
Food/organic	87	65	63.3
Plastic	6	13.2	15.5
Paper and Cardboard	3	3.8	6.4
Grass and Wood	–	–	6.8
Glass	1	4.9	1.2
Metal	1	1	0.6
Rubber, Leather	–	0.6	0.1
Textile	–	–	2.5
Ceramic and Stone	–	–	1.5
Other	2	11.5	2.1

<sup>a</sup>MoE, 2004.

<sup>b</sup>Kum et al., 2005.

<sup>c</sup>JICA, 2005.

# Nature of biomass

- Municipal solid wastes (MSW)

Table 7. Amount of materials recycled in 2003 [2]

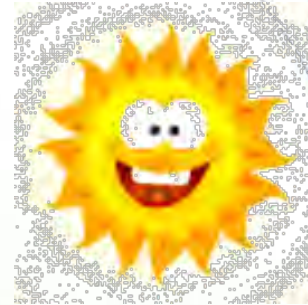
Type of waste	Amount of material	
	[kg day <sup>-1</sup> ]	[%]
Office paper	5060	11.2
Cardboard	13 200	29.2
PET bottles	520	1.2
Plastics	5755	12.7
Aluminium	1905	4.2
Ferrous/ferric metal	7317	16.2
Other metals	217	0.5
Glass bottles	1991	4.4
Other glass	4500	10.0
Food waste	705	1.6
Other	4000	8.9
Total	45 170	100

Source: JICA [2005].

# **ENERGY FROM BIOMASSES**

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**BY DR. KUOK FIDERO**



# Different Types of Bioenergy

## 1. Gaseous



**Biogas**

## 2. Liquid



**Plant Oil**

## 3. Solid



**Logs**



**Wood Gas**

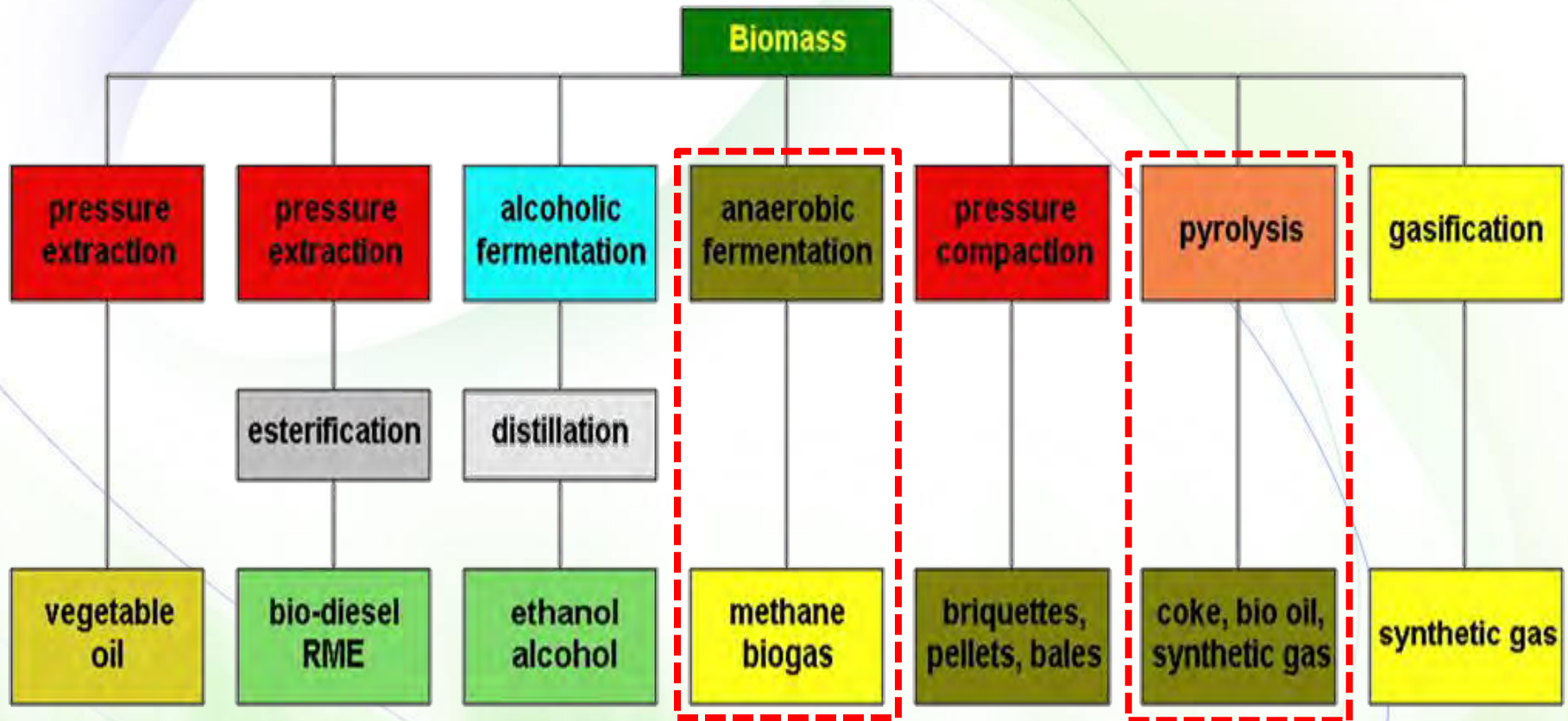


**Biodiesel**



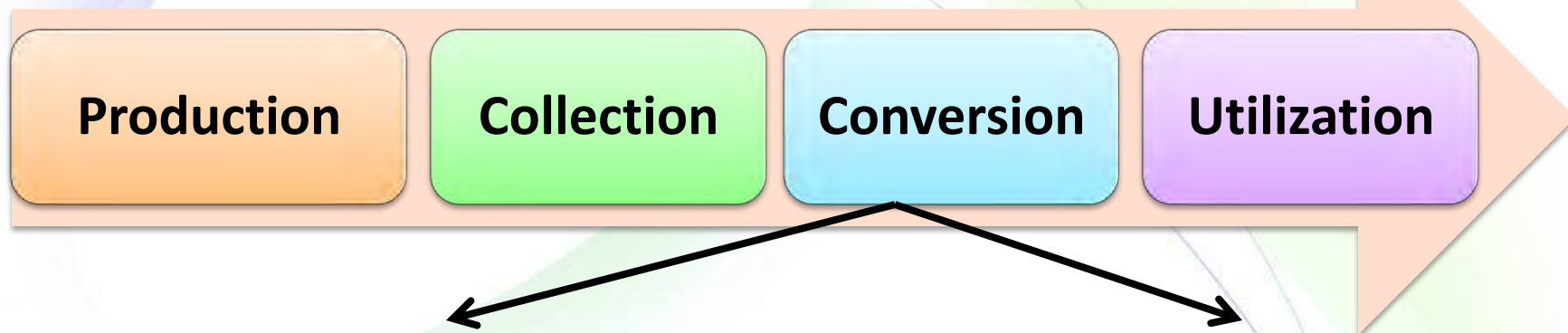
**Chips**

# Energetic Conversion Possibilities for Biomass



# Biomass Energy Conversion

## Steps in Biomasses Utilization



### **Biochemical conversion:**

processes through chemical reactions by the action of enzymes, fungi and microorganisms; for biomasses:

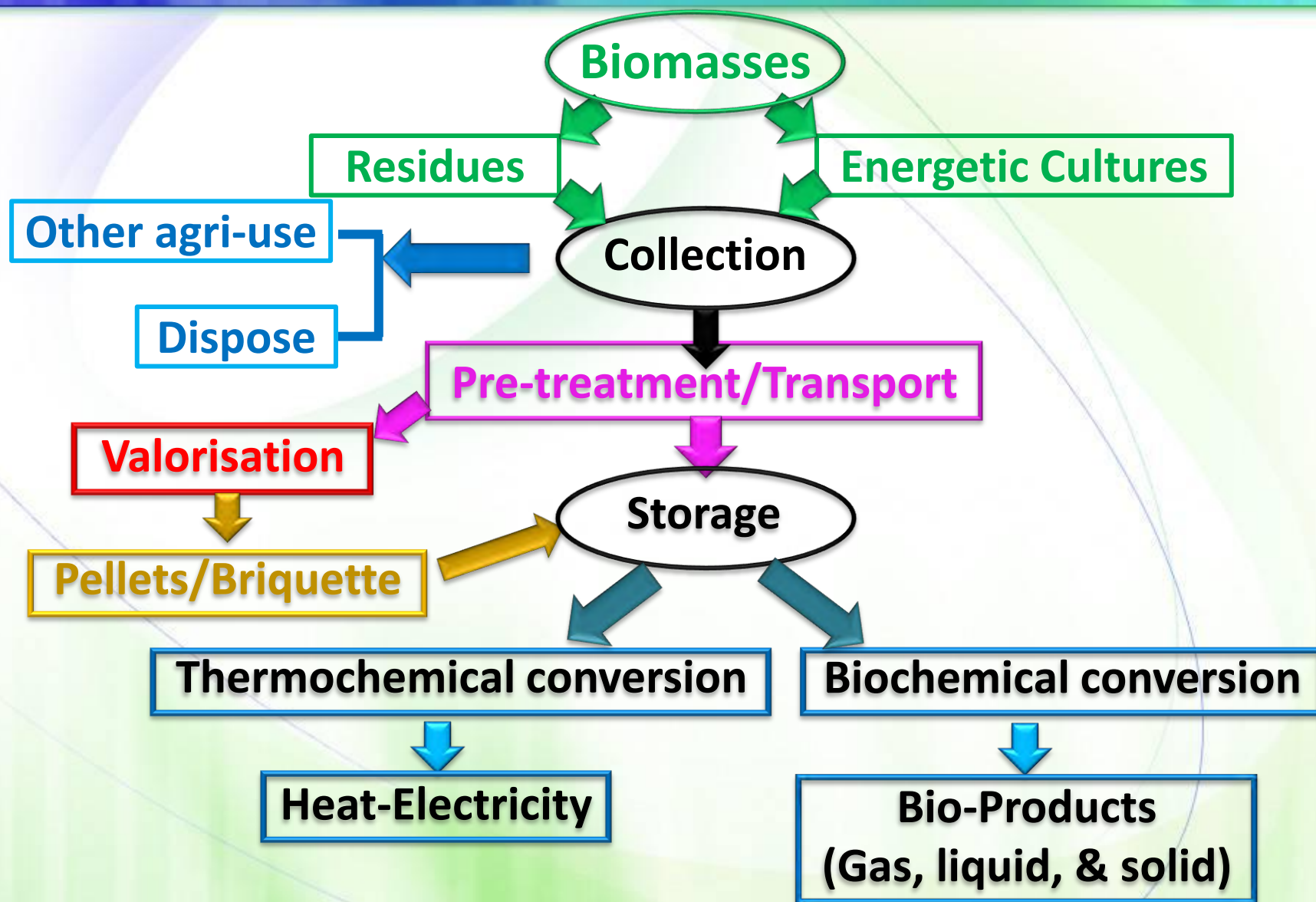
- C/N ratio is lower than 30
- Humidity higher than 30%

### **Thermochemical conversion:**

processes through the action of heat allowing chemical reactions necessary to transform the material into energy; for biomasses:

- C/N ratio is higher than 30
- Humidity less than 30%

# Biomass Energy Conversion



# Biochemical Conversion: *Anaerobic digestion*

**Anaerobic digestion:** is a complex natural process that involves biodegradation of the organic substance by microorganism in the absence of oxygen, resulting in the formation of bio-gas.

## Organic matter

- Organic matter or organic material is matter comes from a recently living organism; is capable of decay, or the product of decay; or is composed of organic compounds.
- Organic compounds comprise all chemical compounds containing carbon-hydrogen (C-H) bonds.
- Large number and diversity of such compounds exist

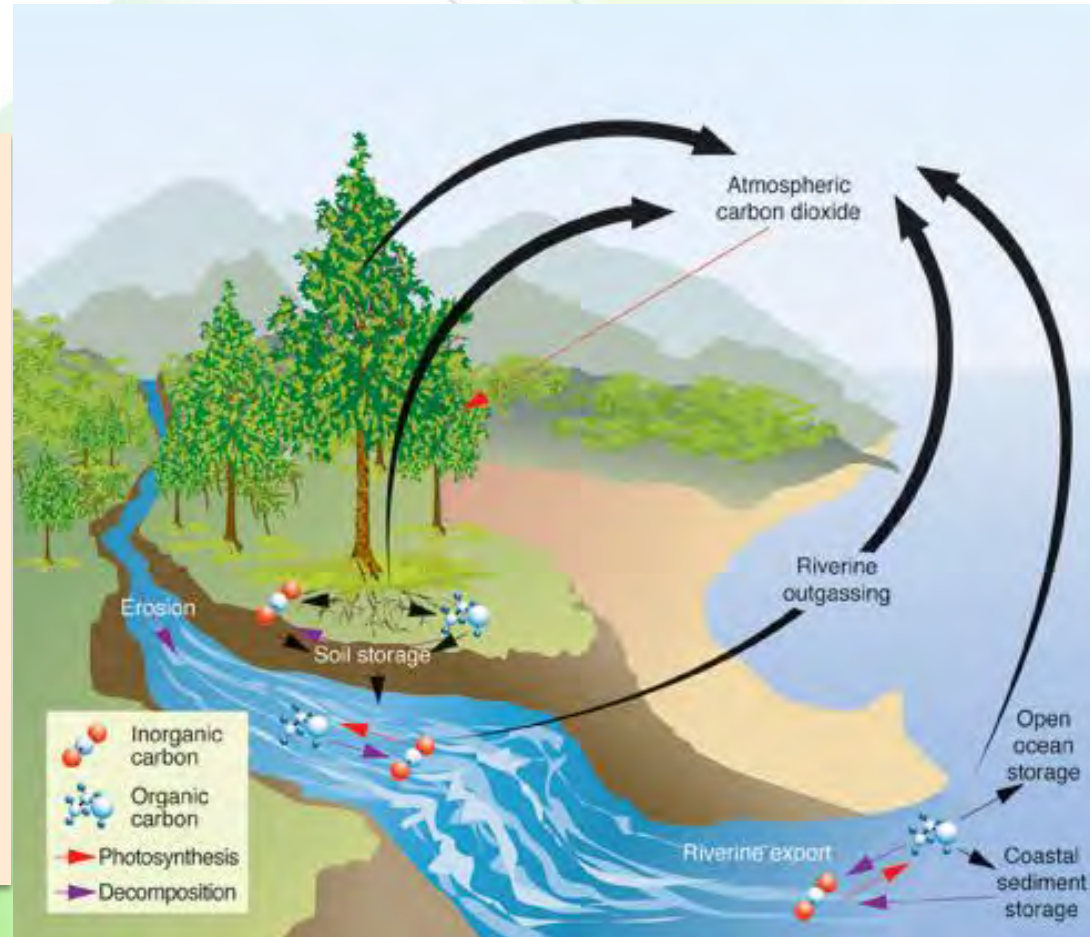


Figure 2. Carbon cycle  
(Source: <https://www.llnl.gov/str/March06/Brown.html>)

# Microorganisms

## Microorganisms

- Too small to be seen by the naked human eye.
- Microorganisms include bacteria, fungi, archaea or protozoa.
- Single-celled.
- Live almost everywhere.
- Play a major role in nutrient recycling in ecosystems acting as decomposers.

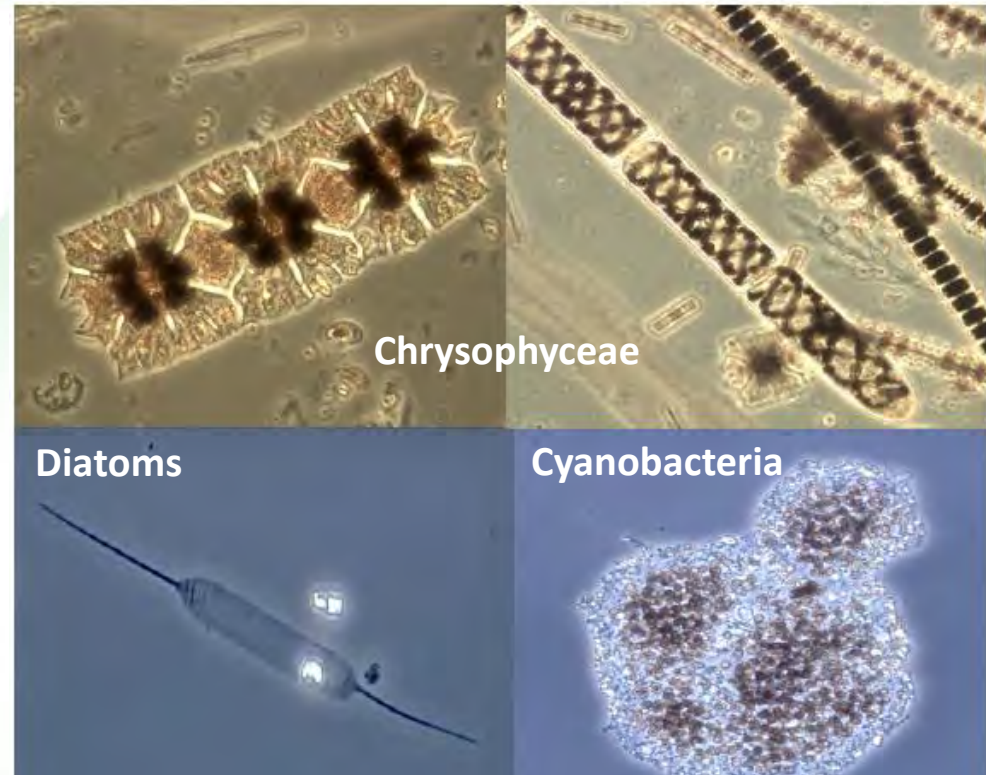
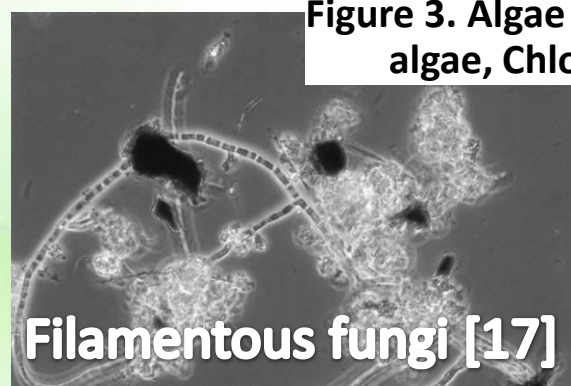
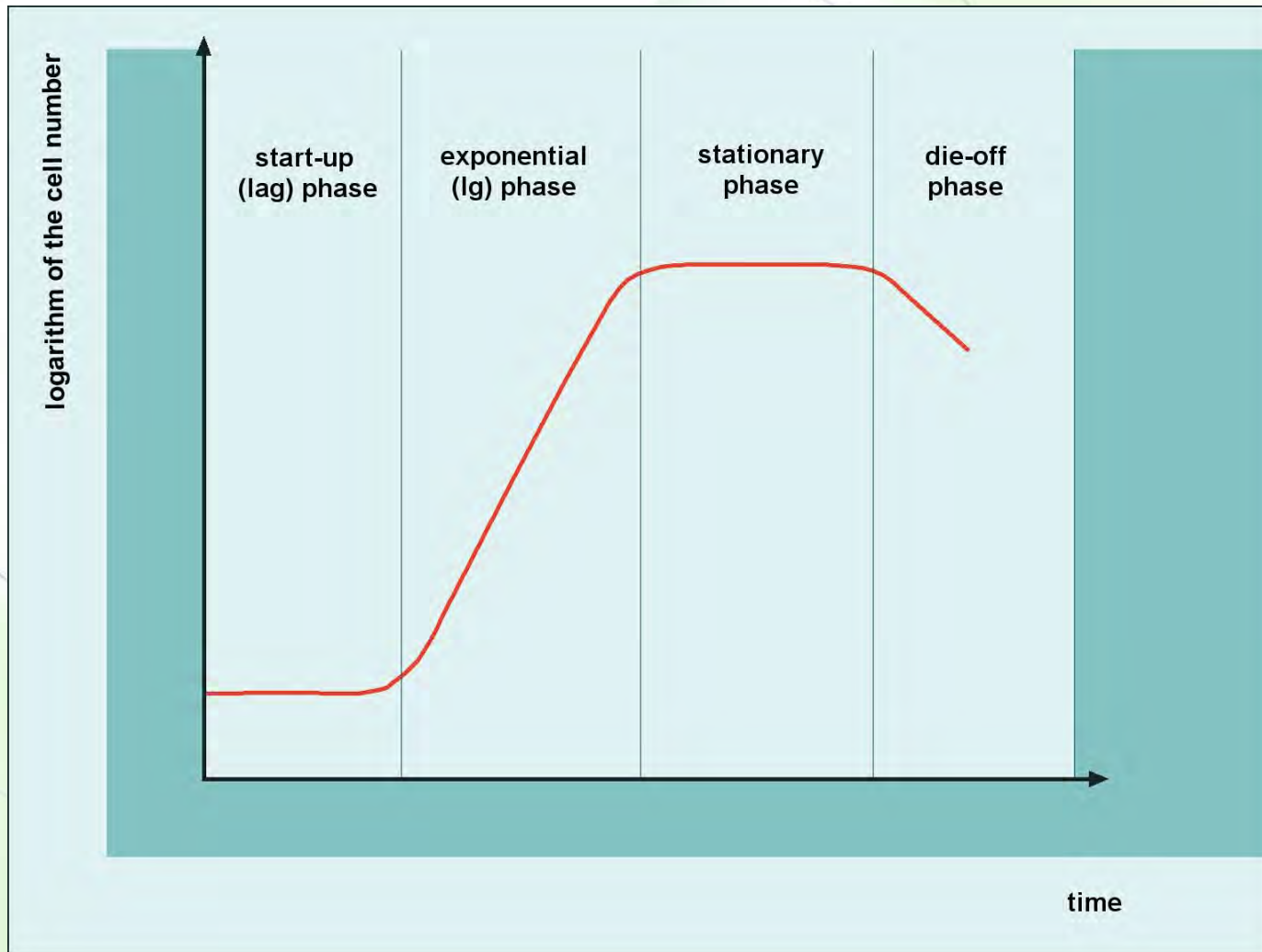


Figure 3. Algae composition in Se San River; green algae, Chlorophyceae and golden algae [16].



# Microorganisms

## Growth function of a batch cell culture



# Biochemical Conversion: *Anaerobic digestion*

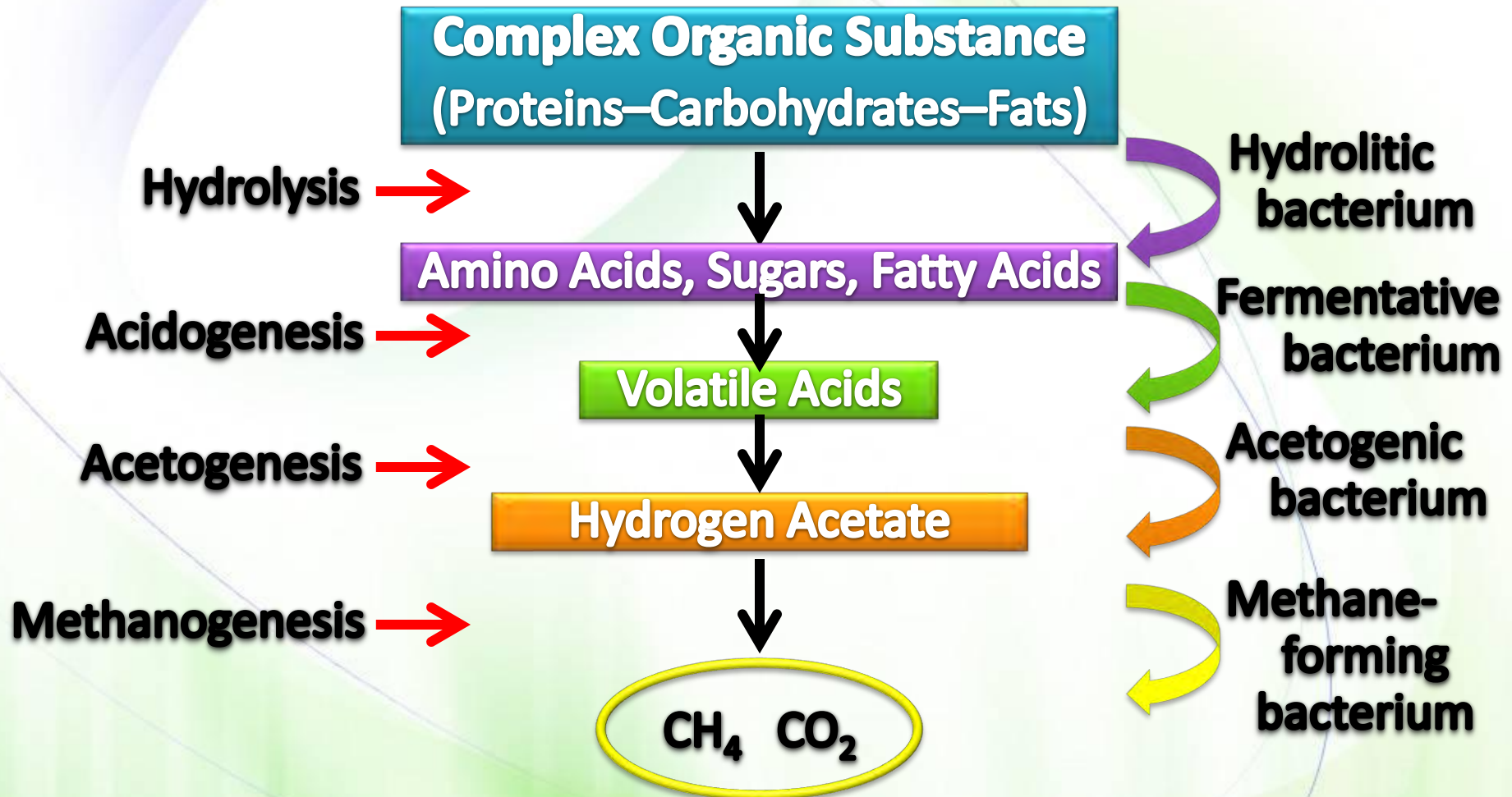


Figure 4. Anaerobic digestion process steps [1]

# Biochemical Conversion: *Anaerobic digestion*

## Anaerobic Degradation

### Stage 1

- Hydrolysis: substrate (proteins, carbohydrates, lipids) converted into dissolved compounds (amino acids, sugars, fatty acids).

### Stage 2

- Acidogenesis: dissolved compounds are taken up in fermentative bacterial cell with production of volatile fatty acids, alcohols, lactic acid, and mineral compounds viz carbon dioxide, hydrogen, ammonia, and hydrogen sulphide gas.

### Stage 3

- Acetogenesis: products of Acidogenesis are converted into acetate, hydrogen, and carbon dioxide.

### Stage 4

- Methanogenesis: is often the rate limiting step in the overall digestion process. Methane is produced from acetate or from the reduction of carbon dioxide by hydrogen using acetotrophic and hydrogenotrophic bacteria respectively.

# Biochemical Conversion: *Anaerobic digestion*

## Methanogenesis

Acetotrophic methanogenesis:  $\text{CH}_3\text{COOH} \longrightarrow \text{CH}_4 + \text{CO}_2$

Hydrogenotrophic methanogenesis:  $4\text{H}_2 + \text{CO}_2 \longrightarrow \text{CH}_4 + 2\text{H}_2\text{O}$

Two important points must be emphasized with respect to the different processes that occur during anaerobic digestion:

1. Only appr. 30% of organic matter is converted into methane via hydrogenotrophic pathway; therefore, acetotrophic methanogen is vital for anaerobic digestion.
2. Souring phenomenon is the limiting rate and cause of operational failure of anaerobic digestion since methanogenesis well develops at neutral pH values.

# Biochemical Conversion: *Anaerobic digestion*

**Anaerobic digestion processes:** can be classified based on the mass fraction of the dry substance to be digested:

- Wet digestion if lower than 10% of dry substance in substrate
- Semi-dry digestion if 10—20% of dry substance in substrate
- Dry digestion if higher than 20% of dry substance in substrate

**Temperature range for anaerobic digestion:**

- Psychrophilic: if the process temperature is below 20 °C.
- Mesophilic: if the temperature is between 20 °C and 40 °C.
- Thermophilic: if the temperature is between 50 °C and 65 °C.

# Biochemical Conversion: *Anaerobic digestion*

## Input Materials

- Substrate is the key factor for anaerobic digestion since the ease and availability of nutrients for various microorganisms depend on types of substrates.
- Physical characteristics: particle size and moisture content > 30%.
- Chemical characteristics: complexity and nature of substrates with C/N ratio < 30.
  - Easily degradable: fresh vegetable trimmings, garbage, kitchen and food waste, livestock manures, etc.
  - Hardly degradable: cellulose/lignin (wood)

# Biochemical Conversion: *Anaerobic digestion*

## Input Materials

Table 8. C/N ratio of some of the commonly used raw materials [19].

No.	Raw materials	C/N Ratio	No.	Raw materials	C/N Ratio
1	Duck dung	8	8	Water hyacinth	25
2	Human excreta	8	9	Elephant dung	43
3	Chicken dung	10	10	Straw (maize)	60
4	Goat dung	12	11	Straw (rice)	70
5	Pig dung	18	12	Straw (wheat)	90
6	Sheep dung	19	13	Saw dust	above 200
7	Cow dung/ Buffalo dung	24			

# Biochemical Conversion: *Anaerobic digestion*

## Input Materials

Table 9. Gas production potential of various types of manure [18].

Type of manure	Gas production per Kg manure (m <sup>3</sup> )
Cattle (cows and buffaloes)	0.023 - 0.040
Swine	0.040 - 0.059
Chickens	0.065 - 0.116
Human	0.030 - 0.050

## Environmental Factors

- **Temperature:** Methanogens are inactive in extreme high and low temperatures. The optimum temperature is 35° C. When the ambient temperature goes down to 10° C, gas production virtually stops [18].
- **pH:** Optimum biogas production is achieved when the pH value of input mixture in the digester is between 6 and 7. Rate of methanogenesis decreases at pH lower than 6.5. When the methane production level is stabilized, the pH range remains buffered between 7.2 to 8.2 [18].

# Biochemical Conversion: *Anaerobic digestion*

## Environmental Factors

- **Loading rate:** Loading rate is the amount of raw materials fed per unit volume of digester capacity per day. If the plant is overfed, acids will accumulate and methane production will be inhibited; or in the case of underfed, the gas production will also be low [18].
- **Retention time/Hydraulic retention Time:** Average period that a given quantity of input remains in the digester. In general the optimum retention time can vary between 30—100 days [18].

$$HRT = V/U$$

Where  $HRT$  = hydraulic retention time (day),  $V$  = digester volume ( $m^3$ ),  $U$  = input substrate per unit of time ( $m^3/day$ )

## Environmental Factors

- **Toxicity:**
  - Mineral ions, heavy metals, antibiotics and the detergents are some of the toxic materials that inhibit the normal growth of microbes in the digester [18].
  - Small quantity of mineral ions (e.g. sodium, potassium, calcium, magnesium, ammonium and sulphur) stimulates the growth of bacteria, while very heavy concentration of these ions will have toxic effect [18].

# Biochemical Conversion: *Anaerobic digestion*

## Environmental Factors

Table 10. Toxic level of various inhibitors for anaerobic digestion[20].

No.	Inhibitors	Inhibiting concentration	No.	Inhibitors	Inhibiting concentration
1	Sulphate	5000 ppm	7	Sodium	3500 - 5500 mg/l
2	Sodium Chloride	40 000 ppm	8	Potassium	2500 - 4500 mg/l
3	Nitrate	0.05 mg/ml	9	Calcium	2500 - 4500 mg/l
4	Copper	100 mg/l	10	Magnesium	1000 - 1500 mg/l
5	Chromium	200 mg/l	11	Manganese	Above 1500 mg/l
6	Nickel	200 – 500 mg/l			

# Biochemical Conversion: *Anaerobic digestion*

## Output products

Table 11. Composition of Biogas [18].

Description	Volume (%)
Methane ( $\text{CH}_4$ )	50 – 70
Carbon dioxide ( $\text{CO}_2$ )	30 – 40
Hydrogen ( $\text{H}_2$ )	5 – 10
Nitrogen ( $\text{N}_2$ )	1 – 2
Water vapour ( $\text{H}_2\text{O}$ )	0.3
Hydrogen sulfide ( $\text{H}_2\text{S}$ )	Traces



# Biochemical Conversion: *Anaerobic digestion*

## Output products

Table 12. Biogas compared with different fuels [18].

Type of fuel	Unit (U)	Calorific value (kWh/U)	Application	Efficiency (%)	U/m <sup>3</sup> Biogas
Wood	Kg	5.0	Cooking	12	5.56
Charcoal	Kg	8.0	Cooking	25	1.64
Hard coal	Kg	9.0	Cooking	25	1.45
Diesel	Kg	12.0	Engine	30	0.55
Electricity	KWh	1.0	Motor	80	1.79
Biogas	m <sup>3</sup>	6.0	Cooking	55	1

# Biochemical Conversion: *Anaerobic digestion*



**Human-waste biogas digester**



**Floating biogas digester**

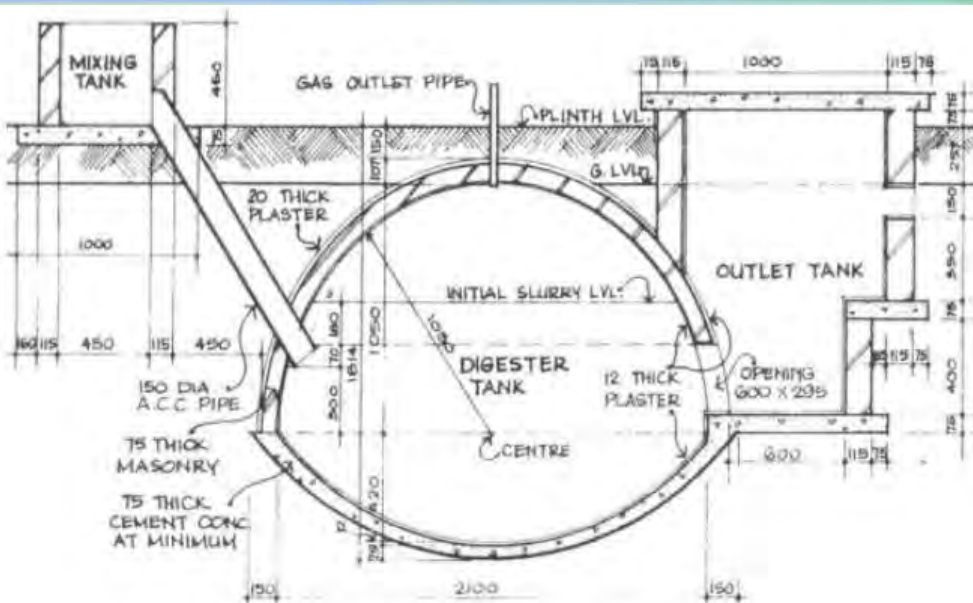


**Livestock-manure biogas digester**

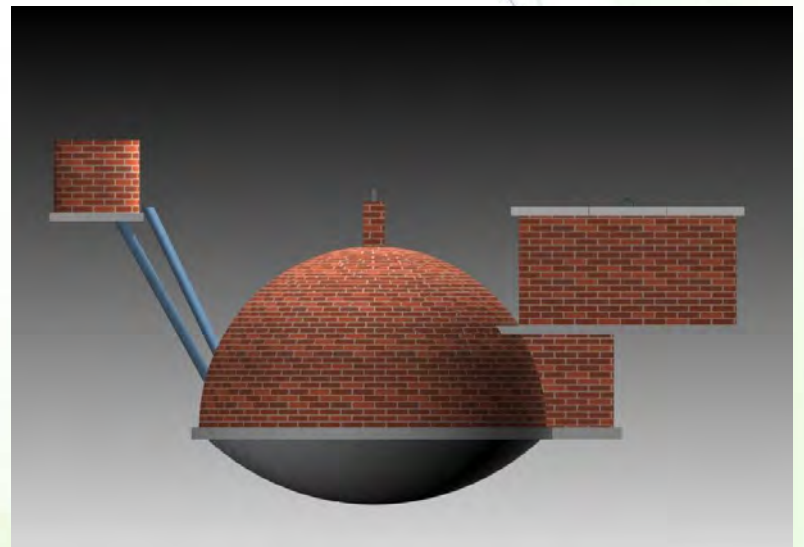


**Biogas bag**

# Biochemical Conversion: *Anaerobic digestion*



Deen-bandhu biodigester model-India



# Thermochemical conversion: *Pyrolysis*

- **Pyrolysis:** a process consists of a thermochemical conversion that allows transforming the organic substance into final fuel products (solid, liquid, gaseous); the most common known use is the creation of charcoal.
- **Pyrolysis:** takes place only in
  - Absence of oxidizing agents, or with
  - A limited presence of these agents so that the oxidation reactions can be neglected.
- The heat required for the evolution of the process can be indirectly supplied through the reactors walls or directly by re-circulating a heating tool in the bed.

# Thermochemical conversion: *Pyrolysis*

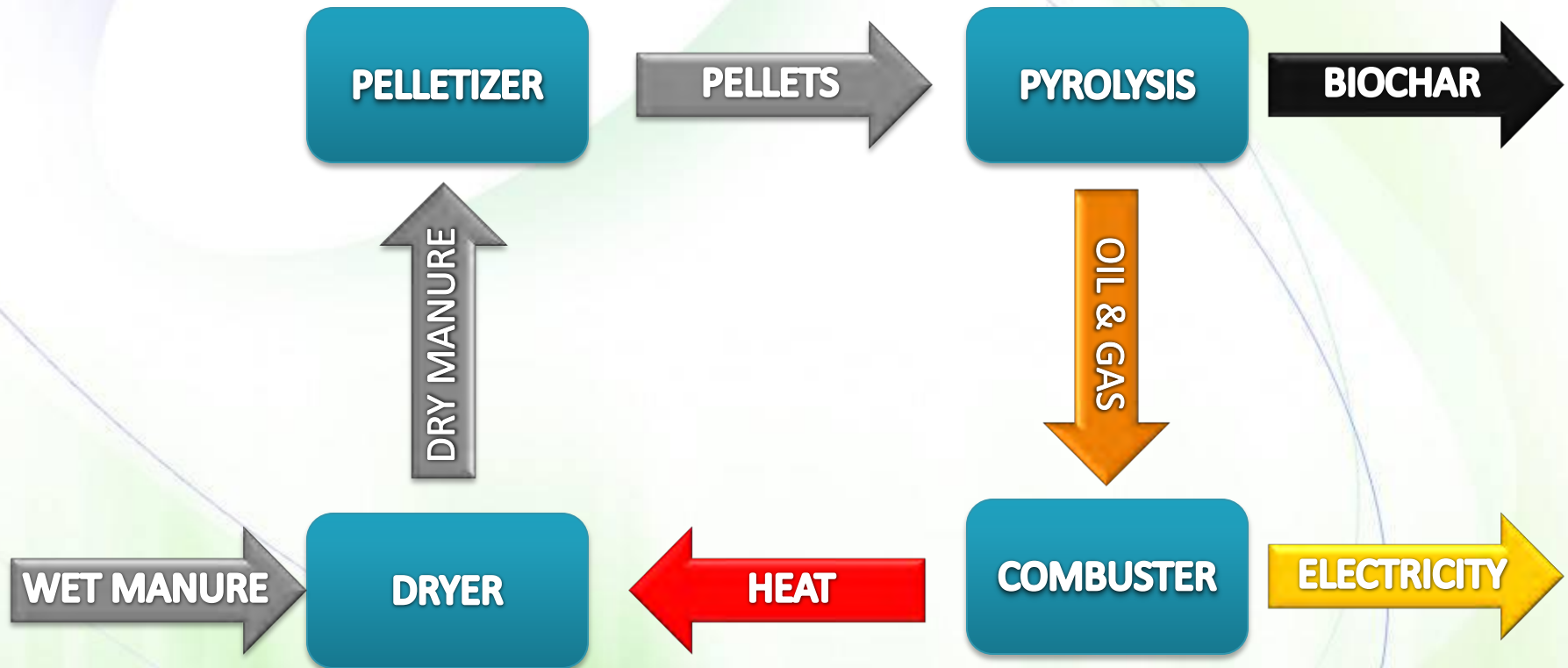
## Pyrolysis

Table 13. Brief description of the pyrolysis processes [1].

Typology	Temperature (°C)	Characteristics
Carbonization	300–500	Only recovers solid fraction
Conventional pyrolysis	< 600	Three fractions of same proportion
Fast pyrolysis	500–650	Production at 70–80% of liquid fraction
Flash pyrolysis	>700	Production at 80% of liquid fraction

# Thermochemical conversion: *Pyrolysis*

## Pyrolysis Application



Source: <http://www.dorset.nu/en/page/home-gm/products/pyrolyse.html>

# Thermochemical conversion: *Pyrolysis*

## Input Material for Pyrolysis

- Pyrolysis can be used on various materials, such as:

- Woodchips
- Poultry Manure
- Sewage Sludge
- Other Biomasses



# Thermochemical conversion: *Pyrolysis*

## Environmental Factors

- The main parameters that influence the process are [1]:
  - Temperature and pressure;
  - Speed of feed heating;
  - Dimensions and shape of the biomass to be treated;
  - Presence of additional catalysts;
  - Residence times of the solid phase and volatile phase in the reactor.

# Thermochemical conversion: *Pyrolysis*

## Output products

- The products of pyrolysis, although they differ depending on the feed material, can include the following [1]:
  - A fuel gas, mainly made of CO, CO<sub>2</sub> (if oxygen is present in the basic material), H<sub>2</sub> and light hydrocarbons;
  - A liquid product (obtainable from the condensation of the vapor phase);
  - A solid carbon product (char) and the cinders.



# Thermochemical conversion: *Pyrolysis*

## Output products

- The products of pyrolysis can be used for the following purposes [1]:
  - **Gas:** It can be burnt to give heat to the reactor involved in the pyrolysis or it can be applied as a fuel in turbo-gas or internal fuel engines.
  - **Tar:** In most of cases, it is not directly applicable as a fuel because of its high viscosity and acidity due to the presence of oxygenated organic compounds.
  - **Aqueous solution:** This fraction is derived from the pyrolysis of the feed's humidity. It helps in the dissolution of the organic oxygenated species that originate from the pyrolysis as organic acids, etc, which are otherwise difficult to dispose.
  - **Char:** These solid carbonaceous residuals can be used as fuel or find application in the chemical industry.

# Thermochemical conversion: *Pyrolysis*



Source: <http://www.sgfe-cambodia.com/products>

# Environmental Aspects

- Biomasses are considered neutral energy sources in terms of greenhouse effects because their combustion does not result in an increase in the concentration of atmospheric carbon dioxide;
- CO<sub>2</sub> cycle is closed given that the quantity of CO<sub>2</sub> (Greenhouse gas) emitted in the combustion phase is equivalent to that absorbed by the plant during their growth;
- However, taking into account the entire life cycle of the combustibles that form the biomass does not result in a nil balance of CO<sub>2</sub> as far as the production, working and transport steps are taken into account.

# Environmental Aspects

- $\text{CH}_4$  as the product of anaerobic digestion is also known as Greenhouse gas.  $\text{CH}_4$  gas greatly contributes to the Global Warming since it has significant effects on the ability of Earth to retain heat energy while doing nothing to shield Earth from light energy.
- Therefore, it is vital to capture  $\text{CH}_4$  greenhouse gas not only to mitigate Global Warming but also to use it as the energy source.

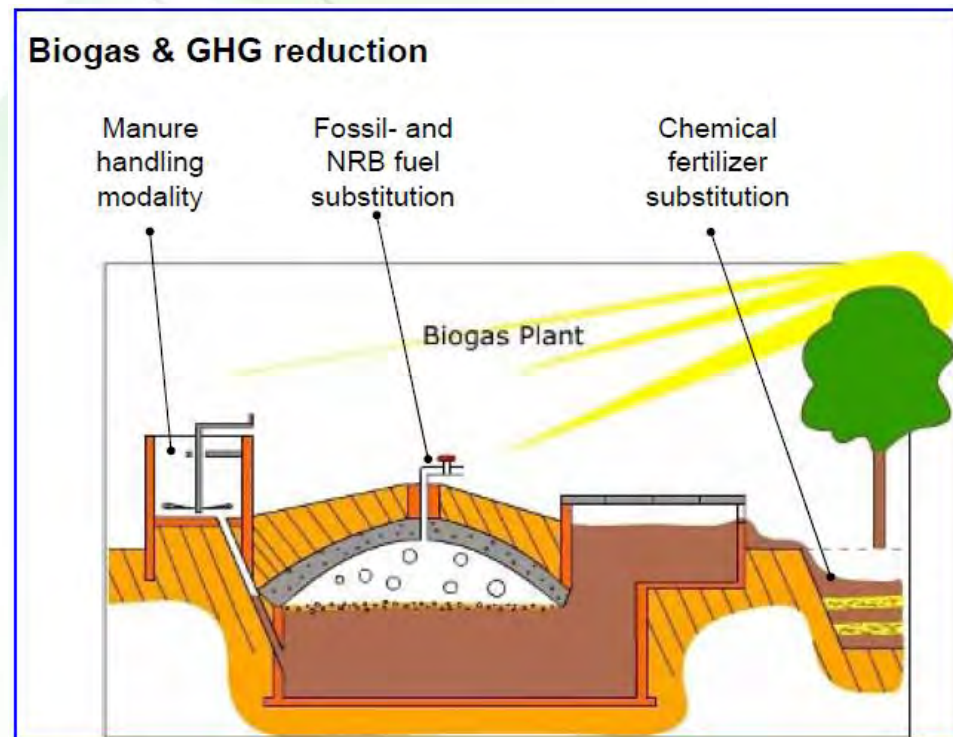


Figure 7. Green house gas (GHG) reduction and emission trading with the use of biodigester [21]

# Environmental Aspects

Table 14. List of CO<sub>2</sub> balance for the fuels obtained from the main biomass production. The avoided emissions were estimated as a function of the substituted fossil fuel (coal, diesel, methane) by taking into account the respective calorific powers [1].

	Avoided emissions	Produced emissions	Medium balance
<b><i>Wooden biomass</i></b>	<b><i>Kg CO<sub>2</sub>/m<sup>3</sup></i></b>	<b><i>Kg CO<sub>2</sub>/m<sup>3</sup></i></b>	<b><i>Kg CO<sub>2</sub>/m<sup>3</sup></i></b>
Chips	200–350	25–35	170–320
Briquettes and pellet	650–1,100	90–95	560–1,010
<b><i>Agricultural residuals</i></b>	<b><i>Kg CO<sub>2</sub>/ha</i></b>	<b><i>Kg CO<sub>2</sub>/ha</i></b>	<b><i>Kg CO<sub>2</sub>/ha</i></b>
Winter-autumn cereal straw	300–1,100	20–75	250–1,050
Stocks, corn cobs, maize sculls	800–1,600	50–110	720–1,520
Rice straw	300–850	25–65	250–800
<b><i>Dedicated cultures</i></b>	<b><i>Kg CO<sub>2</sub>/ha</i></b>	<b><i>Kg CO<sub>2</sub>/ha</i></b>	<b><i>Kg CO<sub>2</sub>/ha</i></b>
Fiber sorghum	22,000–50,000	700–1800	20,000–48000
Miscanthus	17,000–58,000	500–1500	16,000–57,000

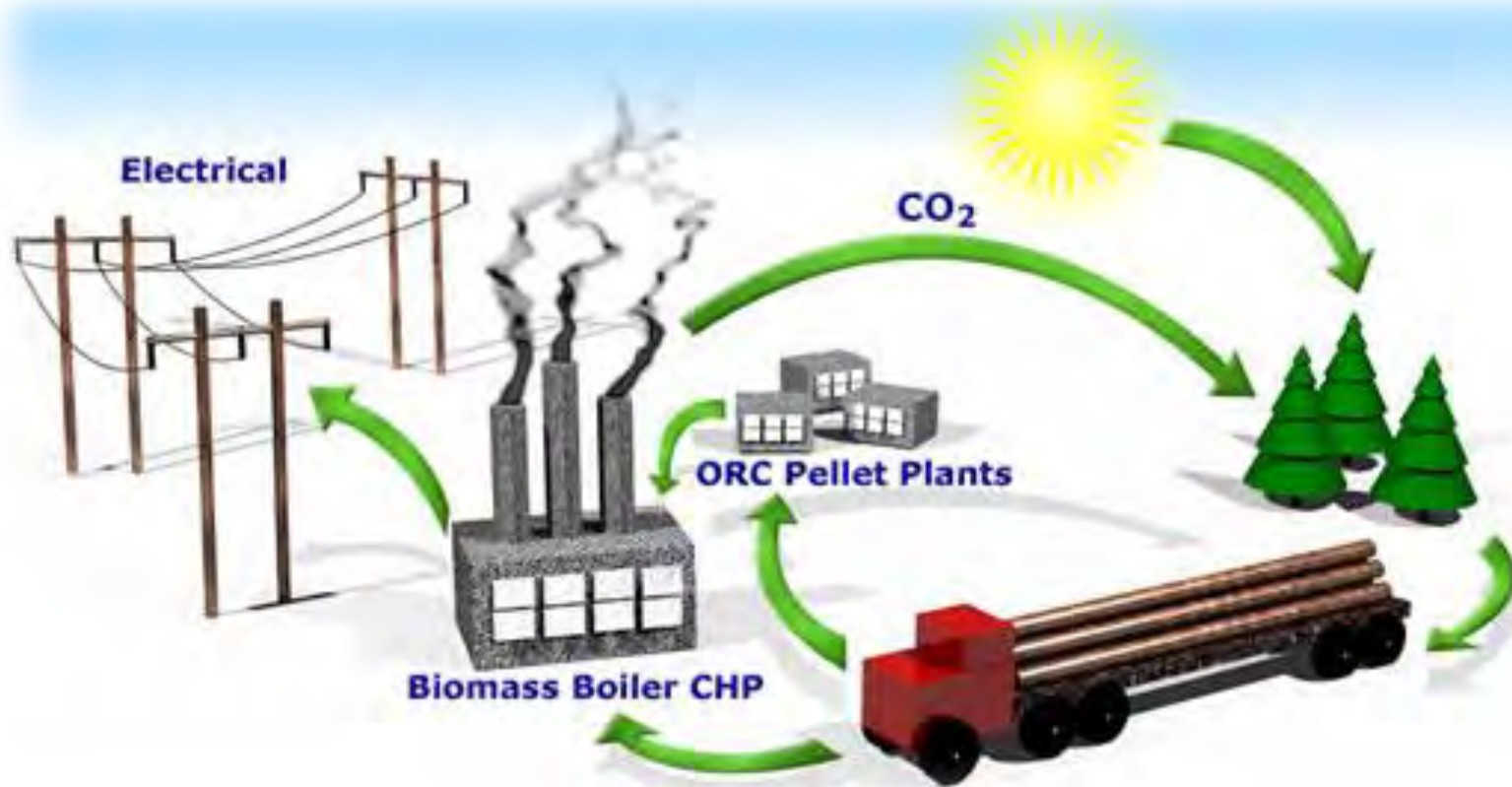
# Environmental Aspects

- Another possibility of reducing the atmospheric emissions connected with the use of fossil sources is represented by the use of biogas, which is obtained by the anaerobic digestion process.

Table 15. Comparison between the main biogas emissions for the main fossil fuels [1].

	SO <sub>2</sub> (Kg/TJ)	NO <sub>x</sub> (Kg/TJ)	Dusts (Kg/TJ)
Mineral oils	140	90	20
Gas	3	90	2
Mineral coal	300	150	20
Biogas	3	50	3

# Environmental Aspects



Source: <http://wihresourcegroup.wordpress.com/2011/05/20/biomass-energy-clean-green-renewable-energy/>

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