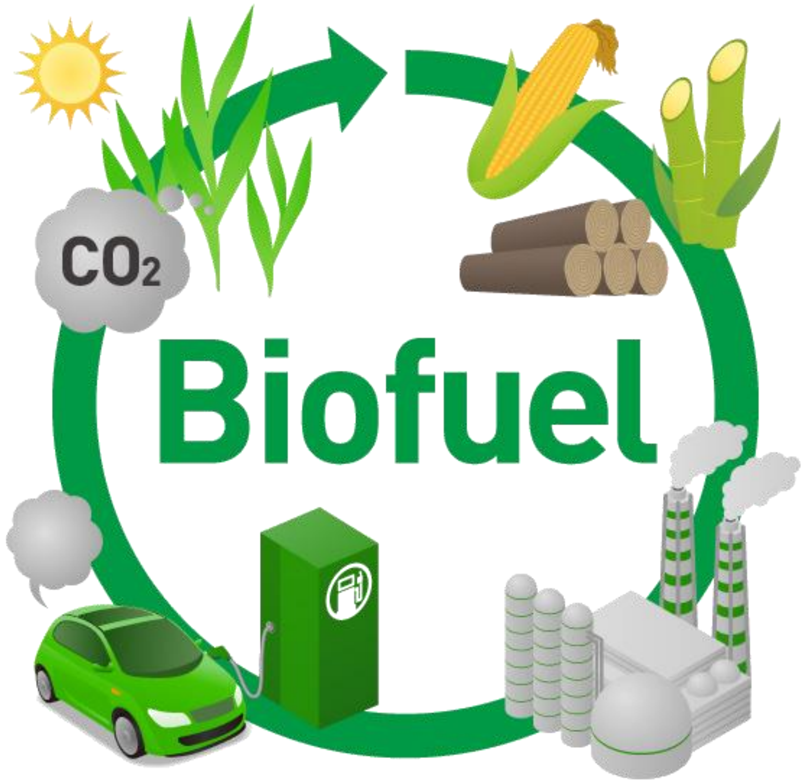
Unit II - WWW

Waste to Energy Conversion Routes

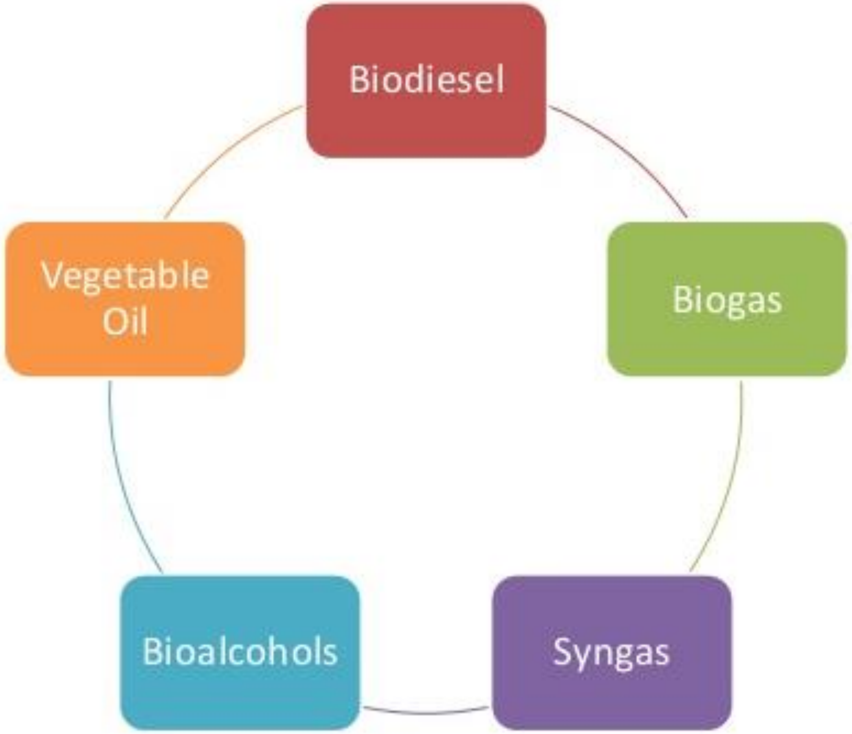
An Introduction on Biofuel

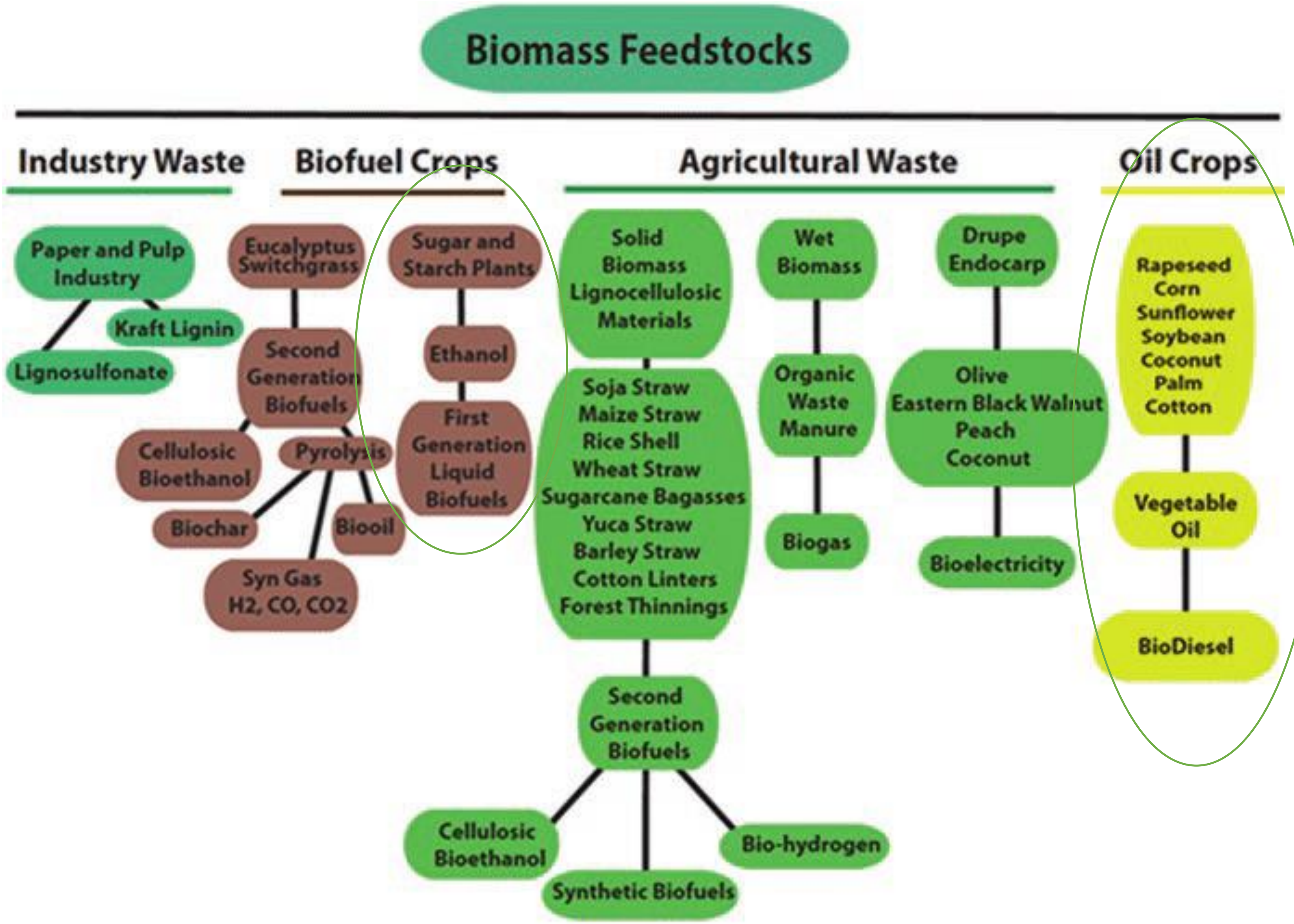
- The dramatic rise in oil prices seen in the last decade has also enabled liquid biofuels to become cost-competitive with petroleum-based transportation fuels, and this has led to a surge in research and production around the world



FIRST GENERATION BIOFUEL

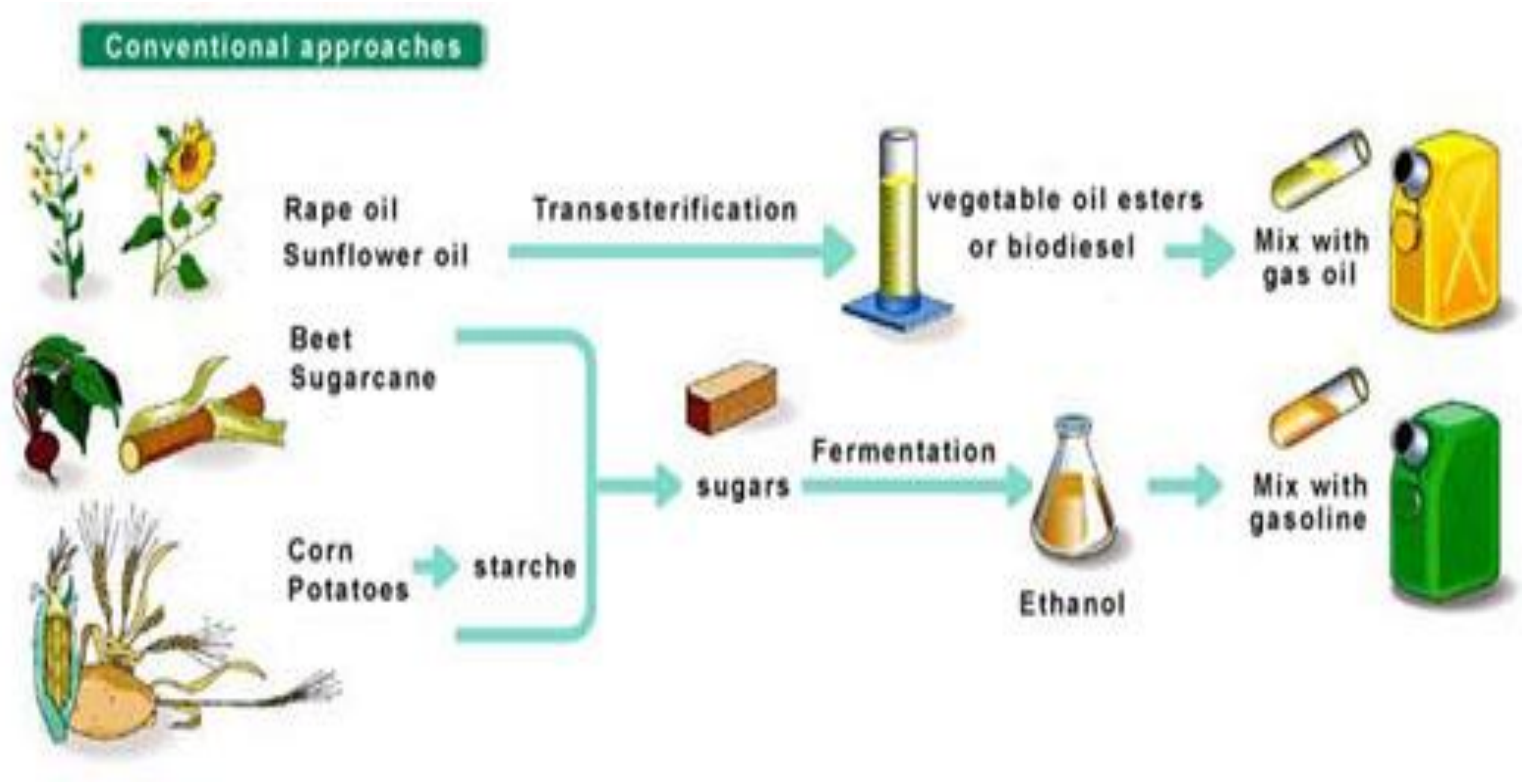
- The production process is considered ‘established technology’





Biomass Feedstocks
Industry Waste
Biofuel Crops
Agricultural Waste
Oil Crops
Paper and Pulp Industry
Kraft Lignin
Lignosulfonate
Eucalyptus Switchgrass
Second Generation Biofuels
Cellulosic Bioethanol
Pyrolysis
Biochar
Biooil
Syn Gas H2, CO, CO2
Sugar and Starch Plants
Ethanol
First Generation Liquid Biofuels
Solid Biomass Lignocellulosic Materials
Soja Straw
Maize Straw
Rice Shell
Wheat Straw
Sugarcane Bagasses
Yuca Straw
Barley Straw
Cotton Linters
Forest Thinnings
Second Generation Biofuels
Cellulosic Bioethanol
Synthetic Biofuels
Bio-hydrogen
Wet Biomass
Organic Waste Manure
Biogas
Drupe Endocarp
Olive
Eastern Black Walnut
Peach
Coconut
Bioelectricity
Rapeseed
Corn
Sunflower
Soybean
Coconut
Palm
Cotton
Vegetable Oil
BioDiesel

First generation substrates



Forms of fuel

Biodiesel

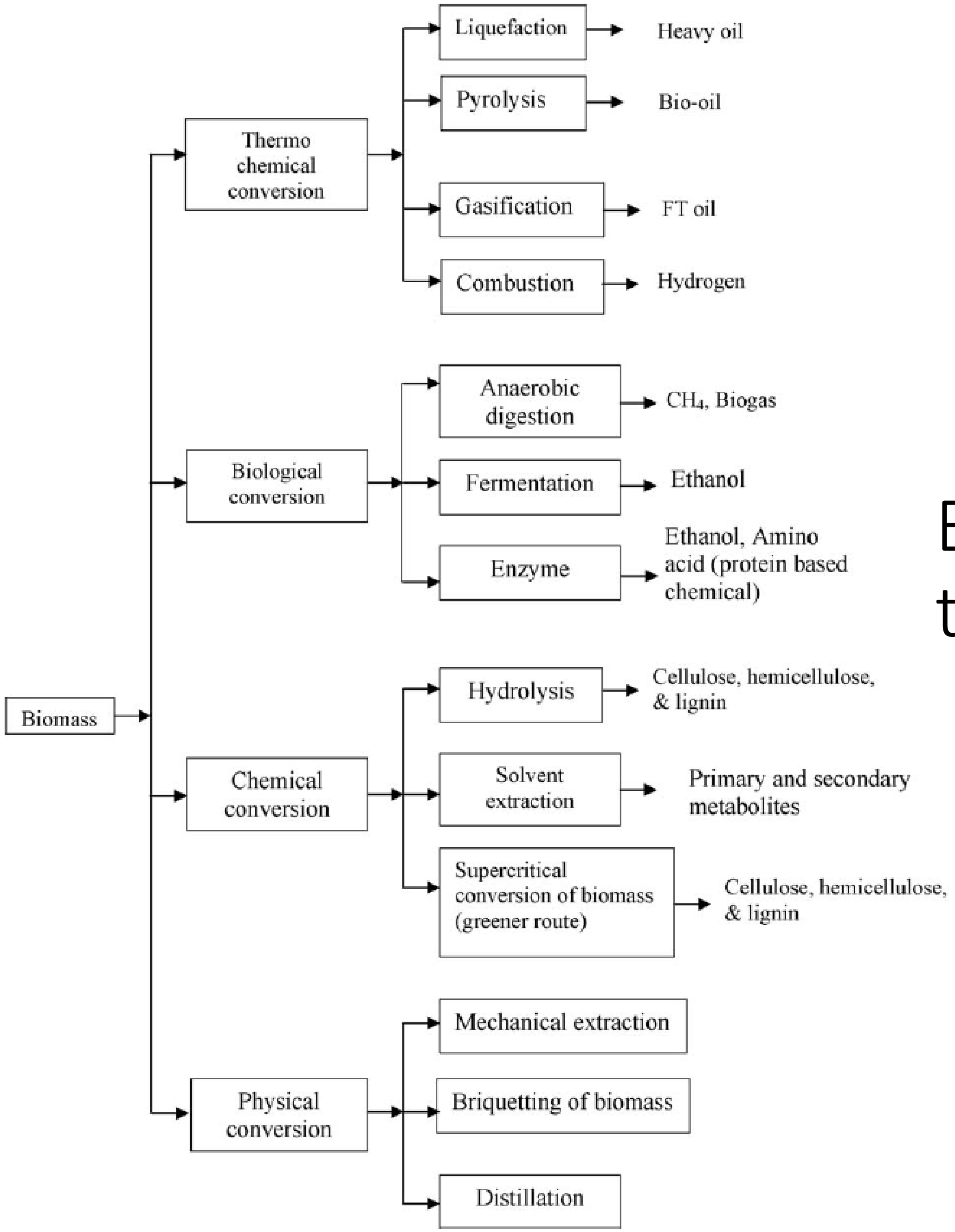
- Biodiesel is a substitute of diesel and is produced through transesterification of vegetable oils, and residual oils and fats, with minor engine modifications; it can serve as a full substitute as well

Bioethanol

- Bioethanol is a substitute of gasoline and it is a full substitute for gasoline in so called flexi-fuel vehicles. It is derived from sugar or starch through fermentation. Bioethanol can also serve as feedstock for ethyl tertiary butyl ether (ETBE) which blends more easily with gasoline

Biomethane

- biomethane, is a fuel that can be used in gasoline vehicles with slight adaptations. It can be produced through anaerobic digestion of liquid manure and other digestible feedstock



Biomass conversion technologies

Biofuel

- In the biofuel production, feedstock alone represents more than 75% of the overall bioethanol as well as biodiesel production cost.
- Selection of the best feedstock is very crucial to ensure low production cost that can give competitive edge to fossil fuel.
- First-generation biofuel that is currently being commercialized in different countries is primarily produced from grain crops as feedstock

Bioenergy Conversion Technologies

- There are four types of conversion technologies currently available, each appropriate for specific biomass types and resulting in specific energy products:
- 1. **Thermal conversion** is the use of heat, with or without the presence of oxygen, to convert biomass materials or feedstocks into other forms of energy. Thermal conversion technologies include direct combustion, pyrolysis, and torrefaction.
- 2. **Thermochemical conversion** is the application of heat and chemical processes in the production of energy products from biomass. A key thermochemical conversion process is gasification
- 3. **Biochemical conversion** involves use of enzymes, bacteria or other microorganisms to break down biomass into liquid fuels, and includes anaerobic digestion, and fermentation.
- 4. **Chemical conversion** involves use of chemical agents to convert biomass into liquid fuels

Thermal conversion

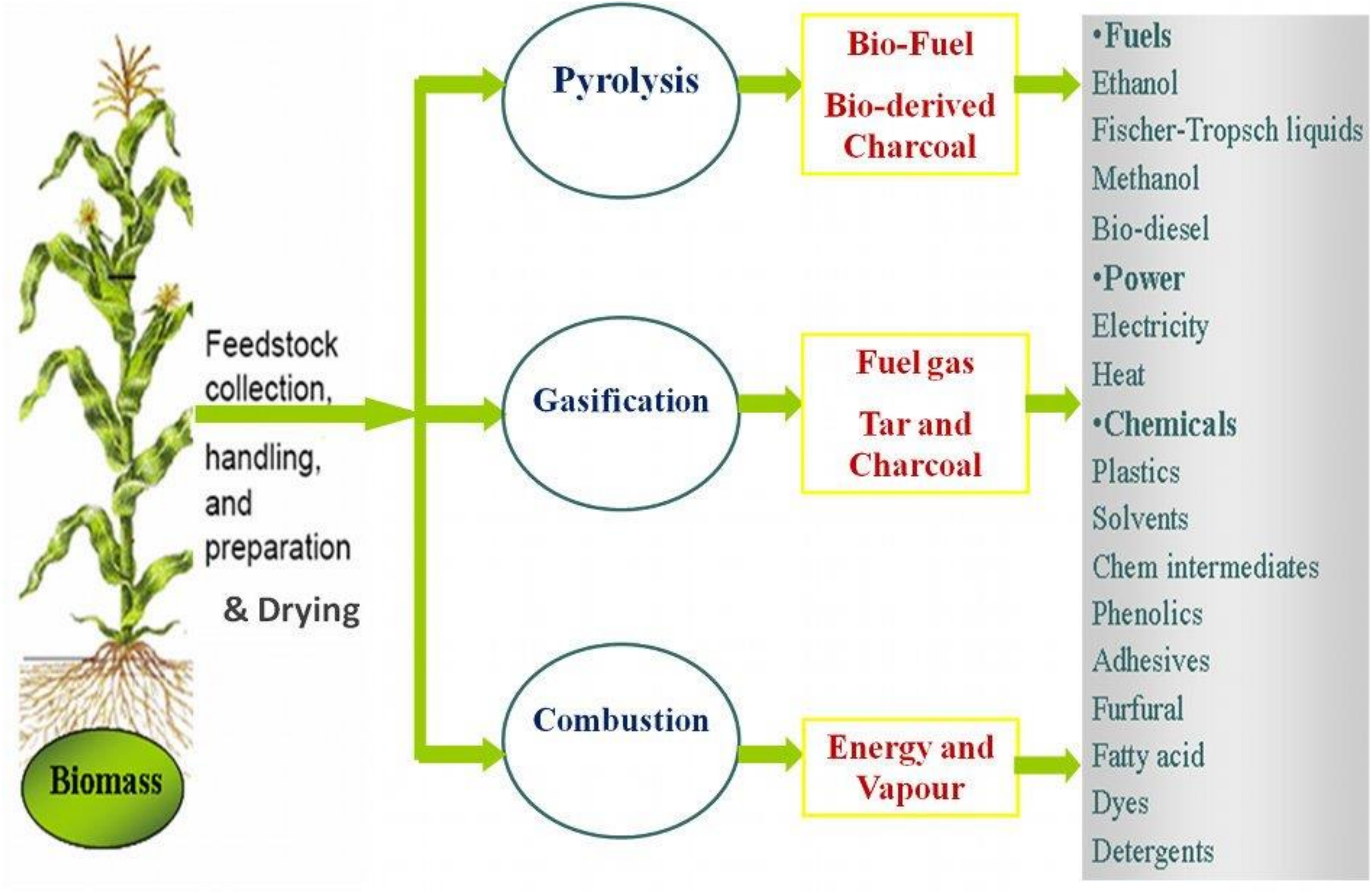
- It involves the use of heat as the primary mechanism for converting biomass into another form

➢Combustion

➢Pyrolysis

➢Torrefaction

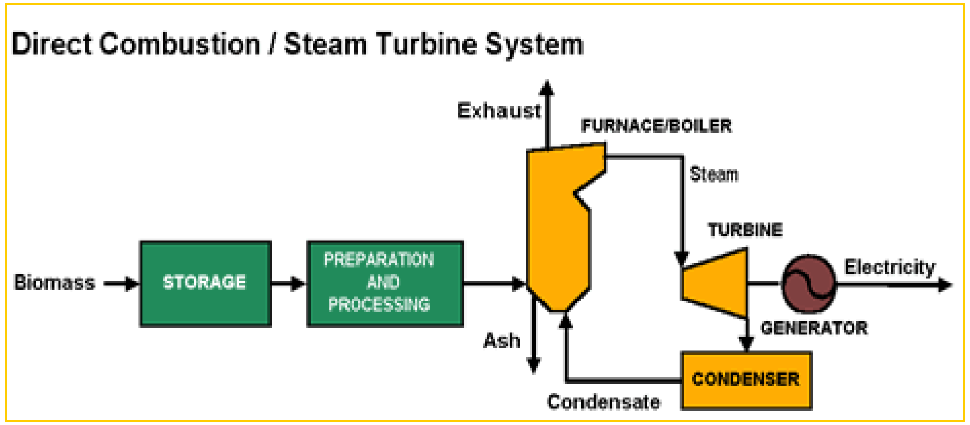
➢Gasification



Feedstock collection,
handling,
and
preparation
& Drying
Biomass
Pyrolysis
Gasification
Combustion
Bio-Fuel
Bio-derived Charcoal
Fuel gas
Tar and Charcoal
Energy and Vapour
•Fuels
Ethanol
Fischer-Tropsch liquids
Methanol
Bio-diesel
•Power
Electricity
Heat
•Chemicals
Plastics
Solvents
Chem intermediates
Phenolics
Adhesives
Furfural
Fatty acid
Dyes
Detergents

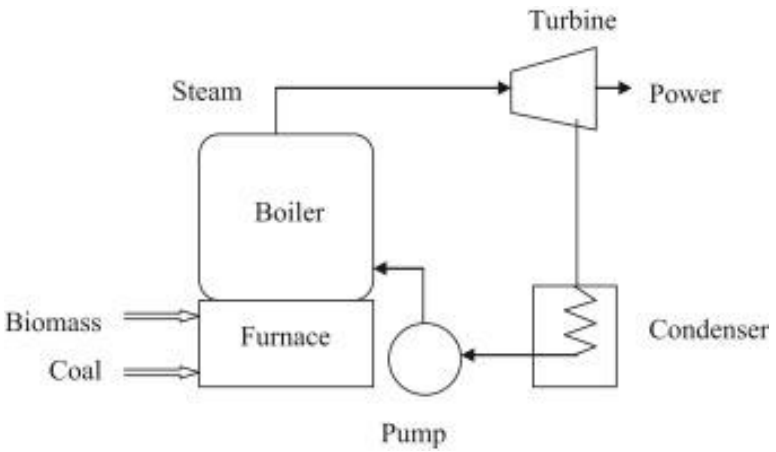
Combustion

- Direct combustion is the burning of biomass in the presence of oxygen.
- Furnaces and boilers are used typically to produce steam for use in district heating/cooling systems or to drive turbines to produce electricity.
- In a furnace, biomass burns in a combustion chamber converting the biomass into heat.
- The heat is distributed in the form of hot air or water. In a boiler, the heat of combustion is converted into steam.
- Steam can be used to produce electricity, mechanical energy, or heating and cooling.
- A boiler's steam contains 60-85% of the energy in biomass fuel.



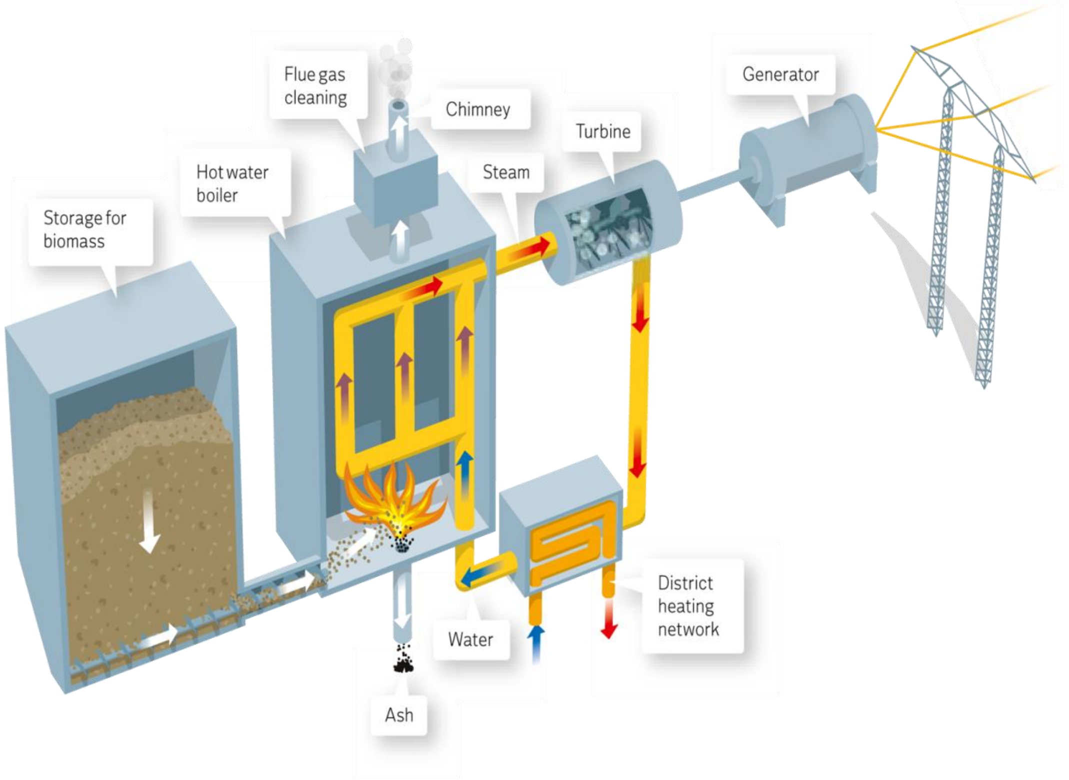
Co-firing

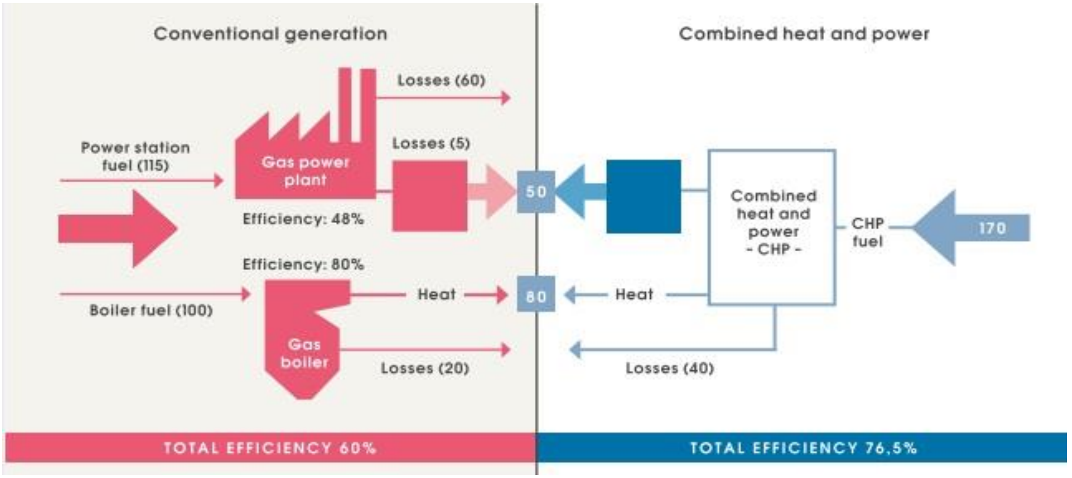
- Co-firing is a practice which has permitted biomass feedstocks to be used early on in the renewable energy transformation.
- Co-firing is the combustion of a fossil-fuel (such as coal or natural gas) with a biomass feedstock.
- Co-firing has a number of advantages, particularly when electricity is an output. If the conversion facility is situated near an agro-industrial or forestry product processing plant, large quantities of low cost biomass residues are available to be burnt with a fossil-fuel feedstock.
- It is now widely accepted that fossil-fuel power plants are usually highly polluting in terms of sulfur, CO_2 and other GHGs.
- Use of existing equipment, with modifications, to co-fire biomass may be a cost-effective means for meeting more stringent emissions targets.
- Biomass fuel's comparatively low sulfur content allows biomass to potentially offset the higher sulfur content of fossil fuel



Co-generation

- Biomass can also be used in co-generation, also called combined heat and power (CHP) which is the simultaneous production of heat and electricity.
- All power plants produce heat as a by-product of electricity production, and this heat is typically released to the environment through cooling towers (which release heat to the atmosphere) or discharge into near-by bodies of water.
- However, in CHP processes, some of the "waste heat" is recovered for use in district heating.
- Co-generation coverts about 85% of biomass' potential energy into useful energy.





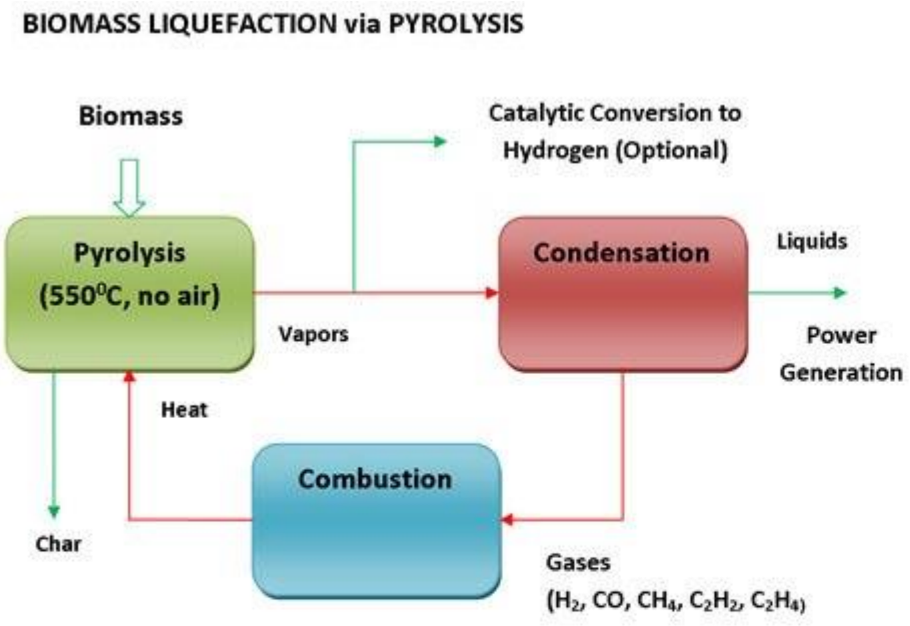
Pyrolysis and torrefaction

- These processes do not necessarily produce useful energy directly, but under controlled temperature and oxygen conditions are used to convert biomass feedstocks into gas, oil or forms of charcoal.

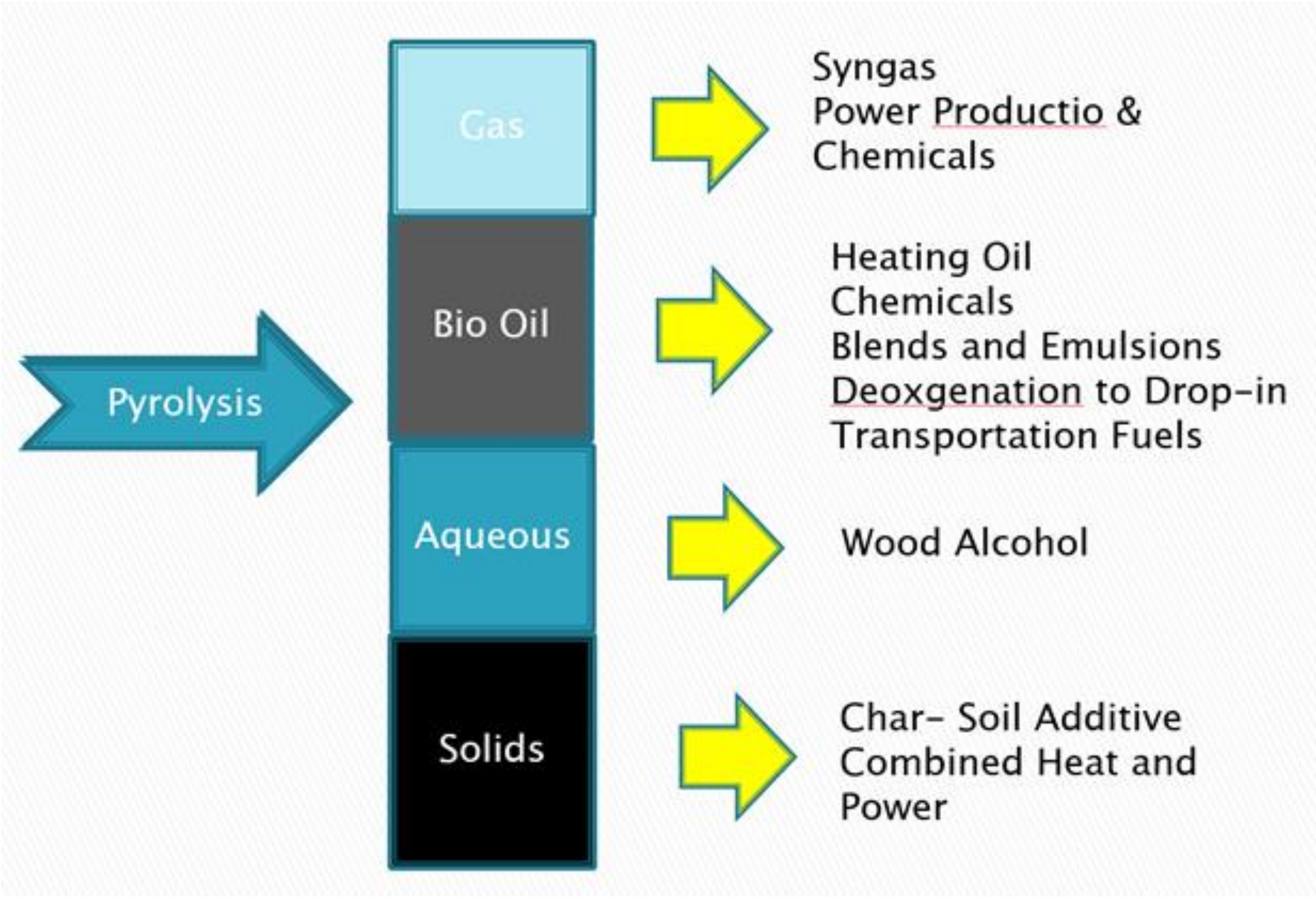
- These energy products are more energy dense than the original biomass, and therefore reduce transport costs, or have more predictable and convenient combustion characteristics allowing them to be used in internal combustion engines and gas turbines.

Pyrolysis

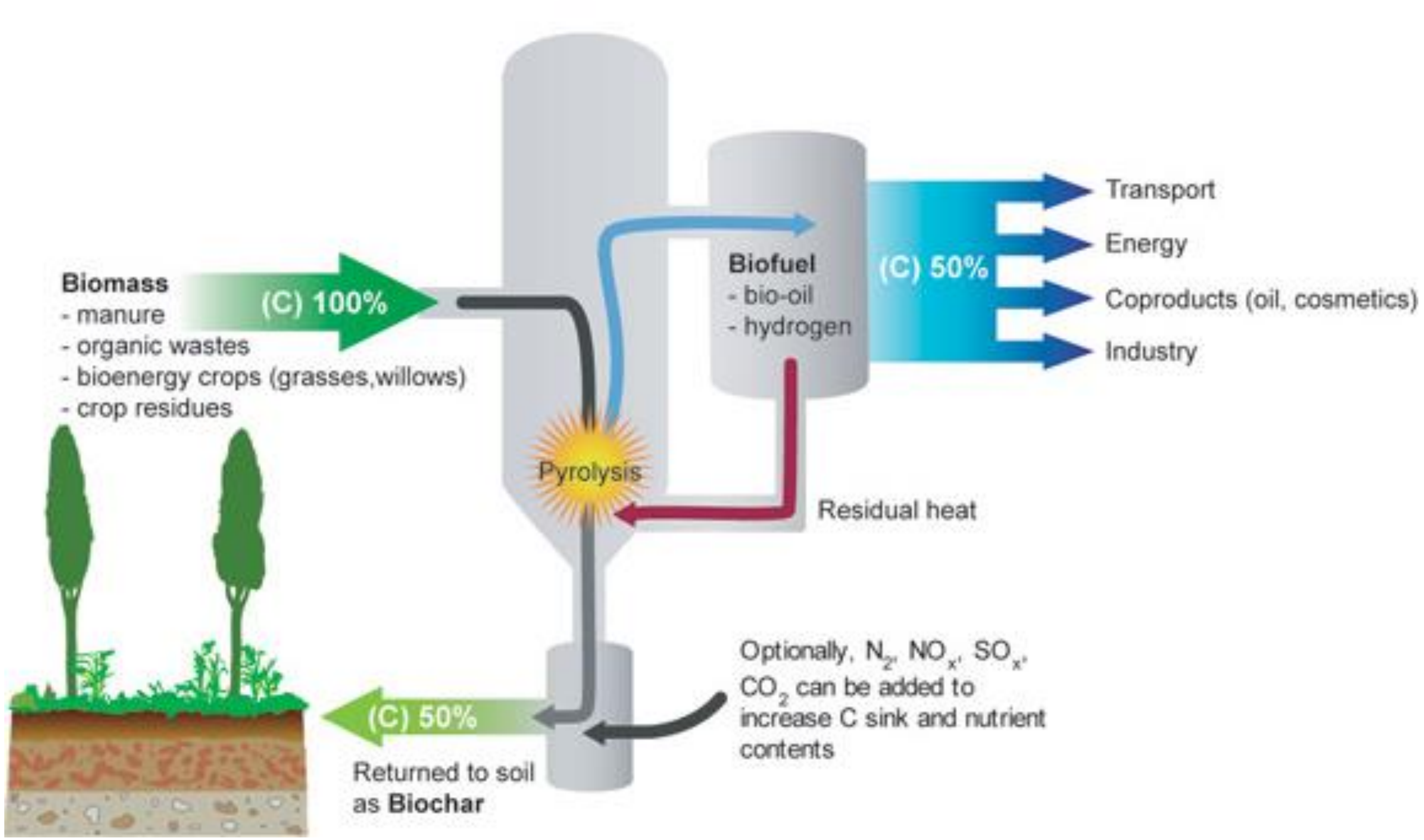
- Pyrolysis is a processes of subjecting a biomass feedstock to high temperatures (greater than 430 °C) under pressurized environments and at low oxygen levels
- In the process, biomass undergoes partial combustion. Processes of pyrolysis result in liquid fuels and a solid residue called char, or biochar
- Biochar is like charcoal and rich in carbon. Liquid phase products result from temperatures which are too low to destroy all of the carbon molecules in the biomass so the result is production of tars, oils, methanol, acetone, etc.



Products of pyrolysis



Biochar Bioenergy cycle



Torrefaction

- Torrefaction, like pyrolysis, is the conversion of biomass with the application of heat in the absence of oxygen, but at lower temperatures than those typically used in pyrolysis
- Temperatures typically range between 200-320 °C
- During the process, water is removed and cellulose, hemicellulose and lignins are partially decomposed
- The final product is an energy dense solid fuel frequently referred to as “bio-coal”

Thermochemical conversion

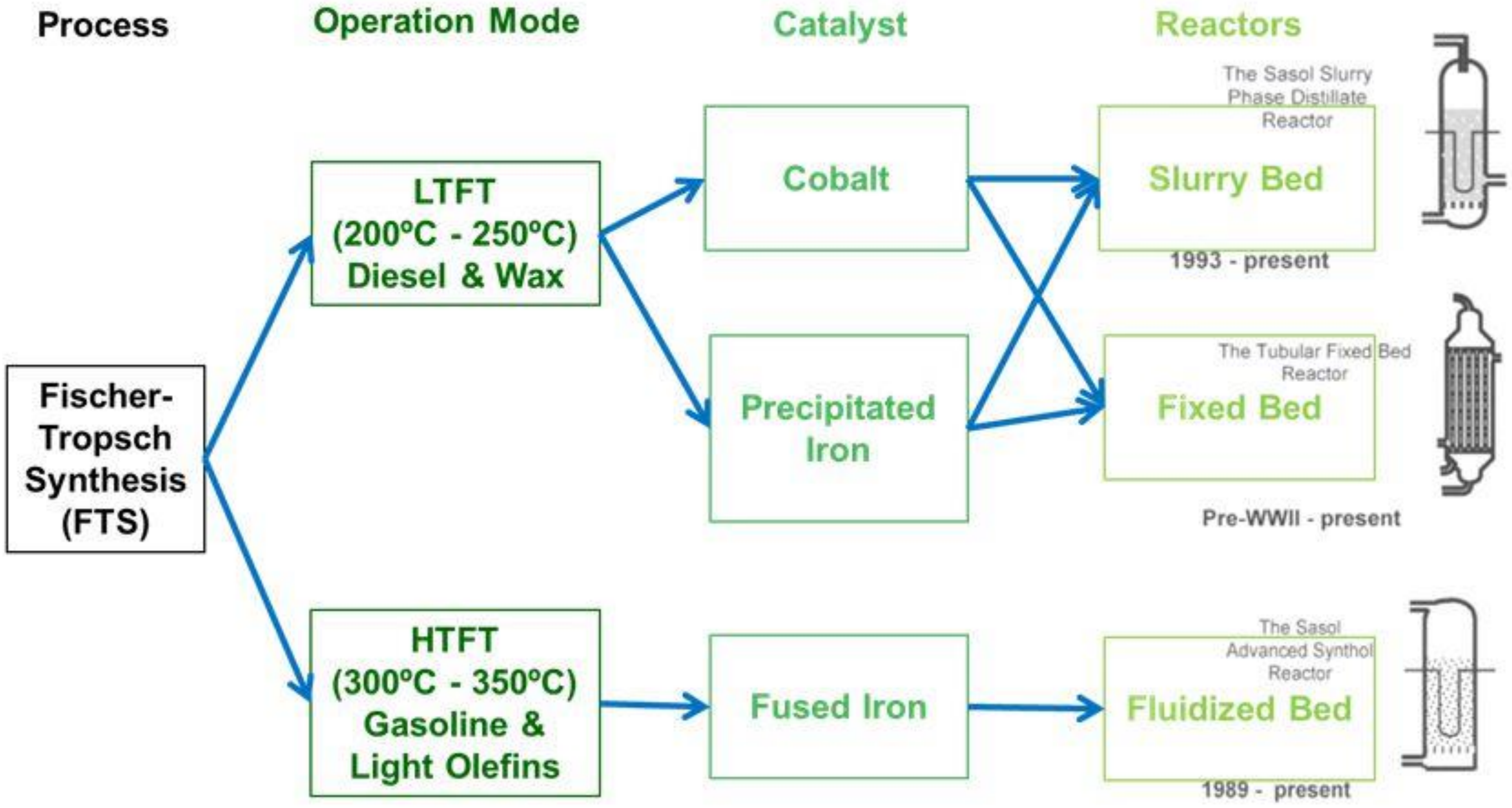
- Thermochemical technologies are used for converting biomass into fuel gases and chemicals. The thermochemical process involves multiple stages

1. The first stage involves converting solid biomass into gases.
2. In the second stage the gases are condensed into oils.
3. In the third and final stage the oils are conditioned and synthesized to produce syngas.

- Syngas contains carbon and hydrogen and can be used to produce ammonia, lubricants, and through the Fischer-Tropsch (FT) process can be used to produce biodiesel.

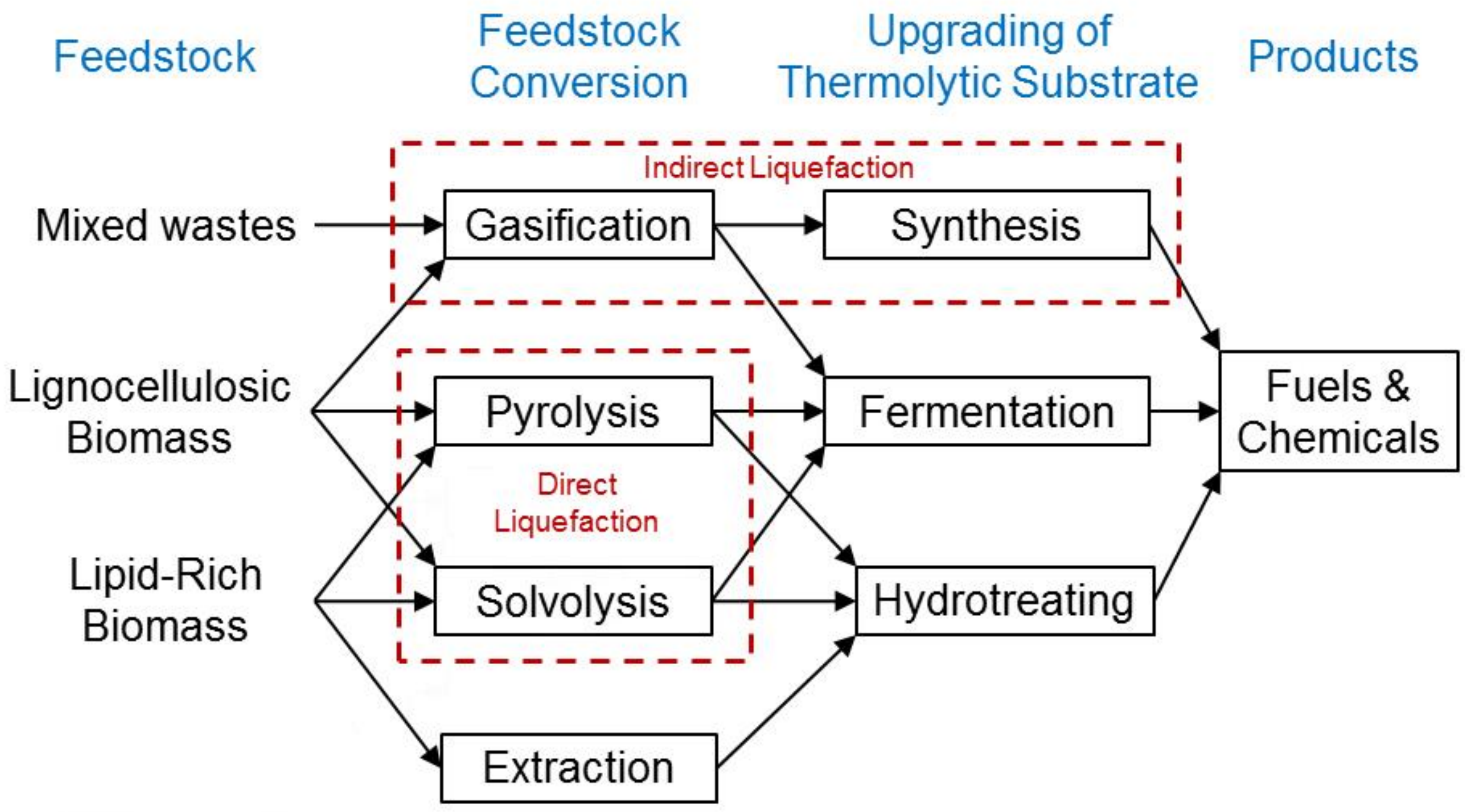
Fischer Tropsch Synthesis

$$CO + 2H_2 \rightarrow (CH_2) + H_2O$$



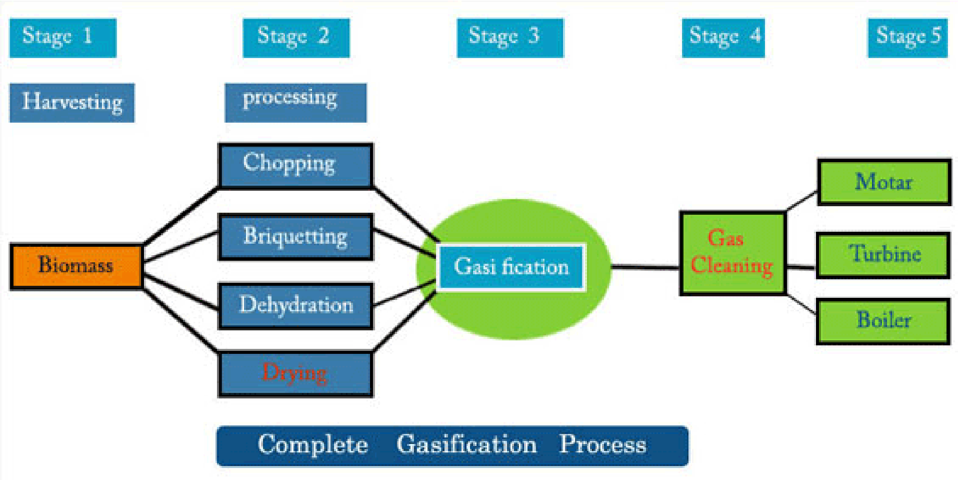
Fuels from FT process

Thermochemical processing options

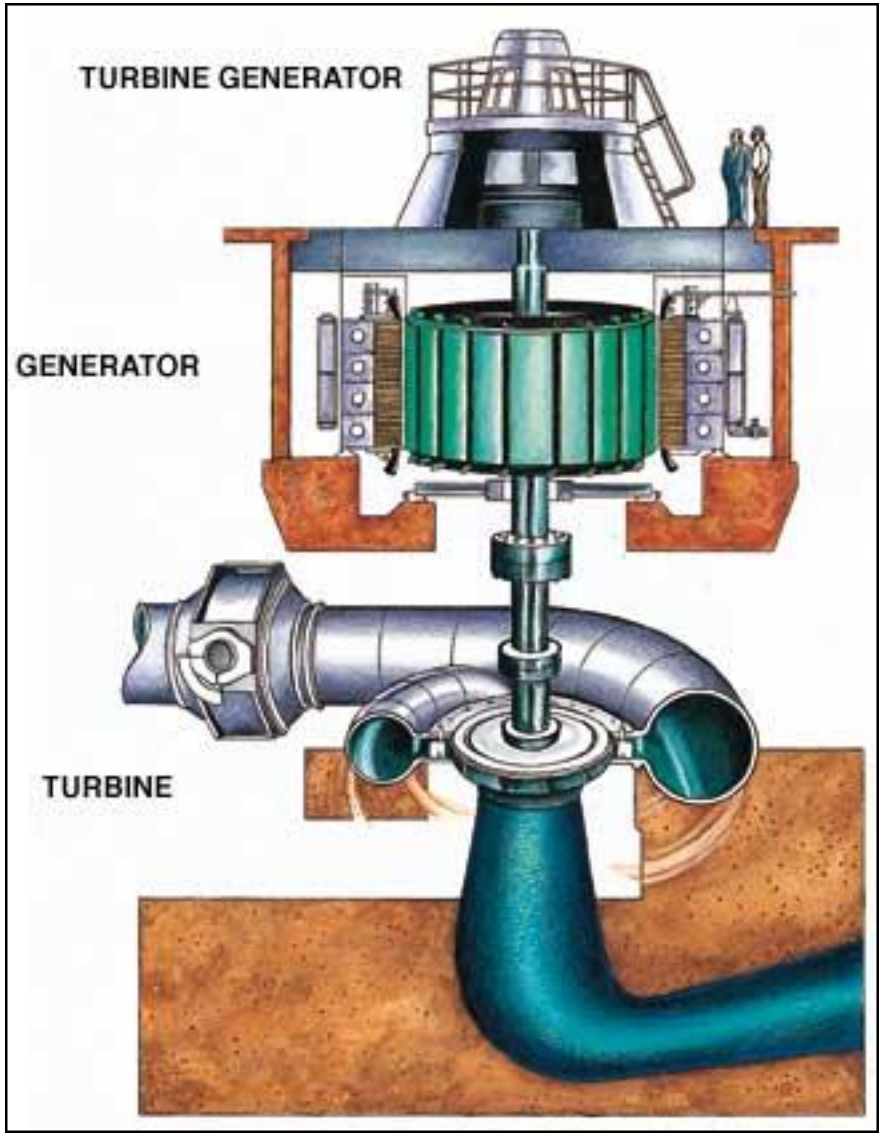


Gasification

- Gasification is the use of high temperatures and a controlled environment that leads to nearly all of the biomass being converted into gas.
- This takes place in two stages: partial combustion to form producer gas and charcoal, followed by chemical reduction.
- These stages are spatially separated in the gasifier, with gasifier design very much dependant on the feedstock characteristics.
- Gasification requires temperatures of about 800°C.
- Gasification technology has existed since the turn of the century when coal was extensively gasified in the UK and elsewhere for use in power generation and in houses for cooking and lighting.
- A major future role is envisaged for electricity production from biomass plantations and agricultural residues using large scale gasifiers with direct coupling to gas turbines.



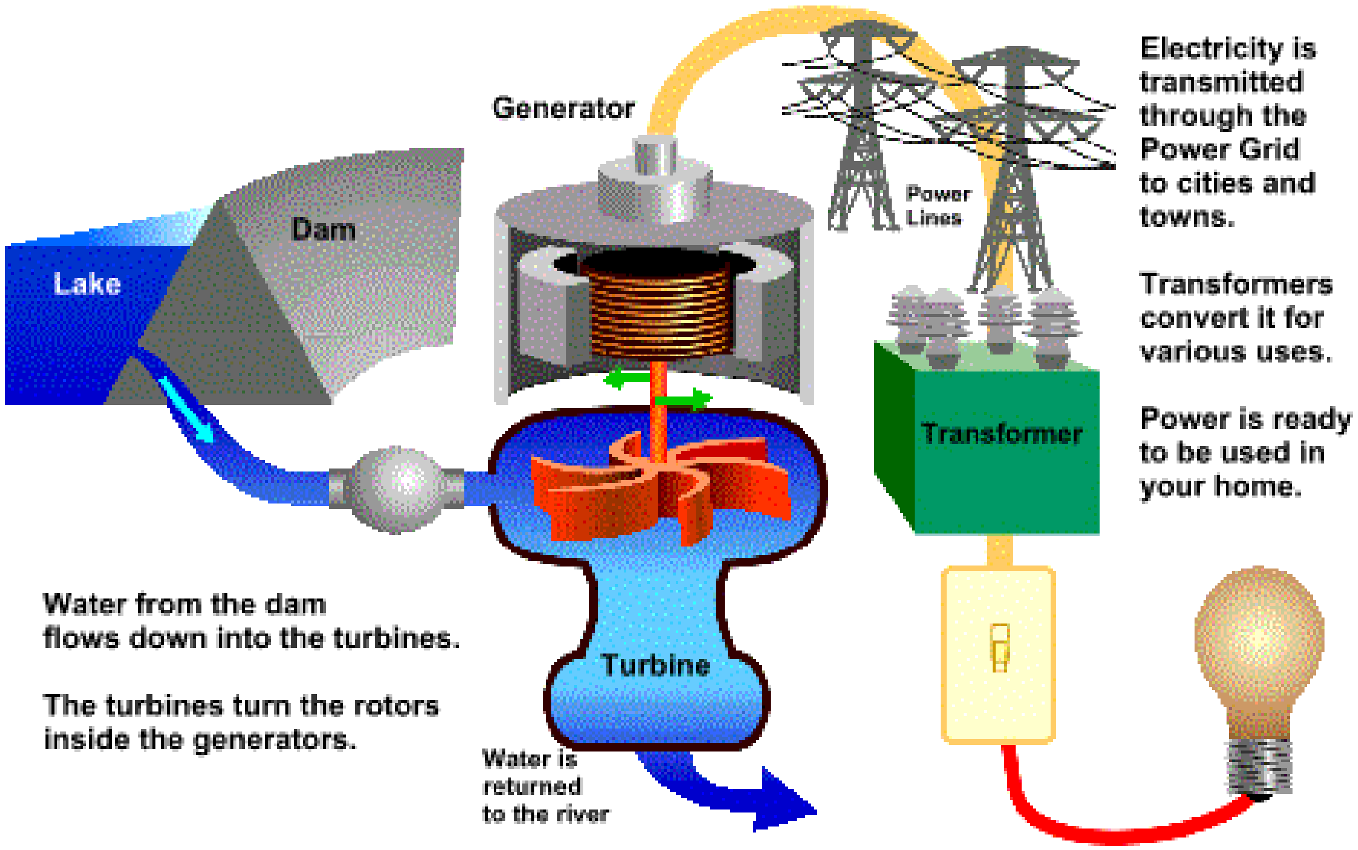
Hydroelectric Power

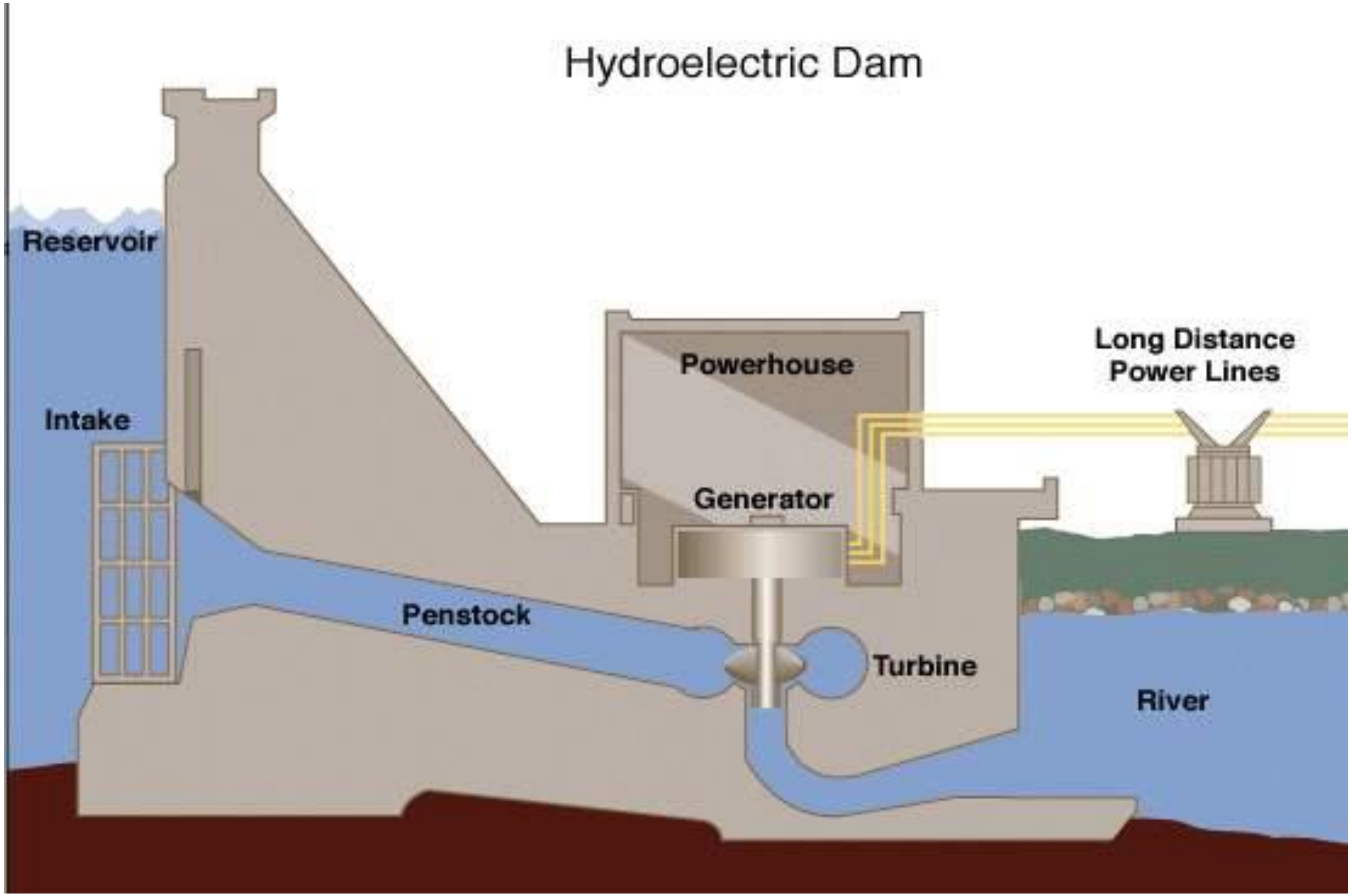


Flowing water is directed at a turbine (remember turbines are just advanced waterwheels). The flowing water causes the turbine to rotate, converting the water’s kinetic energy into mechanical energy.

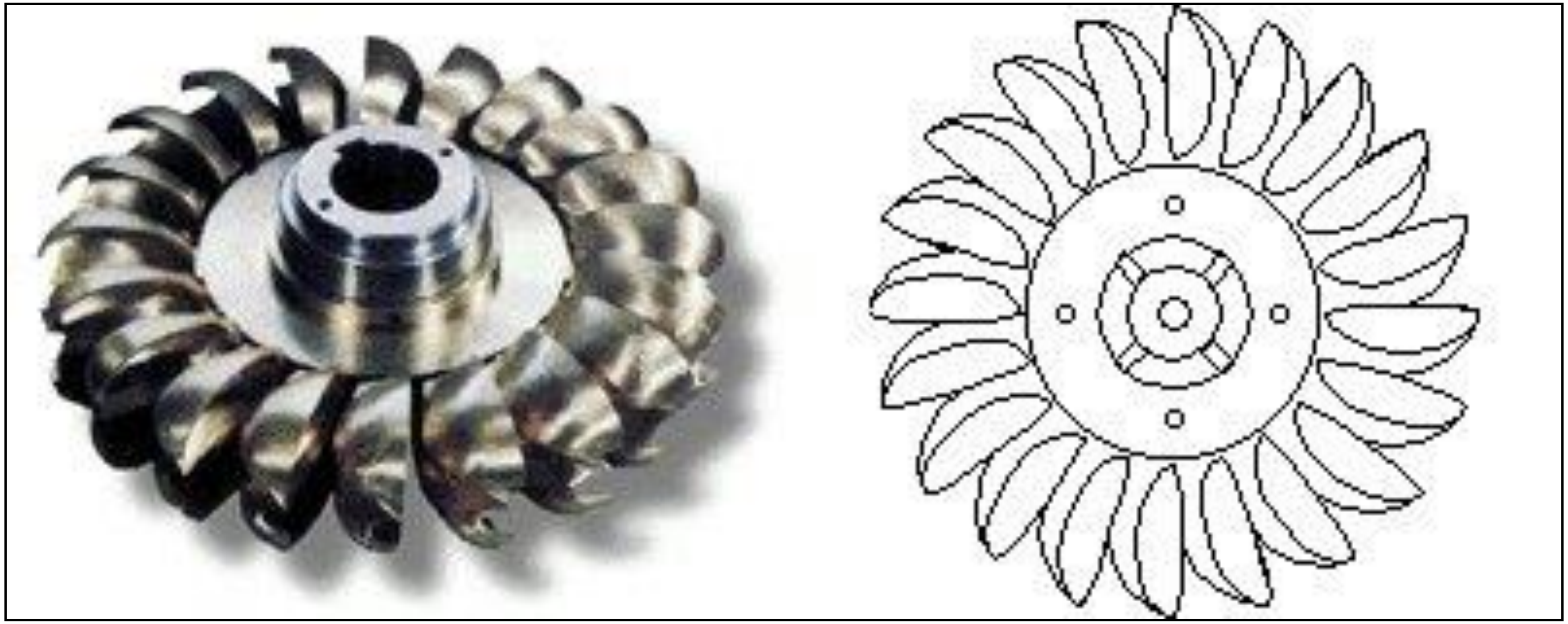
How a Hydroelectric Power System Works

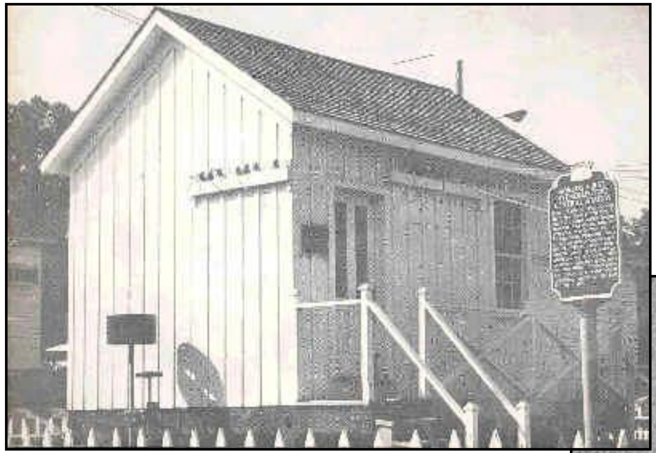
The mechanical energy produced by the turbine is converted into **electric energy** using a turbine generator. Inside the generator, the shaft of the turbine spins a magnet inside coils of copper wire. It is a fact of nature that moving a magnet near a conductor causes an electric current.

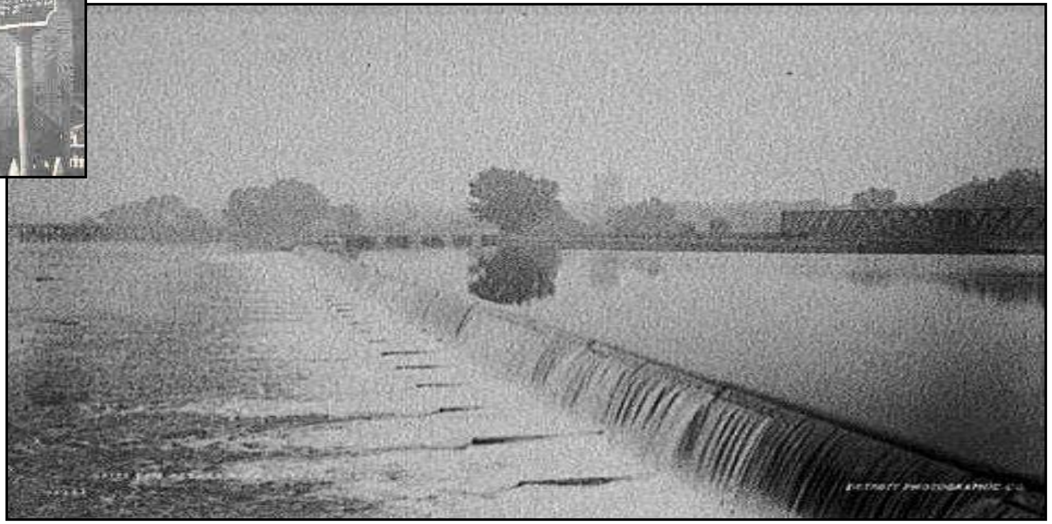



Hydroelectric Dam
Reservoir
Intake
Powerhouse
Long Distance
Power Lines
Generator
Penstock
Turbine
River

Waterwheel technology advanced over time. **Turbines** are advanced, very efficient waterwheels. They are often enclosed to further capture water’s energy.







Not long after the discovery of electricity, it was realized that a turbine's mechanical energy could be used to activate a generator and produce electricity. The **first hydroelectric power plant was constructed in 1882** in Appleton, Wisconsin. It **produced 12.5 kilowatts of electricity which was used to light two paper mills and one home.**

How much electricity can be generated by a hydroelectric power plant?

The amount of electricity that can be generated by a hydropower plant depends on two factors:

- **flow rate** - the quantity of water flowing in a given time; and
- **head** - the height from which the water falls.

The greater the flow and head, the more electricity produced.

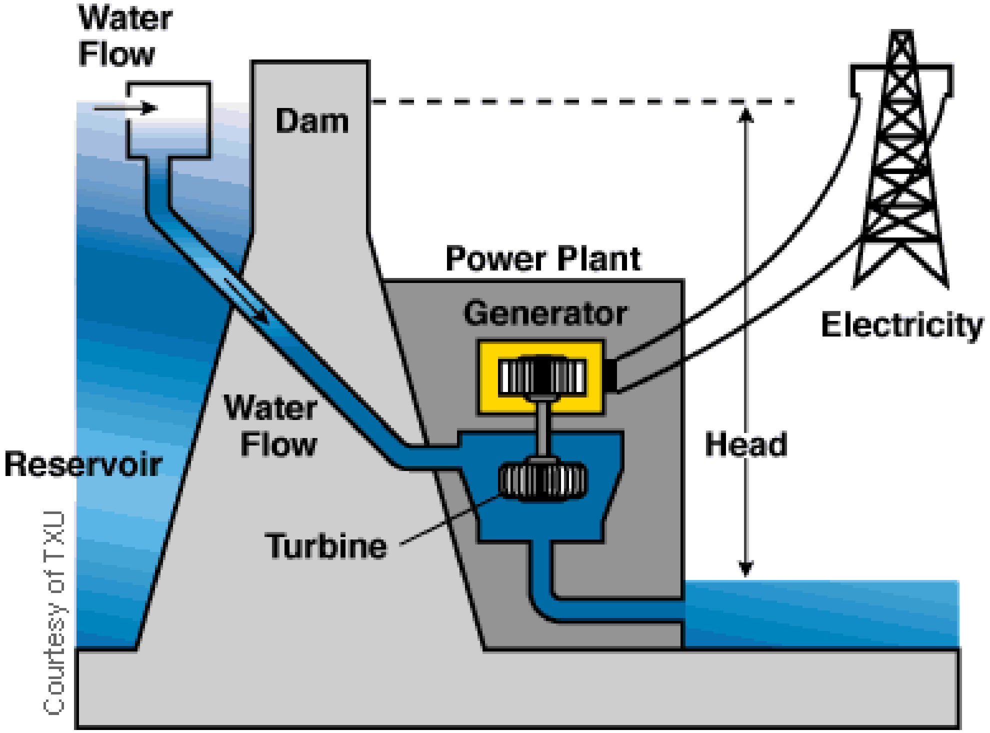
Flow Rate = the quantity of water flowing

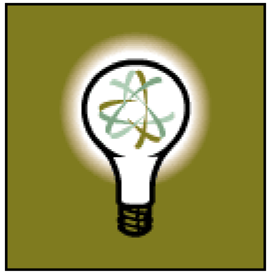
When more water flows through a turbine, more electricity can be produced. The flow rate depends on the size of the river and the amount of water flowing in it. Power production is considered to be **directly proportional** to river flow. That is, twice as much water flowing will produce twice as much electricity.

Head = the height from which water falls

The farther the water falls, the more power it has. The higher the dam, the farther the water falls, producing more hydroelectric power.

Power production is also **directly proportional** to head. That is, water falling twice as far will produce twice as much electricity.





A standard equation for calculating energy production:

$$\text{Power} = \frac{(\text{Head}) \times (\text{Flow}) \times (\text{Efficiency})}{11.8}$$

Power = the electric power in kilowatts or kW

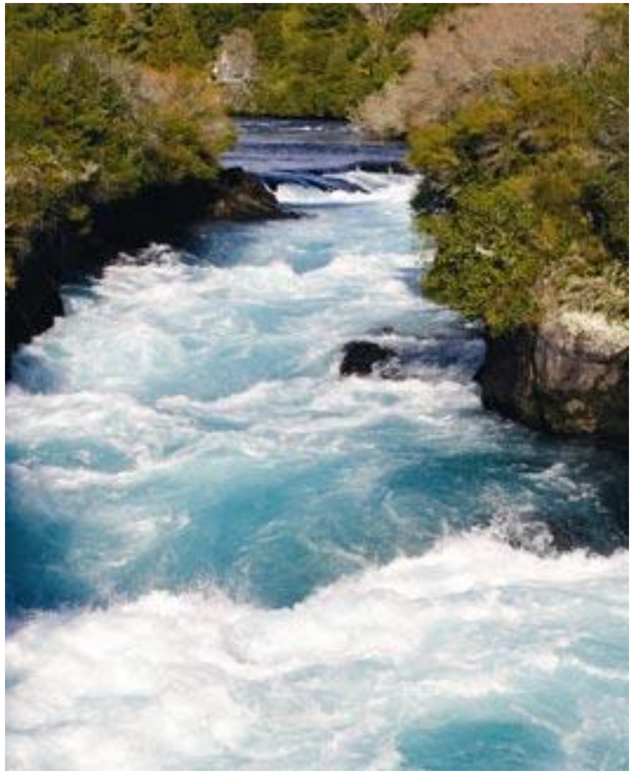
Head = the distance the water falls (measured in feet)

Flow = the amount of water flowing (measured in cubic feet per second or **cfs**)

Efficiency = How well the turbine and generator convert the power of falling water into electric power. This can range from 60% (0.60) for older, poorly maintained hydroplants to 90% (0.90) for newer, well maintained plants.

11.8 = Index that converts units of feet and seconds into kilowatts

Advantages



- Renewable Energy
- Clean Energy Source
- Domestic Energy Source
- Generally Available As Needed
- Provides Recreational Opportunities
- Water Supply and Flood Control

Energy from coal

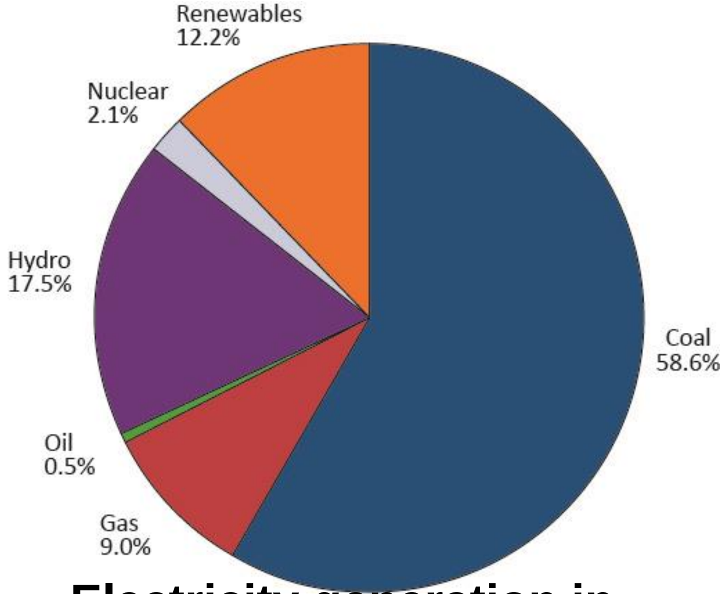
- ❖Coal is a fossil fuel formed from plants that were buried millions of years ago. The high-temperature, high-pressure conditions underground transformed the plants physically and chemically, forming coal.

- ❖Carbon is the main component of coal, which also contains varying amounts of other components, like hydrogen, oxygen, sulphur and other impurities.

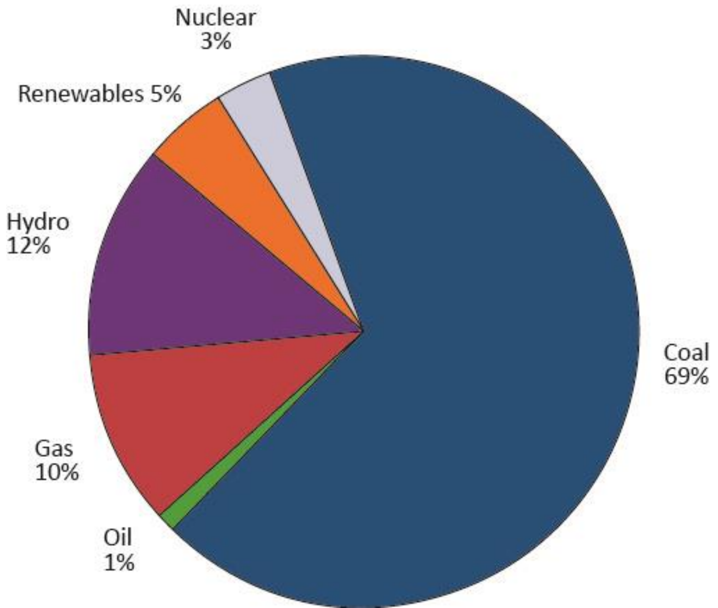
- ❖Main parameters used to define coal are calorific value, ash, moisture and sulphur.

- ❖Many different classifications of coal are used around the world, reflecting a broad range of ages, composition and properties.

Indian Installed power generation capacity



Electricity generation in India (2011-2015)



Coal mine site

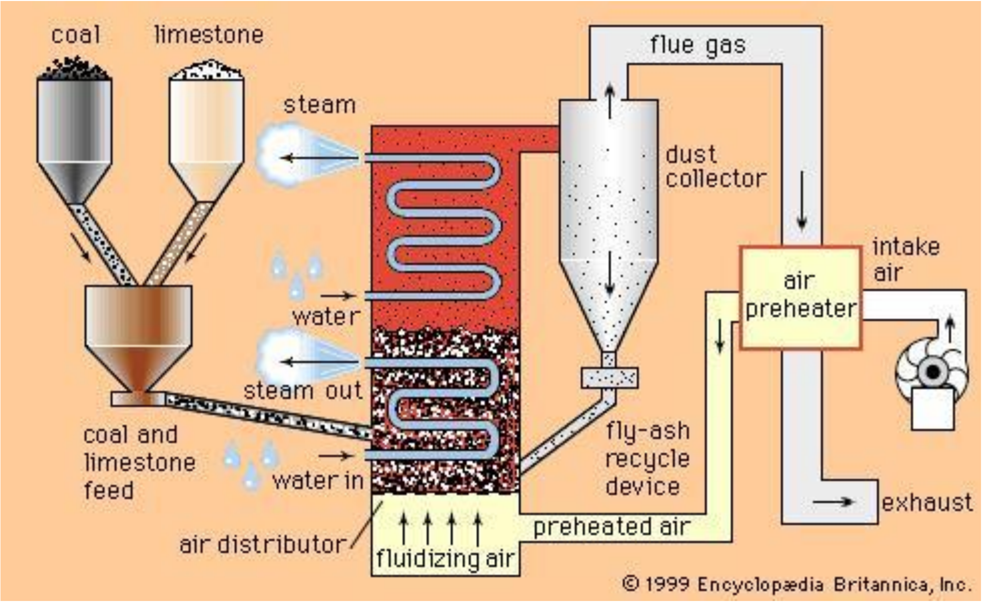
- Coal, the second source of primary energy (roughly 30%), is mostly used for power generation (over 40% of worldwide electricity is produced from coal).
- In addition, coal is used to produce virtually all non-recycled iron. Coal is abundant, affordable, easy to transport, store and use, plus free of geopolitical tensions; all these attributes made it very popular.
- On the other hand, pulverized coal plants are the most carbon-intensive source of power generation, and this is a real issue, as CO_2 emissions need to be dramatically and urgently reduced.
- Whereas more efficient plants are built across the world, the transition from subcritical to supercritical (and ultra-supercritical) technology is very slow.
- And even worse news is that the dramatic reduction of CO_2 emissions that our climate targets require is possible only through development of carbon capture and storage (CCS) technologies.

❖ Conversion of coal into energy

❖ The process of converting coal into electricity has multiple steps and is similar to the process used to convert oil and natural gas into electricity:

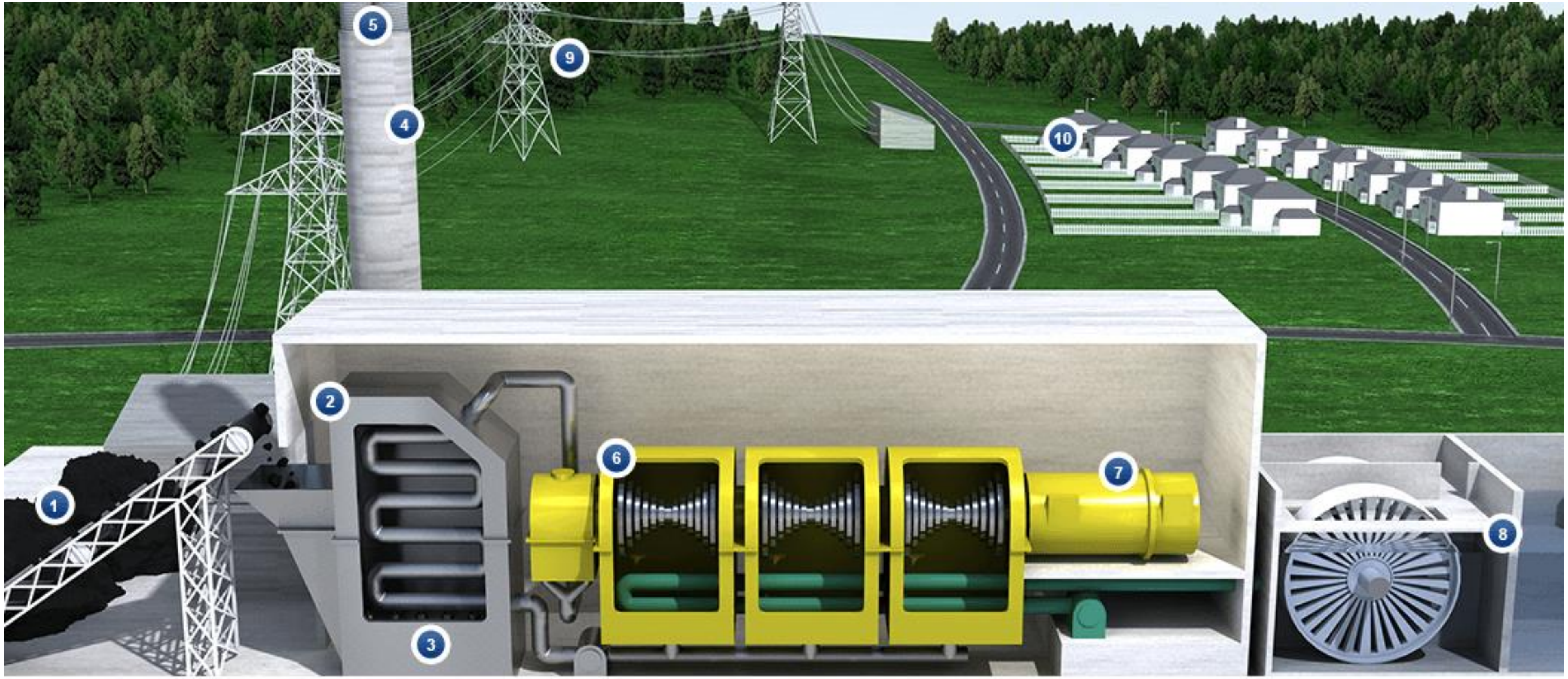
- A machine called a pulverizer grinds the coal into a fine powder.
- The coal powder mixes with hot air, which helps the coal burn more efficiently, and the mixture moves to the furnace.
- The burning coal heats water in a boiler, creating steam.
- Steam released from the boiler powers an engine called a turbine, transforming heat energy from burning coal into mechanical energy that spins the turbine engine.
- The spinning turbine is used to power a generator, a machine that turns mechanical energy into electric energy. This happens when magnets inside a copper coil in the generator spin.
- A condenser cools the steam moving through the turbine. As the steam is condensed, it turns back into water.
- The water returns to the boiler, and the cycle begins again.

- Other new processes of using coal to make electricity include the following:
- *Fluidized bed combustion* (FBC), in which coal is inserted into a bed of particles suspended in air that react with the coal to heat the boiler and make steam
- *Combined-cycle systems*, in which (1) gas produced by heating coal operates a combustion turbine connected to a generator and (2) the exhaust gases from this turbine heat water, which in turn operates a steam-powered generator



Fluidized bed combustion

Combined-cycle systems



1. Coal supply
2. Boiler
3. Ash systems
4. Exhaust stack
5. Exhaust plume
6. Steam turbine
7. Turbine generator
8. Water supply
9. Electricity transmission (power lines)
10. Consumer homes and businesses

Classification of biofuels

- Biofuels
  - Liquid
    - Bioethanol
    - Biodiesel
    - Biobutanol
    - Bioalkanes and alkenes
  - Gaseous
    - Biomethane
    - Biohydrogen
    - Biohythane

Concept of ‘C’ neutral fuels

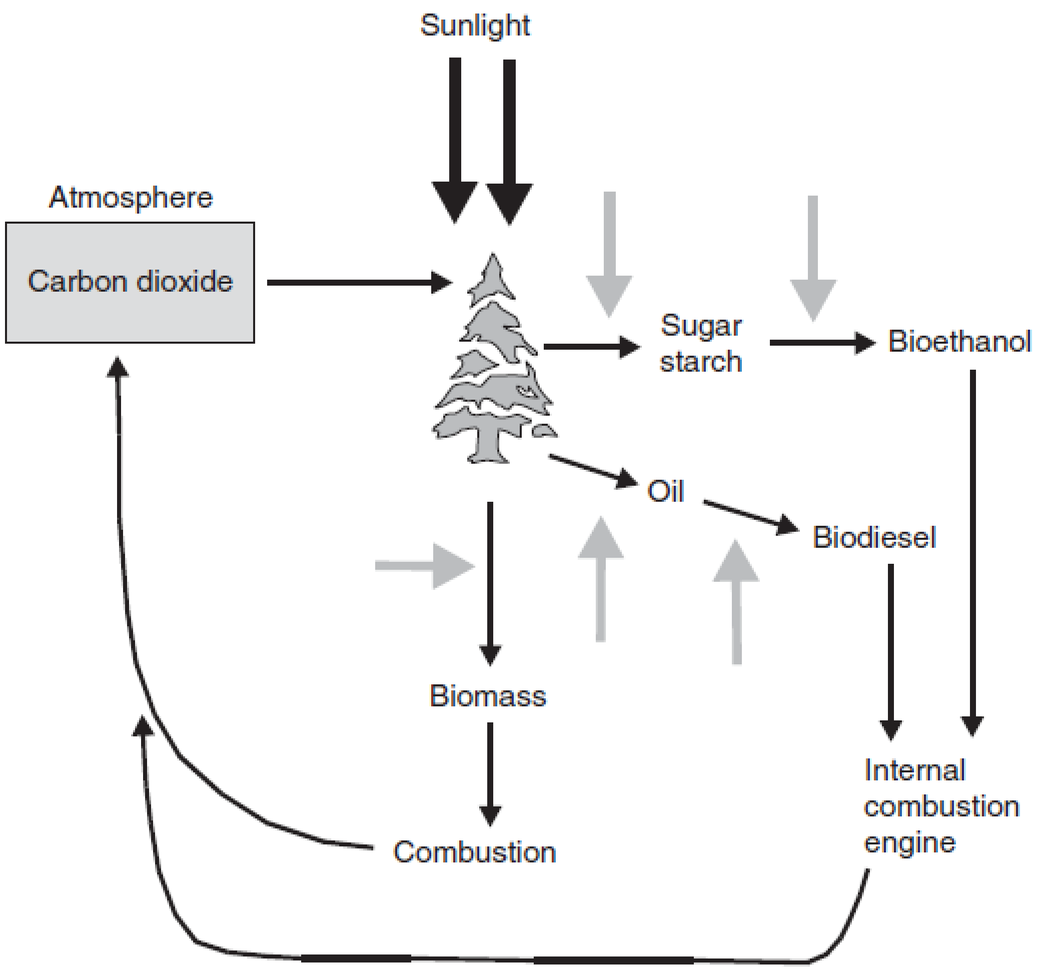
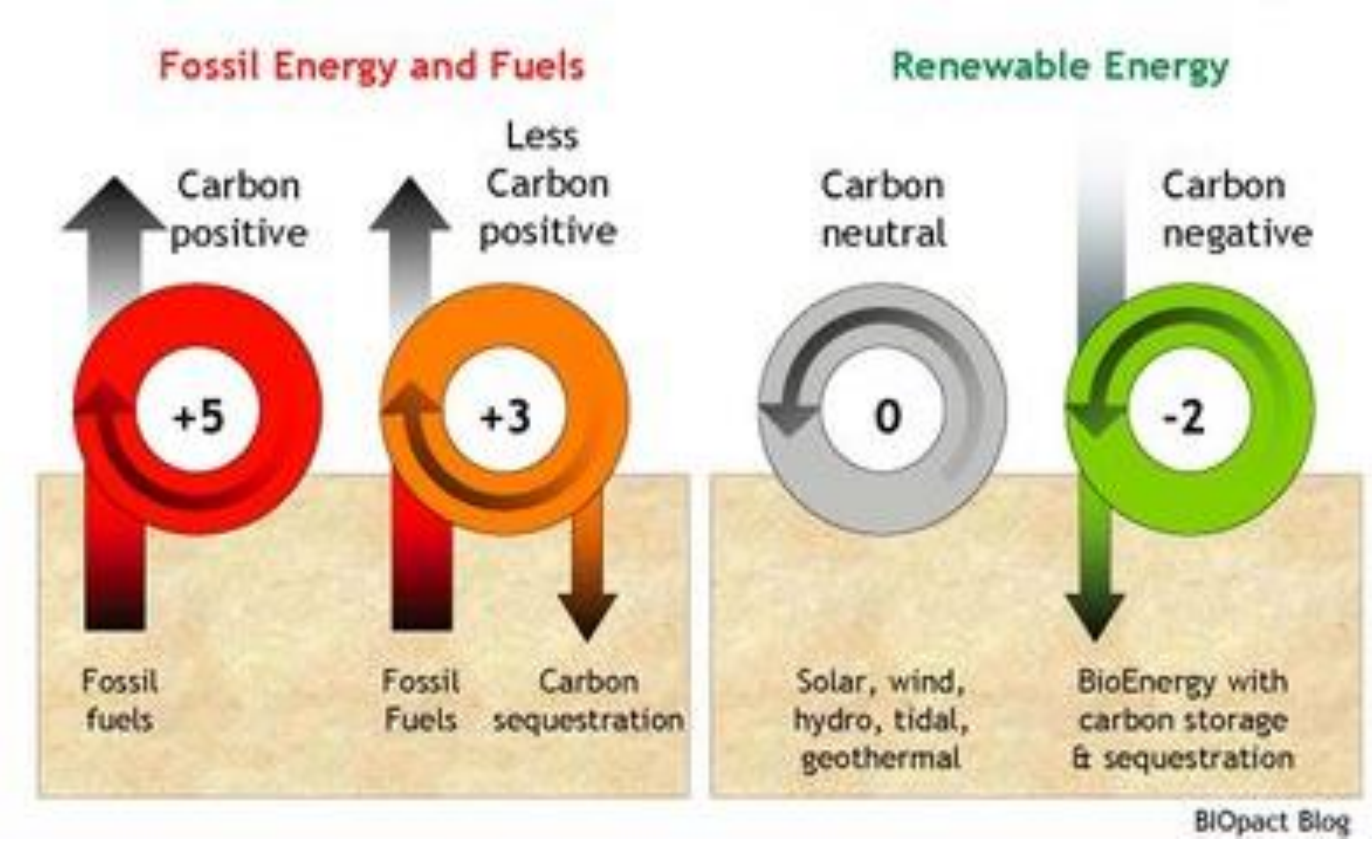


Fig. 1.15. Concept of carbon-neutral fuels, where carbon dioxide released on combustion has been previously fixed in photosynthesis. However, the arrows indicate that energy, probably from fossil fuels, has been expended in harvesting, extraction and processing of these fuels. This will reduce the amounts of carbon dioxide saved.

Comparison of carbon footprint



Biothanol production

- **Bioethanol is the most widely used liquid biofuel.**
- Currently, the **worldwide production of bioethanol reached 41 billions litres.**
- The **largest producers in the world** are **Brazil (37%), the US (33%), and Asia (14%).**
- **Production of bioethanol from sugarcane in Brazil** reached **16.4 billion liters**, accounting for nearly 18% of the country's automotive fuel needs.
- In Brazil, **ethanol-powered and flexible-fuel vehicles are manufactured for operation with hydrated ethanol**, an azeotrope of ethanol (**around 93% v/v) and water (7%).**
- **Brazil has achieved complete self-sufficiency in oil.**
- Recently, US surpassed Brazil as the world's largest producer of bioethanol (18 billion litres compared to 16 billion litre, respectively)

Uses and properties of ethanol:

- Ethanol is commonly **used as an oxygenated fuel additive** to reduce emissions of CO, NOx and hydrocarbons.
- Numerous common ethanolic motor-fuel formulations are being used with increasing frequency

Common ethanolic motor formulations

Fuel[a]	Ethanol content (% v/v)
Hydrous ethanol (Alcohol)(Brazil)	95.5
E85 (North America)	85
Gasoline (Brazil)	24
E10 (gasohol)(North America)	10
Oxygenated fuel (USA)	7.6
Reformulated gasoline (USA)	5.7
Biodiesel' (Sweden)	15

[a]Hydrous ethanol contains 4.5 % (v/v) water. The other formulations contain hydrocarbons and a trace of water

- Ethanol has a higher octane rating than petroleum fuels enabling combustion engines to run at higher compression ratios and thus give superior net performance.

- In addition, ethanol exhibits higher vapour pressure and heat of vaporization than gasoline and therefore increased power outputs are observed while using ethanol

Background: 'Generations' of Biofuel

Third generation : **Algal based and GE applied technologies**

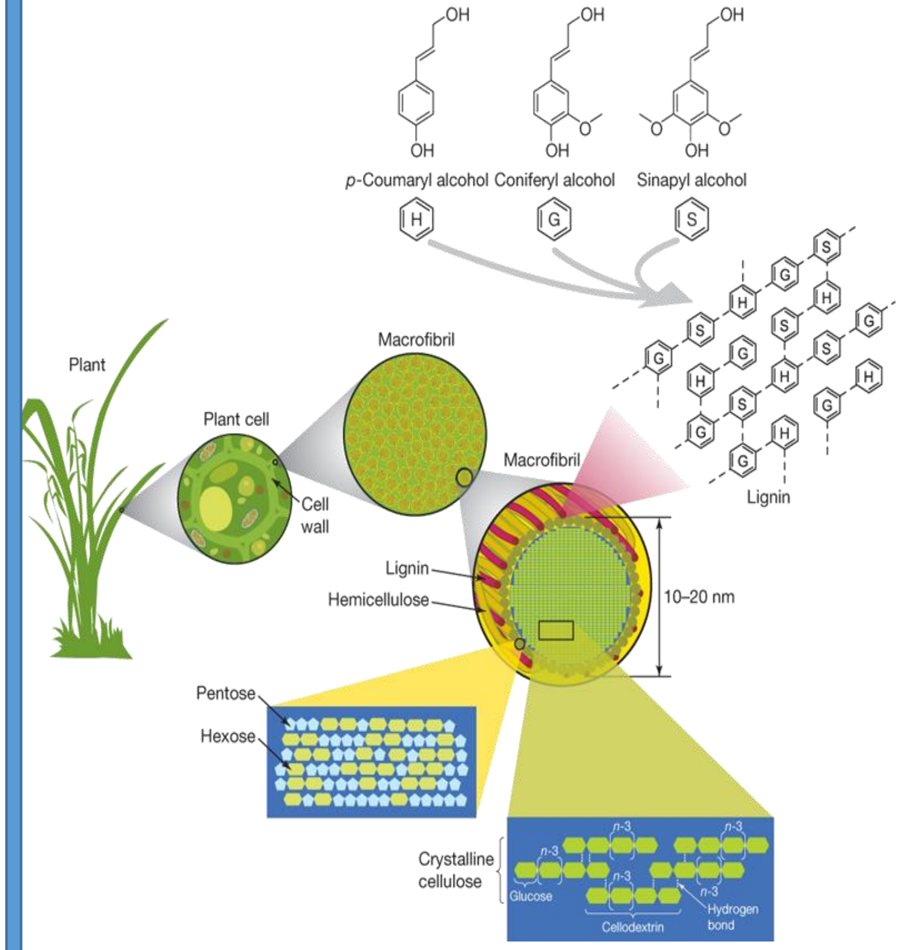
Second generation : **Non-edible lignocellulosics**

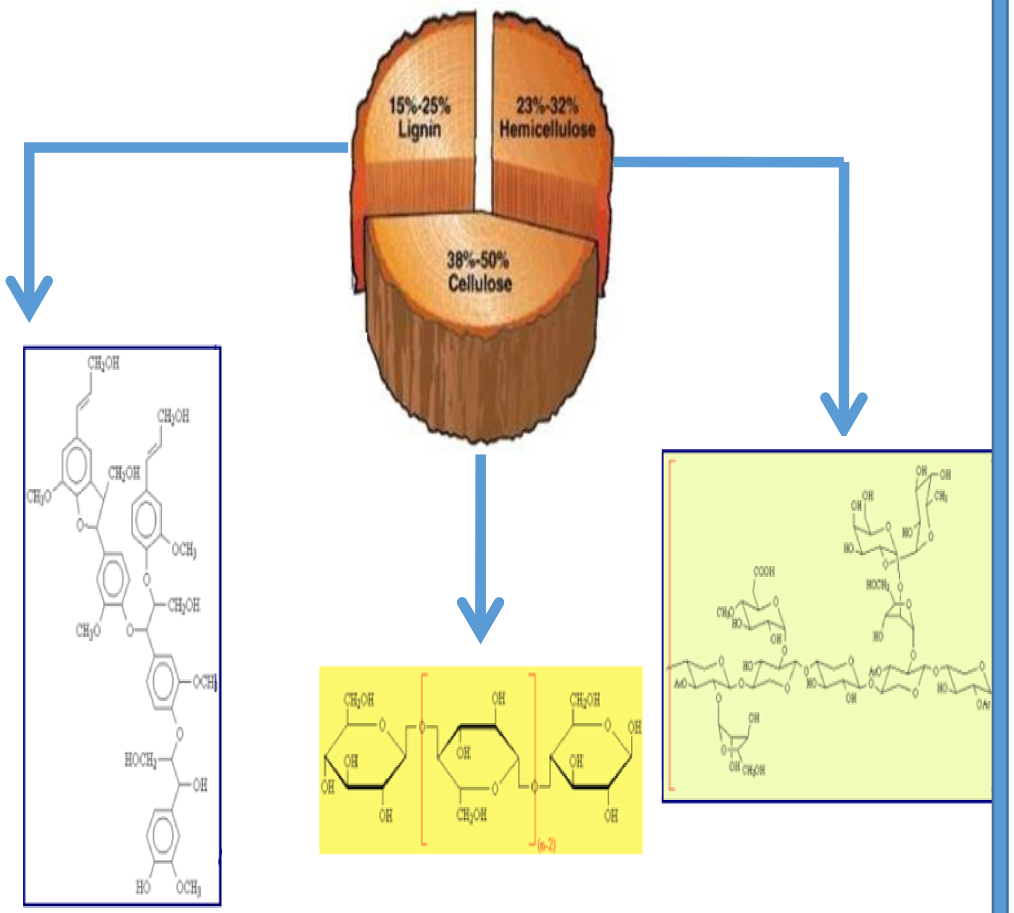
First generation: **Sugarcane, maize, corn , vegetable oils, etc.**

Lignin+holocellulosic = Lignocellulosics

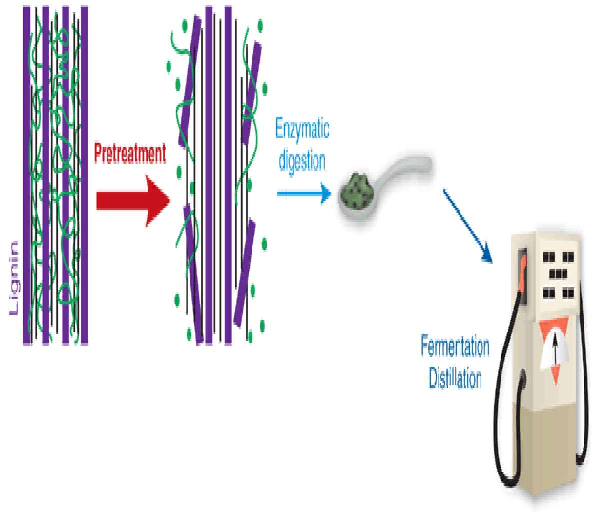
Lignocellulosic bioethanol

Lignocellulose structure





Lignin: A bottleneck for bioethanol production



- Lignin impedes access of hydrolytic enzymes to wall polysaccharides
- It interferes with pretreatment processes
- lignin degradation products inhibit fermentation
- lignin is not fermentable (recalcitrant)

How to remove or degrade lignin?

Different modes for lignin removal/degradation

- **Acid Hydrolysis**
- Alkali Hydrolysis
- **Physical Pretreatment**
- **Physico-chemical pretratment**
- **Biological pretreatment**

Costly, hazardous, loss of target biomolecules energy and labor intensive

Rationale for Biological pretreatment

Biological pretreatment

Biodepolymerization of lignin

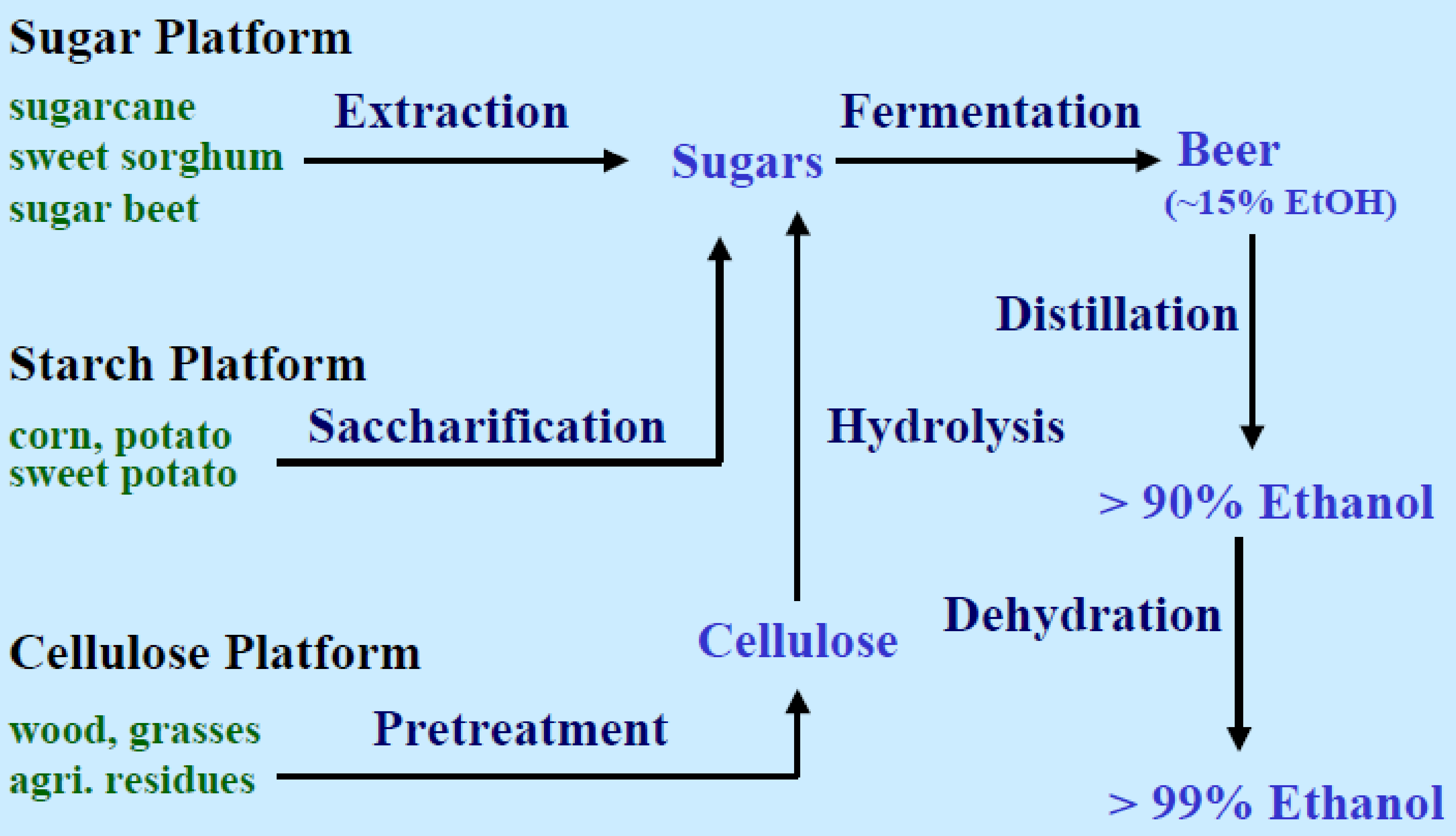
- High yield
- Minimal by-product formation
- Low substrate loss
- Low toxic compound generation
- Mild operating conditions
- Target specificity
- Re-usable
- Eco-friendly

Done either by using the microorganisms directly or by using the enzymes produced by various microorganisms

Microorganisms: *Botrytis cinerea*, *Phanerochaete chrysosporium*, *Stropharia coronilla*, *Pleurotus ostreatus* and *Trametes versicolor*

Enzymes: Manganese peroxidase , Lignin peroxidase, Laccases

Bio-Ethanol Production Processes



Starch-to-Ethanol Process

- Hydrolysis

$$\underset{\text{Starch}}{(C_6H_{10}O_5)_n} + n\,H_2O \xrightarrow{\text{Amylases}} \underset{\text{Glucose}}{n\,C_6H_{12}O_6}$$

- Fermentation

$$\underset{\text{Glucose}}{C_6H_{12}O_6} \xrightarrow{\text{Microbes}} \underset{\text{Ethanol}}{2\,C_2H_5OH} + 2\,CO_2$$

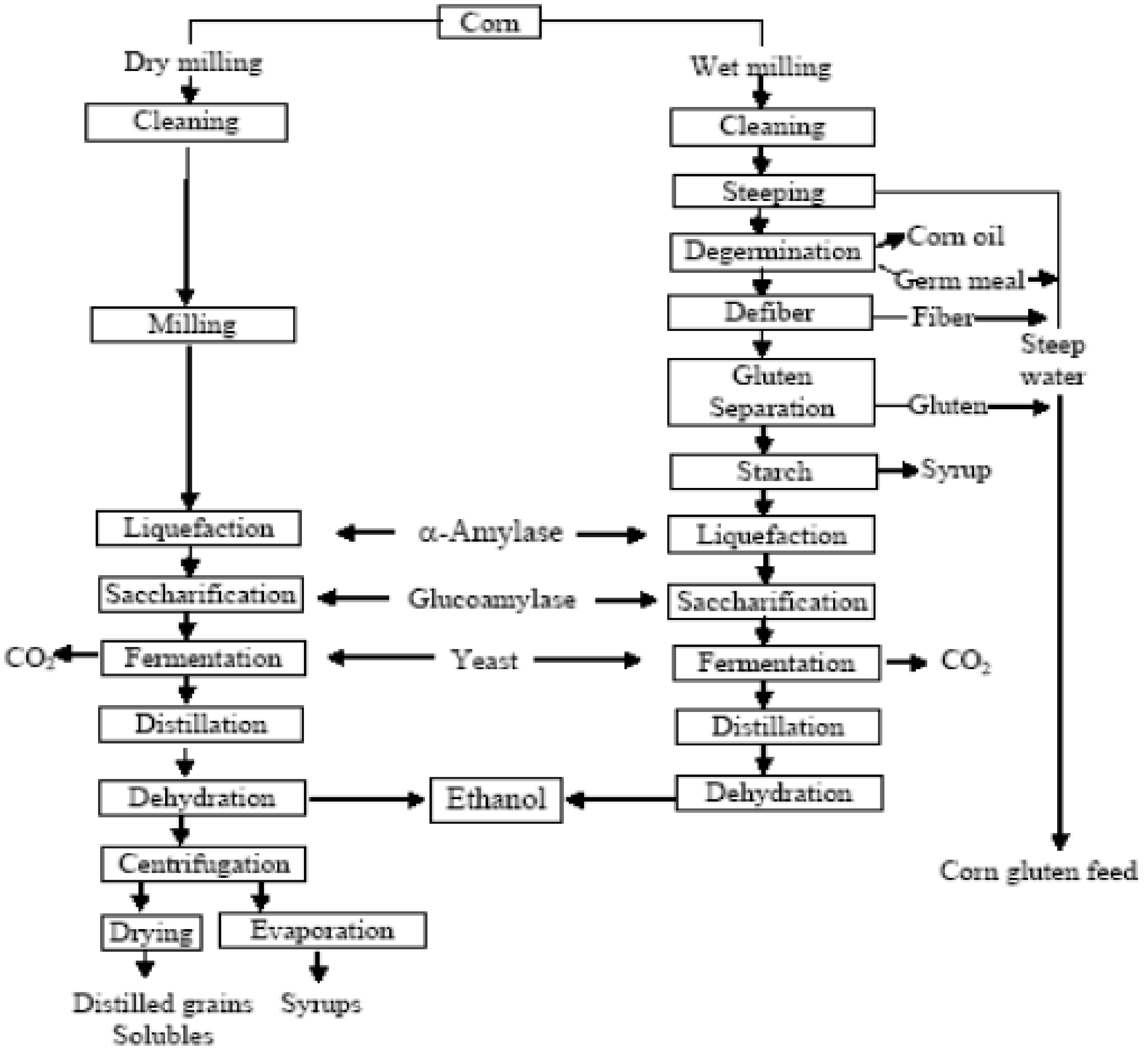
Starch-to-Ethanol Process

Starch-rich biomass: Corn, wheat, barley, sorghum, rice, potato, sweet potato

Chemical composition:

	Water %	Starch %	Proteins %	Fat %	Fiber %	Minerals %
Corn	7-16	65-70	8-10	3-5	1-1.5	1.5-2
Potato	68-85	9-25	1-3.5			0.5-1.8
Sweet Potato	60-80	10-30	Sugar 5%			

Corn-to-Ethanol Process



Cellulose-to-Ethanol Process

Cellulosic biomass:

- ✓ Woody biomass (trees):

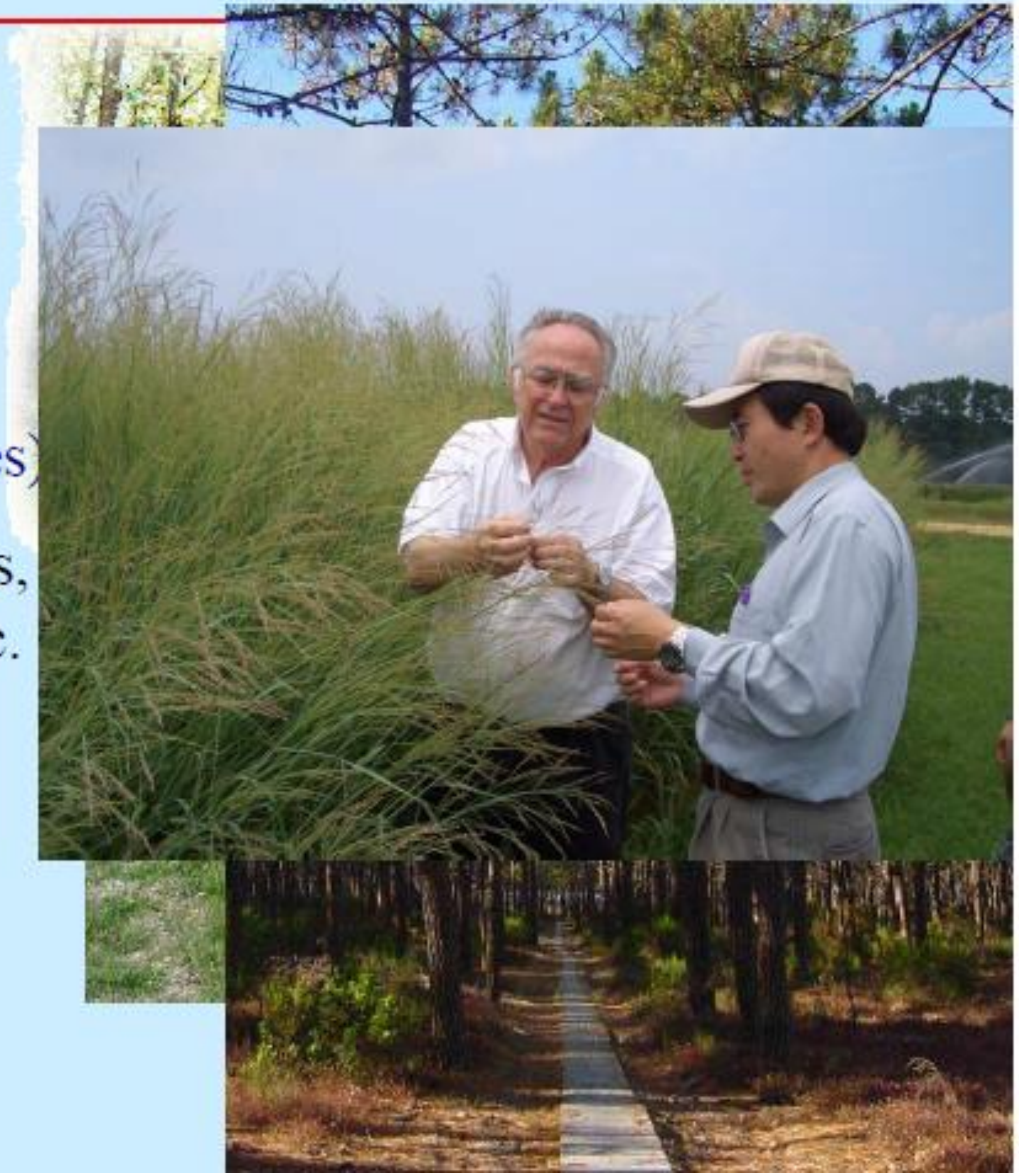
  Pine, aspen, willow, etc.

- ✓ Herbaceous biomass (grasses):

  Switch grass, Bermuda grass,
  corn stover, wheat straw, etc.

- ✓ Waste cellulosic materials:

  Waste paper,
  solid waste, etc.



Cellulose-to-Ethanol Process

- Enzymatic hydrolysis (saccharification)

$$\underset{\text{Cellulose}}{(C_6H_{10}O_5)_n} + n\,H_2O \xrightarrow{\text{Cellulases}} \underset{\text{Glucose}}{n\,C_6H_{12}O_6}$$

- Fermentation

$$\underset{\text{Glucose}}{C_6H_{12}O_6} \xrightarrow{\text{Microbes}} \underset{\text{Ethanol}}{2\,C_2H_5OH} + 2\,CO_2$$

Major Composition

	Cellulose	Hemicellulose	Lignin
Hardwood stems	40 - 55%	24 - 40%	18 - 25%
Softwood stems	45 - 50%	25 - 35%	25 - 35%
Switchgrass	45%	31%	12%
Costal Bermuda grass	35%	22%	20%
Corn stover	39%	22%	21%
Wheat straw	30%	50%	15%
White paper	85 - 99%		1 - 15%
Newspaper	40 - 50%	25 - 40%	18 - 30%

Lignocellulosic Biomass

Cellulose $\xrightarrow{\text{Hydrolysis}}$ Hexose $\xrightarrow{\text{Fermentation}}$ Ethanol

Hemicellulose $\xrightarrow[\text{Hydrolysis}]{\text{Pretreatment}}$ Hexose $\xrightarrow{\text{Fermentation}}$ Ethanol

Hemicellulose $\longrightarrow$ Pentose $\xrightarrow{\text{Fermentation}}$ Ethanol

Lignin $\xrightarrow{\text{Direct Combustion}}$ Heat

Lignin $\xrightarrow{\text{Gasification}}$ Syn gas (CO, H_2, CO_2, CH_4)

Examples of non-edible lignocellulosics

Ricinus communis

Lantana camara

Kans Grass

Bambusa bamboos

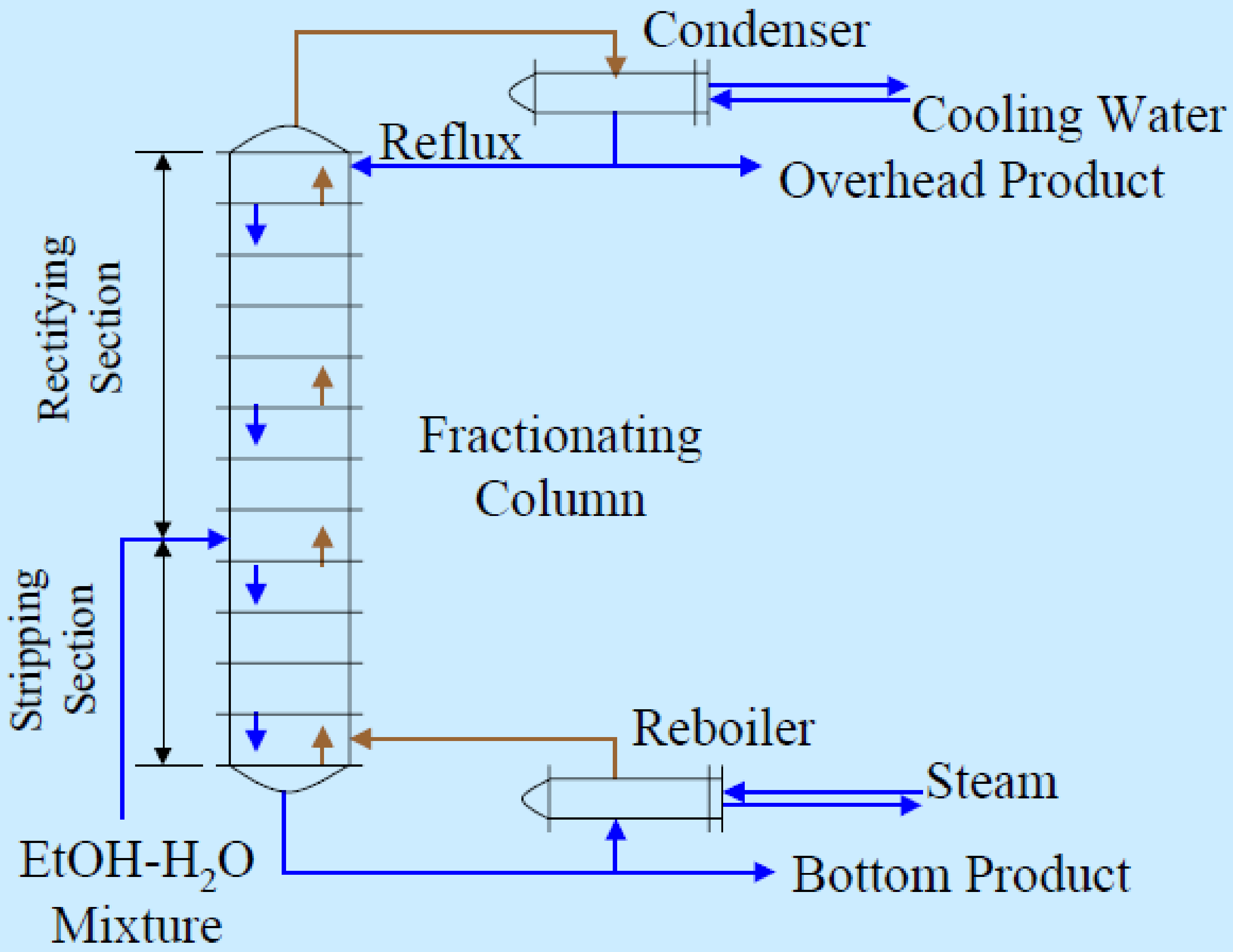
Cotton Stalk

Sugar cane Top

➢These species are mostly non-edible due to high toxin content (eg. lantanedeneA , B, ricin and triterpene acid) and have been found to be toxic to animals

➢Such species would not compete for land use with food crops and could be grown at relatively dry zones

Distillation: Ethanol – Water mixture



Biodiesel

- India consumes almost five times more diesel fuel than gasoline
- Renewable fuel
- Non-toxic and biodegradable
- It can be used in existing diesel engines without modification
- It can be blended in at any ratio with petroleum diesel

Feed stocks for biodiesel production

- Food Vs Fuel dilemma
- Exorbitant cost
- Acreage

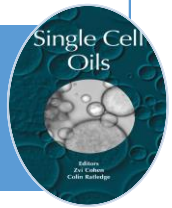
Edible oils

- Longer incubation
- Lack of infrastructure
- Non remunerative

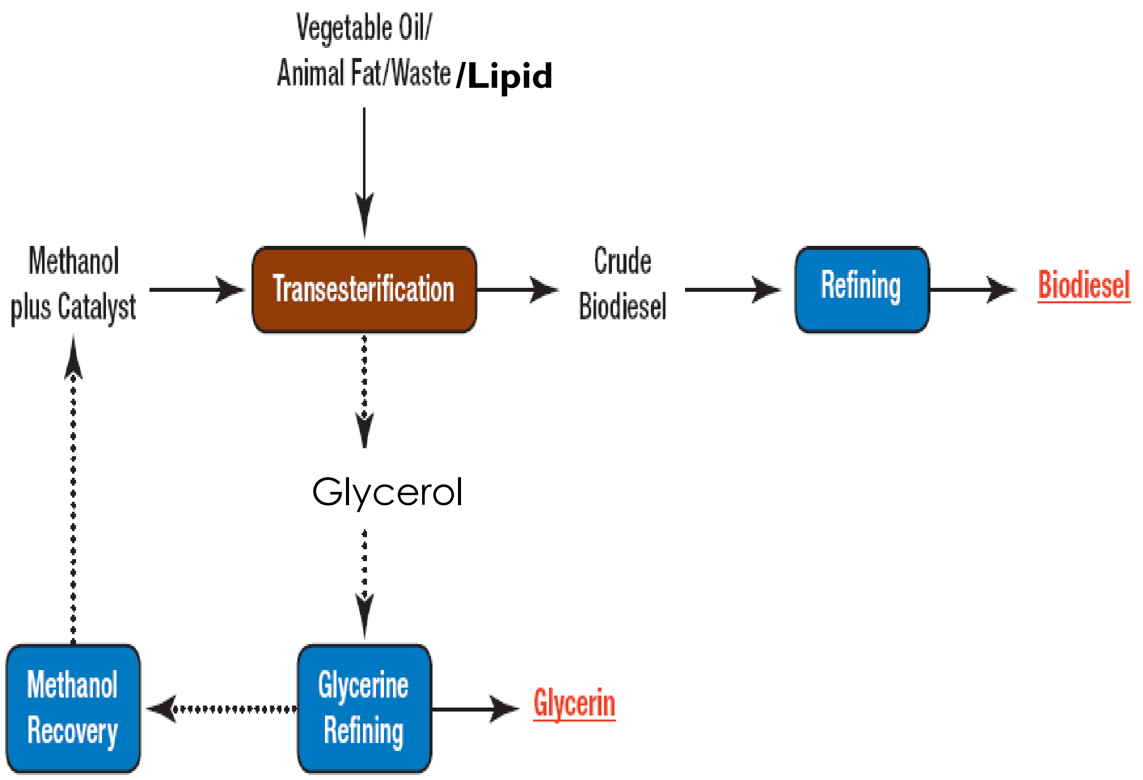
Non-edible oils

- Shorter incubation
- Easy to scale up
- Similar lipid composition with vegetable oils

Oleaginous microorganisms



Biodiesel Production Process



Source: NREL , 2008. Biodiesel Handling and Use Guide

Biodiesel from vegetable oils: Process steps

- Oil extraction
- Degumming process
- Determine the amount of methanol and catalyst
- Transesterification process
- Neutralization
- Methanol recovery
- Crude glycerin and biodiesel separation
- Crude biodiesel purification

Biodiesel from vegetable oils: Process steps

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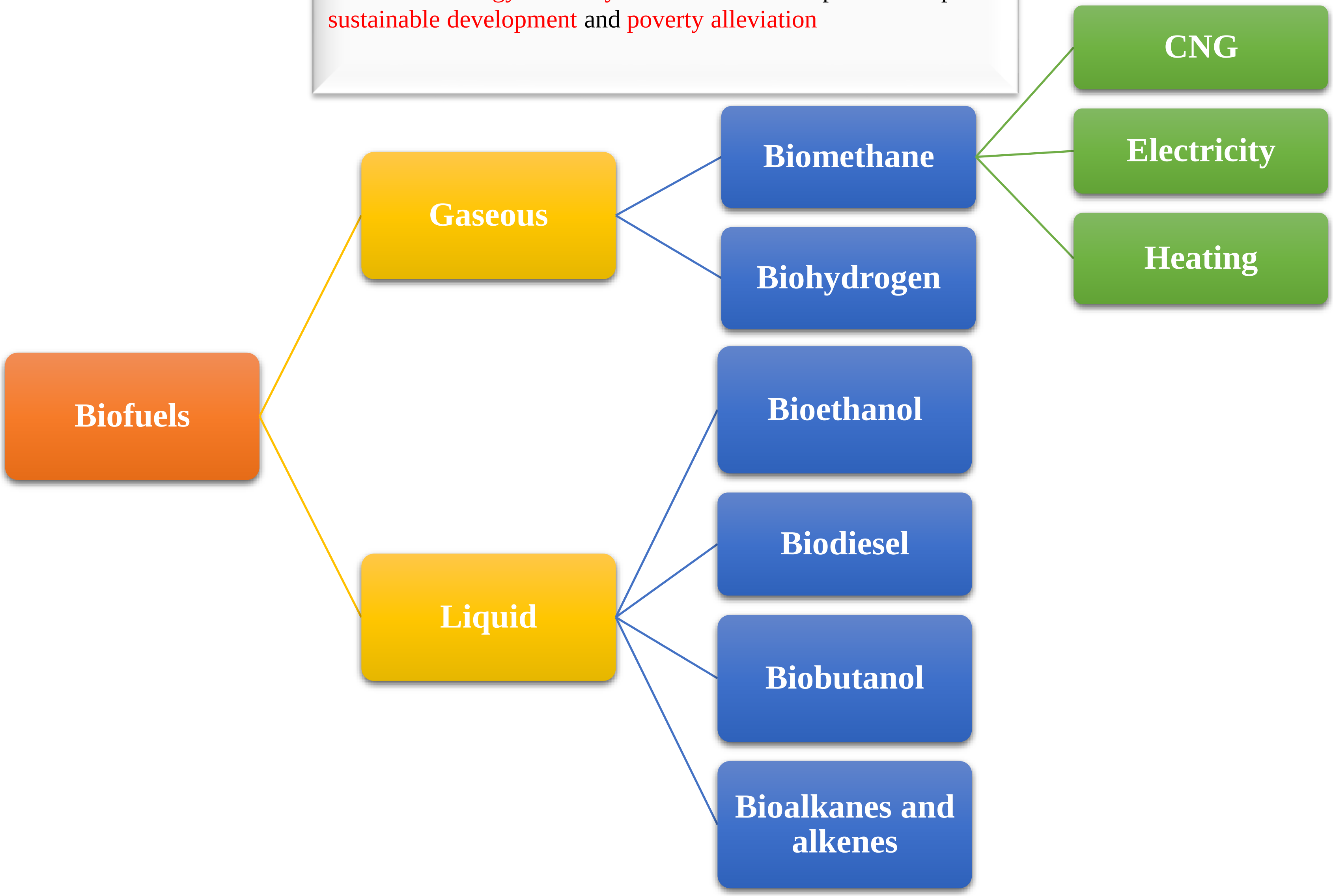
Gaseous biofuel-Biomethane

Biomethane

According to the UN, energy security is a prerequisite to achieve the millennium development goals and biogas is one of the means to obtain energy security and thus an important step for sustainable development and poverty alleviation



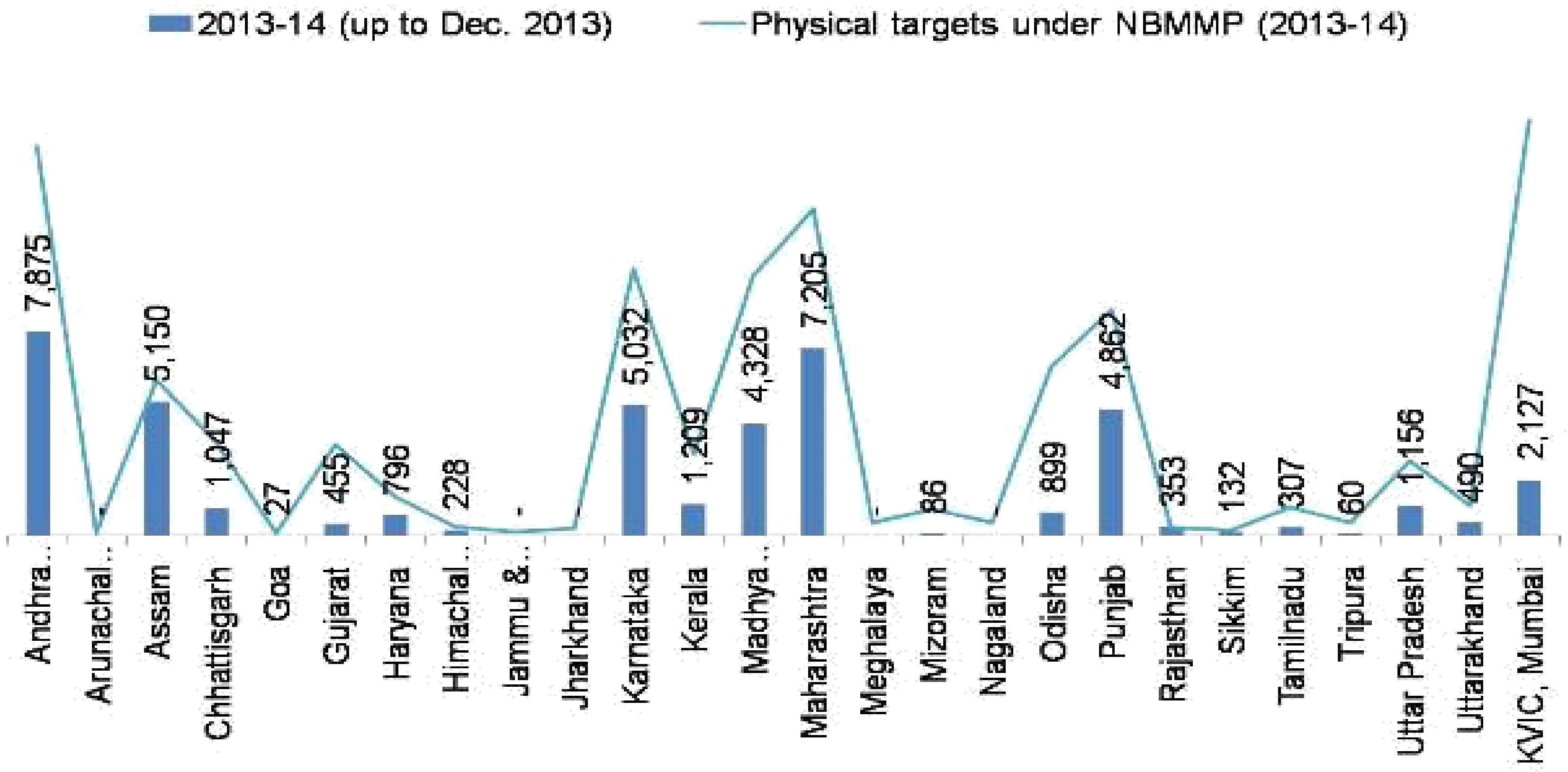
Biogas Dissemination Programmes in India

1. National Biogas and Manure Management Programme (NBMMP)
2. Biogas Based Distributed/Grid Power Generation Programme
3. Recovery of Energy from Industrial Wastes
4. Recovery of Energy from Urban Wastes

Biogas – State-wise targets and achievement

- The Ministry of New and Renewable Energy (MNRE) has also implemented a National Biogas and Manure Management Programme (NBMMP) for setting up family type biogas plants mainly in rural areas including remote villages
- With the increased support and initiation by Ministry of New and Renewable Energy (MNRE) to use the locally available organic wastes for anaerobic digestion, the cumulative total installation of 45.45 lakh family type biogas plants were installed till March, 2013 which is about 36.85 per cent of the estimated potential

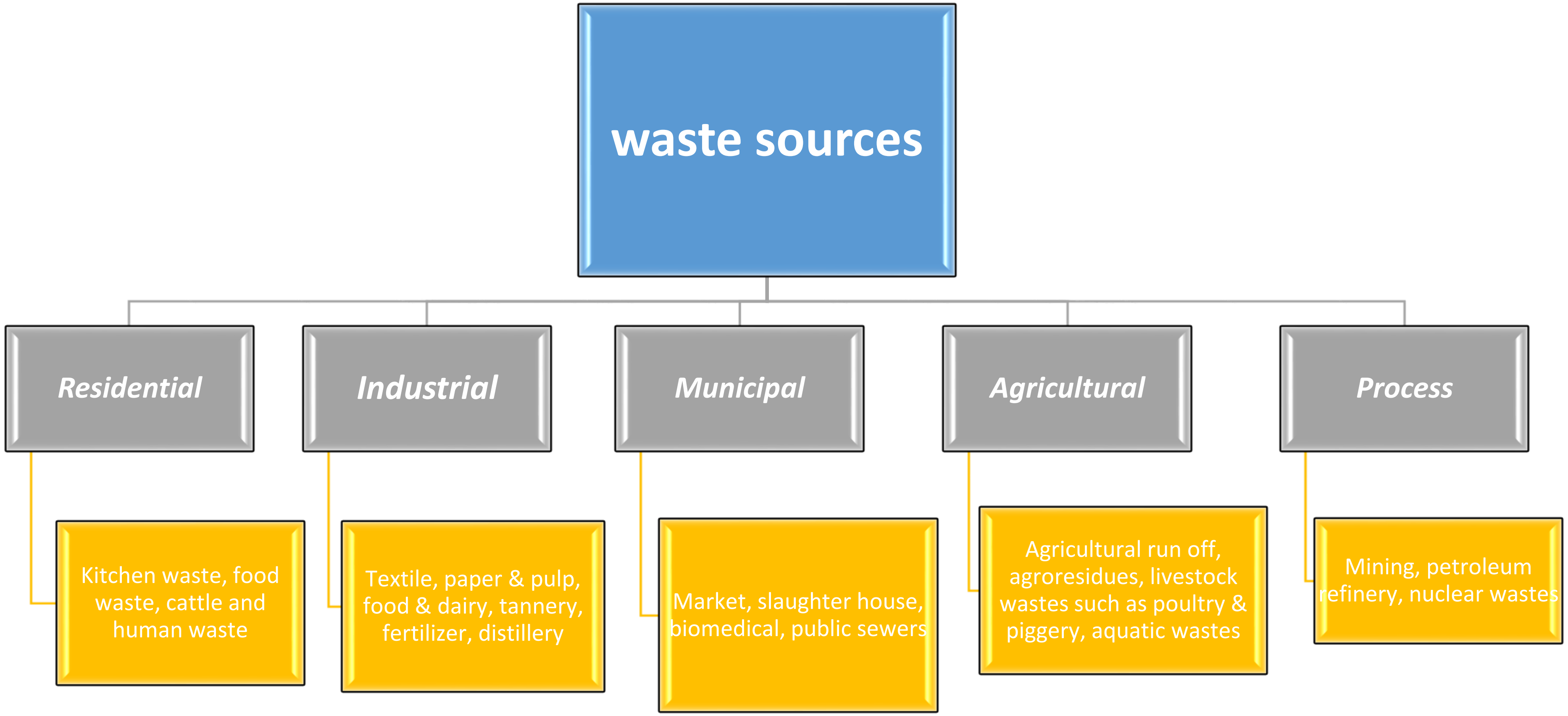
State wise Installed family size biogas plants



Biogas in India

- Household biogas plants mainly based on cattle manure for cooking and lighting
- Biogas plants based on cattle manure, slaughterhouse and vegetable market wastes for heat, electricity or motive power
- Biogas from urban and industrial wastes and effluents
- Co-digestion of farm / agricultural residues with urban and industrial wastes

Waste sources and classification
Potential raw materials for biogasification



Biogas Potential from Agro-industrial wastes

Waste	Biogas potential in terms of electricity (MW)
Sugar	363
Pulp and paper	58
Starch	129
Distillery	503
Milk processing	69
Slaughterhouse	94
Poultry	65
Total	1281

Potential of biogas in India

- It is estimated that India can produce power of about 17,000 MW using biogas. This is over 10% of the total electricity installed capacity in India

- A capacity of approximately 302 MW has been commissioned through 54 projects, and 39 new projects are being commissioned, which will deliver an additional 270 MW (Source: European Business and Technology Centre)

- With a calorific value of about 5000 KCal / m^3, biogas is an excellent fuel for heating purposes as well as for generating electricity

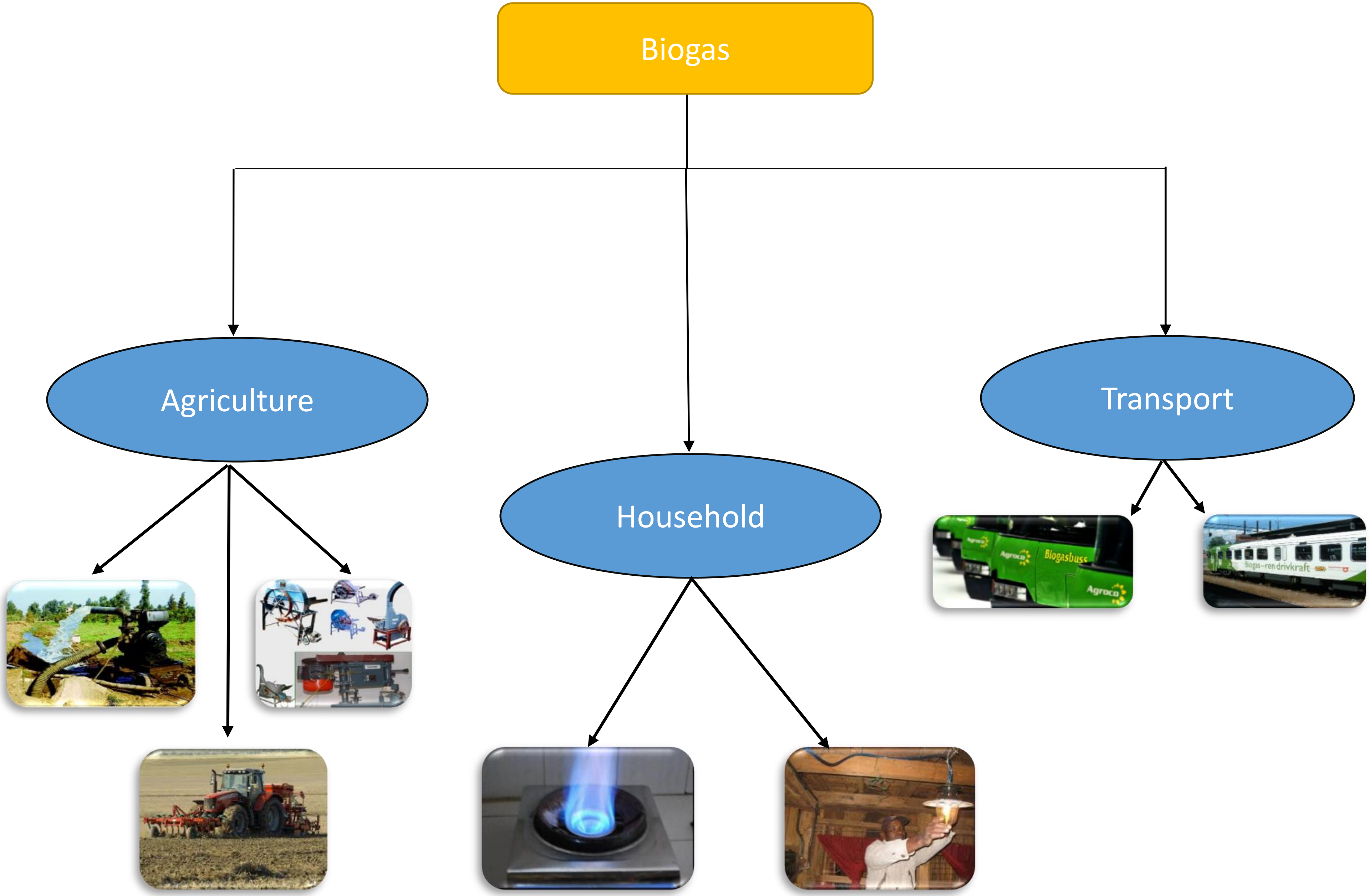
Current need and campaigns launched by Government of India

Unnat Chulha Abhiyan

- Launched to deploy improved cook stoves for providing cleaner cooking energy solutions in rural areas using biomass
- Save rural women from the carcinogenic fumes emitted when traditional fuels are burnt

Swachh Bharat Abhiyan

- Clean India
- Supporting urban local bodies in designing, executing and operating waste disposal systems
- 100% collection and scientific processing/disposal/reuse/recycling of municipal solid waste


Biogas
Agriculture
Household
Transport

Paradigm shift

- Time saving
- Health benefit
- Uplift of rural women employment
- Waste utilization
- Environment clean up

Anaerobic digestion

Anaerobic Digestion Solution

Process Input

Energy Crops

Manure

Industrial waste

Source separated organics (SSO)/ Municipal Solid Waste (MSW)

Restaurant/ Food Industry Waste

Wastewater Treatment Plant Sludge

Anaerobic Digestion

Process Output

Electricity

Biogas

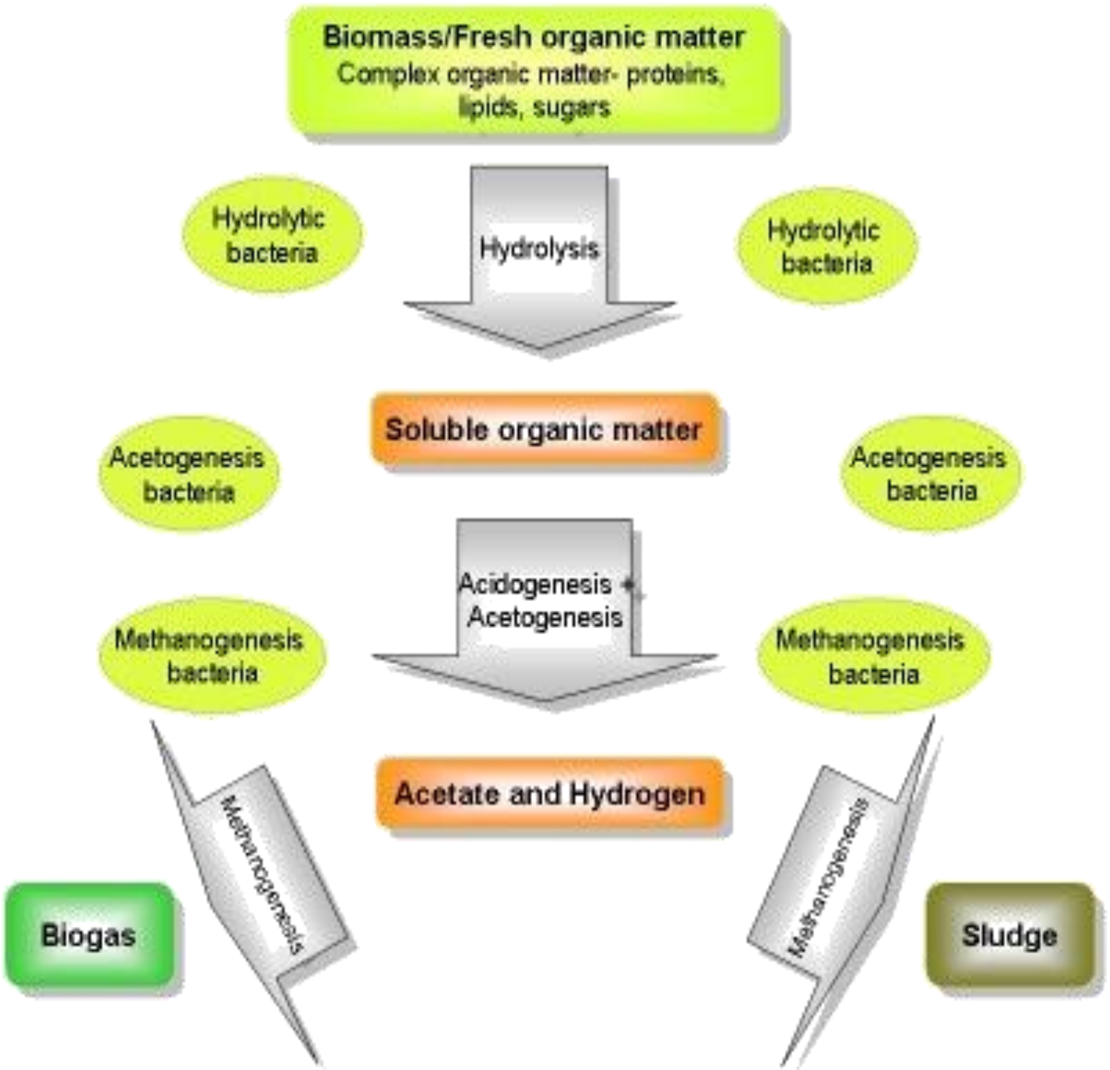
Renewable Fuel

Biofertilizer

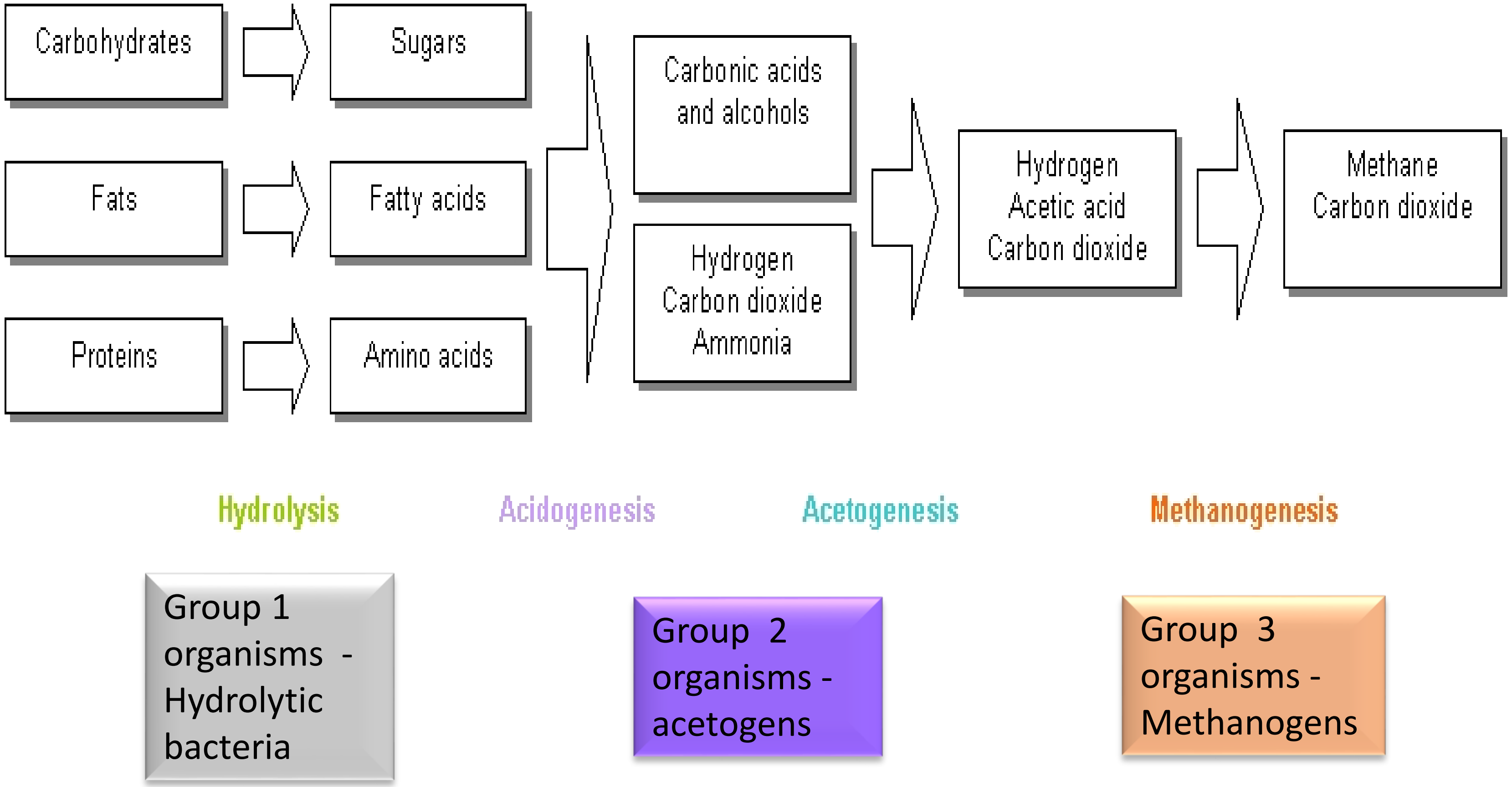
Reusable water

Compost

Stages of AD

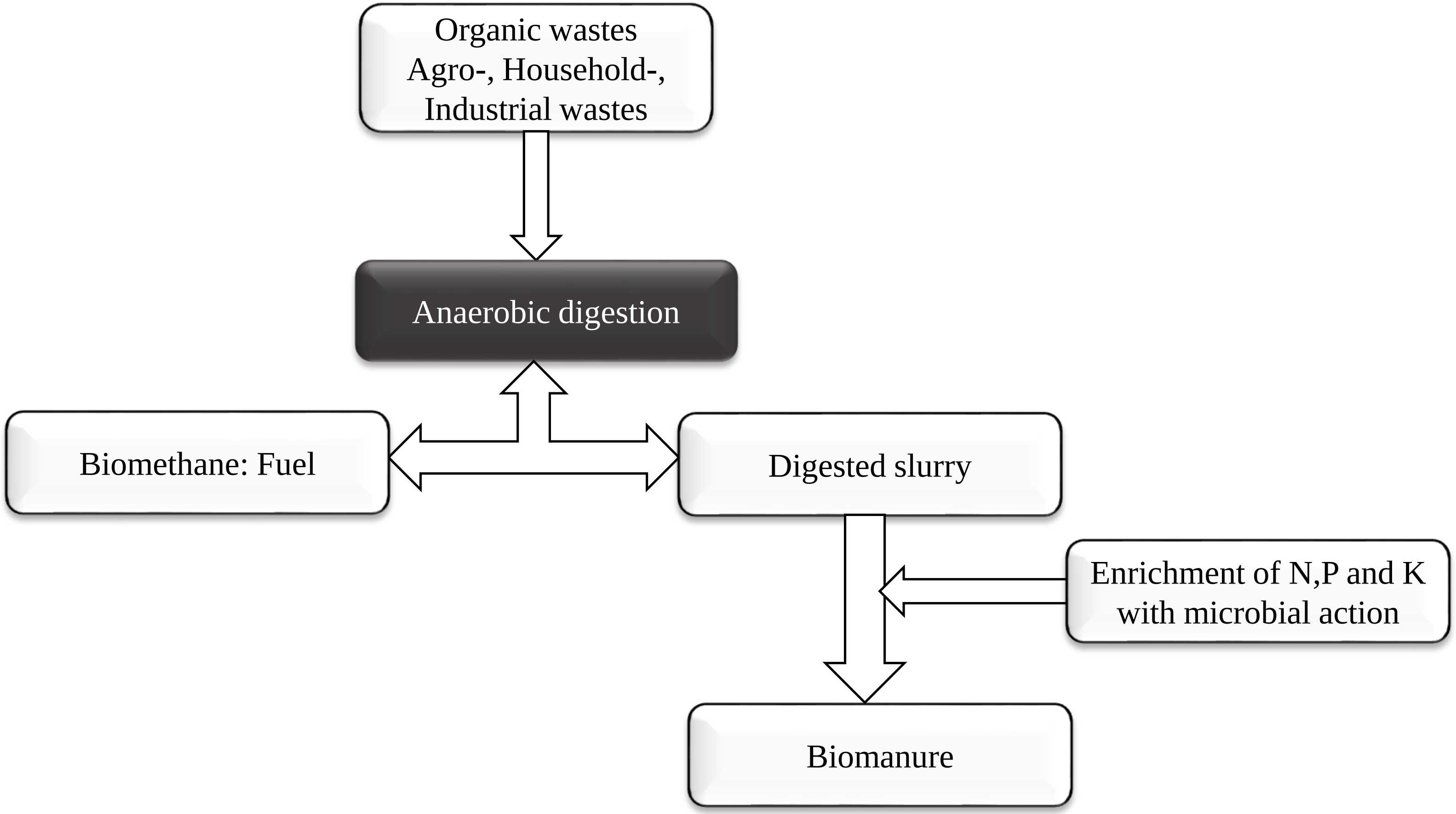

Biomass/Fresh organic matter
Complex organic matter- proteins, lipids, sugars
Hydrolytic bacteria
Hydrolysis
Hydrolytic bacteria
Soluble organic matter
Acetogenesis bacteria
Acetogenesis bacteria
Acidogenesis + Acetogenesis
Methanogenesis bacteria
Methanogenesis bacteria
Acetate and Hydrogen
Methanogenesis
Methanogenesis
Biogas
Sludge

Bacterial reactions in stages of anaerobic digestion



Microbes involved in anaerobic digestion

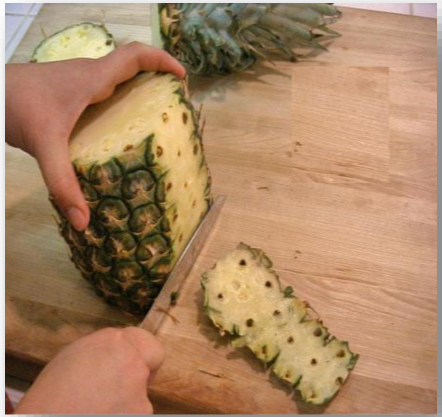
Group 1 Organisms	Group 2 Organisms	Group 3 Organisms
• *Actinomycetes* • *Aerobacter* • *Clostridium* • *Cellulomonas* • *Desulphovibrio* • *Klebsiella* • *Ruminococcus*	• *Clostridium thermoaceticum* • *Clostridium fervidus* • *Clostridium thermoautotrophicum*	• *Methanobacterium bryantii* • *Methanobacterium formicicum* • *Methanococcus voltae*


Organic wastes
Agro-, Household-,
Industrial wastes
Anaerobic digestion
Biomethane: Fuel
Digested slurry
Enrichment of N,P and K
with microbial action
Biomanure

Biomethanation from Agro-industrial waste

Substrates used for Biomethane production

Vegetable wastes



Pineapple wastes

Improper disposal results emission of GHG's

Potato wastes

Aquatic weed – *Pistia (water lettuce)*

Menace to the water bodies and aquatic ecosystem

Considered to be one of the potential habitat for filarial/malarial vector

Biomethane flame from an agro waste digestion set

Future use

Waste to Wealth

to Wheels

Need for an improvement in Commercialization

Compressed Natural Gas (CNG) → Compressed Biomethane (CBM)

Liquefied Natural Gas (LNG) → Liquefied Biomethane (LBM)

Hindering factors of biogas programmes

- Technically, problems have arisen from installing too large a capacity plant, either by accident or design
- Too large a plant was found to lead to under feeding, and eventual failure of the plants to produce gas. Under feeding was also found to occur due to the under collection of dung, estimated typically at 30-40% of the required capacity, and principally due to cattle being worked in the field, which would also lead to a reduction in gas production
- In some areas, the plant may not be technically feasible all year round due to low winter temperatures that inhibit methanogenesis
- Sometimes the plants are faulty in their construction, or develop problems that lead to the non-functioning of the plant
- Often, specially trained masons in biogas plant construction were overlooked, due to their higher cost, in favor of cheaper trainees, or those with no training at all

Hindering factors of biogas programmes

- Subsidized conventional fuels, such as electricity, along with free connection to the grid for farmers, will continue to make non-renewable technology the cheapest option, unless subsidies for biogas can be brought into line, or prices of conventional fuels are raised

- Cultural practices may also hinder general uptake, due to reluctance to adopt different behaviour, particularly regarding the use of latrines in biogas system

Constraint factors for successful implementation of biogas technology

Excluding factors	**Critical factors**
Climate too cold or too dry	Low income of the target group
Irregular or low gas demand	Unfavourable macro- and micro-economics
Under 20 kg dung/day available or under 1000 kg live weight of animals per household in indoor stabling	Good supply of energy throughout the year, therefore only moderate economic incentives for biogas technology
	Irregular gas demand
No stabling or livestock in large pens	Gas appliances not available
No building materials available	High building costs
No or very little water available	Low qualification of builders
Integration of biogas plant into the household and farm routines not possible	Institution has only limited access to the target group
No suitable institution can be found for dissemination	No substantial government interest

Reference: Information and Advisory Service on Appropriate Technology ISAT/GTZ (1999c)

Desired Policy for Promoting Biomethanation Sector

- Mandatory provision for installation of Biogas-Fertilizer plants
- Introduction of Generation based Incentives for biogas based Power
- Introduction of financial incentives for Bio-fertilizers and Bio-pesticides similar to chemical fertilizers
- Exemption from VAT and other taxes
- Preparation of Standards for Compressed Biogas (CBG) and Bio-fertilizer and bio-pesticide
- Development of CBG cylinders
- Acceptance as vehicular fuel

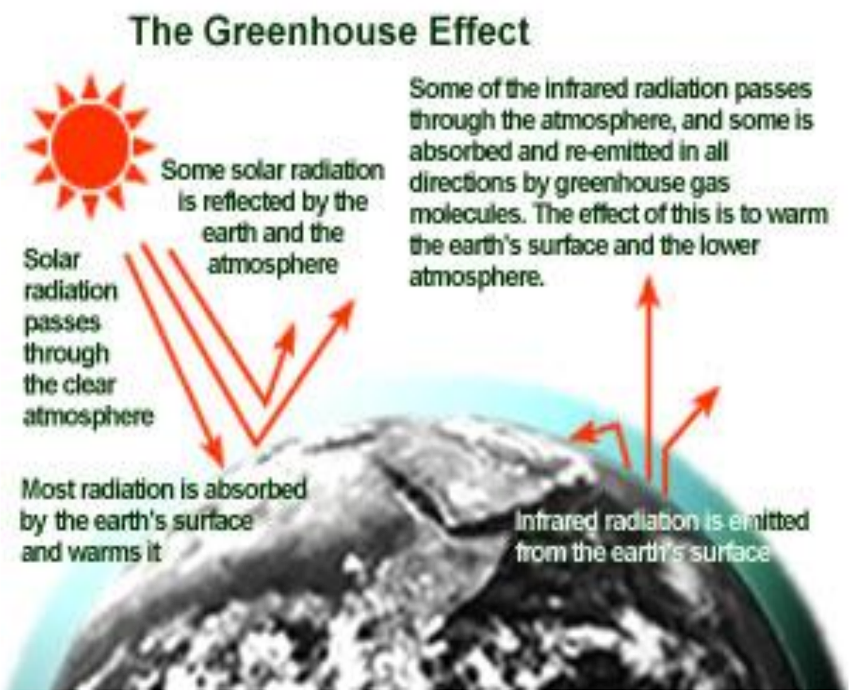
Source: Ministry of New and Renewable Energy

Outline

- Importance of hydrogen production
- Types of hydrogen production
  - Fermentative
  - Photosynthetic
- The hydrogenase enzyme
- Hydrogen production by *Chlamydomonas reinhardtii*
- Research proposal

Importance of Hydrogen as an Alternative Fuel

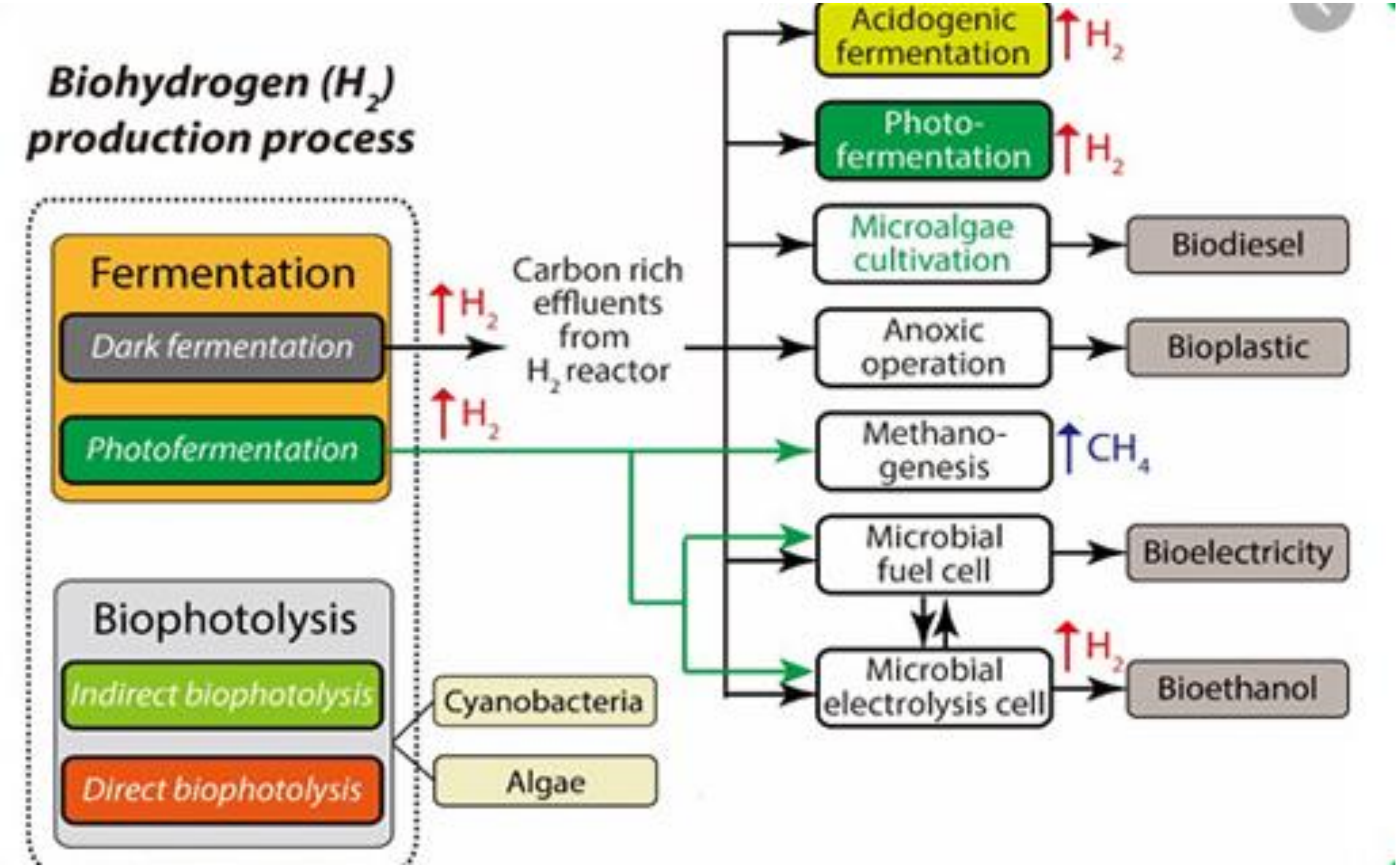
- Increased levels of CO_2 from fossil fuels cause an increase in the Greenhouse Effect
- One of the detrimental effects of the Greenhouse Effect is Global Warming
- Combustion of Hydrogen produces water, which is not detrimental to the environment



Microbial Hydrogen Production

- Types of microbial hydrogen production
  - Fermentative
  - Photosynthetic (aerobic/anaerobic)
- Most interest in hydrogen production research in US during the Energy Crisis of the 1970s
- Interest in hydrogen production again in 1990s due to the awareness of Global Warming, etc.

Microbial Hydrogen Production



Fermentative Production of Hydrogen

- *Clostridia* species - *Clostridia beijerincki*
  - Used in fuel cell that produced 15mA over 20 days using waste from alcohol distillery (Taguchi *et al* 1992)
- Methanogens -*Methanotrix soehngenii*
- Archeabacteria -*Pyrococcus furiosus* (hyperthermophile)
- *Eschericia coli* - Formate Hydrogen Lyase pathway, which is inefficient

Photosynthetic Production of Hydrogen

- Purple Sulfur bacteria (*Thiocapsa* and *Chromantium*)
- Non-Sulfur bacteria (*Rhodospirillum* and *Rhodopseudomonas*)
- Green Algae (*Chlamydomonas reinhardtii*)
- Advantages:
  - Photosynthetic organsims produce more hydrogen than fermentative organisms (Nandi and Sengupta 1998)
  - **Photosynthetic organisms only require light and water**

Photosynthetic Hydrogen Production Mechanisms

- The purple sulfur bacteria and the non-sulfur bacteria produce hydrogen through a reversible hydrogenase and as a by-product of denitrification.
- *Chlamydomonas reinhardtii* a green algae, produces hydrogen through hydrogenase.
- Hydrogenase is induced under anaerobic conditions

Hydrogenase

- Many bacteria use it for H_2 dissimulation to use the electrons for electron transport
- Two types of hydrogenases
  - Nickel-Iron centered - dissimulate hydrogen
  - Iron-only centered - evolve H_2

Advantages of Using C. reinhardtii

- Cheap and easy to grow
  - Requires fluorescent light and 5% CO_2
  - Grows at room temp. in water
- Mutants have been isolated that are more energetically efficient (lack Photosystem I)
- Research into its life cycle and flagella have yielded useful molecular techniques for studying the organism

Chlamydomonas reinhardtii

- Green-alga (eukaryotic)
- Biflagellated, unicellular, photosynthetic
- Reproduces asexually or sexually under adverse conditions

Chlamydomonas reinhardtii