Green and Sustainable Technologies(2C)
Biofuel

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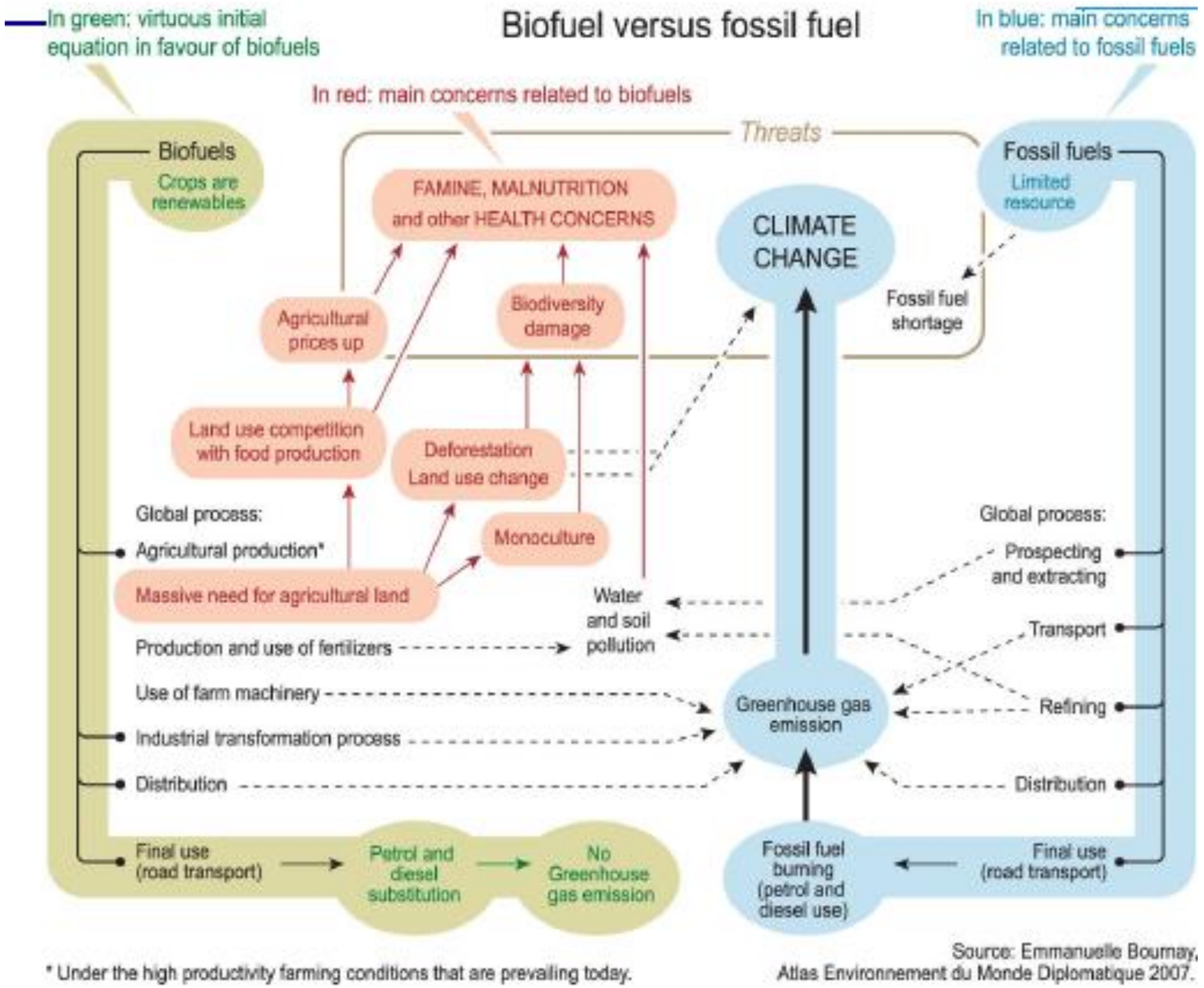
Introduction

- Biofuel is part of bioenergy, obtained from renewable sources.
- Bioenergy is stored in the material produced by photosynthesis, or as a by-product of waste (including organic waste).
- Biomass resources comprise conventional forestry and wood processing by-products, agricultural and energy crops including oil plants, and wastes (Bekers and Viesturs, 1998).

- Biofuels are receiving increasing global attention as an alternate energy resource as they address energy security, climate change and poverty reduction.
- At present, about 90% of energy is generated from fossil fuels and only about 10% is produced from renewable energy sources (Bekers and Viesturs, 1998).

Biofuel vs Fossil fuel



Ref: Le Monde Diplomatique; Bournay 2007.

What makes it different?

- Carbon-based, local, alternative fuel
- Fuel that can fill local niches
- Mostly cleaner burning than fossil fuels
  - Lower CO, CO_2, HC, and PM emissions
  - Higher NOx emissions (up to 10%)
- Can be offset
  - No lead or sulfur
  - Emissions are not toxic
- Smells great if you like fried foods! (eg:biodiesel)

- Requires little to no modification to an engine compared to natural gas Improved engine lubrication
- Many cases of improved gas mileage
- With rising gas prices, biofuel may become a very economical and environmental alternative
- Security of supply
- Sustainability
- Regional (rural) development
- Social structure & agriculture

What will make Biofuels economic

Rising energy prices due to

Scarcity and demand growth

Increased cost of fossill fuel production

Energy Security

Trade disruption

Privately realized value placed on Greenhouse Gas offset

Lower costs of delivered feedstock because of higher yields, improved production practices, lower transport needs

Improved energy recovery efficiency Subsidies

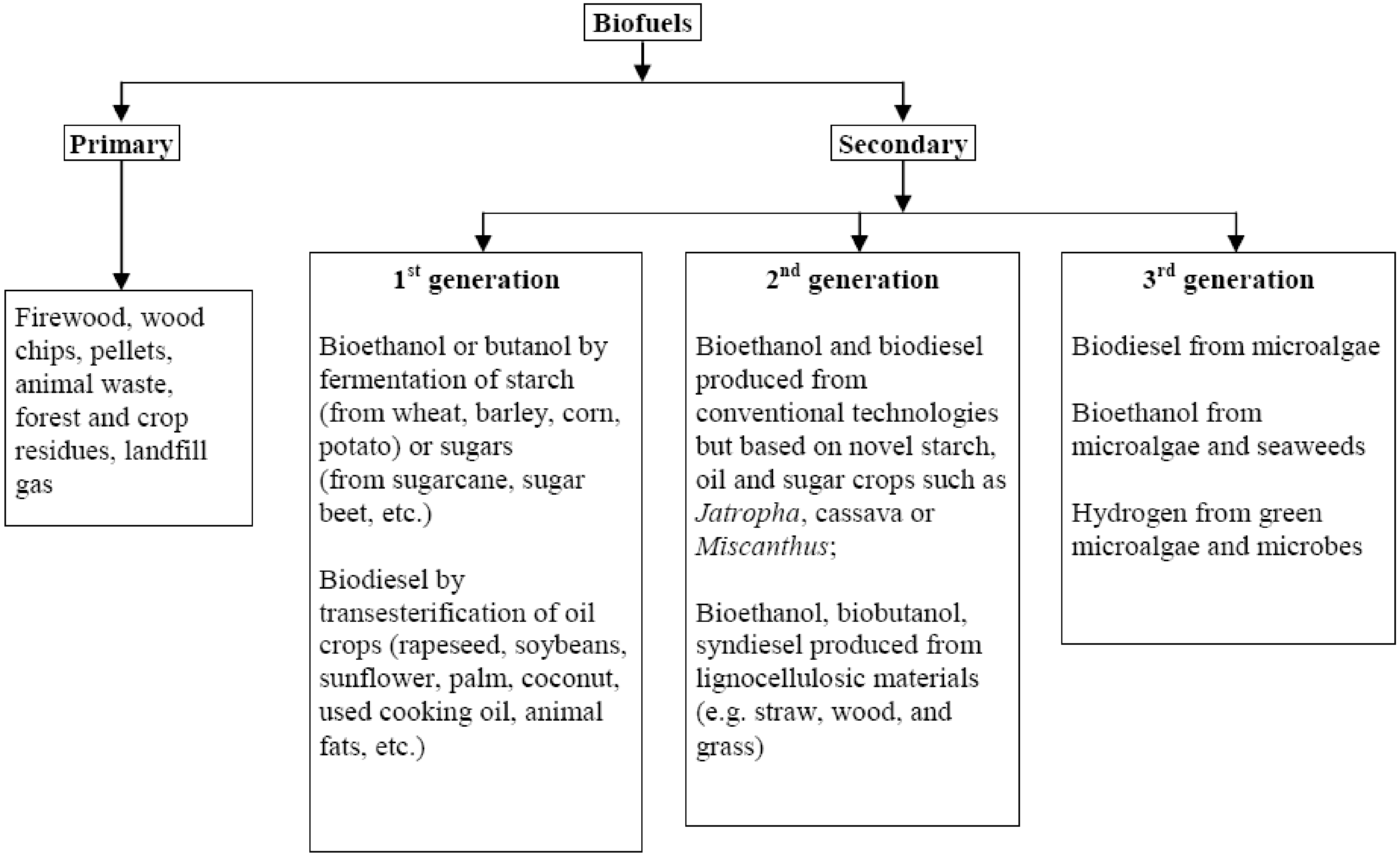
Definition

Biofuels defined:

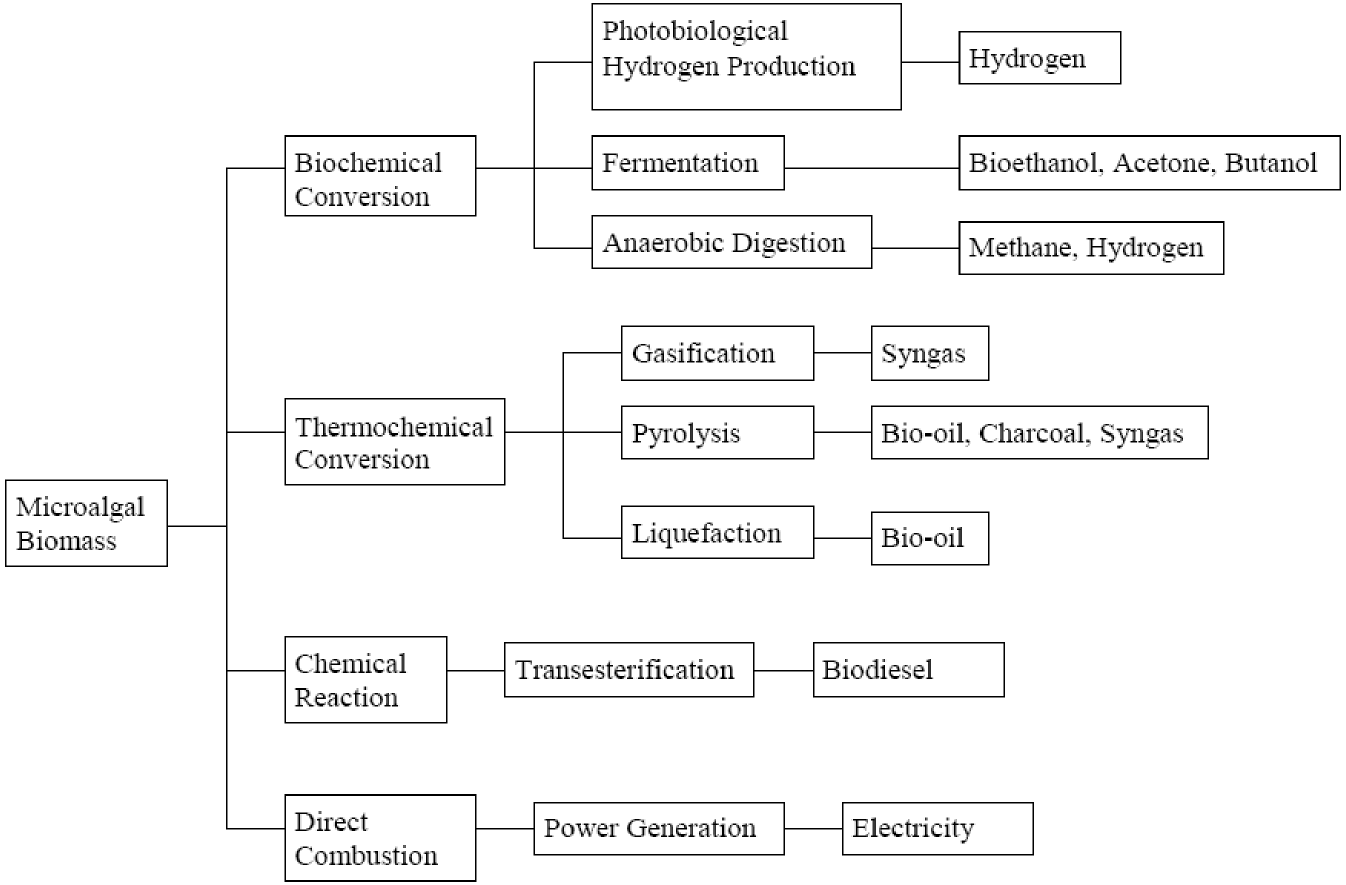
- solid, liquid, or gas fuel based on biological material

Definitions from Wikipedia: www.wikipedia.com.

Classification of biofuels

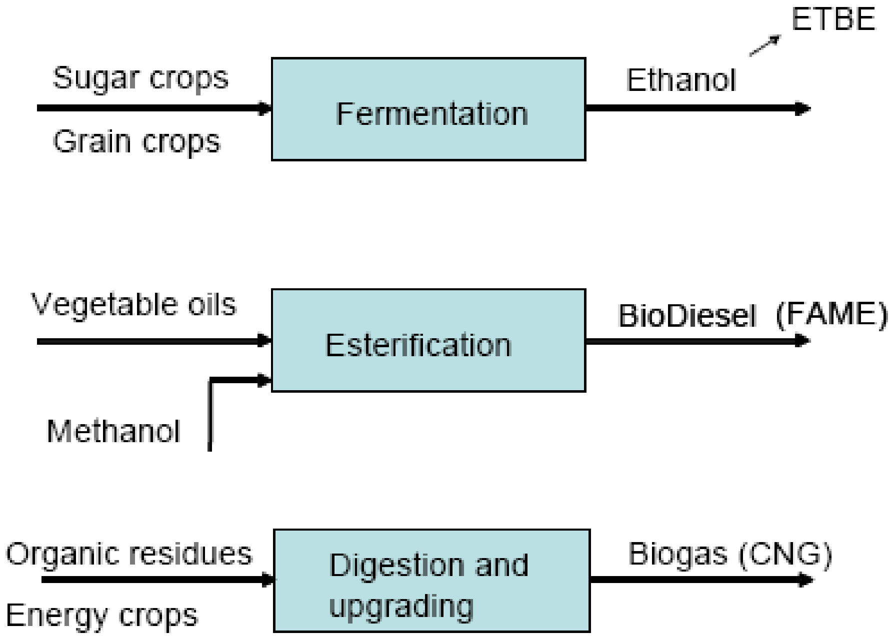


Conversion processes for biofuel production

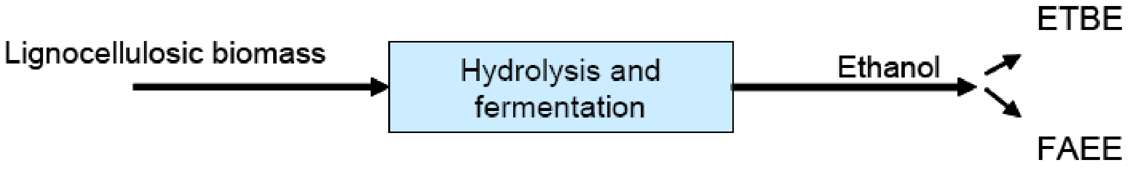


Biofuel transformation processes

First generation



Second generation



Biomass

- Coal
- Tyres
- Sugar Cane Bagasse
- Oil sludge/waste
- Energy crops
- Oil seed rape husks
- Rice and Corn husks
- Packaging Waste
- Chicken Waste
- Wood chips / waste
- Straw
- MSW-RDF
- Nut shells
- Sewage sludge
- Olive pips
- Bone meal
- Leather waste
- Animal litter

Biofuel feedstocks

- **Agricultural and forestry products:**
  - **Grains -Corn, Wheat, Sorghum, Rice**
  - **Sugar Cane**
  - **Timber**
- **Production residues:**
  - **Crop Residue**
  - **Logging Residue**
  - **Manure**
- **Processing products and by products:**
  - **Corn Oil**
  - **Rendered Animal Fat**
  - **Milling Residue**
- **Energy crops:**
  - **Switchgrass**
  - **Willow**
  - **Hybrid Poplar**

Overview of Biofuel Production Technologies

First Generation of Biofuels

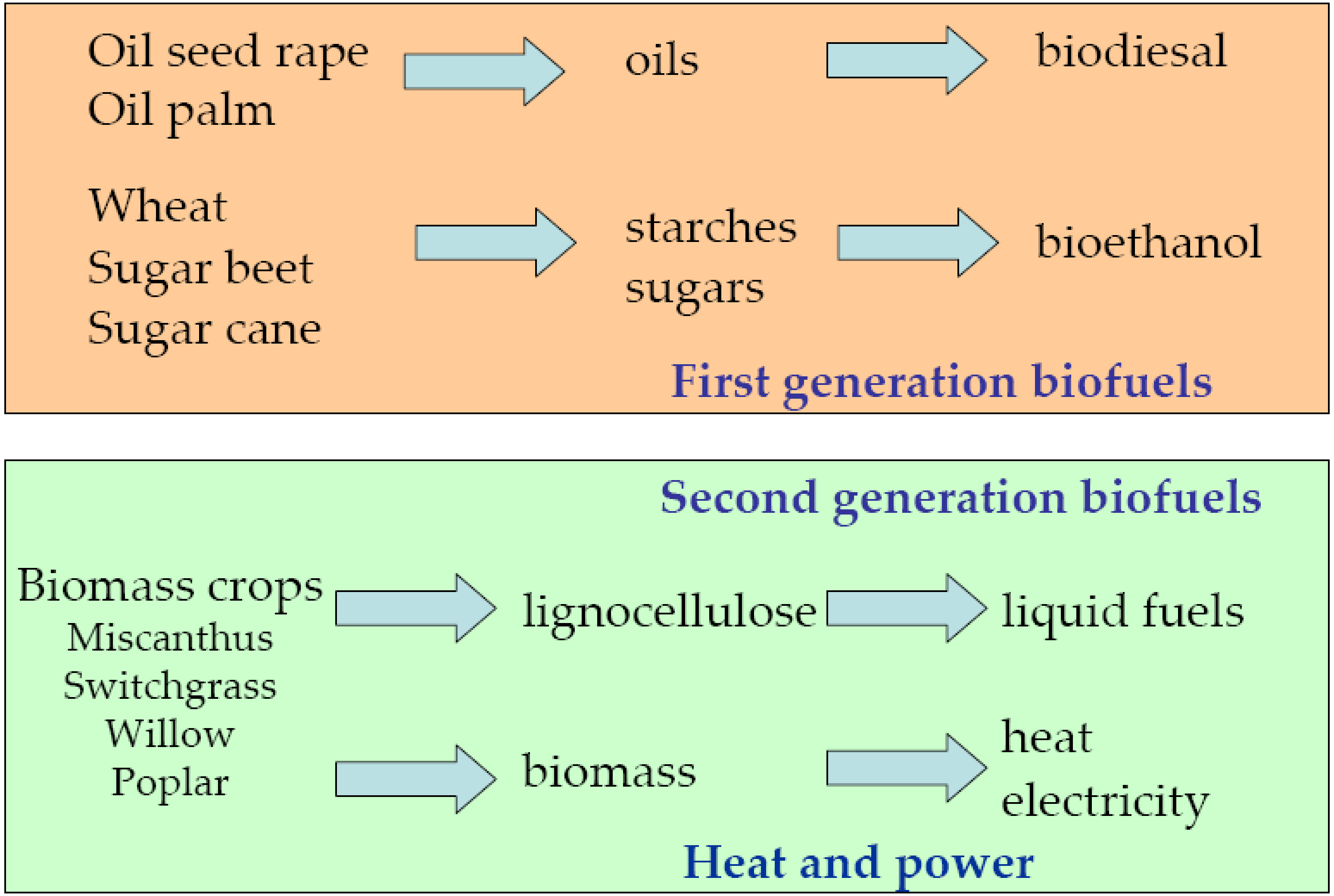
Biofuel type	Specific name	Feedstock	Conversion Technologies
Pure vegetable oil	Pure plant oil (PPO), Straight vegetable oil (SVO)	Oil crops (e.g. rapeseed, oil palm, soy, canola, jatropha, castor, …)	Cold pressing extraction
Biodiesel	- Biodiesel from energy crops: methyl and ethyl esters of fatty acids - Biodiesel from waste	- Oil crops (e.g. rapeseed, oil palm, soy, canola, jatropha, castor, …) - Waste cooking/frying oil	- Cold and warm pressing extraction, purification, and transesterification - Hydrogenation
Bioethanol	Conventional bio-ethanol	Sugar beet, sugar cane, grain	Hydrolysis and fermentation
Biogas	Upgraded biogas	Biomass (wet)	Anaerobic digestion
Bio-ETBE		Bioethanol	Chemical Synthesis

Overview of Biofuel Production Technologies
Second/Third* Generation Biofuels

Biofuel type	Specific name	Feedstock	Conversion Technologies
Bioethanol	Cellulosic bioethanol	Lignocellulosic biomass and biowaste	Advanced hydrolysis & fermentaion
Biogas	SNG (Synthetic Natural Gas)	Lignocellulosic biomass and residues	Pyrolysis/Gasification
Biodiesel	Biomass to Liquid (BTL), Fischer-Tropsch (FT) diesel, synthetic (bio)diesel	Lignocellulosic biomass and residues	Pyrolysis/Gasification & synthesis
Other biofuels	Biomethanol, heavier (mixed) alcohols, biodimethylether (Bio-DME)	Lignocellulosic biomass and residues	Gasification & synthesis
Biohydrogen		Lignocellulosic biomass and biowaste	Gasification & synthesis or biological process

*Use GMO as a feedstock to facilitate hydrolysis / technologies for hydrogen production

Bio energy crops



Source: Karp, Rothamsted Research, 2007

Most important bio-fuel crops

Crop:	Main producing countries:	Land under irrigation (estimates):
Sugar cane	Brazil / India / China / Thailand	14% / 80% / 28% / 64%
Sugar beet	France / USA / Germany / Russia	15% / 53% / 5% / 5%
Cassava	Nigeria / Brazil / Thailand / Indonesia	0%
Maize	USA / China / Brazil / Mexico	21% / 40% / 0% / 17%
Oil Palm	Malaysia / Indonesia / Nigeria / Thailand	0%
Rapeseed	China / Canada / India / Germany	3% / 0% / 8% / 0%
Soybean	USA / Brazil / Argentina / China	10% / 0% / 0% / 29%

Biomass Yield

Metric Tons per Hectare per Year

- Algae.....51.1 [USA average, 1978]
- Sugarcane.....79.2 [Brazilian average, 2005]
- Sorghum.....70 [India average, 2005]
- Cassava.....65 [Nigeria average, 1985]
- Oil palm.....50 [Global average, 2005]

Cultivating Algae for Liquid Fuel Production (*http://oakhavenpc.org/cultivating_algae.htm*); NREL, 2005

Crop:	Fuel product[1]	Annual obtainable yield (l/ha)	Energy yield (GJ/ha) [2]	Evapo-transpiration equivalent (litre / litre fuel)	Potential crop evapotranspiration in mm/ha (indicative)	Irrigated or Rainfed	**Rainfed conditions**	Water Resource Implications under **irrigated conditions**	
							Actual rainfed crop evapotranspiration in mm/ha (indicative)	Irrigation water required (mm/ha)[3]	Irrigation water required in litre / litre fuel
Sugar cane	Ethanol (from sugar)	6000	120	2000	1400	Irrigated / Rainfed	1000	800	1333
Sugar beet	Ethanol (from sugar)	7000	140	786	650	Irrigated / Rainfed	450	400	571
Cassava	Ethanol (from starch)	4000	80	2250	1000	Rainfed	900	0	0
Maize	Ethanol (from starch)	3500	70	1357	550	Irrigated / Rainfed	400	300	857
Oil palm	Bio-diesel	5500	193	2364	1500	Rainfed	1300	0	0
Rape-seed / Mustard	Bio-diesel	1200	42	3333	500	Rainfed	400	0	0
Soybean [redacted]	Bio-diesel	400	14	10000	500	Rainfed	400	0	0

[1] [redacted]nergy density: Bio-diesel 35 MJ/l Ethanol 20 MJ/l

[2] FAO (2006b). Starch market adds value to cassava, on-line available at: http://www.fao.org/ag/magazine/0610sp1.htm.
Global Petroleum Club, Energy Content of Biofuel, on-line available at: http://en.wikipedia.org/wiki/Energy_content_of_Biofuel.
Marris, E. (2006). Drink the best and drive the rest. Nature, 444, 670–672, 7 December.
USDA (2006). The Economic Feasibility of Ethanol Production from Sugar in the United States, on-line available at: http://www.usda.gov/oce/EthanolSugarFeasibilityReport3.pdf.

[3]

Examples of tree-based biofuels: palm oil

- High production: 5000 litres / hectare
- High melting point
- Edible oil with huge international market
- Grown in humid tropics
- Concern about the conversion of tropical forests
- The Roundtable on Sustainable Palm Oil established
- Unilever using sustainable oil from the year 2010

Examples of tree-based biofuels: jatropha curcas

- Non-edible oil
- Grows in drier areas
- Grown in India
- Relatively high oil production possible
- Only competitive with other crops under high international oil prices coupled with lower food

Biofuel

Replacement of petroleum by biodiesel

Vegetable oils

Castor Oil Plant (Thel Endharu)

What is Biodiesel?

- Bio fuel similar to diesel
- Low carbon emitting fuel
- Biodegradable (same as sugar!)
- Local source of energy
- 10x less toxic than salt

What is Biodiesel?

- **Alternative fuel for diesel engines**
- **Made by chemically combining any natural oil or fat with an alcohol**
- **Meets health effect testing (CAA)**
- **Lower emissions, High flash point (>300F), Safer**

Michael et al., 2005

Most European Countries, North America and Canada have active Biodiesel programmes

France currently the largest producer

USA produced 30 million gallons in 2004.

Running a Bus on Vegetable Oil

•The stored energy in vegetable oil can power a vehicle

•A diesel engine will run on straight vegetable oil, but oil needs to be heated prior to use

•Biodiesel can be used in any diesel engine with no modifications to the vehicle.

•Due to difference in viscosity

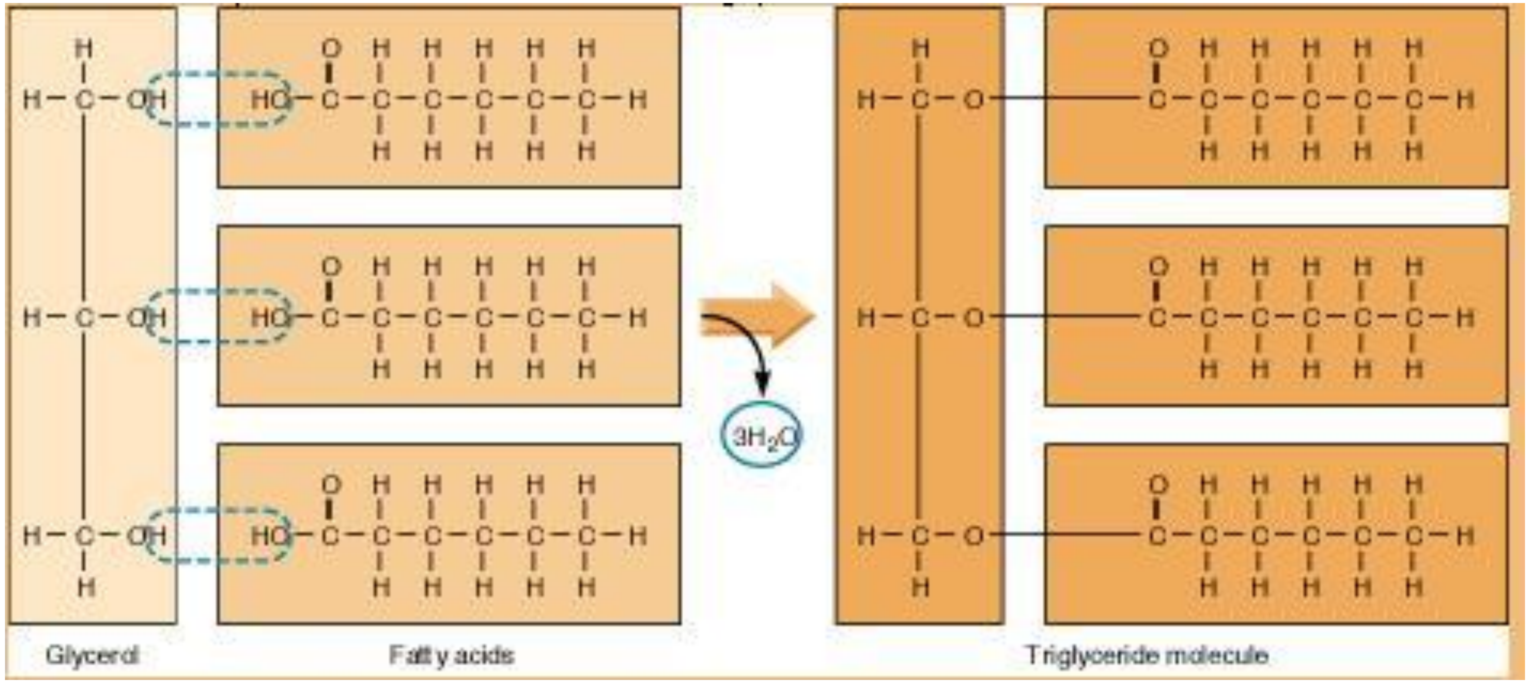
Biodiesel can be used in existing Diesel Engines

- Pure Biodiesel (B100) or blended with petroleum diesel (B20, BXX).
- Rudolf Diesel: peanut oil.
- Little or no engine modifications
- Use existing fuel distribution network.
- Available now

Michael et al., 2005

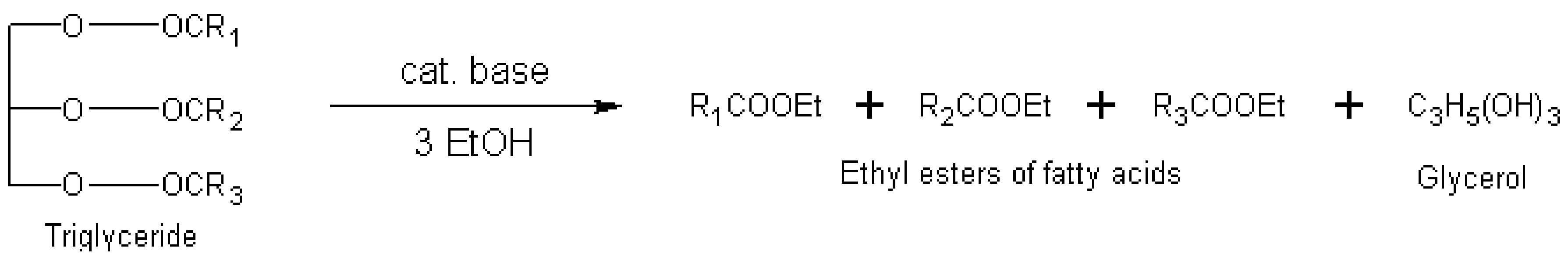
Chemistry of Triglycerides

- Biodiesel is made from the combination of a triglyceride with a monohydroxy alcohol (i.e. methanol, ethanol…).
- What is a triglyceride? Made from a combination of glycerol and three fatty acids:



Bio-diesel

A reaction scheme for transesterification is as follows:



Used vegetable oils, vegetable oils, Algae

Transesterification

While actually a multi-step process, the overall reaction looks like this:

CH2OOR1 catalyst CH2OH
| ↓ |
CHOOR2 + 3CH3OH ⇔ 3CH3OORx + CHOH
| |
CH2OOR3 CH2OH

Triglyceride *3 Methanols* *Biodiesel* *Glycerin*

R1, R2, and R3 are fatty acid alkyl groups (could be different, or the same), and depend on the type of oil. The fatty acids involved determine the final properties of the biodiesel (cetane number, cold flow properties, etc.)

Michael et al., 2005

Individual step of Transesterification

First step, triglyceride turned into diglyceride, methoxide (minus Na) joins freed FA to make biodiesel, Na joins OH from water (from methoxide formation) to make NaOH. Other H joins the diglyceride.

```
  |  |                                   |
HCOR1          H                      HCO           H  O
  |            |                       |            |  |
HCOOR2   +   HCONa   +H2O   ⇔    CHOOR2  + HCOR1   + NaOH
  |            |                       |            |
HCOR3          H                      HCOR3         H
  |   |                               |   |
  H   O                               H   O
```

Triglyceride + *Methoxide* + *H_2O* ⇔ Diglyceride + Biodiesel + NaOH

Industrial Biodiesel System 40.000 ton/year – Client: Brasil Ecodiesel

Industrial Biodiesel System 40.000 ton/year – Client: Brasil Ecodiesel

Industrial Biodiesel System 100.000 ton/year – Client: Brasil Ecodiesel

What makes biodiesel sustainable?

• Reduced reliance on petroleum & crude oil products, all finite resources

• Reduced emissions of greenhouse gases.

• Economic growth in the form of employment in regional & rural areas.

• Diversification of income & economy in these regional & rural sectors.

• Improved air quality, particularly in high smog & population dense areas.

• Reduced production of waste oil

• Positive environmental impacts with sustainable production of feedstocks.

• Reduced pollution for water and soil sources .

• Decreased reliance on external/foreign supplies of oil increased security for energy supplies.

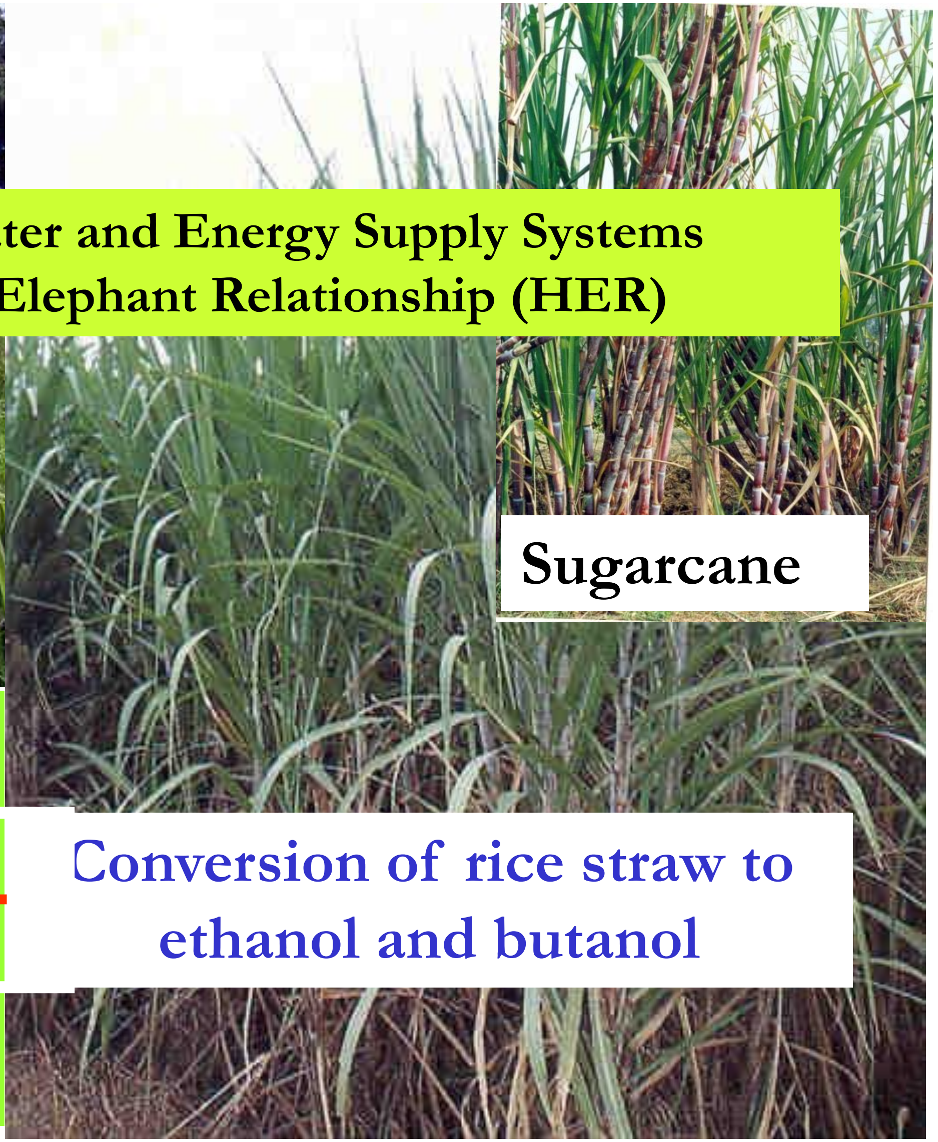
(www.biofuels.coop)

- Biodiesel production involves reacting lipids with an alcohol (often methanol, which is associated with a range of health issues) using a catalyst such as sodium or potassium hydroxide (both caustic) to produce biodiesel and glycerol (Law et al., 2011; Swanson et al., 2007).

- Other noted risks in workers involved in biofuel production include those from air pollution, explosions and fires, and falls (Gunderson, 2008; Hira et al., 1983; Law et al., 2011).

Replacement of petroleum by bioethanol and butanol

Development of Food, Water and Energy Supply Systems
for a Symbiotic Human-Elephant Relationship (HER)



1,000,000 ha
15.6% of
landmass

100%
replacement of
liquid fuels

+

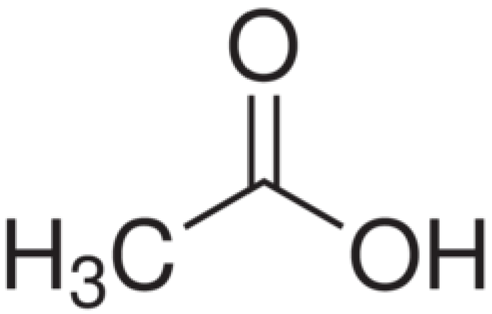
Conversion of rice straw to ethanol and butanol

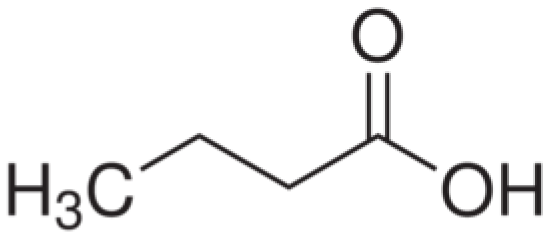
Butanol

For over 40 years, the world's butanol supply has been produced industrially via microbial fermentation.

Butanol is produced as a fermentation product by bacteria; known as, solventogenic *Clostridia*, when cultured on glucose-rich media containing acetic acid and butyric acid.

Much effort is currently being made to reduce production costs to make butanol an economically viable option.





Acetic Acid
MW: 60.05
bp: 117-118 ˚C

Butyric Acid
MW: 88.11
bp: 162 ˚C

Butanol
MW: 74.12
bp: 116 – 118 ˚C

Butanol (also butyl alcohol) refers to a four-carbon alcohol.
Formula : C_4H_9OH.

There are four possible isomeric structures for butanol, from a straight-chain primary alcohol to a branched-chain tertiary alcohol.

As a fuel

- Butanol is considered as a potential biofuel (butanol fuel).
- Butanol at 85 percent strength can be used in cars designed for gasoline (petrol) without any change to the engine (unlike 85% ethanol).
- It contains more energy for a given volume than ethanol and almost as much as gasoline, so a vehicle using butanol would return fuel consumption more comparable to gasoline than ethanol.
- Butanol can also be used as a blended additive to diesel fuel to reduce soot emissions.

Other Uses

- Butanol sees use as a solvent for a wide variety of chemical and textile processes, in organic synthesis and as a chemical intermediate.
- It is also used as a paint thinner and a solvent in other coating applications where it is used as a relatively slow evaporating latent solvent in lacquers and ambient-cured enamels. It finds other uses such as a component of hydraulic and brake fluids.
- Butanol is used in the synthesis of 2-Butoxyethanol[6] .
- It is also used as a base for perfumes, but on its own has a highly alcoholic aroma.
- salts of butanol are chemical intermediates; for example, alkali metal salts of *tert*-butanol are *tert*-butoxides.

Properties of butanol and other biofuels

Fuel	Combustion energy [MJ/dm^3]	Evaporation heat [MJ/kg]	RON Research Octane Number	MON Motor Octane Number
Petrol	32	0.36	91÷99	81÷89
Butanol	29.2	0.43	96	78
Ethanol	19.6	0.92	130	96
Methanol	16	1.2	136	104

Biobutanol Production Methods

- Production of butanol by the anaerobic fermentation is one of the oldest industrial method for obtaining this organic solvent.
- Butanol can be obtained using several chemical technologies.
- It is also possible to produce butanol in the process of fermentation by means of bacteria of the genus
- *Clostridium*. This process occurs under anaerobic conditions butanol as one of the products - called biobutanol

- The most popular bacteria species used for fermentation is Clostridium acetobutylicum.
- Such fermentation is so called ABE (*acetone-butanol-ethanol*), due to the names of the main products of this process, the typical ratio of these compounds being 3:6:1.
- The final concentration of butanol is about 3%

In the course of industrial production of biobutanol, using a fermentation process the factors should be considered,

- Evaluation of the process profitability
- The cost of raw material and its pretreatment, a relatively small amount of product obtained, its significant toxicity
- Cost of product recovery from fermentation broth

- *Clostridium acetobutylicum* belongs to the amylolytic bacteria.
- Therefore a good substrate for production of butanol for these bacteria is starch.
- For the production of butanol there are commonly used agricultural wastes for example: straw, leaves, grass, spoiled grain and fruits etc. which are much more profitable from an economic point of view.
- One looks for other sources of plant biomass, which production does not require a lot of work and costs (eg. algae culture).

- Modern research on ,

1. The production process of biobutanol focuses on finding the best kind of substrate for fermentation process and for efficient strain of bacteria.
2. The genetic modification the bacteria *Clostridium acetobutylicum* and *Clostridium beijerinckii* in order to increase the resistance of bacteria to the concentration of butanol in the fermentation broth

Methods for removal of butanol from the broth

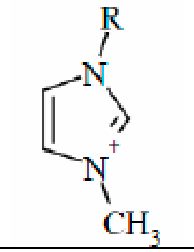
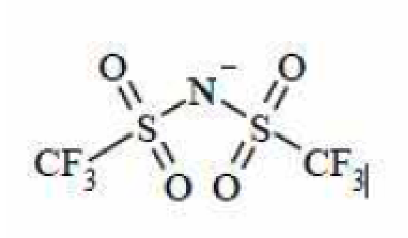
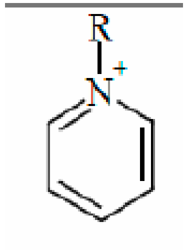
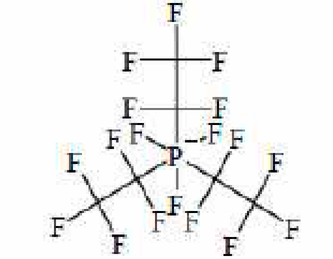
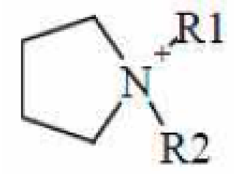
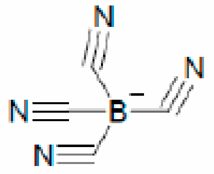
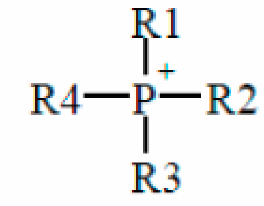
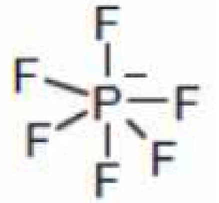
- The method eliminates the toxic effect of butanol on bacterial cells is a systematic removal of this compound from the fermentation broth.
- The traditional method of product recovery is distillation.
- Distillation is a process energetically and economically unfeasible, as the boiling point of water is lower than the maximum concentration of butanol and butanol fermentation broth is 3% by weight.
- Therefore, currently other methods are used such as adsorption, membrane pertraction, extraction, pervaporation, reverse osmosis or "gas stripping"

Butanol recovery by adsorption

- Adsorption is investigated in the butanol separation from fermentation broth but the capacity of adsorbent is very low and cannot be used on industrial or semi - industrial plant.

Butanol recovery by gas stripping

- Among various recovery techniques, gas stripping is a promising technique that can be applied to butanol recovery during ABE fermentation.
- Separation of volatile compounds can be obtained by lowering the pressure, heat or the use of inert gas.

List of cations and ions in ionic liquids, IL	
Cation	Anion
	
	
	
	

Butanol recovery by pervaporation

- Pervaporation is one of the promising techniques for the removal of toxic substances for *Clostridium acetobutylicum* such as butanol, ethanol and acetone.
- This method involves the selective transport by diffusion of some components through a membrane.
- A vacuum applied to the side of permeate.
- The permeated vapours should be condensed on low pressure side.
- The drawback of the method can be high costs to produce low pressure at low pressure side of the membrane.

Application of ionic liquids

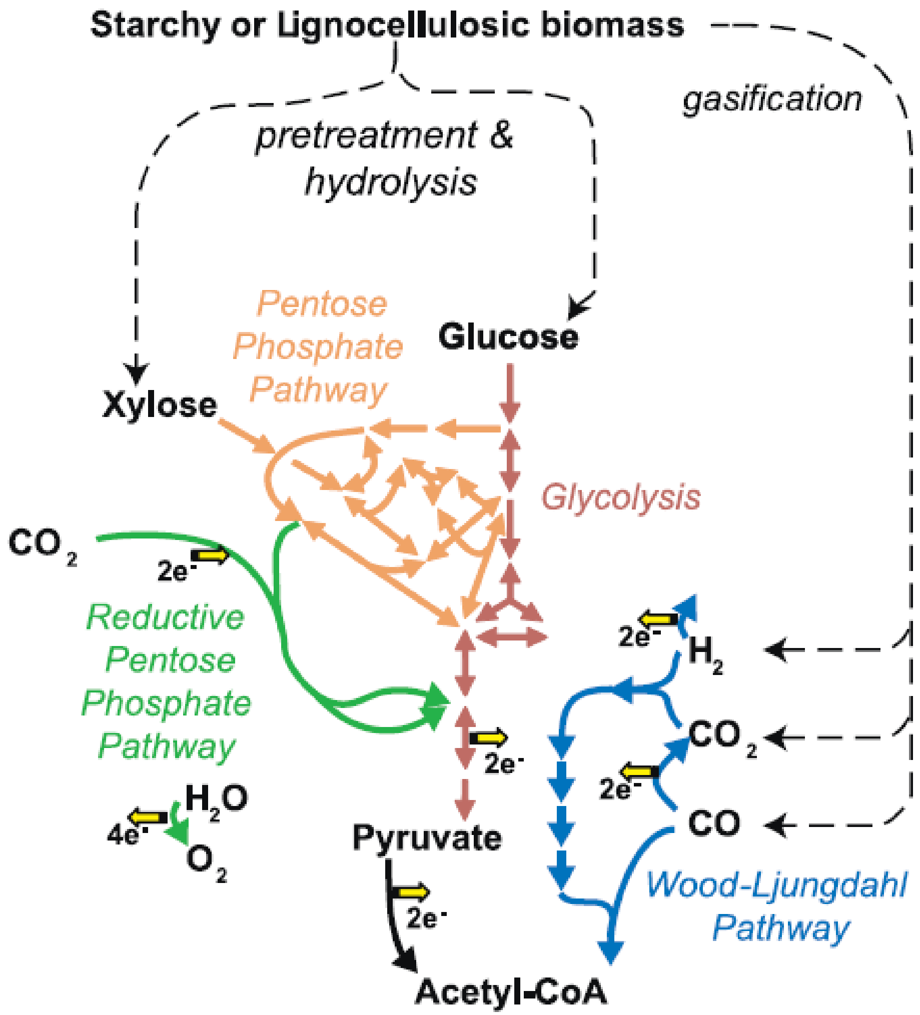
- Release of butanol from fermentation broth is a very difficult technical problem. The
- extraction process using conventional solvents may be useful, but requires the use of
- solvents which are often volatile, toxic and dangerous

Bio-ethanol

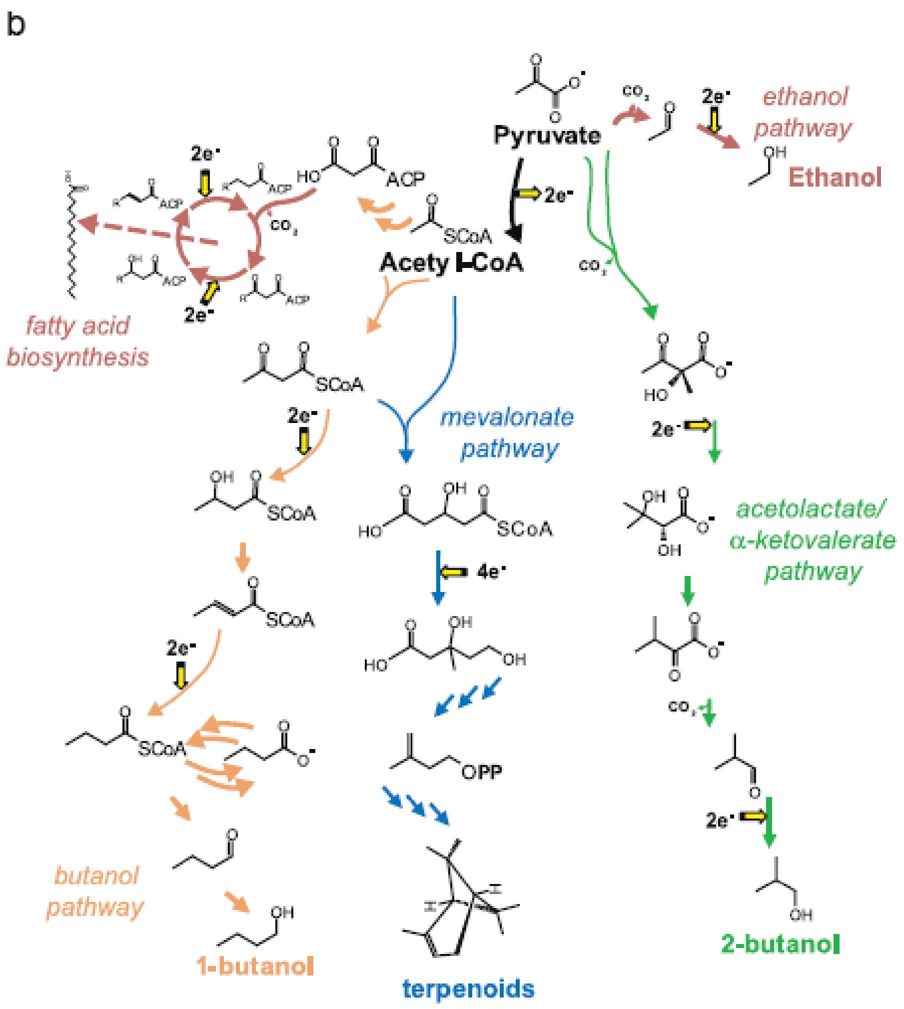
- Bio-ethanol is made by fermenting and then distilling starch and sugar crops

Eg: Maize Sorghum Potatoes, Wheat
Sugar-cane Cornstalks, Fruits Vegetable
Grass MSW

- Ethanol is a highly efficient fuel.



Feed pathways, which convert carbohydrate biomass into the central metabolic intermediates pyruvate and acetyl-CoA



Product pathways, which convert these central intermediates into fuel

Physical properties of ethanol

- Chemical formula - C_2H_5OH
- Molecular weight - 46
- Heating value (kJ/kg)

  - High value 29.76

  - Low value 26.84
- Latent heat of vaporization

  (kJ/kg) 842.82
- Specific gravity (15^0C) 0.794

- Boiling temperature 78.5 ^{0}C
- Stoichiometric ratio 9:1
- Octane number 106
- Energy of Stoichiometric mixture
  (kJ/m^3) 1076.31

Compatibility of Ethanol

- Ethanol largely fails the requirement for compatibility with existing fuel infrastructure.
- Ethanol can cause materials corrosion and draw water into the fuel mixture, properties which render it unsuitable for use in the existing fuel distribution infrastructure.
- Increased use of ethanol in large quantities may thus necessitate large infrastructure investments.

- Alcohol blends up to a 10, 20 or even 25% concentration of alcohol can be used without modify the engine
- Slight modification with carburetor allow the use of blends in the 25-40% range.
- Adding ethanol to petrol "oxygenates" the fuel, it burns more completely and reduces polluting emissions such as carbon monoxide
- If we used solar energy and membrane technology that reduce separation cost to have ethanol concentration close to 100%

However, cellulosic biomass is more difficult to convert into fermentable sugars than is corn or sugarcane, because

(i) Five-carbon sugars, mainly xylose, account for 10–25% of the total carbohydrates;

(ii) Of the presence of lignin, a highly recalcitrant network polymer of aromatic alcohols that accounts for 17–25% of common cellulosic biomasses(Mariset al., 2006);

(iii) Cellulose is much more resistant to hydrolysis than starches and simple oligosaccharides.

- The first obstacle can be overcome through these selection and/or engineering of microbes capable of the anaerobic fermentation of xylose and other five-carbon sugars to ethanol.
- These five-carbon sugars are metabolized via the pentose phosphate. The advantages of Saccharomyces are high ethanol tolerance, and the ability to ferment at low pH and for go medium sterilization.
- The disadvantage is that Saccharomyces (like E. coli and Z. mobilis) cannot utilize cellulose or derived oligosaccharides directly.
- This necessitates that a biorefinery install its own dedicatedon-site cellulase production system, usually involving the aerobic cultivation of organisms such as Trichodermareseei (Zhang et al., 2006).

- Enzymatic degradation of lignin is too slow to be practical industrially, but lignin can be productively burned for power production, or gasified for thermochemical conversion.

- The third obstacle is the most important. Cellulosic biomass recalcitrance necessitates chemical ‘‘pretreatment’’ of cellulosic biomass to a partially hydrolyzed product that cellulase enzymes can more easily digest.

- A number of pretreatment variations have been proposed, but many generate fermentation inhibitors

- Another approach, called consolidated bioprocessing (CBP) and formerly referred to as direct microbial conversion(DMC), uses highly cellulolytic organisms like the thermophilic Clostridium thermocellum either exclusively or in co-culture with other thermophilic, higher-producing sugar fermenters (Lyndetal., 2002; Ng etal.,1981).

- These organisms permit cellulase production, cellulose hydrolysis, and fermentation to occur anaerobically in the same process vessel.

- Advantages are

(i) That the thermophilic nature of these organisms may also obviate requirements for medium sterilization by allowing operation at 60 1C,

(ii) Most clostridia can efficiently use xylose without recombinant modification, and

(iii) The cellulase production and cellulose digestion can occur the same vessel.

Disadvantages of CBP are

(i) The lower solvent resistance of clostridia(Demain et al., 2005),

(ii) Comparative difficulty in genetic modification of clostridia, even despite recent developments(Tyurin et al., 2004),

(iii) Increase denergetic demands for cellulase production in anaerobic environments (Lyndetal., 2002).

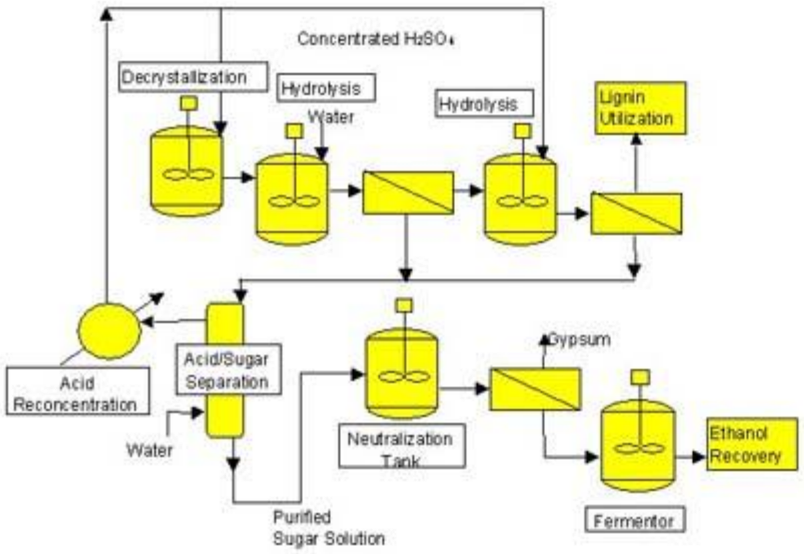
Health risks of ethanol

- Ethanol manufacturing include sodium hydroxide, ammonia, and sulfuric acid (all three are caustic chemicals) as well as yeasts, enzymes and antibiotics.
- Ethanol itself is known to cause skin and eye irritation, but evidence suggests occupational exposure is generally too low to increase cancer risk, at least where hygiene regulations are in place (Bevan et al., 2009).

Concentrated Acid Hydrolysis

- This process is based on concentrated acid decrystallization of cellulose followed by dilute acid hydrolysis to sugars at near theoretical yields.
- Separation of acid from sugars, acid recovery, and acid reconcentration are critical unit operations.
- Fermentation converts sugars to ethanol.

Generalized schematic of concentrated sulfuric acid process



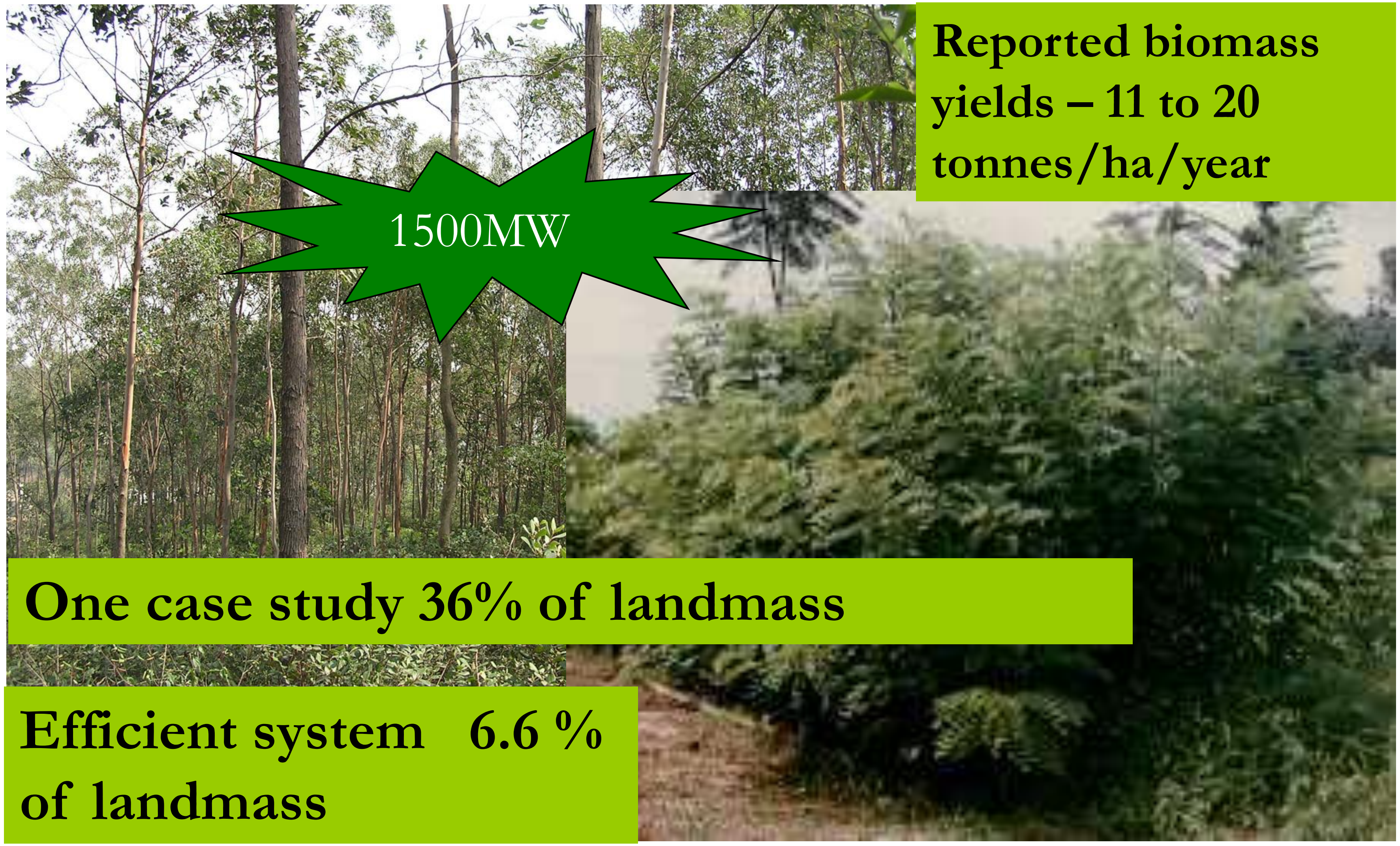
Commercial Status

- The concentrated sulfuric acid process has been commercialized in the past, particularly in the former Soviet Union and Japan.
- However, these processes were only successful during times of national crisis, when economic competitiveness of ethanol production could be ignored.
- Conventional wisdom in the literature suggests that the Peoria and TVA processes cannot be economical because of the high volumes of acid required.
- Improvements in acid sugar separation and recovery have opened the door for commercial application.
- Two companies in the United States are currently working with DOE and NREL to commercialize this technology by taking advantage of niche opportunities involving the use of biomass as a means of mitigating waste disposal or other environmental problems. (file:///C:/Users/DELL/Desktop/to%20do/biofuel_lecture/biofuel/Biofuels%20-%20Concentrated%20Acid%20Hydrolysis.htm

Syngas

- Syngas, sometimes called producer gas, is a mixture of carbon monoxide, hydrogen, and carbon dioxide.
- It can be prepared easily from biomass(or fossil fuels)by treatments at high temperature in the absence of oxygen (Suttonetal., 2001). Syngas can serve as the sole carbon and energy source for a variety of microorganisms, including ethanol and butanol producers.
- Carbon monoxide is oxidized to carbon dioxide by water via carbon monoxide dehydrogenase(CODHs).
- This reaction provides reducing power for anabolic COmetabolism via the Wood–Ljungdahl pathway(Ragsdale, 2004), where CO is converted to acetyl-Co Aviaacetyl-Co Asynthetase (ACS)enzyme

Replacement of Coal by Dendro thermal



Reported biomass yields – 11 to 20 tonnes/ha/year

One case study 36% of landmass

Efficient system 6.6 % of landmass

Energy densities, maximum yields and compatibility with existing fuel distribution infrastructure for various types of biomass and liquid fuels

	Molar energy density (kJ/mol)	Formula mass	Volumetric energy density (MJ/L)	Mass energy density (MJ/kg)	Bulk density (kg/L)	Maximum stoichiometric yield from glucose (kg/kg)	Infrastructure compatibility?
Petrofuels							
Gasoline		100–105	34.7	42.3	0.72–0.78	–	Yes
No. 2 diesel		~200	38.3	45.3	0.80–0.89	–	Yes
Example biofuels feedstocks							
Hybrid poplar wood	–	–	6–7.1	19.38 (dry basis)	0.310–0.370	–	No
Glucose	2803	180.155	24.3	15.6	1.562	–	No
Syngas ($CO+H_2$)	569	30.026		18.95	–	–	No
Candidate biofuels							
Ethanol	1367	46.07	23.6	29.9	0.792	0.511	No
n-Butanol	2676	74.121	29.2	36.1	0.81	0.411	Probable
Vegetable oil (canola)	35390	~887	36.2–36.7	39.8–40.0	0.910–0.917	~0.353	No
Biodiesel (methyl-esterified virgin canola)	12080	~298	35.7	40.6	~0.88	–	Partial and increasing
α-Pinene (representative terpenoid)	6205	136.234	38.9	45.5	0.8539	0.324	Unknown

- The potential of biofuel as an alternative source of energy in these ASEAN nations indicates that biofuel will form an important part of energy supply in these countries.

- A large variety of biofuel support policies are in place ranging from tax exemptions, mandatory blending targets,’sub-sidies and other financial schemes to stimulate the development and adoption of biofuels in the region.

Impacts and way forward

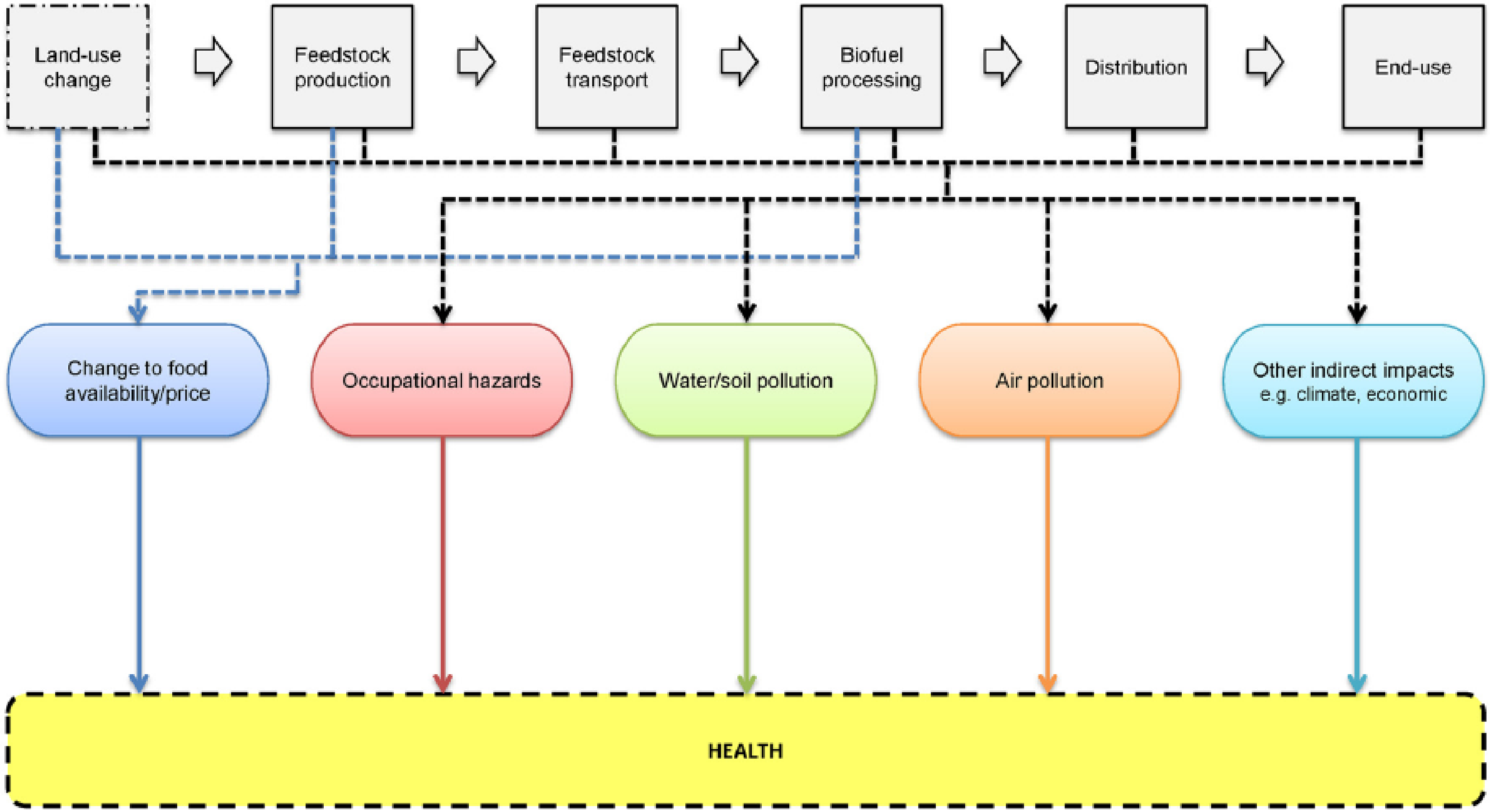
- Although biofuel development possess a number of socio- economic, environmental and technical benefits over fossil fuels, their impact particularly on land use, food prices and overall welfare of the farmers is still debated and cannot be overlooked.

- Biofuel development creates incentive to convert forests into biofuel crops thereby affecting land use and biodiversity.

- These ASEAN countries need to ensure that the energy security concern does not jeopardize the income and welfare of the poor.
- Although the biofuel expansion may generate additional income within the agriculture sector and open export markets for developing nations, the undernourished and vulnerable populations might remain unable to purchase food at these prices despite production capacity and food availability

- Opportunities under carbon finance of Kyoto Protocol, such as Clean Development Mechanism(CDM) could play a role to further raise the biofuels production and utilization in these countries.
- Production of second and third generation biofuels has been identified as one of the prioritized options for possible renewable energy mitigation technology under the national Technology Needs Assessment for climate change mitigation in Thailand.
- Biofuel development in these countries must take into account the full spectrum of market and societal values, such as forgone food and agricultural output, impacts on environmental services and overall improvement in the well being of the rural poor

Schematic depicting the life-cycle and major pathways to health associated with liquid biofuel production and use



- Production of second generation biofuels using agricultural residues and energy crops provide incentives to reduce the environmental impacts as Well as ensure welfare benefits to the poor.

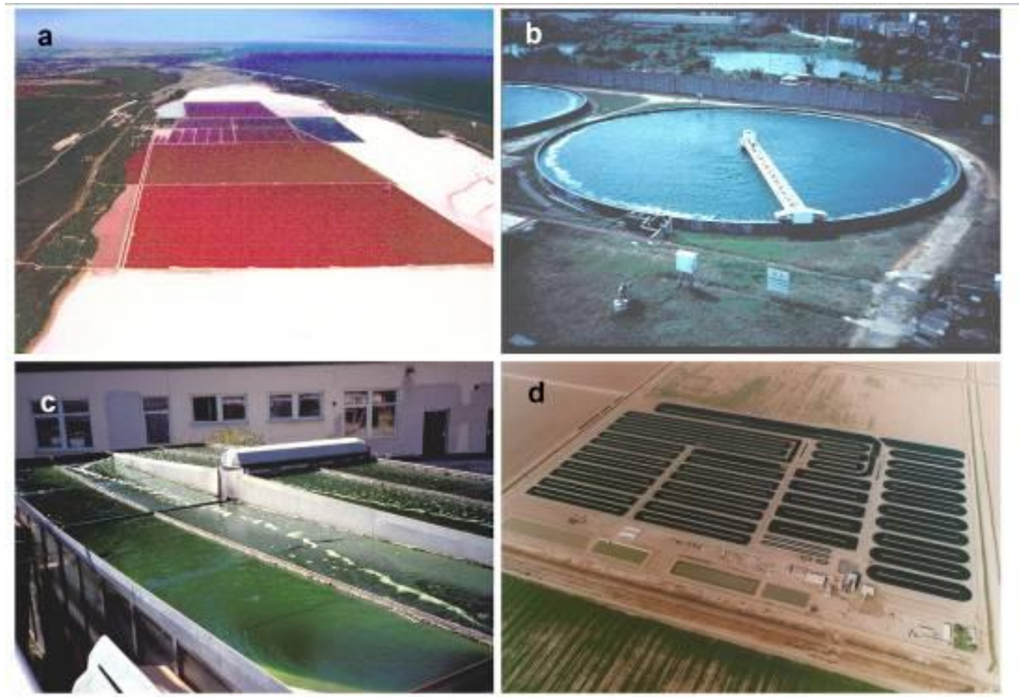
II. Policies to support biofuels

Instruments for supporting biofuels

- biofuel blending obligations (mandates)
- excise duty exemptions
- tariff protection
- crop (feedstock) subsidies
- R&D and investment supports
- fuel standards

Why Microalgae?

- Slow growth of higher plants
- High fresh water requirement of higher plants
- High cost of land for growing higher plants
- No competition with food supply



(Moheimani, xx)

Potential species

- There are many marine and freshwater species
- Photosynthetic, calcified, etc.
- High Lipid productivity
- High growth rate (45-180 times canola)

(Moheimani, xx)

Algae Biotechnology transforms Carbon Management from a Cost into a Revenue

Algal Biotechnology Converts Flue Gases & Sunlight into Biofuels through Photosynthesis

"Used" Algae have Multiple Potential Uses

Cleaned Gases

Power Plant / Energy Source

GreenFuel bioreactor

Flue Gases

NOx + CO2 from combustion flue gas emissions

Patented Algal Biotechnology

Co-Firing → **Green Power** Aus$60/t

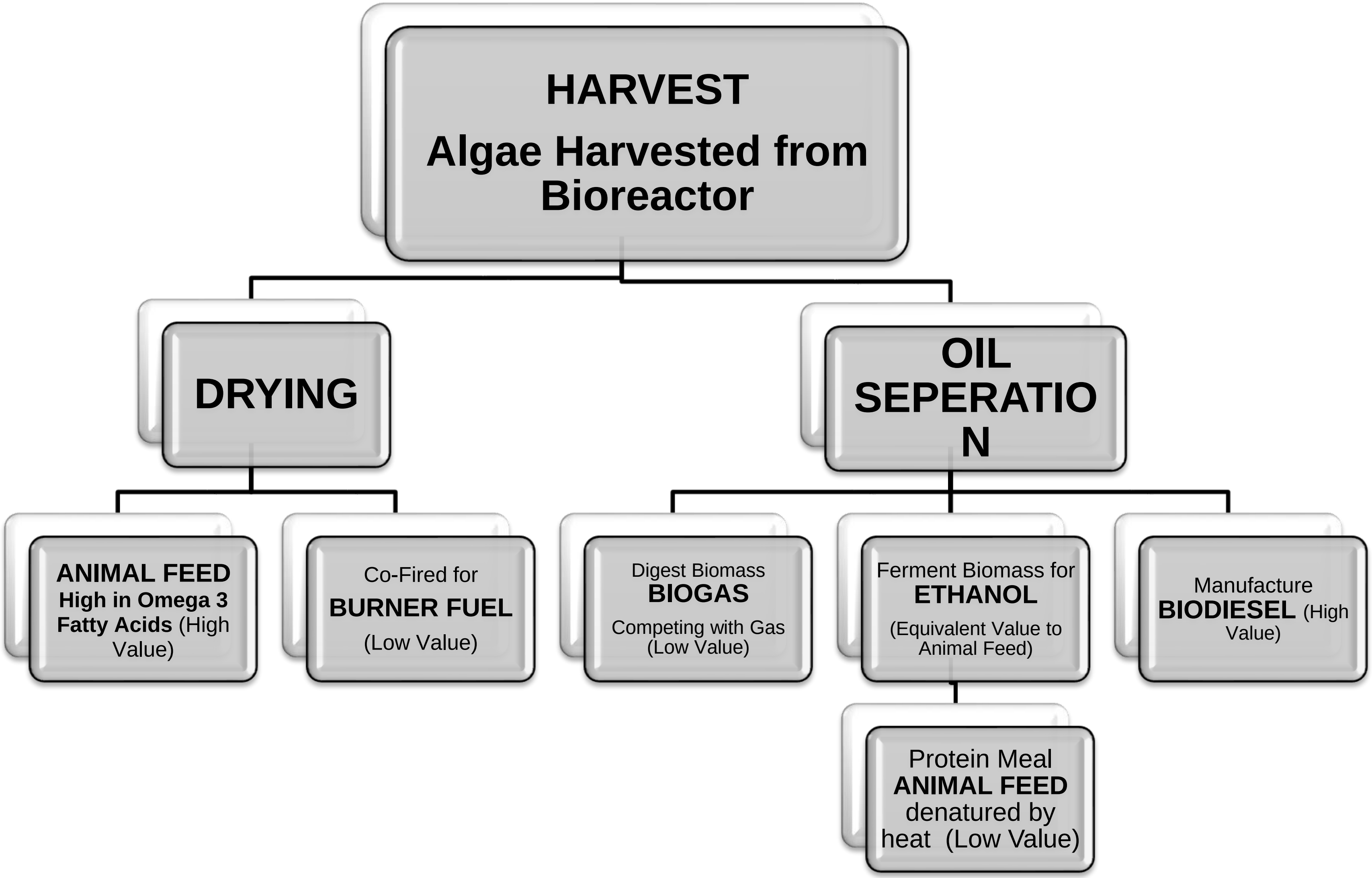
Esterification → **Biodiesel** Aus$700/t

Fermentation → **Ethanol** Aus$380/t

Drying → **Protein Meal** Aus$400/t

(Moheimani, xx)

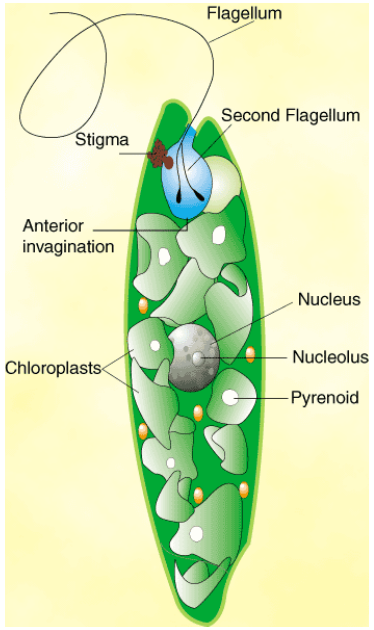
Potential Uses for Micro-Algae



(Moheimani, xx)

What is Algae?

- **Algae**
  - Simple plant
  - Most live in water
  - Photosynthetic
    - Capture light energy
    - Convert inorganic to organic matter
  - Nonvascular
  - Use lipids and oils to help float in water
  - Range from small, single-celled species to complex multicellular species, such as the giant kelps



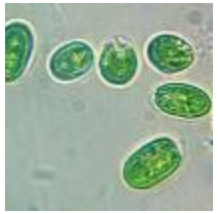
Background

- Location
  - Most habitats
- How many
  - Over 36,000 species
- How does it feed?
  - Photosynthesis
  - All have chlorophyll
- Uses
  - food, fertilizer, foodstock, pharmaceutical, pollution control, water treatment, dyes, agar, **Fuels**

(Sommers, 2007)

Why make it a fuel?

- Algae can be used to make biodiesel
- Produces large amounts **oil**
  - When compared to terrestrial crops grown for the same purpose
  - Algae contain anywhere between 2% and 40% of lipids/oils by weight
  - Once harvested, this oil can be converted into fuels for transportation, aviation or heating
- High growth rate and easy to grow
  - Warm Seasons
    - *Amphora sp.*
    - *Tetraselmis suecica*
  - Cold Seasons
    - *Monoraphidium minutum*
  - Use of diatoms and green algae



(Sommers, 2007)

Types

- Red Algae
  - Benthic
  - Macro

- Green Algae
  - Chlorophyll a and b
  - Plants
  - Freshwater

- Brown Algae
  - Benthic
  - Macro
  - Kelp
  - Marine

- Diatoms
  - Single celled
  - Silica cell wall

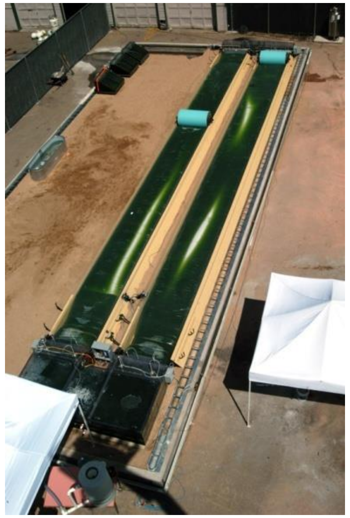
- Blue Green Algae
  - Vertical migration
  - Fix N_2 from air
  - Freshwater

- Dinoflagellates
  - Toxic; suck out O_2
  - Cause red tides
  - Organic matter

(Sommers, 2007)

Harvesting Biodiesel

- Microalgae have much faster growth-rates than terrestrial crops
- Algal-oil processes into biodiesel as easily as oil derived from land-based crops
- Use microalgae
  - Less complex structure
  - Faster growing rate
  - High oil content
- How to harvest
  - Open-pond systems
    - Can be difficult
    - Type of algae has to be hardy
    - Can be less hardy and grow slower
  - Use Bioreactor Tubes
  - Use existing infrastructures
    - Provides the raw materials for the system, such as CO_2 and nutrients
    - Changes those wastes into resources.



(Solix BioFuels, 2006)

Importance

- Algae is easy to grow
- Can produce a high yield of oil
- Oil can be processed into biodiesel
- Help to solve dependence on fossil fuels
- Can be better for the Earth

(Sommers, 2007)

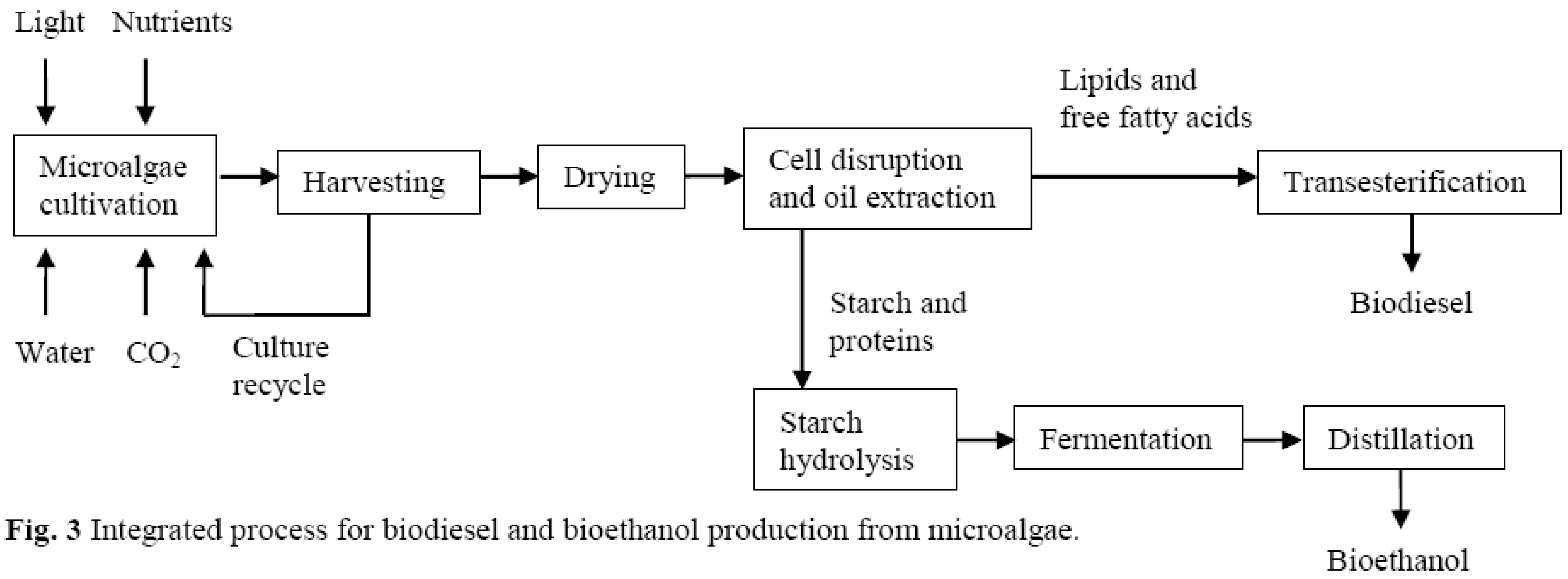


Fig. 3 Integrated process for biodiesel and bioethanol production from microalgae.

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