Biomass and Biofuels

Prof. Tony Bridgwater
BioEnergy Research Group
Aston University, Birmingham B4 7ET

Biomass

- Energy crops
- Agricultural and forestry wastes
- Industrial & consumer wastes

Why convert biomass?

- Biomass is a low energy density material with a low bulk density
- It is a widely dispersed resource
- It is difficult and costly to transport and store
- In N Europe, yields are limited by sunlight, rather than water as in S Europe, and land quality
- In Europe there are few sites that can sustainably produce more than about 100,000 dry t/y (~ 25MWe)
- Biomass is being increasingly traded internationally with one proposal for a 3 Gwe power plant in Rotterdam based entirely on imported biomass.

Renewable transport fuels

Oxygenates
- Methanol
- Ethanol
- Butanol
- Mixed alcohols
- Dimethyl ether

Hydrocarbons
- Biodiesel
- Synthetic diesel
- Synthetic gasoline
- Methane (SNG)

Other
- Hydrogen

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1st and 2nd generation biofuels

First generation biofuels are from foodstuffs such as:

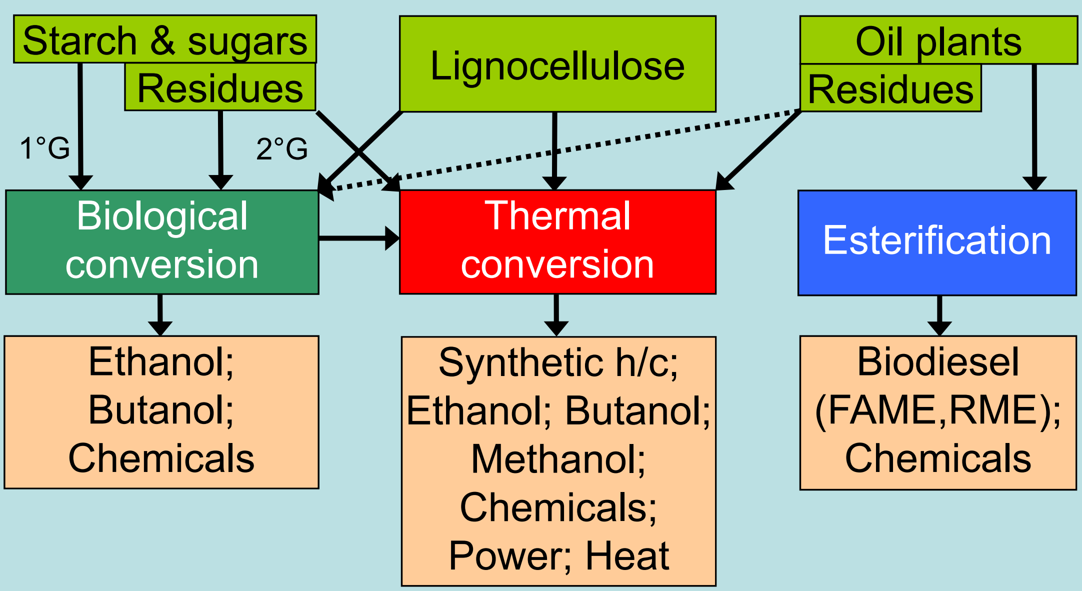
- Ethanol from sugar or corn – about 2 t/ha/y in Europe and North America, up to 6-7 t/ha/y from sugar cane in Brazil
- Biodiesel from vegetable oils – about 1-1.2 t/ha/y

These are, and will continue to be, important in introducing biofuels although the productivity is low.

Second generation biofuels are from whole crops such as wood, energy crops, residues, wastes. These are known as ligno-cellulosic feedstocks, Products include:

- Synthetic diesel – about 4 t/ha/y
- Methanol – about 8 t/ha/y
- Ethanol – about 5 t/ha/y

Feeds, processes, products



Thermal vs biological

- Thermal conversion
  - Dry feed needed
  - Fast processes
  - Less selective - Mixed products
  - More versatile in range of products and applications
- Biological conversion
  - Wet feed acceptable
  - Slow processes
  - More selective - Single product generally (e.g. ethanol)
  - Less versatile

Renewable transport fuels

Oxygenates	Generation	Process
Methanol	2°	Thermal
Ethanol	1° & 2°	Biological or Thermal
Butanol	1° & 2°	Biological or Thermal
Mixed alcohols	2°	Thermal
Dimethyl ether	2°	Thermal
Hydrocarbons		
Biodiesel	1°	Physical + chemical
Synthetic diesel	2°	Thermal
Synthetic gasoline	2°	Thermal
Methane (SNG)	1° & 2°	Thermal
Other		
Hydrogen	1° & 2°	Thermal or Biological

Bioethanol

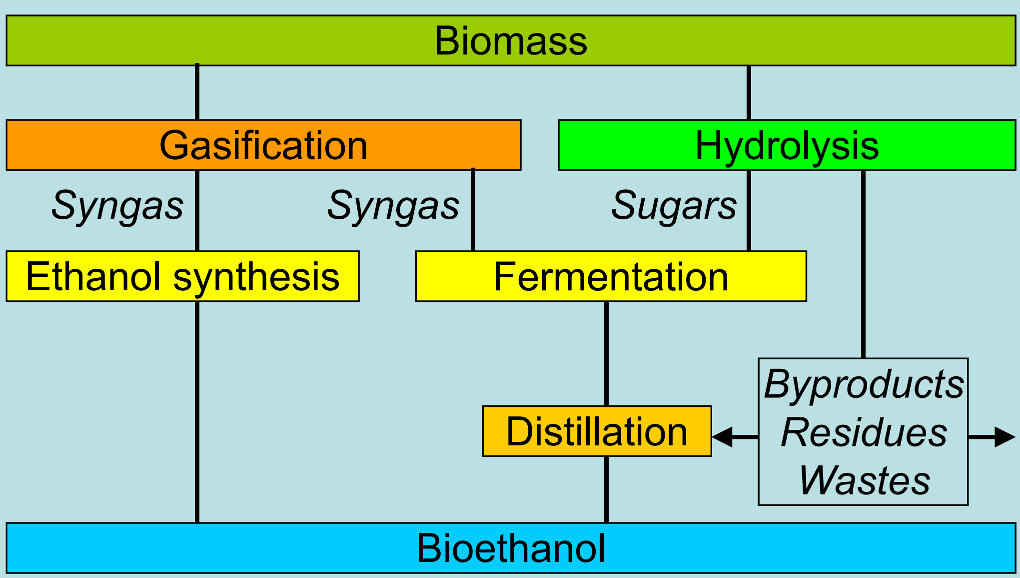
- Limited to 5% in gasoline in Europe (E5). Newer vehicles may tolerate 10% (E10)
- E85 (85% ethanol) is used in USA and E100 in Brazil
- Some problems remain
  - Logistical and market compatibility
  - Engine warranties
  - Vapour pressure
  - Materials
  - Fuel compatibility
- Flexible fuel cars available that can operate on any blend of ethanol and gasoline

Bioethanol in Brazil

Bioethanol technology

- Mature technology for 1st generation from sugar and corn.
- Developing technology for 2nd generation from lignocellulosics. Features include:
  - Acid/enzyme hydrolysis is needed to release the C6 and C5 sugars and separate lignin. This needs to be optimised.
  - C6 sugar fermentation is commercial.
  - C5 sugars fermentation needs to be demonstrated.
- Lignin needs to be utilised for energy efficiency
- Separation by distillation is preferred, but other separation methods are being developed such as membranes.
- In some cases more energy is input than is derived in the ethanol, and significant efficiency improvements are needed.

2° Generation bio-ethanol



Biodiesel

Methyl (or ethyl) esters of vegetable oil e.g. rape, soy, sunflower etc to reduce viscosity of raw oil and improve other properties.
RME = Rape Methyl Ester

FAME = Fatty Acid Methyl Ester

Applications

Limited to 5% in diesel in Europe due to engine warranty, materials and compatibility concerns

Renewable transport fuels

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Hydrocarbons		
■ Biodiesel	1°	Physical + chemical
■ Synthetic diesel	2°	Thermal
■ Synthetic gasoline	2°	Thermal
■ Methane (CSNG)	1° & 2°	Thermal
Other		
■ Hydrogen	1° & 2°	Thermal or Biological

Synthetic hydrocarbons

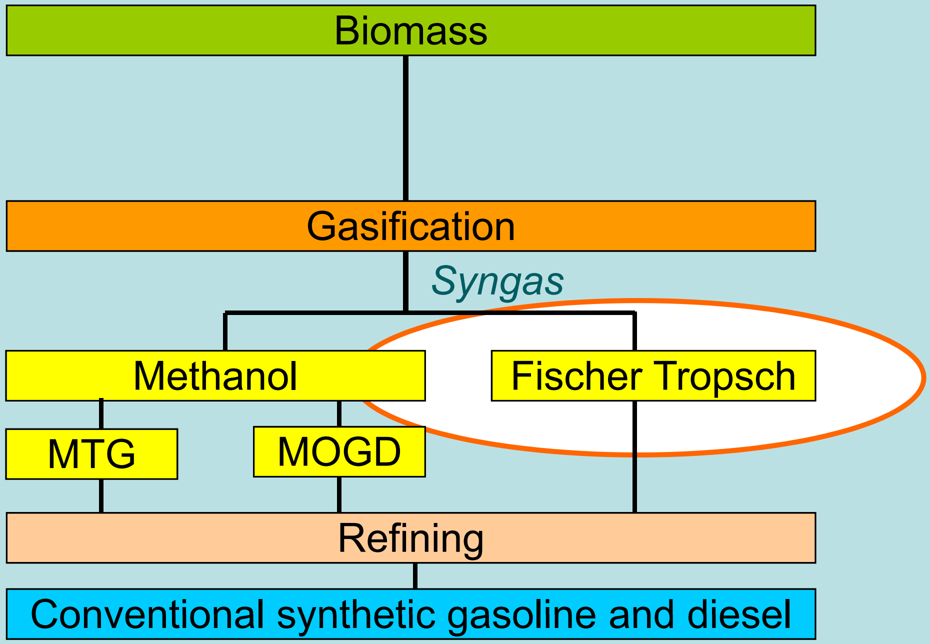
- Synthetic hydrocarbons include diesel, gasoline, kerosene
- They are entirely compatible with conventional fuels in all proportions, but are much cleaner.
- At least in the medium term, these are likely to be the biofuels of choice due to their marketability.

- The process is based on thermal biomass gasification to clean syngas and synthesis such as Fischer-Tropsch or methanol + MTG or MOGD
- Proven from coal in South Africa and from gas in Far East
- Biomass gasification technology is unproven at large scale. Gas cleaning is claimed to not be a problem, but there is no large scale experience

Routes to bio-hydrocarbon fuels

1. Thermal gasification to synthetic hydrocarbons
   a) + Fischer Tropsch
   b) + Methanol synthesis + upgrading by MTG or MOGD
2. Pyrolysis + upgrading
3. Hydro-processing vegetable oil

1: Biofuels via gasification



Gasification + Fischer-Tropsch

The minimum economic size of Fischer Tropsch is widely considered to be 20,000 bbl/day or 1 million t/y biofuels.

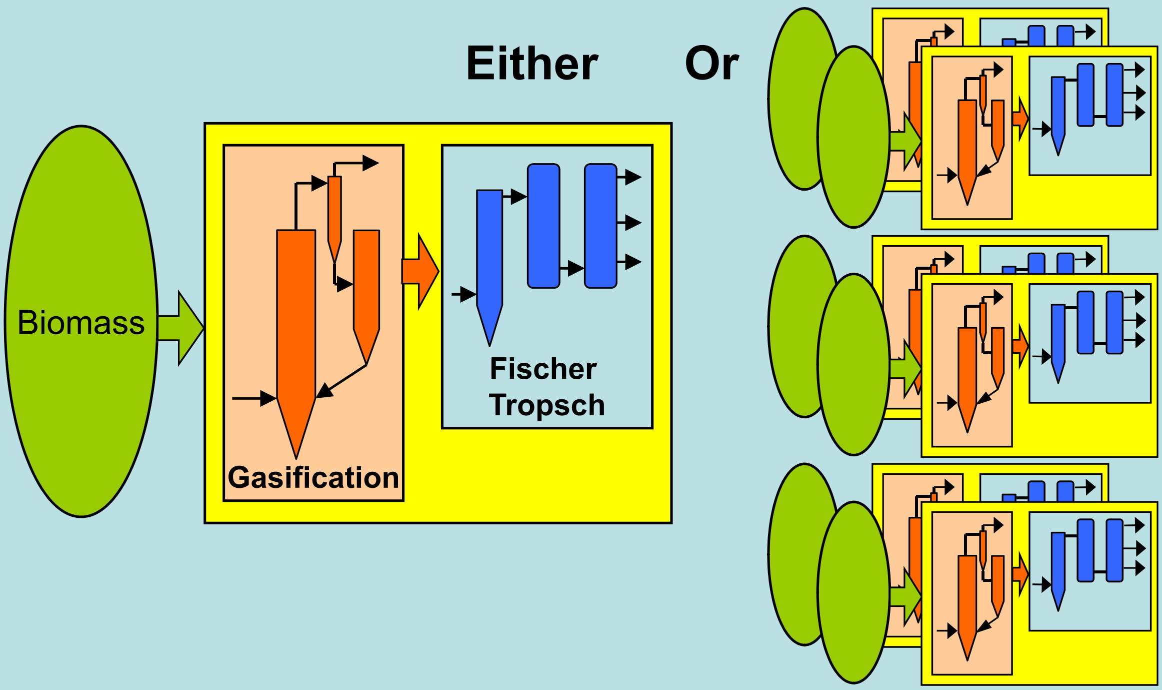
This requires about 5 million t/y biomass.

Biomass is a widely dispersed resource that is collected and transported over large distances at significant cost.

This leaves 2 options:

1. Large gasification plants integrated with FT synthesis at up to 5 million t/y biomass input.
2. Small multiple gasification plants integrated with downscaled Fischer-Tropsch (FT) hydrocarbon synthesis. Maybe 100,000 to 500,000 t/y biomass

Gasification + Fischer-Tropsch



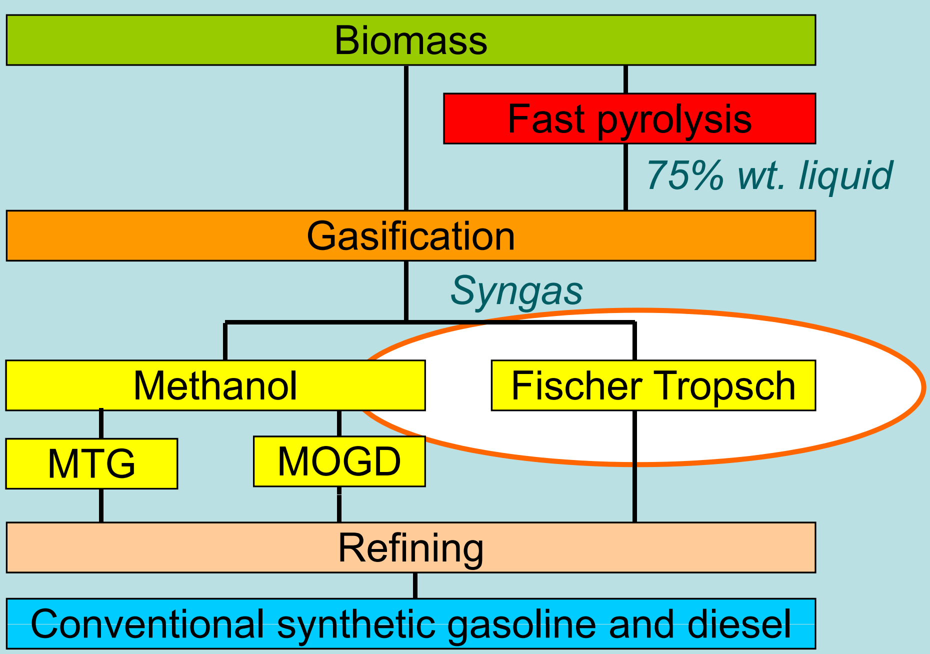
Challenges of gasification

- The necessary scale of solid biomass gasification has not been demonstrated for either option
- Gas cleaning and conditioning is a major technical and economic challenge. This increases as the extent and type of biomass contamination grows. Clean and consistent woody or annual energy crops are currently favoured, but these will face increasing competition.
- In all cases, economies of scale and feed costs dominate biofuel product costs
- Co-processing with coal is an interesting possibility

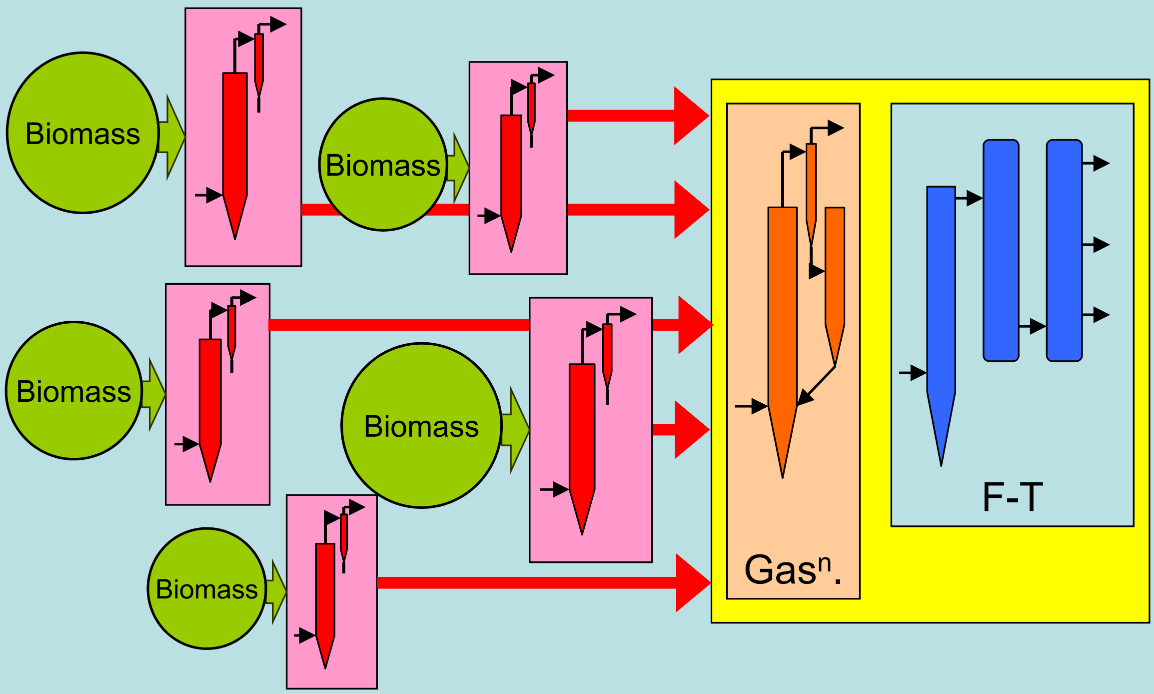
Alternative biomass transport

- Conversion of biomass to a liquid at source will reduce transport costs, reduce environmental concerns and reduce gasification costs.
- Pressurised oxygen gasification of liquids is easier and lower cost than solid biomass
- Fast pyrolysis is an available technology that can produce high yields of mobile liquid with up to 10 times the energy density of biomass and in a form that is easier to store and to transport and to process.

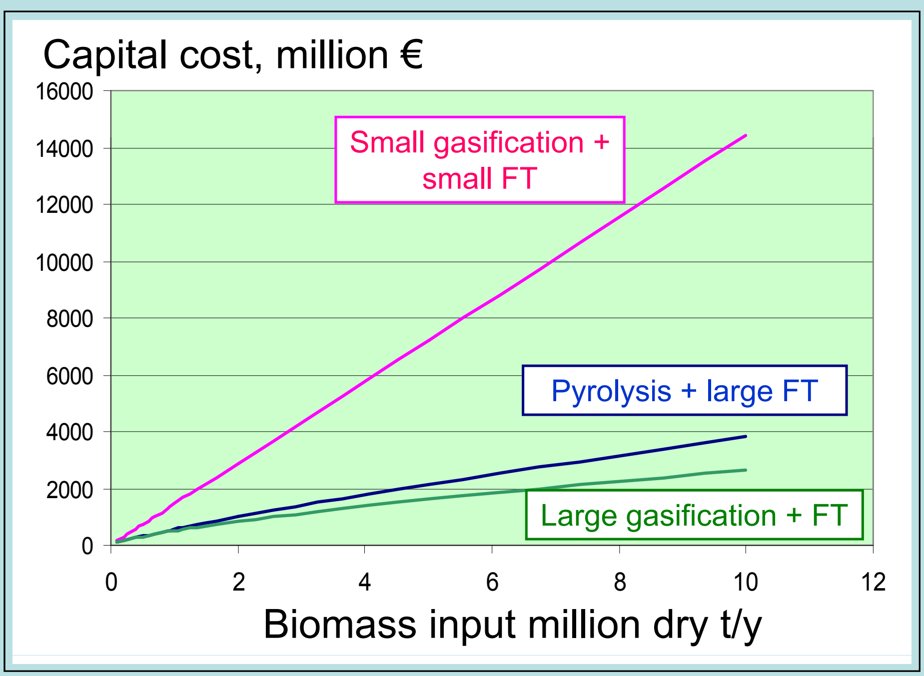
Pyrolysis for pretreatment



Pyrolysis + Fischer Tropsch



Capital costs



Small FT unproven

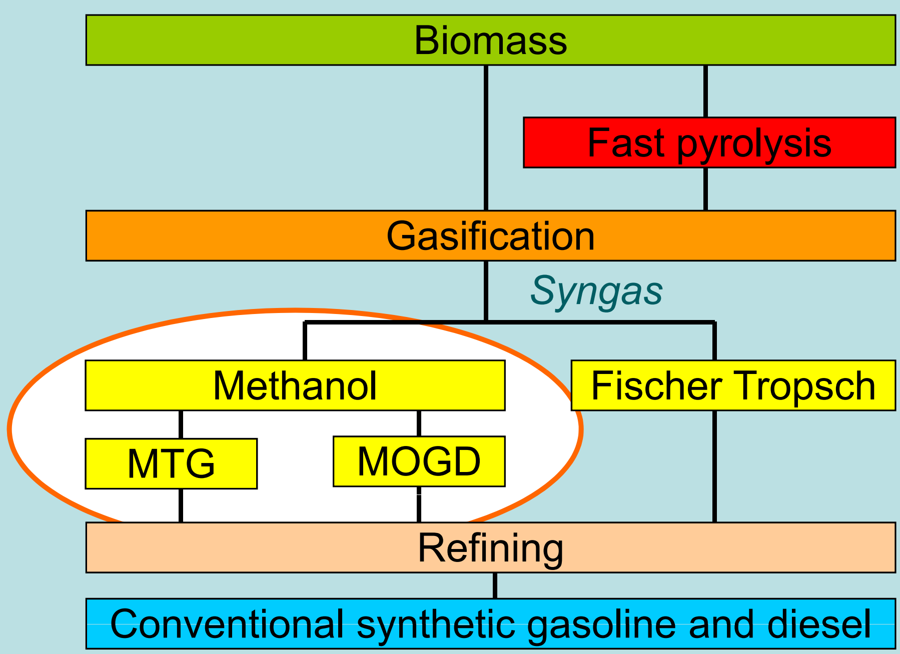
Small pyrolysis & large FT proven

Large gasification unproven

Comparison

- Capital cost increase of ~5% due to diseconomies of scale in small pyrolysis plants
- Capital cost reduction of ~10% due to lower raw material handling costs
- Capital cost reduction of ~5% due to lower gasification costs in feeding a liquid at pressure compared to solid biomass
- Capital cost reduction of ~5% due to lower severity gas cleaning requirements compared to solid biomass
- Efficiency loss of ~8% due to additional processing step

Hydrocarbons via methanol



Methanol based processes

- The same gasification considerations apply as with FT
- Methanol – well established technology from natural gas.
- MTG Methanol To Gasoline – commercial technology
- MOGD Methanol to Olefins, Gasoline and Diesel – well researched technology.

BUT

- MeOH, MTG, MOGD are more selective
- FT diesel is about 50% efficient on an energy basis,
- Methanol + MTG is about 64% overall on an energy basis BUT requires an additional processing step.

Routes to bio-hydrocarbon fuels

1. Thermal gasification to synthetic hydrocarbons
   a) + Fischer Tropsch
   b) + Methanol synthesis + upgrading by MTG or MOGD
2. Pyrolysis + upgrading
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2: Upgrading bio-oil directly

Direct production of liquids is attractive. Production of hydrocarbons requires rejection of the oxygen in bio-oil:

- **Hydro-processing** rejects oxygen as H_2O
  - Requires hydrogen, high pressure
  - Gives projected yield of around 25% naphtha-like product for refining, **without** considering the hydrogen requirement
- **Zeolite cracking** rejects oxygen as CO_2
  - Close coupled process requiring constant catalyst regeneration as in a FCC unit.
  - No hydrogen requirement, no pressure
  - Gives projected yield of around 20% aromatics for refining
  - This has only been researched.

Costs of upgraded bio-oil

	Yield, wt%	€/t product	HHV, GJ/t	€/GJ product	€/toe
Wood feed (daf)	100	67	20	3	145
Pyrolysis oil output	70	147	19	8	331
Hydrotreated oil	26	516	42	12	529
Diesel output	23	592	44	13	578
Aromatics output	21	471	44	11	460
Gasoline output	22	453	44	10	443
FT diesel	20		42		
MTG gasoline	26		43		
Crude oil at $100/bbl	-	560	43	15	560

Basis: 1000 t/d daf wood feed at 67 €/dry t, 2006

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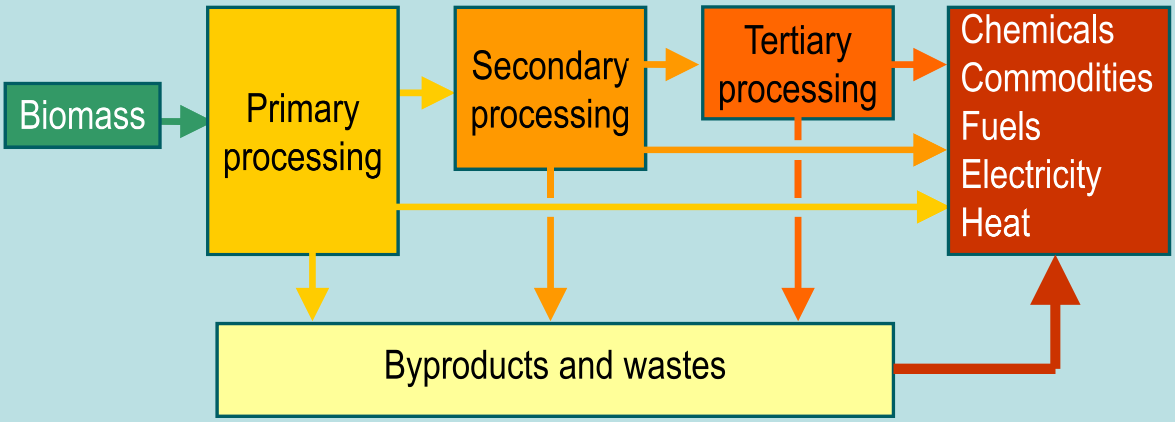
3: Hydro-processing vegetable oil

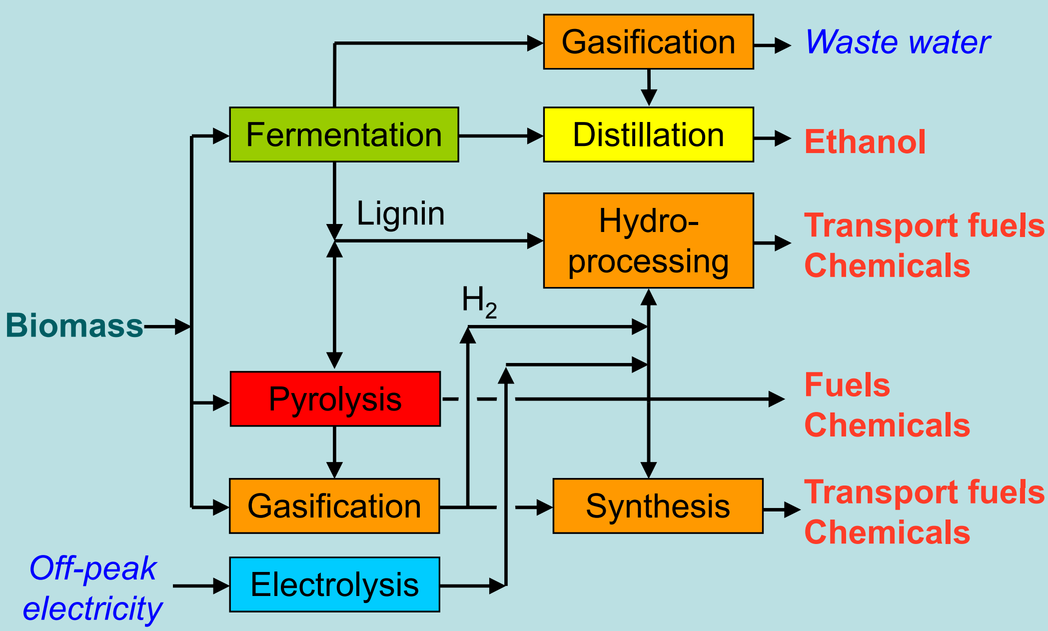
- Bio-diesel (by esterification of crude vegetable oil) is currently limited to 5% of conventional diesel.
- Vegetable oil can be hydroprocessed to synthetic diesel and Neste have built a 100,000 t/y plant in Finland and several other plants are in construction, based on palm oil and other vegetable oils.
- Generation "1½" as feed is a foodstuff and product is 2nd generation equivalent
- The hydrogen requirement is much less than fast pyrolysis liquid, but the vegetable oil productivity, sustainability and food competition issues remain.

Biorefinery concepts

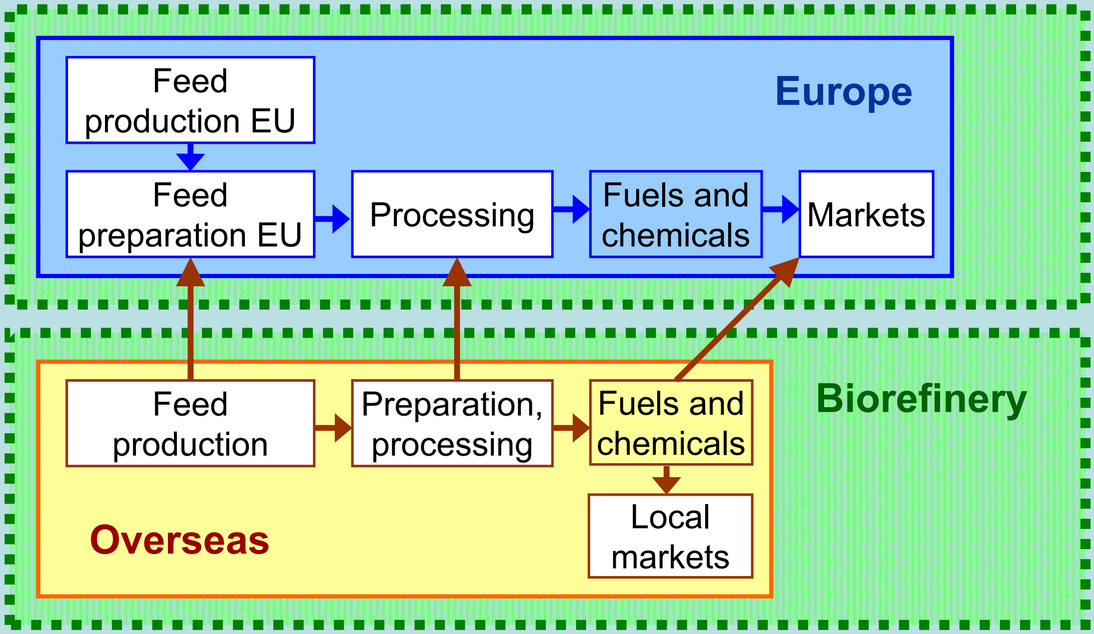
- Integrated production of higher value chemicals and commodities, as well as fuels and energy,
- Optimise use of resources, maximise profitability, maximise benefits, minimise wastes



Biorefinery options



Scenarios



Challenges

- Improve 1st and 2nd generation bioethanol technology
- Improve lignocellulosics pretreatment for 2nd generation
- Demonstrate C5 fermentation
- Demonstrate large scale thermal gasification and gas cleaning & conditioning
- Develop small scale hydrocarbon synthesis
- Develop and demonstrate fast pyrolysis liquids upgrading
- Develop integrated biorefineries
- Improve catalysts
- Robustly compare alternative systems
- Reduce costs
- Consider CCS with bioenergy
- Ensure there is a significant environmental contribution
- Consider biomass and biofuel trading

Key issues

Apart from technology improvement and demonstration, there are wider issues:

- Competition for land in producing food or fuel. This is more important in land scarce countries such as the UK.
- Competition between use of crops for food or fuel
- Biomass improvement – yield and quality
- Sustainability of biofuels
- Environmental contribution – how big are the benefits

Thank you

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