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Biomass Pyrolysis

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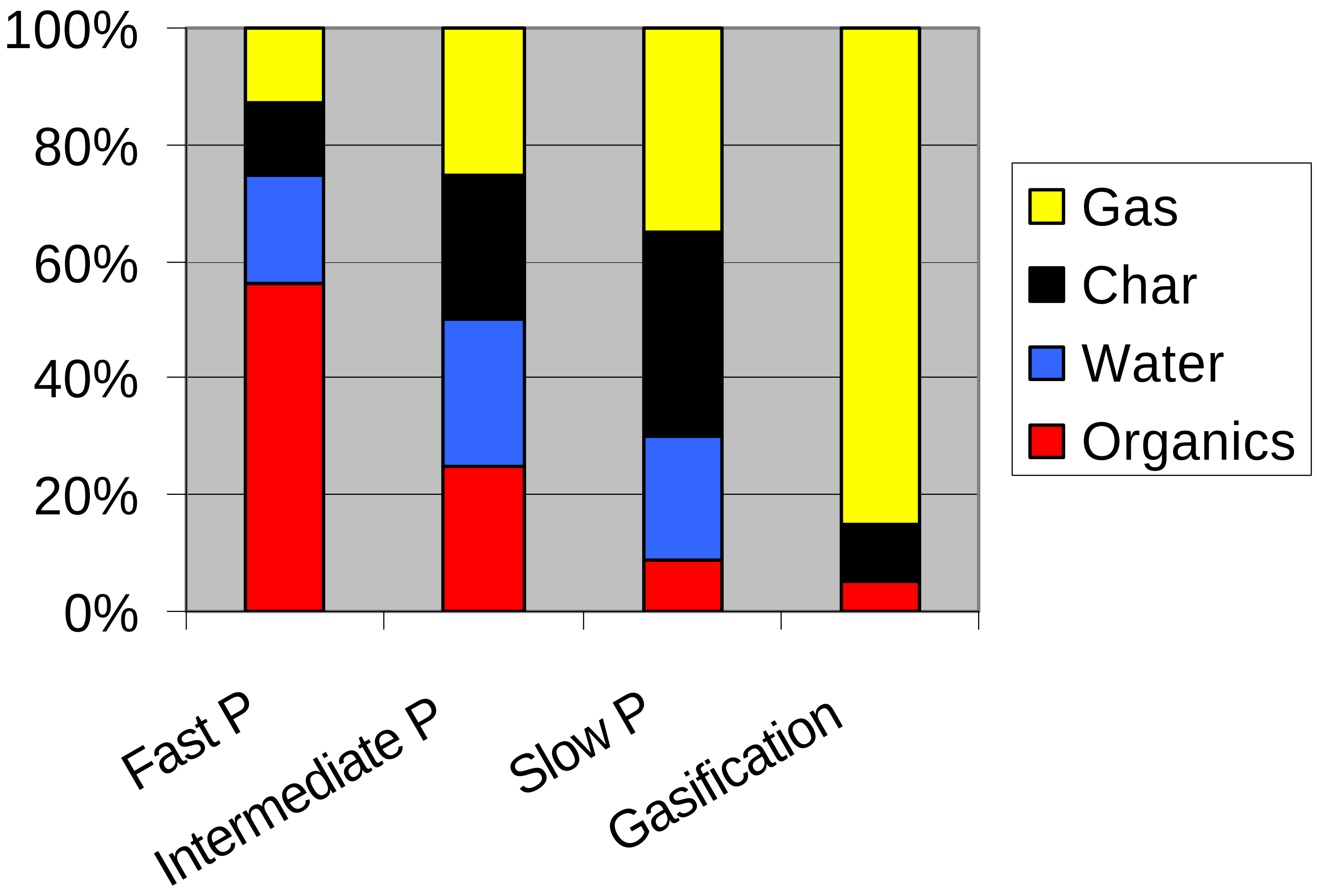
What is pyrolysis?

- Biomass is heated in the absence of air or oxygen to decompose or devolatilise the biomass into:
  - Solid char
  - Liquid as bio-oil, tar or pyroligneous liquor
  - Gas
- Three products are always produced
- Product yields depend on biomass, vapour and solids residence time, and temperature
- There are several modes of pyrolysis ....

Pyrolysis modes

Mode	Conditions *Wt % products*	*Liquid*	*Char*	*Gas*
Fast	~ 500ºC; very short hot vapour residence time (RT) ~1 s; short solids RT	75%	12%	13%
Inter-mediate	~ 500ºC; short HVRT ~10-30 s; moderate solids RT	50% in 2 phases	25%	25%
Slow	~ 400ºC; long HVRT; very long solids RT	35%	35%	30%
Torre-faction	~ 300ºC; long HVRT; long solids RT	Vapours	85% solid	15% vapours
Gasif-ication	~ 800-900ºC; short HVRT; short solids RT	1-5%	<1% (all burned)	95-99%

Process and product flexibility



Fast pyrolysis technology

- Fast pyrolysis aims to maximise liquids. This is achieved with very high heating rates usually requiring very small particle sizes of generally <3mm in size and < 10% moisture
- Clean wood gives highest liquid yield up to 75 wt.% on dry biomass feed. This is homogenous i.e. single phase, and low viscosity.
- The charcoal forms about 10-15 wt.% of the products. It retains virtually all the alkali metals.

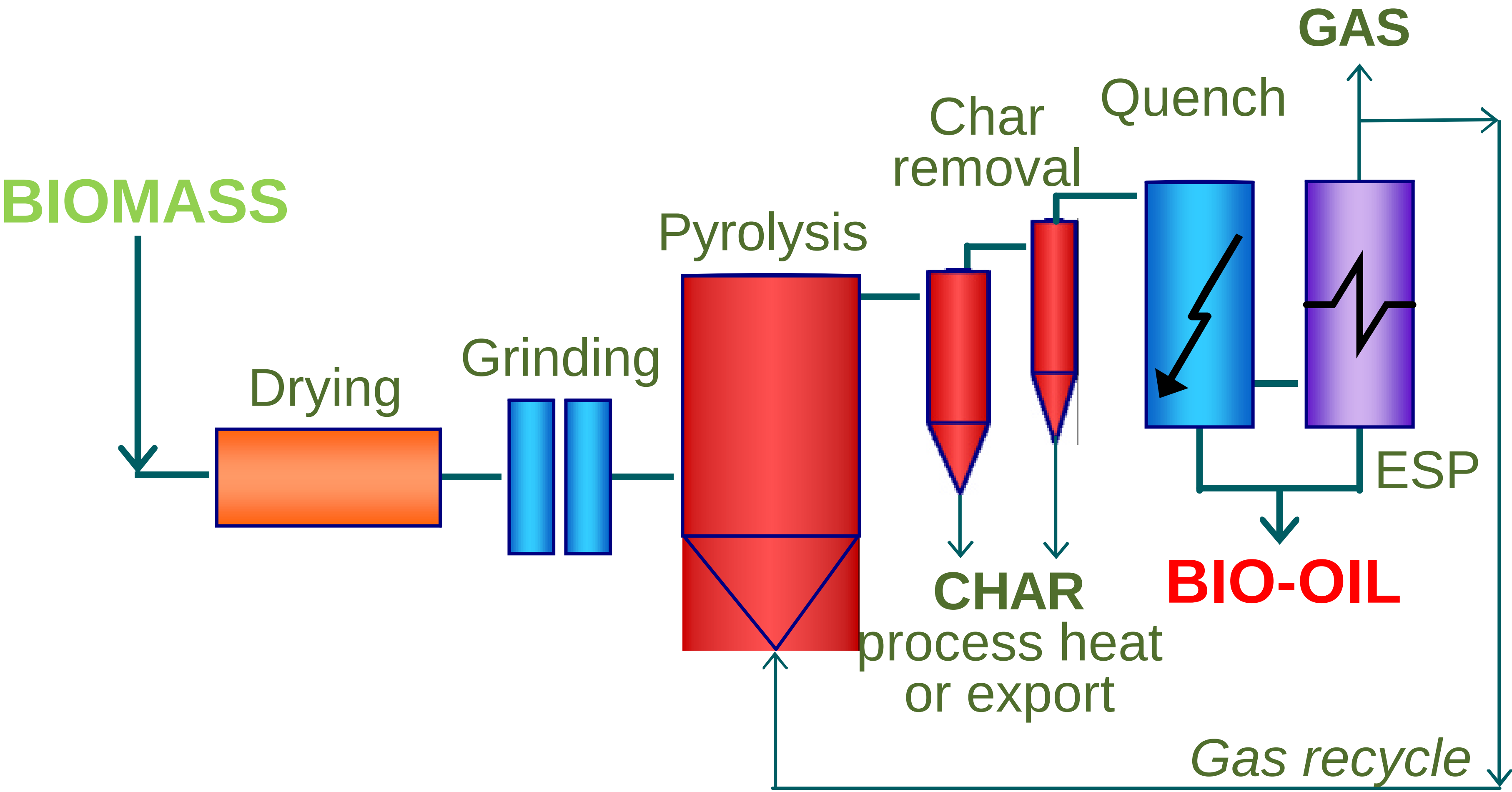
Fast pyrolysis reactors

Fluid bed
Spouted fluid bed
Transported bed
Rotating cone
Ablative

} **Commercial activities**

Circulating fluid bed
Vortex
Centrifuge reactor
Augur or Screw
Radiative-convective
Entrained flow
Microwave
Moving bed and fixed bed
Ceramic ball downflow
Vacuum

Typical fast pyrolysis reaction system



Fast pyrolysis: commercialisation

Dynamotive: 100 t/d and 200 t/d plants in operation in Canada

BTG: **5**0 t/d plant in Malaysia. 100 t/d in planning

Ensyn: 100 t/d plant in operation in Canada + 6 others in USA + 400 t/d planning

Fast pyrolysis liquid – bio-oil

Moisture content		25 %
pH		2.5
Specific gravity		1.20
Elemental analysis	C	56.4 %
	H	6.2 %
	O	37.3 %
	N	0.1 %
	Ash	0.1 %
HHV as made		17 MJ/kg
Viscosity (at 40°C)		40-100 cp
Solids (char)		0.1 %
Vacuum distillation residue		Max. 50%

Opportunities

- Fast pyrolysis can be used:
  1. for pretreatment and densification
  2. as a source of liquid fuel for direct use
  3. as a source of biofuels
  4. as a source of chemicals
  5. for byproduct / residue processing
  6. a combination of some or all of these

- It can be

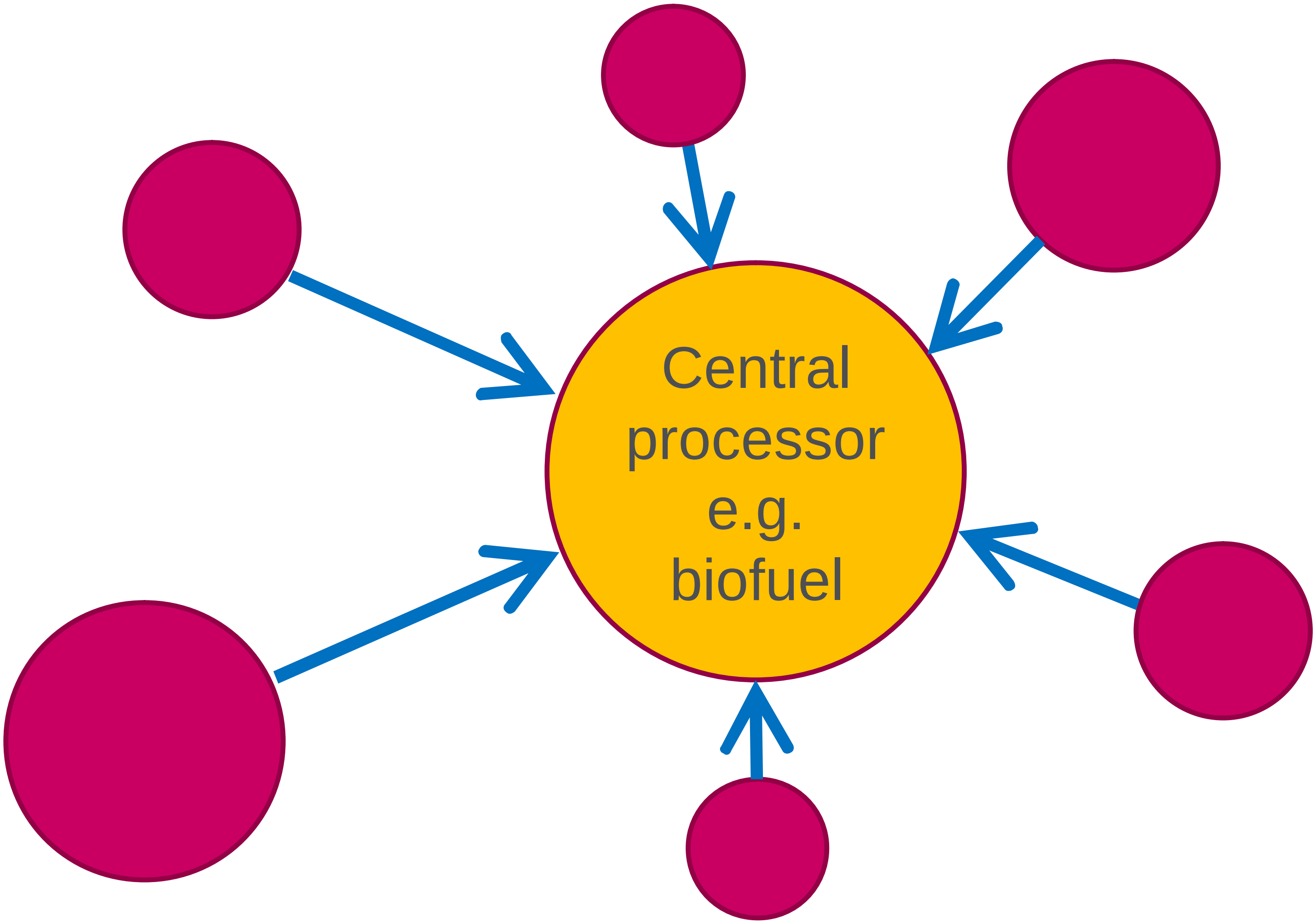
A. the primary processing method or

B. a supplementary processing method

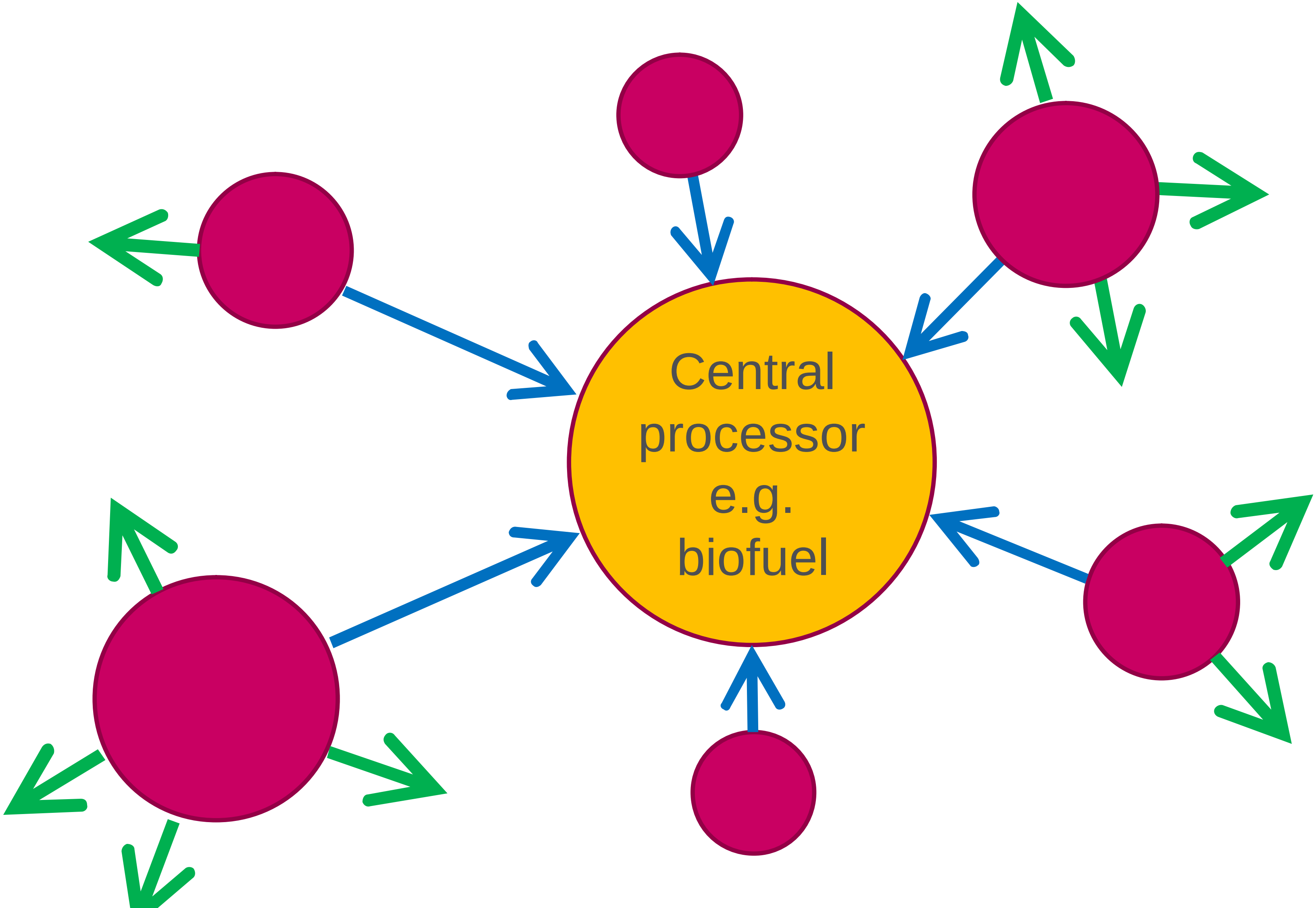
1 - Pretreatment and densification

- Bulk density
  - Biomass density can be as low as 100 kg/m^3
  - Bio-oil density is 1200 kg/m^3
- Bio-oil liquid storage
  - Tanks and pumps
  - No windblown refuse
  - No vermin
  - No mechanical handling
- Bio-oil handling and processing
  - Pumps or gravity feed
  - No mechanical handling
- Bio-oil transport
  - Pumps or gravity feed to enclosed vehicles or vessels
  - Optimum use of loading weight restrictions on vehicles.

Decentralised fast pyrolysis

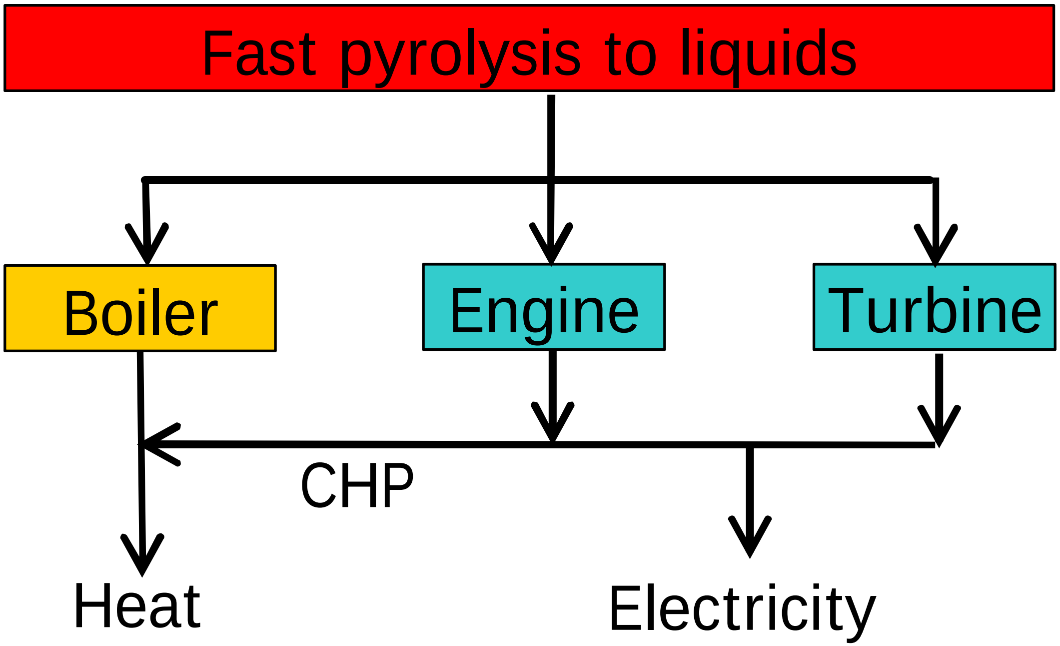


Decentralised fast pyrolysis & local use



2 - Direct use of whole bio-oil

- Heat and power

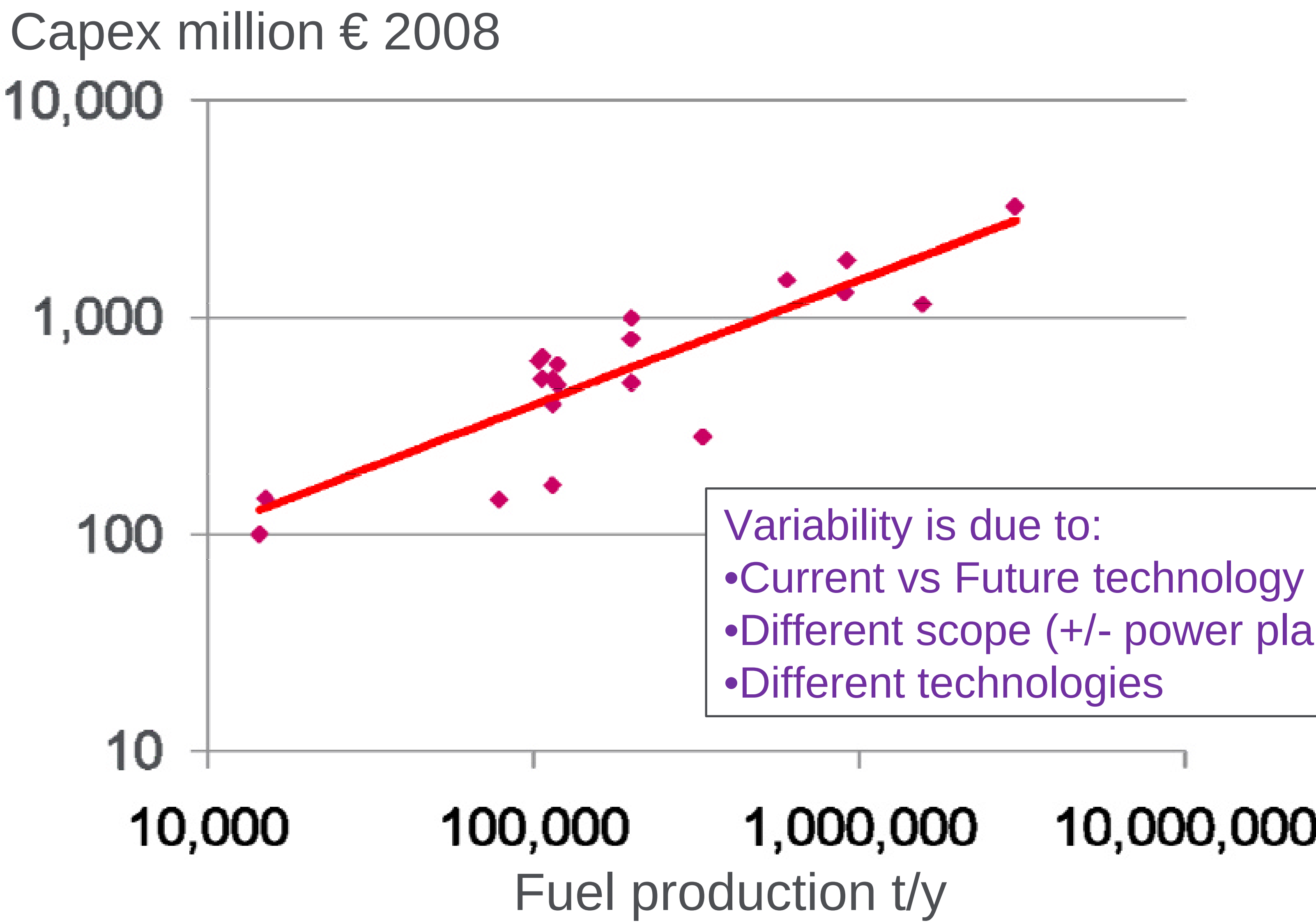


- Chemical substitution
  - Phenolics in wood resins
  - Preservatives

3 - Bio-oil for biofuels

- 3A - Indirect production
  - Via gasification of bio-oil followed by hydrocarbon or alcohol synthesis
  - Many technical and economic advantages of gasification of bio-oil rather than solid biomass but with additional costs
- 3B - Direct production
  - Via catalytic upgrading of liquid or vapour
  - Product can be integrated into a conventional refinery

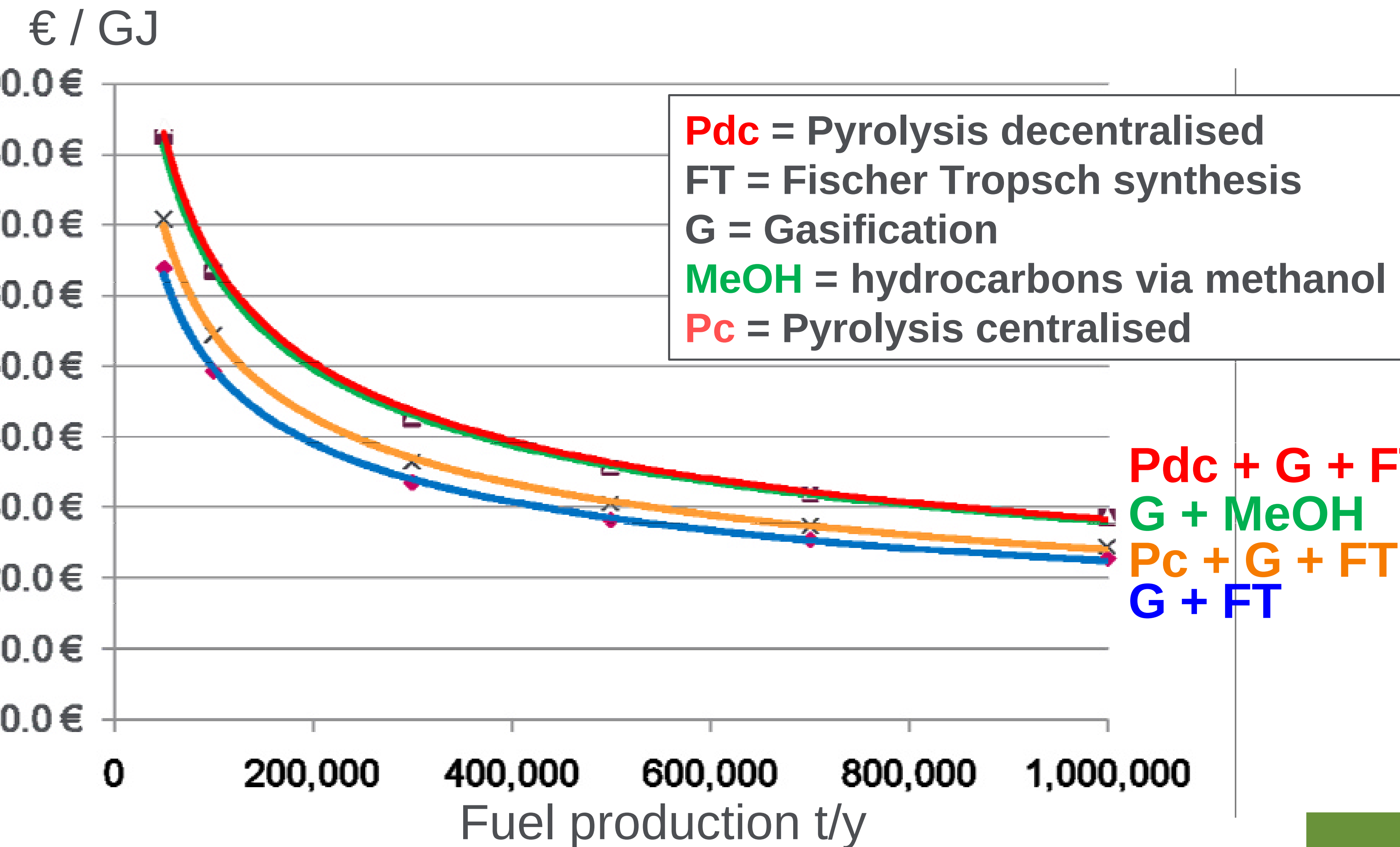
BTL capital costs



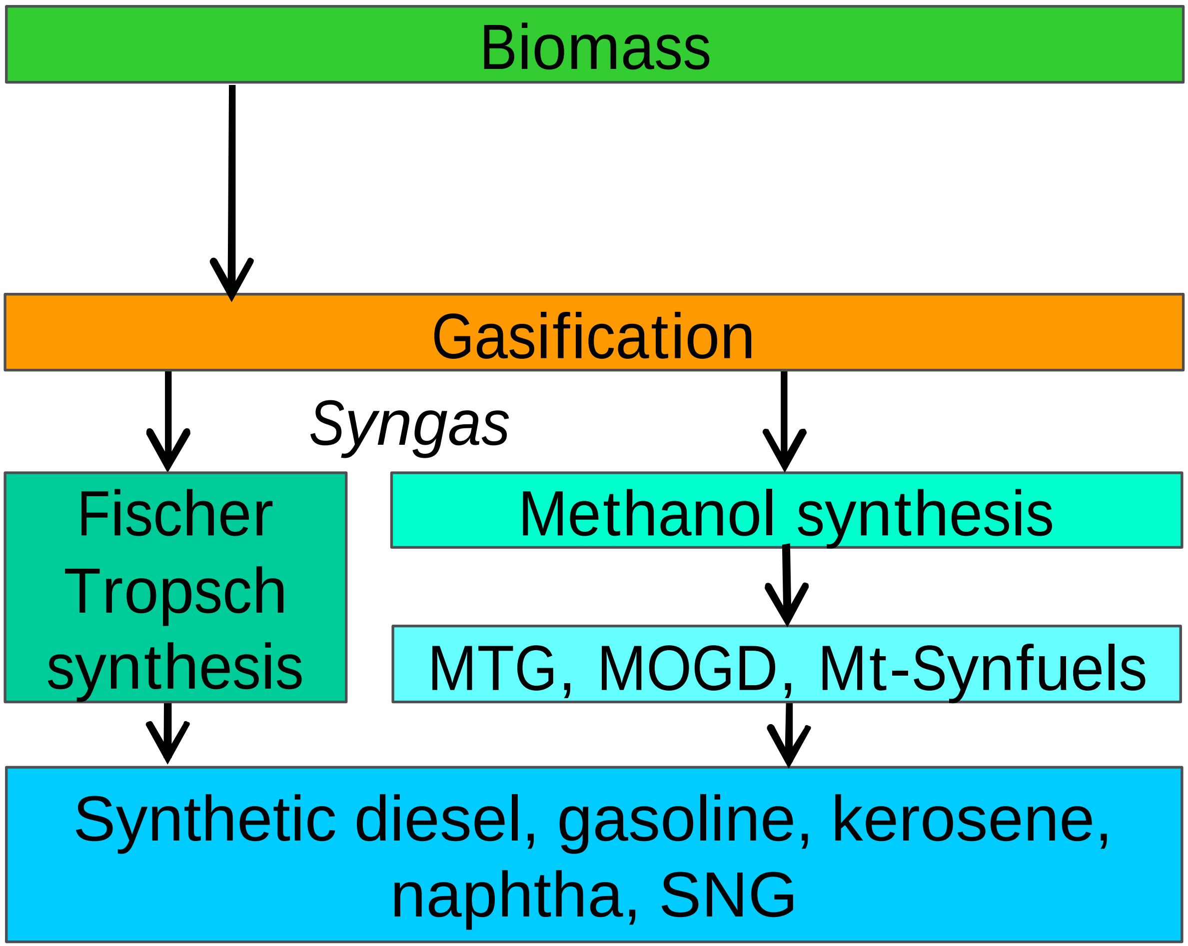
Variability is due to:

- Current vs Future technology
- Different scope (+/- power plant)
- Different technologies

Production cost of biofuels



3A - Bio-oil for biofuels - indirect



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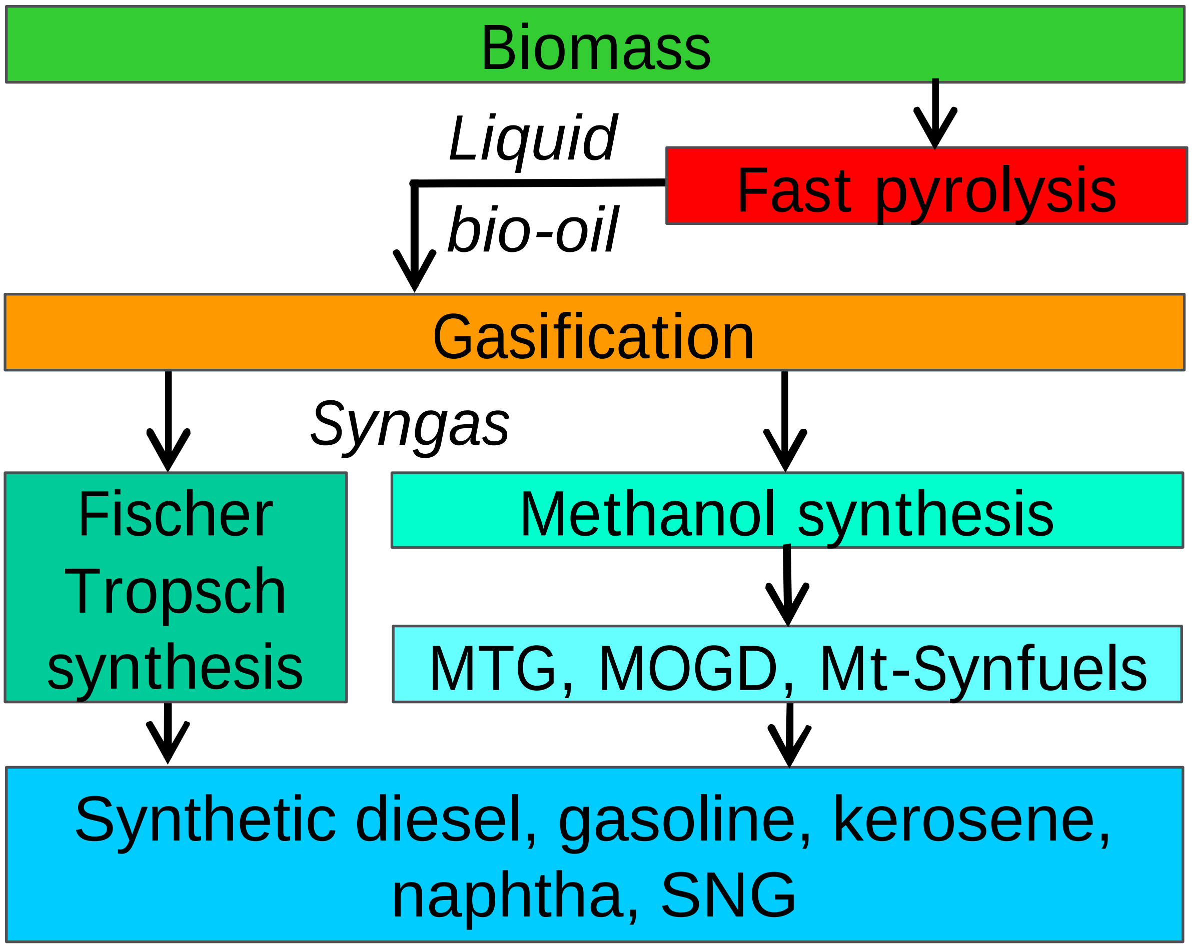
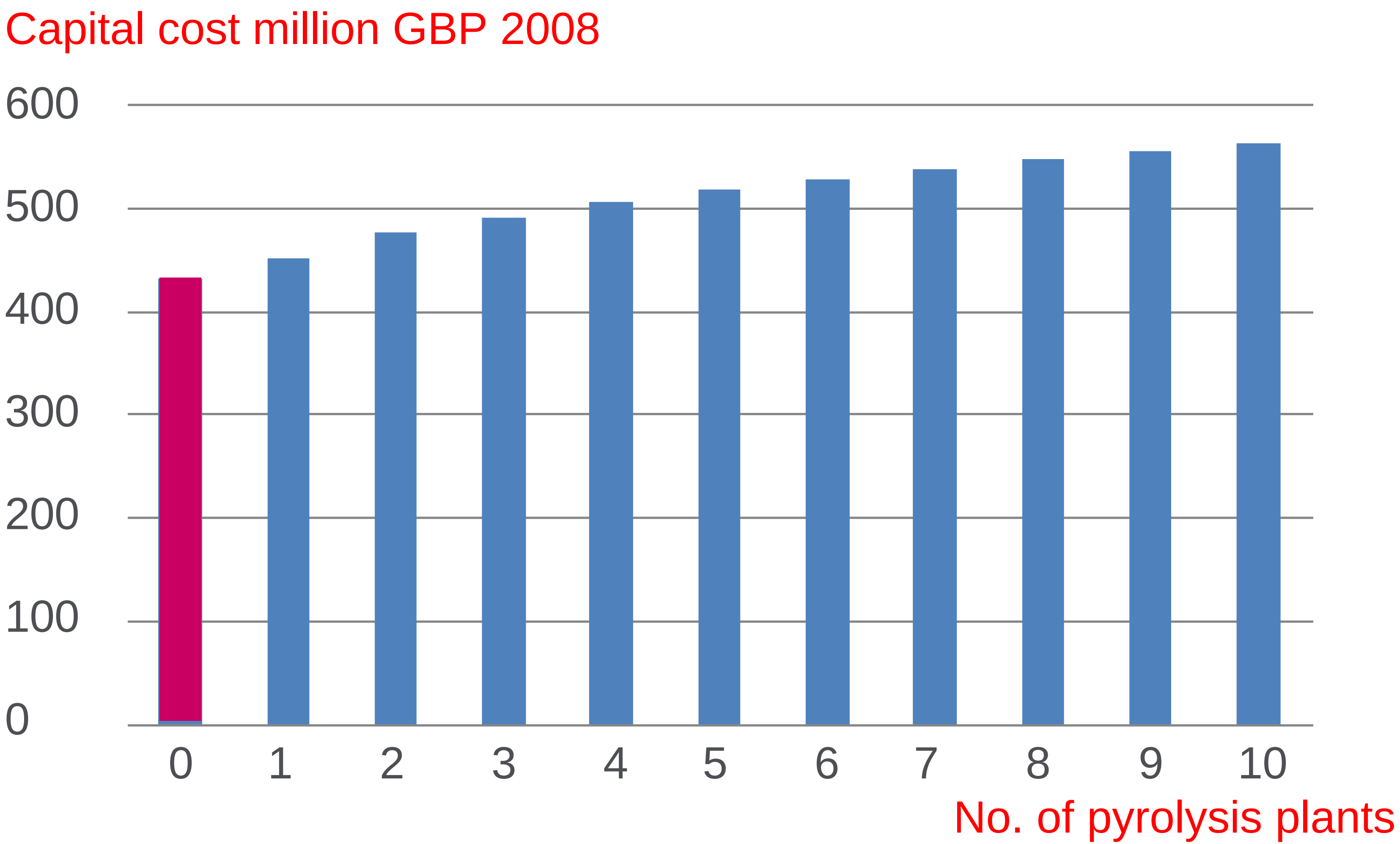


Fast pyrolysis for pre-treatment

Impact from using liquid bio-oil	Capex	Perform-ance	Product cost
Transport costs	Lower	Higher	Lower
Handling and storage costs	Lower	None	Lower
Very low alkali metals	Lower	Higher	Lower
Liquid feeding to a pressurised gasifier	Lower	Higher	Lower
Lower gas cleaning requirements	Lower	Higher	Lower
Higher costs for fast pyrolysis	Higher	Lower	Higher
Lower efficiency from additional pyrolysis step	Higher	Lower	Higher

Effect of pyrolysis plants on capex

Capital cost of Pyrolysis + Gasification + Fischer-Tropsch at 700,000 t/y biomass



3B - Bio-oil upgrading - direct

Bio-oil contains 35-40% oxygen which has to be rejected for production of hydrocarbons

- Hydro-treatment rejects oxygen as H_2O
  - Liquid processing with hydrogen and high pressure
  - Projected yield of around 15% naphtha-like product for refining to diesel, using co-produced hydrogen
  - Product fractions can be upgraded
- Zeolite cracking rejects oxygen as CO_2
  - Close coupled process for upgrading vapours requiring constant catalyst regeneration. No hydrogen requirement, no pressure
  - Projected yield of around 18% aromatics for refining to gasoline

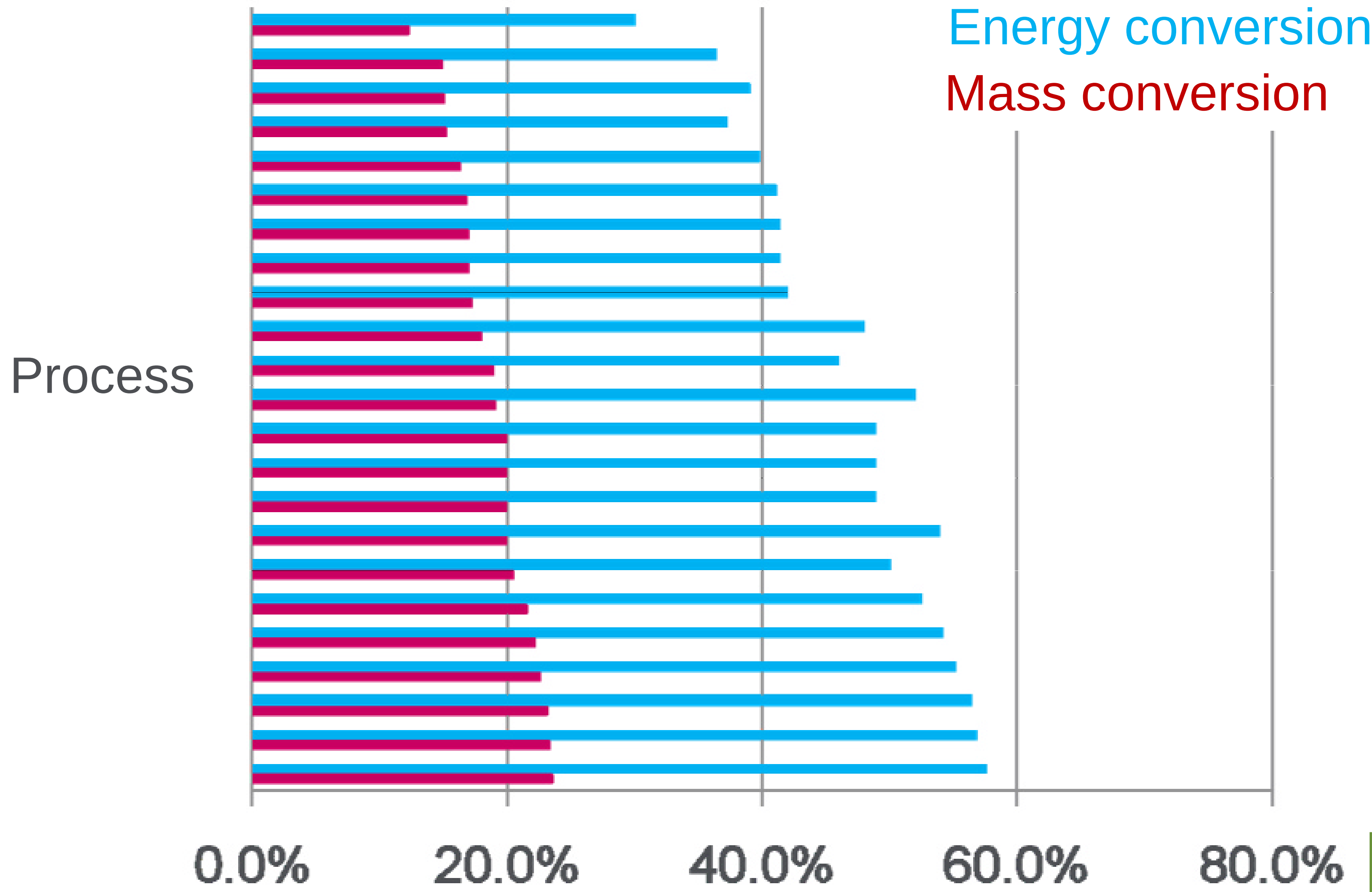
Costs of bio-hydrocarbons

	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
Diesel (EXCL H2) &	23	592	44	13	578
Diesel (INCL H2 from biomass) &	13	880	44	20	860
Gasoline &	22	453	44	10	443
FT diesel #	20	1060	42	25	1030
MTG gasoline #	26	1320	43	31	1320
Crude oil at $100/bbl	-	560	43	15	560

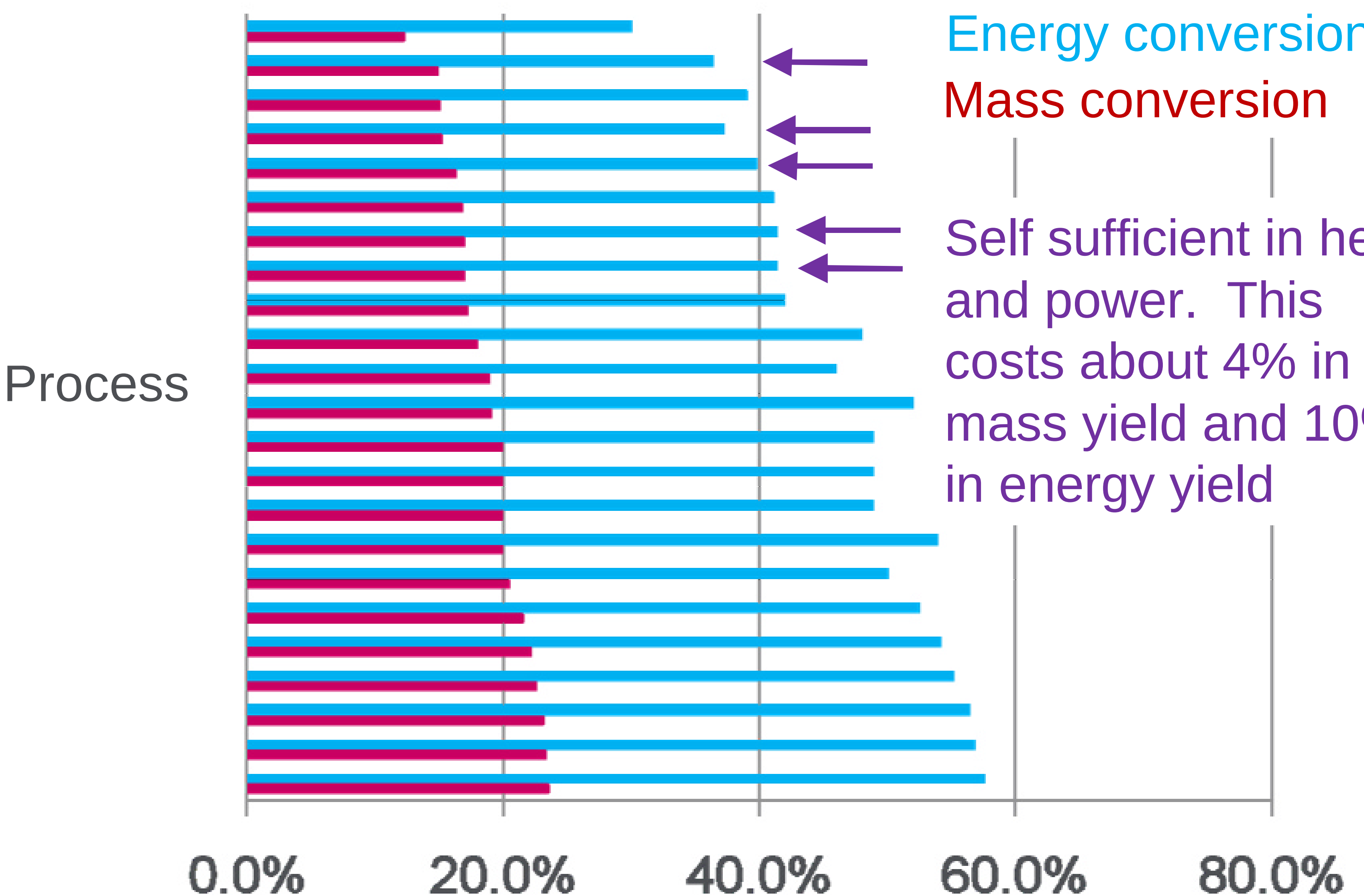
& Basis: 1000 t/d daf wood feed at 67 €/dry t, 2006

Basis: 1 mt/y product derived by gasification (DENA report) 2006

Analysis of BTL performance



BTL energy self sufficiency



Self sufficient in heat and power. This costs about 4% in mass yield and 10% in energy yield

4 - A source of chemicals

Fractionated oil

- ? Liquid smoke (commercial)
- ? Anhydrosugars
- ? Asphalt
- ? De-icers
- ? Fuel additives
- ? Hydrogen
- ? Preservative
- ? Resin precursors
- ? Slow release fertiliser

Specific chemicals

- ? Acetic acid (commercial)
- ? Furfural
- ? Hydroxyacetaldehyde
- ? Levoglucosan
- ? Levoglucosenone
- ? Maltol
- ? Phenol and phenolics

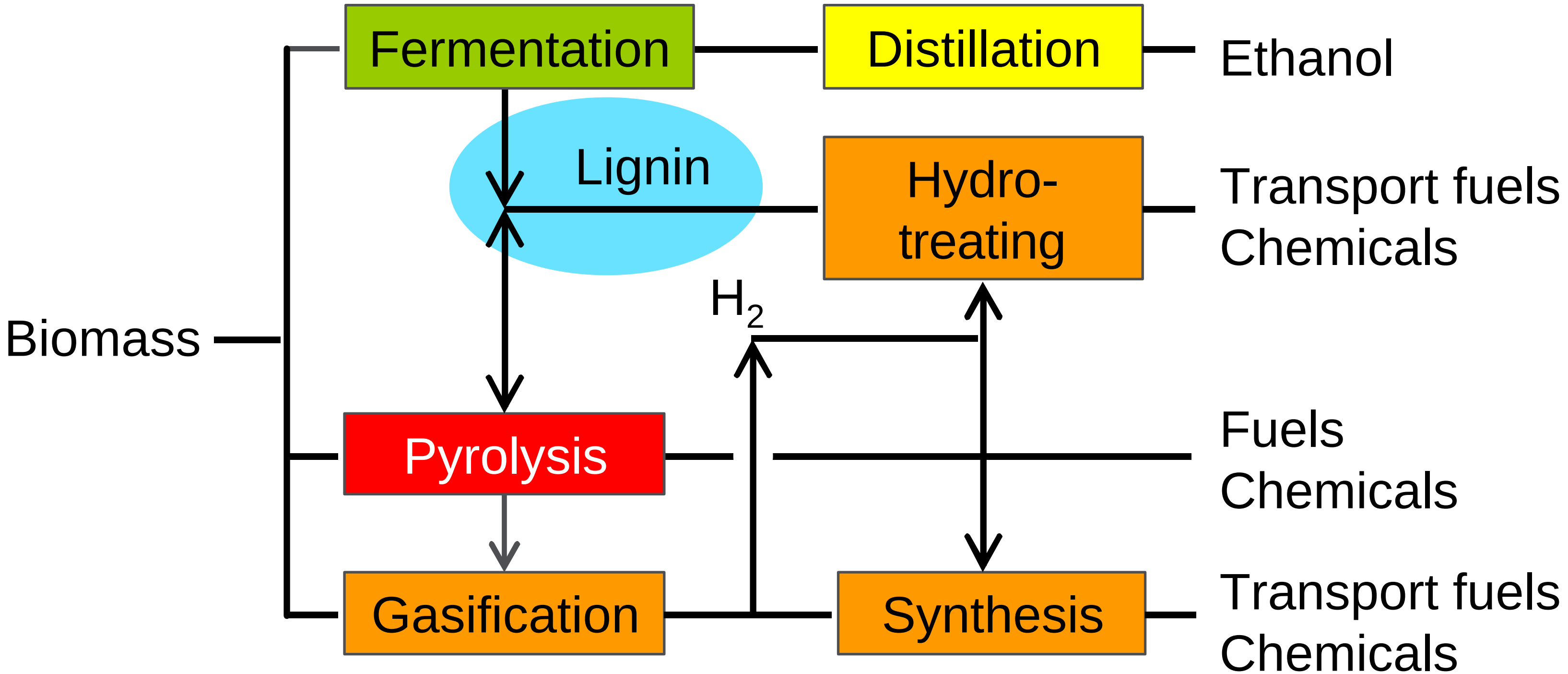
5 - Fast pyrolysis for residue processing

- Residues, byproducts and wastes from biomass and bioenergy processes can be pyrolysed to recover chemicals, fuels or energy. Examples include:
  - Lignin from bioethanol
  - Anaerobic digestion residues
  - Sewage sludge

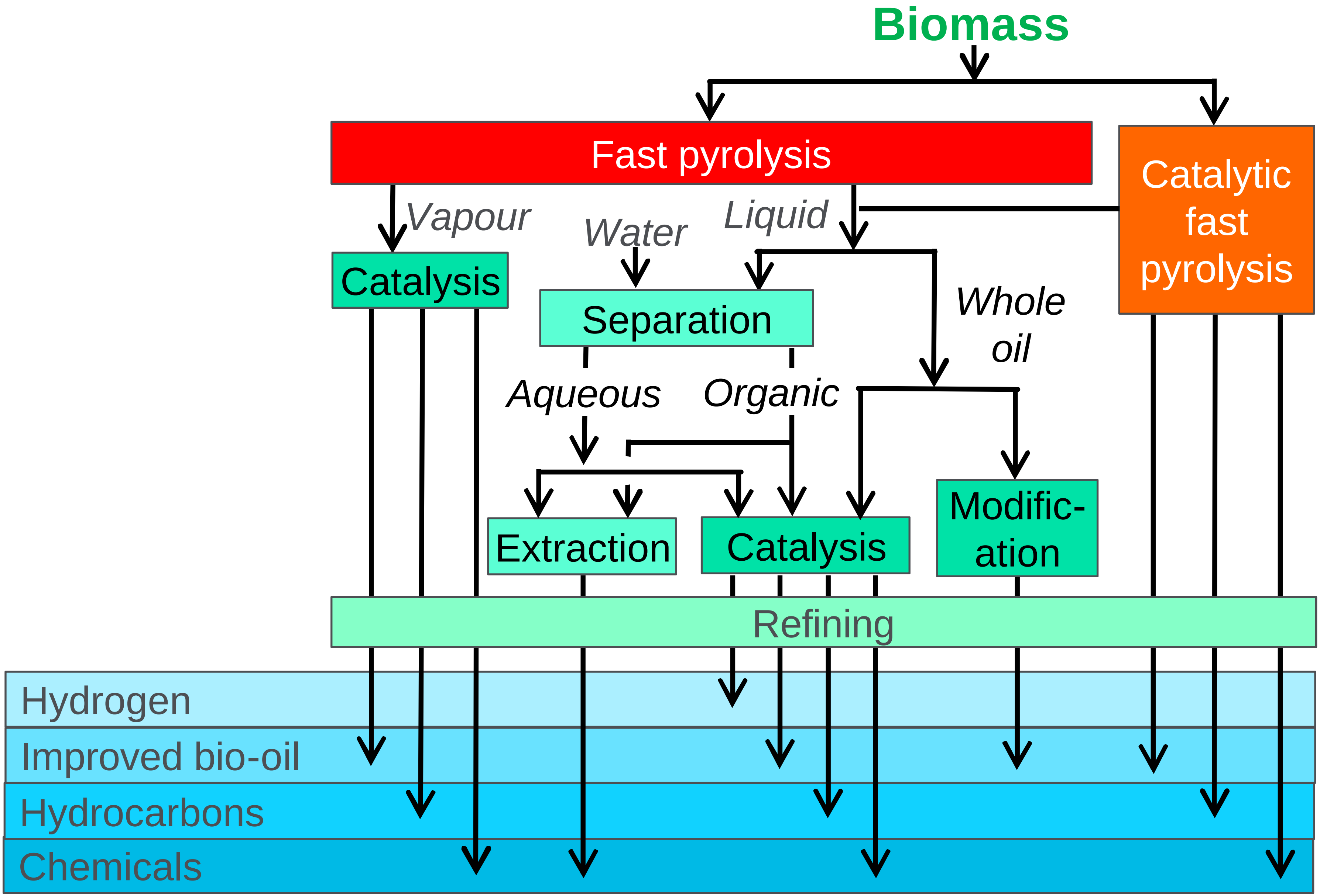
- Fast pyrolysis can provides a supporting role in a biorefinery to produce additional energy and/or products as well as reducing wastes for disposal.

Lignin

- Lignin is a major byproduct e.g the bioethanol industries
- It is a unique naturally derived aromatic product with considerable potential
- It is claimed that you can make anything out of lignin except money!



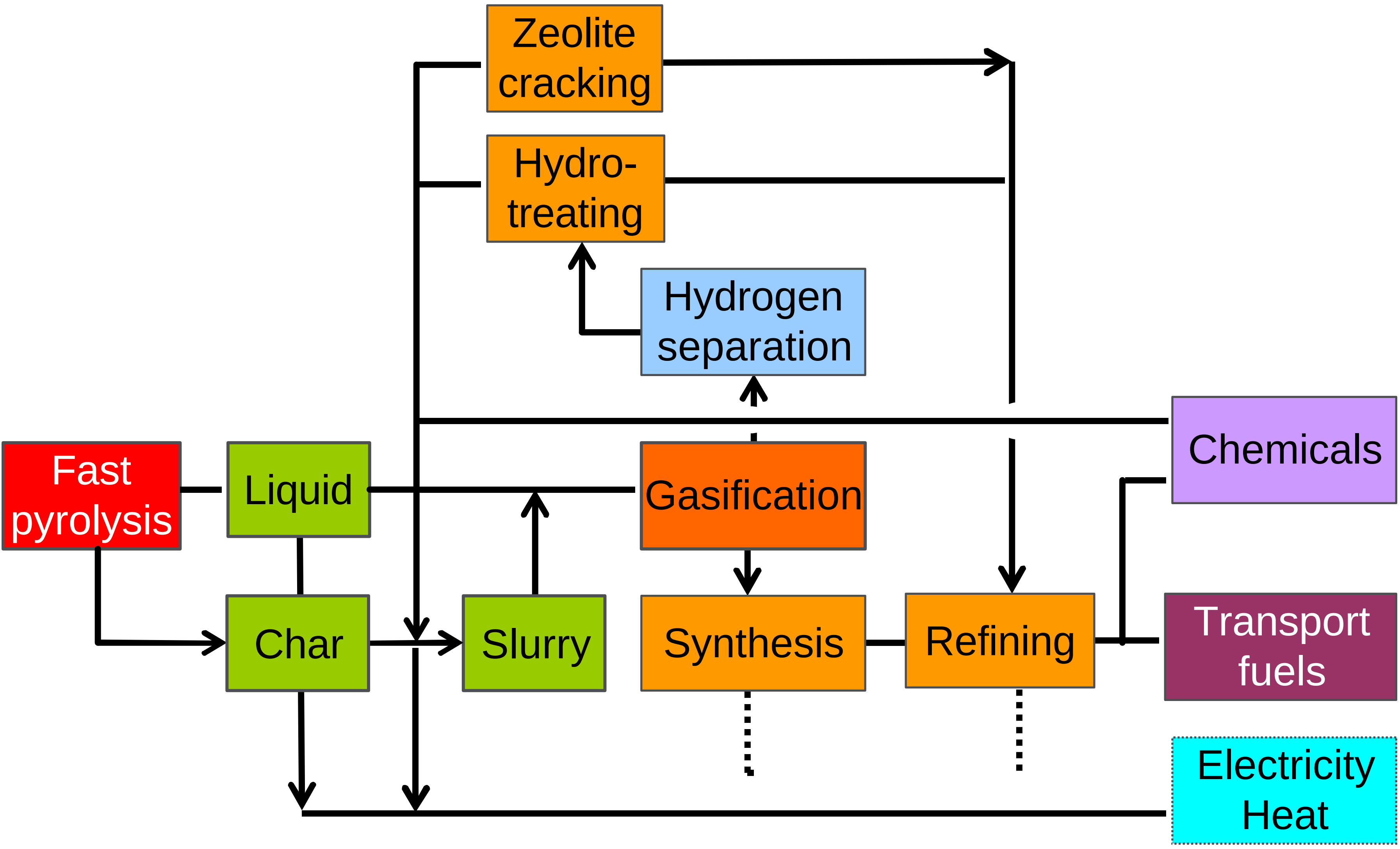
6 – Combinations



What is an upgraded product?

- There are at least 26 quality specifications for bio-oil
- The end use and its specifications and limitations need to be defined in order to identify the critical or most important criteria
- Upgrading to meet any conventional use is likely to require multiple upgrading steps as required in fossil fuel production.

Fast pyrolysis for primary conversion



Intermediate pyrolysis

- Processes include rotary kiln, screw, auger, moving bed, fixed bed
- Intermediate pyrolysis can process more difficult materials with handling and/or feeding and/or transport problems.
- The charcoal forms about 25 wt.% of the products. It retains all the alkali metals.
- Due to the mechanical and abrasive action of the reactor, the charcoal will tend to be small particle size.
- The liquid is 2 phases – aqueous and organic. The organic fraction can be used in engines
- The gas can be used in engines, including with the liquid

Slow pyrolysis

- Processes include batch kilns and retorts, continuous retorts e.g. Lambiotte and Lurgi
- Feed size and shape is important
- Heating can be direct (air addition) or indirect
- Charcoal is mostly lump with smaller particles and dust
- Gases, vapours and liquids are seldom collected or processed. Exceptions include Usine Lambiotte (now shut own) and proFagus (Chemviron, Degussa) in Germany (still operating)

Batch kilns and charcoal handling

Abandoned charcoal kilns in Namibia

Charcoal sorting and packaging in Namibia – shows dust problem

Continuous retorts & chemical recovery

Usine Lambiotte primary distillation column

Usine Lambiotte carbonisers and liquid distribution

Usine Lambiotte outputs & revenues 2000-2001 from ~100,000 t/y wood

	t/year	€/t	k€/y	%
Charcoal	25,000	*100	2,500	
Total pyroligneous liquid	40,000			
Water	30,000			
Organics	10,000			
Acids and alcohols	3,830	452	1,732	
Oils	310	1,258	390	
Fine chemicals	56	49,732	2,785	
Fuel	5,804	90	522	
Total organics	10,000	543	5,429	
Total income			7,929	

Opportunity from ~100,000 t/y wood

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Challenge – management of byproducts

What is not recovered for sale has to be disposed of.
High income from chemicals recovery can support good practice waste disposal

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Torrefaction

- This is very low temperature pyrolysis. It enhances the properties of the biomass by:
  - removing water,
  - reducing hemicellulose,
  - Improving heating value,
  - Improving storability
  - Improving the friability of the product for subsequent processing e.g. grinding as required for co-firing and entrained flow gasification
- Vapours can either be:
  - Burned to provide some process heat or waste disposal
  - Collected to yield potentially valuable chemicals

Charcoal production - Biochar

- Traditional slow pyrolysis process for solid fuel for cooking, leisure and metallurgy e.g. Iron and steel in Brazil and silicon in Australia
- Recent attention has focussed on use of char for carbon sequestration and soil conditioning - biochar. Char recycles potassium in biomass, provides a microbial base for soil, and improves soil texture.
- There is much debate on the costs and benefits.
- Care is needed to manage the non-char products

Fast pyrolysis char spreading trials

Pyrophoric – spontaneously ignites when fresh

Small particle size – from maximum 3 mm from fluid beds down to fine dust

Availability – If process heat is provided by charcoal there is no char product.

Conclusions and recommendations

- Pyrolysis is very flexible in the process and products.
- Fast pyrolysis provides a liquid as an energy carrier
- The liquid is alkali metal free which has advantages
- Decentralised pyrolysis plants offer system improvements
- There is a small cost penalty for using fast pyrolysis for pretreatment
- Bio-oil can be used for fuel, chemicals or biofuels

- Fast pyrolysis technology needs to be improved to reduce costs and increase liquid yield and quality
- Fast pyrolysis liquid upgrading needs to be further developed and demonstrated
- Biochar is of great interest but questionable economics

Thank you