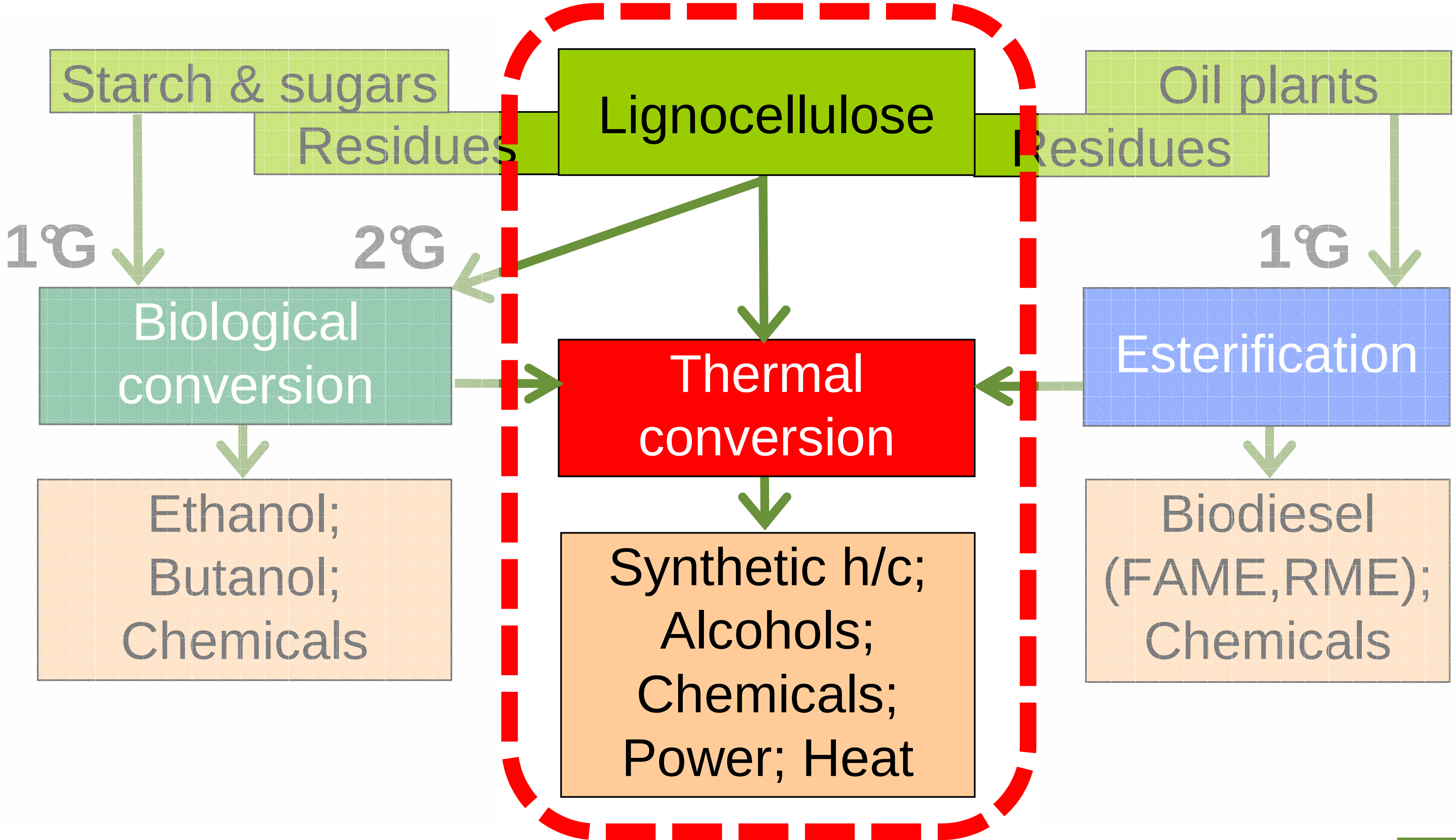
Aston University
Birmingham

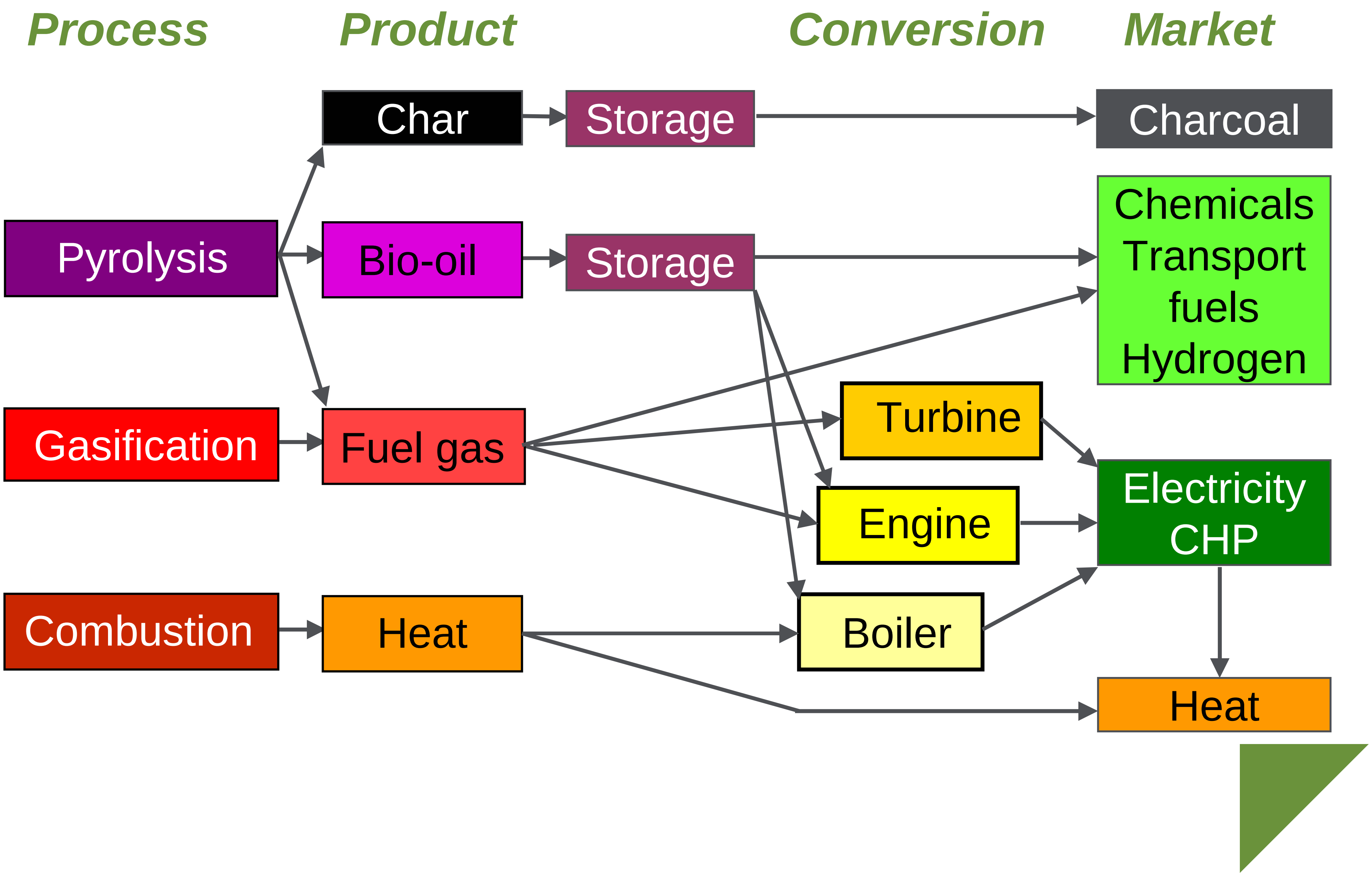
Pyrolysis and Gasification of Biomass

Tony Bridgwater
Bioenergy Research Group
Aston University, Birmingham B4 7ET, UK

Biomass, conversion and products



Thermal processes and products

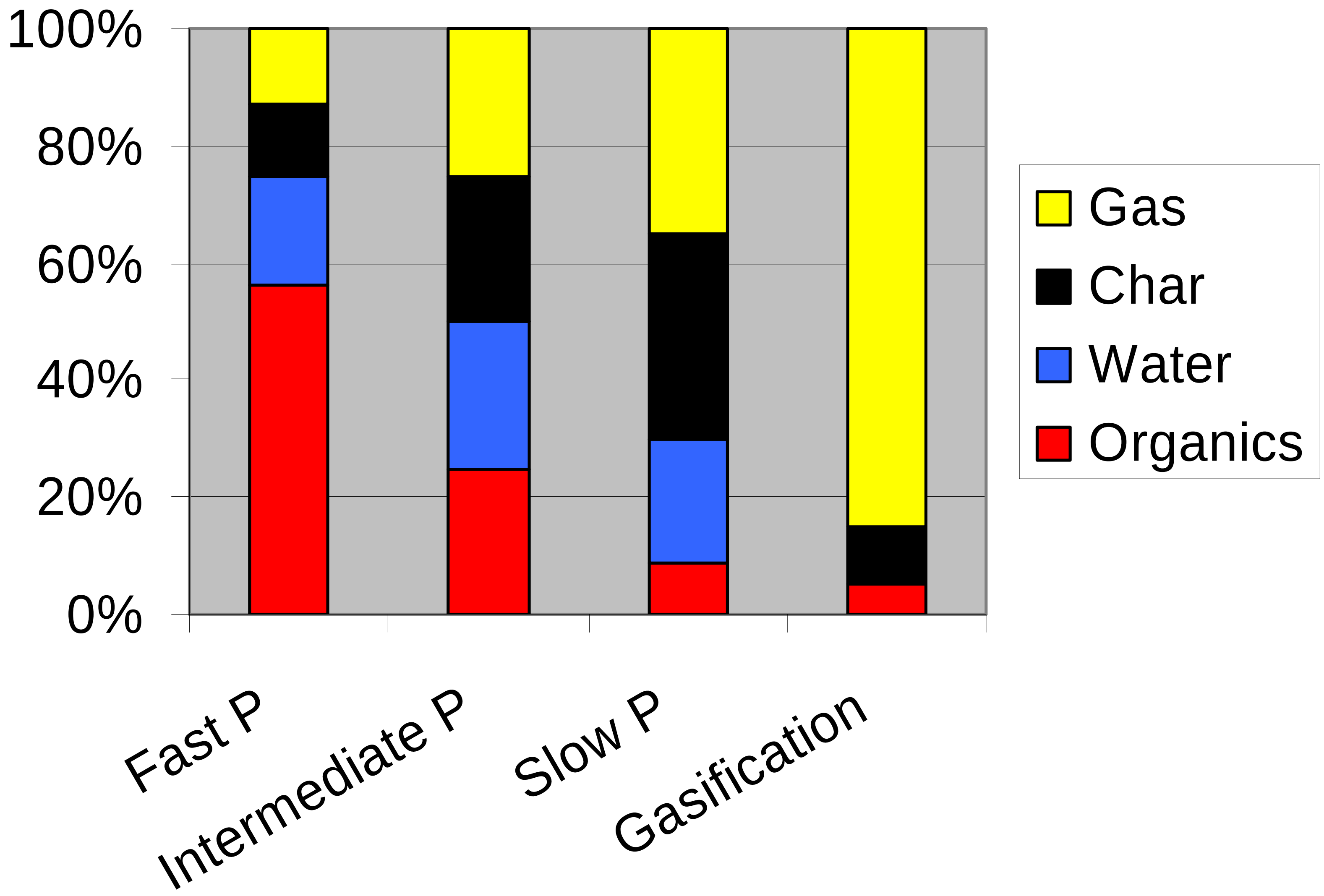


What is pyrolysis?

- Heating in the complete absence of air or oxygen resulting in depolymerisation and decomposition of the constituents of biomass

Mode	Conditions *Wt %*	*Liquid*	*Char*	*Gas*
Fast	~ 500ºC, short hot vapour residence ~ 1 s	75%	12%	13%
Intermediate	~ 500ºC, short hot vapour residence ~ 10-30 s	50%	20%	30%
Slow	~ 400ºC, long vapour residence hrs → days	30%	35%	35%
Gasification	~ 800ºC, long vapour residence times	5%	10%	85%

Product flexibility

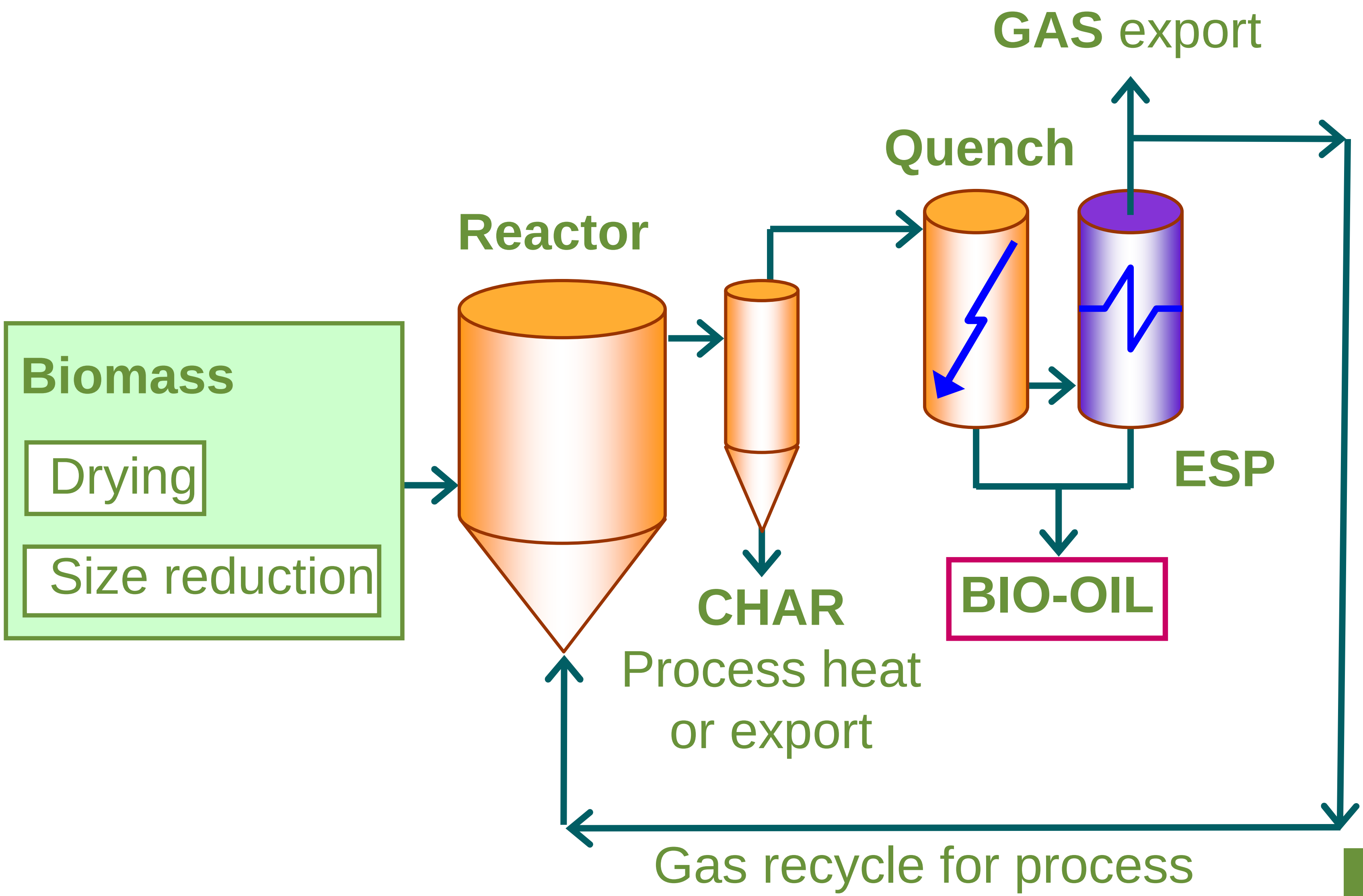


Fast pyrolysis for liquids

- Biomass is heated as quickly as possible
- To a carefully controlled temperature (~500°C)
- Products are cooled as quickly as possible (<2 s)
- Up to 75% wt. yield of liquid is produced – bio-oil

- The liquid has some unique properties:
  - Dark brown mobile liquid,
  - Combustible, but not flammable,
  - Not miscible with hydrocarbons,
  - Heating value ~ 17 MJ/kg,
  - Density ~ 1.2 kg/l

Fast pyrolysis process



Fast pyrolysis: the reality

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

BTG: 50 t/d plant in Malaysia

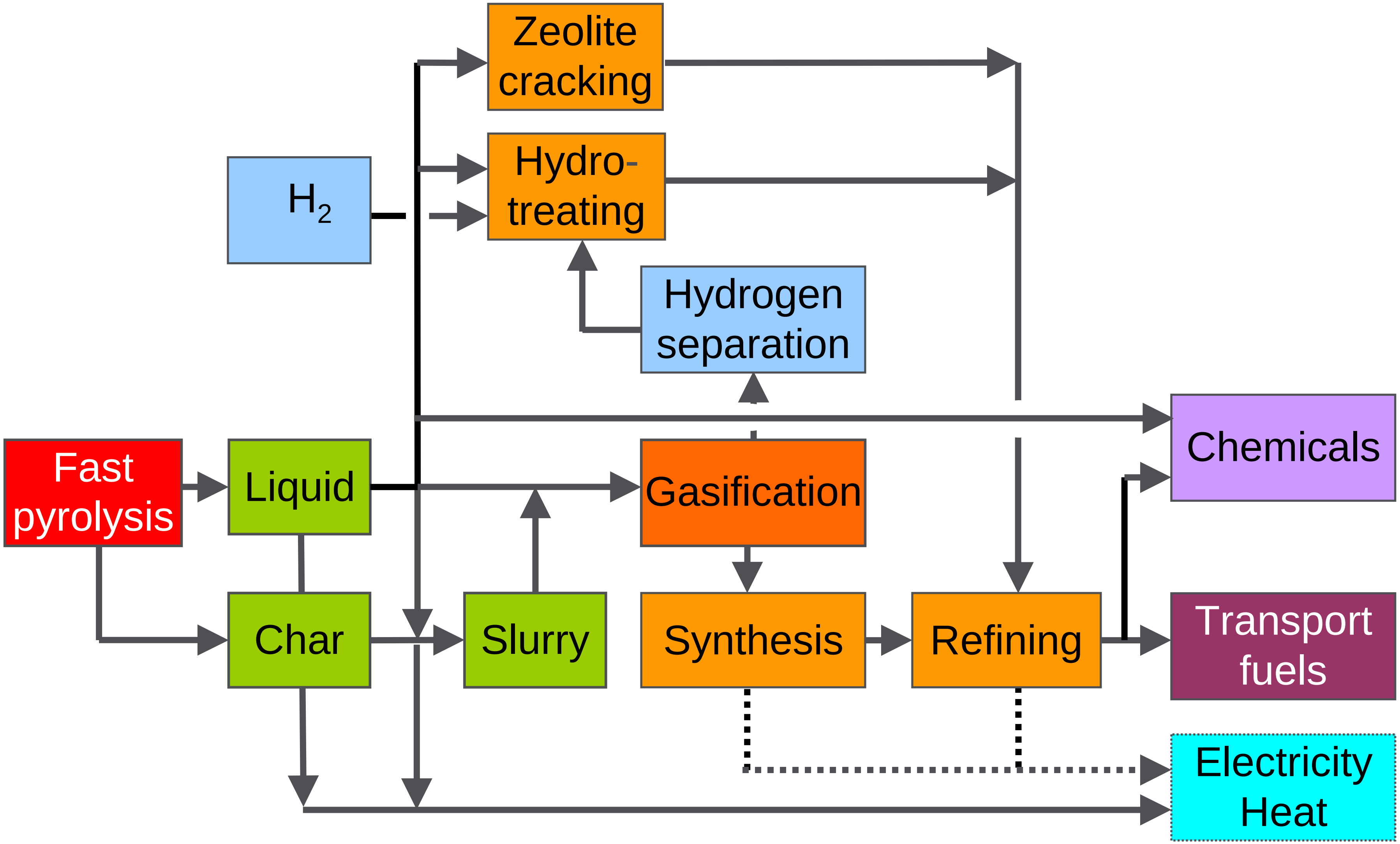
Ensyn: 100 t/d plant in operation in Canada + 6 others

Fast pyrolysis: the promise

- Valuable and useful liquid product
- Valuable charcoal by-product
- High yields – 75% wt. liquid
- High efficiency – 70% energy yield
- No external energy needs - self sufficient
- Perfectly safe
- No emissions
- Very versatile
- Useful for
  - Heat
  - Power
  - Chemicals and commodities
  - Transport fuels

- Energy carrier
- Electricity
- Heat
- Biofuels
- Chemicals

Process and product versatility



Pyrolysis product upgrading

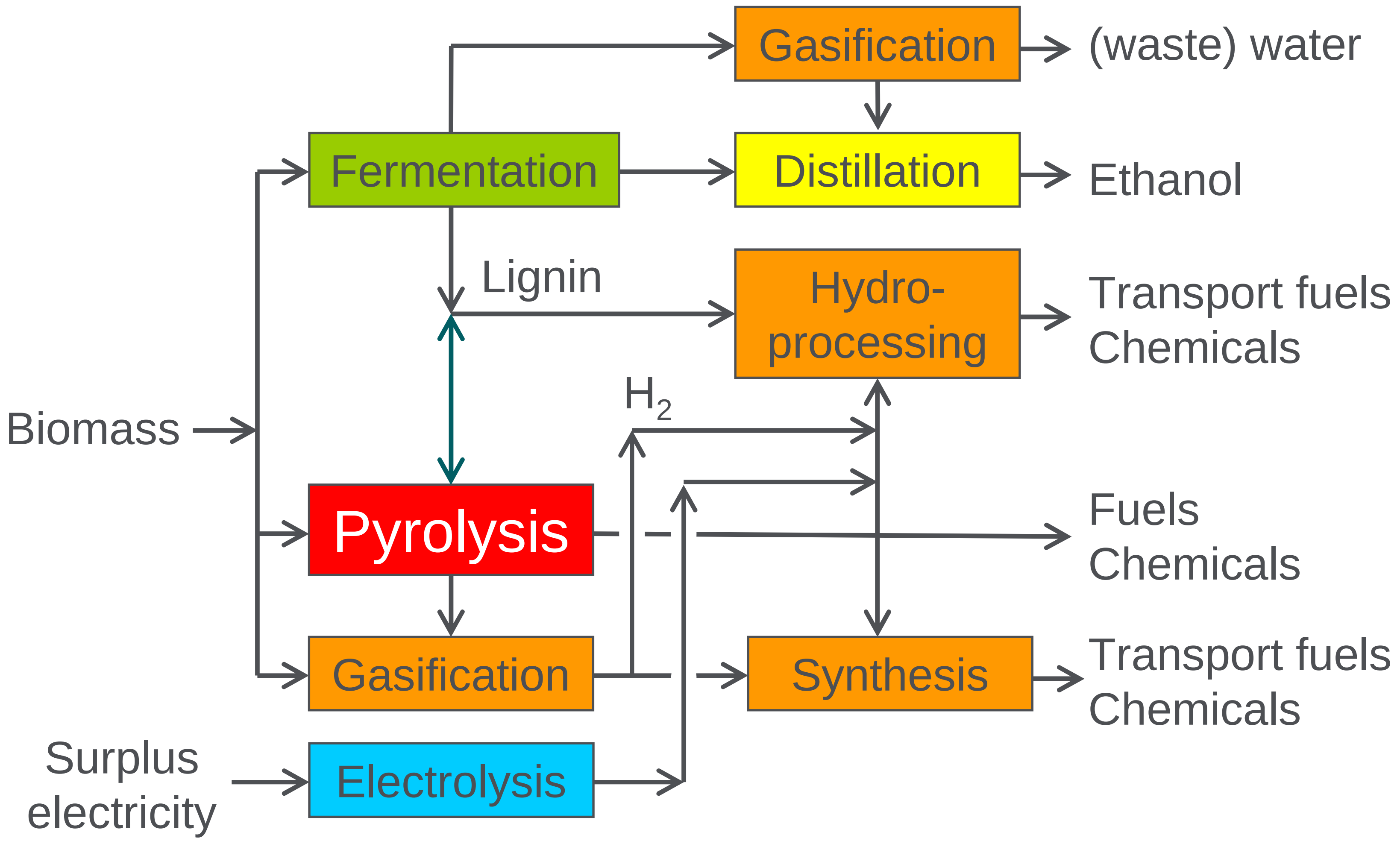
- **Hydro-processing** rejects oxygen as H_2O
  - Requires hydrogen, high pressure
  - Gives projected yield of around 25% naphtha-like product for refining, **without** considering the hydrogen requirement
- **Zeolite cracking** rejects oxygen as CO_2
  - Close coupled process requiring constant catalyst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

Pyrolysis: the opportunities

Fast pyrolysis offers the following:

- Direct production of a liquid fuel with immediate heat, power and chemicals applications
- Direct production of high energy liquid product to improve logistics and operation of bioenergy systems, with energy density up to 10 times greater than biomass
- Potential for decentralised biomass processing to optimise bioenergy supply chains through storage and transport of a liquid
- Versatile processing and products
- Potential for biorefineries

Biorefinery with pyrolysis



Fast pyrolysis conclusions

- Pyrolysis is of particular interest due to the flexibility of the process and use of the products.
- It provides a liquid for storage and/or transport as an energy carrier or fuel
- Decentralised pyrolysis plants can improve system performance
- It can be used directly as a fuel; for chemicals; or transport fuels
- Fast pyrolysis technology should be improved to reduce costs and increase liquid yield and quality
- Fast pyrolysis liquids upgrading should be further developed and demonstrated

What is gasification?

- Gasification is the substantial or complete conversion of carbonaceous or organic material into a permanent gas, usually containing CO, H_2, CO_2, CH_4 and minor amounts of higher hydrocarbons and trace impurities

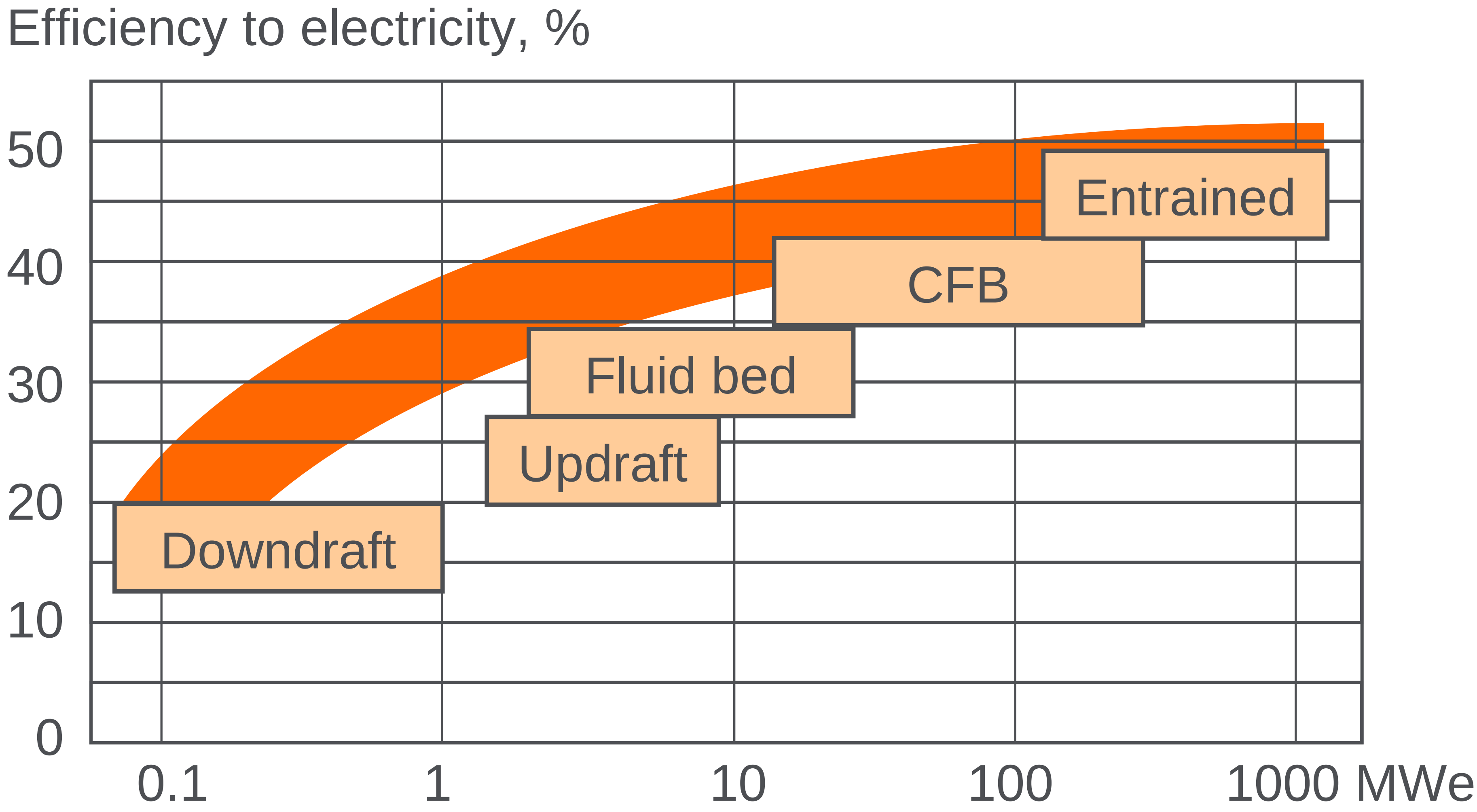
There are several processes:

- **Thermal** or thermochemical and **Biological** i.e. anaerobic digestion
- **Thermal** gasification can be **oxidative** or **anaerobic** i.e. pyrolysis

Gasification methods

Type	*Gas HV*	*Efficiency*	*Comments*
Oxidative Air Oxygen	 ~5 MJ/Nm^3 ~12 MJ/Nm^3	 High Moderate	 Simple High cost and high energy use
Indirect (steam or pyrolytic)	~17 MJ/Nm^3	Low	More complex, Gas needs compression
Pressure Air Oxygen	 ~5 MJ/Nm^3 ~10 MJ/Nm^3	 High Moderate	Higher cost, but higher efficiency potential. Needed for biofuel synthesis

Gasifier sizes and performance



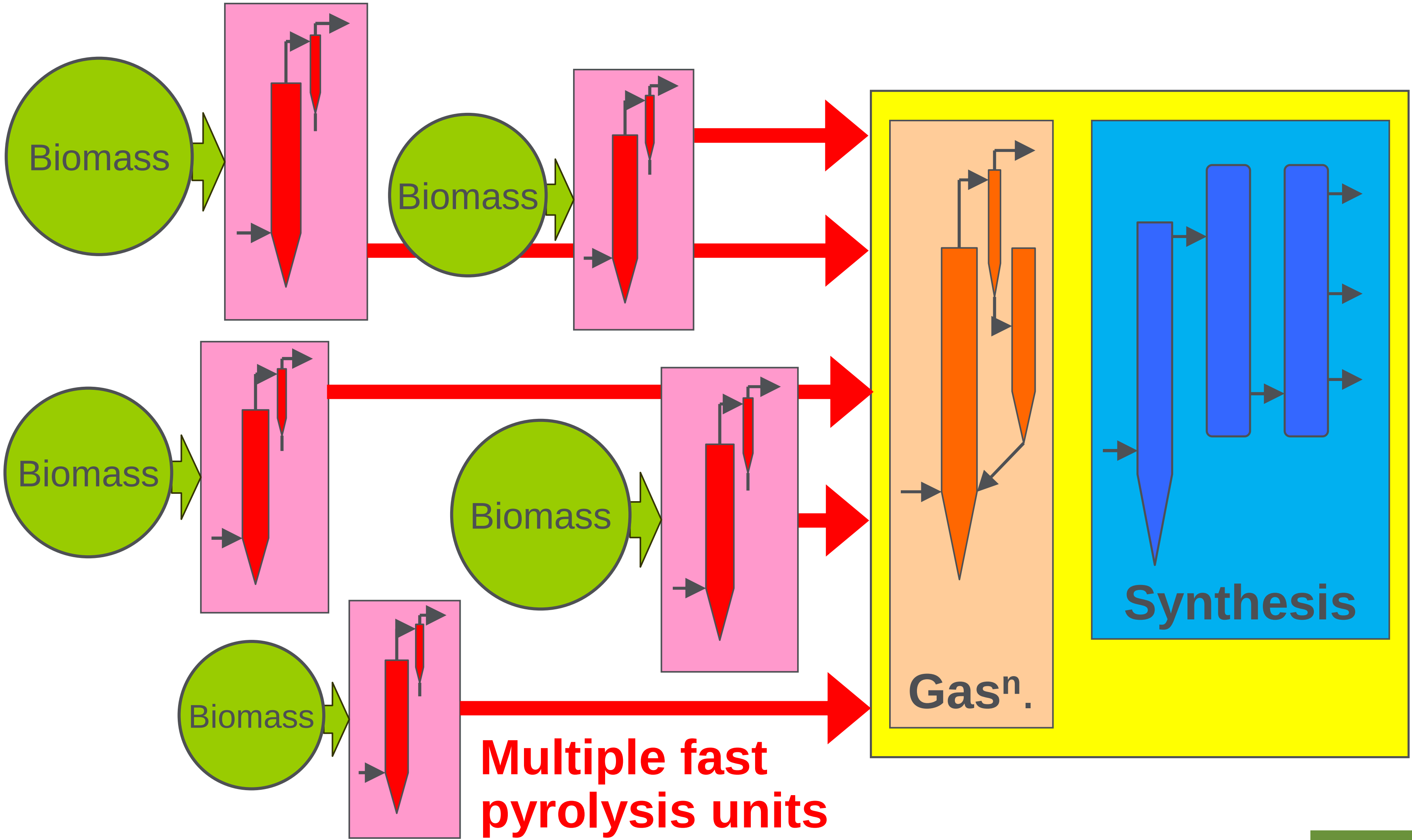
Gasifiers

- Fixed bed
  - Downdraft limited to <10 t/d each unit
  - Updraft limited to ~70 t/d each unit. Significant tars.
- Fluid bed
  - BFB limited to ~200 t/d
  - CFB less constrained on size, limited to ~500 t/d
- Entrained flow
  - Requires small particle size, no size limits
- **Operating conditions**
  - Pressure = high cost;
  - Oxygen = high cost + high energy
  - Indirect gasification needs compression. Compression = high cost + high energy

System requirements - large scale

- Entrained flow gasifier requires small feed size or liquids
  - Extensive experience with coal and some with biomass
  - Grinding biomass has high economic and energy cost
  - Torrefaction gives a dry and brittle feed that can be processed like coal = higher preparation costs
  - Fast pyrolysis gives a liquid that is nearly completely free of alkali metals = higher preparation costs
- Pressure = higher cost and higher efficiency; pressure is needed for biofuels
- Oxygen for nitrogen free gas = high cost + high energy
- Indirect gasifiers give nitrogen free gas but are not large scale and cannot be pressurised
- **Large scale** gives higher efficiency from combined cycle for electricity and better energy integration for biofuel synthesis. Considered essential for biofuel synthesis.

Decentralised fast pyrolysis concept



Higher cost for pyrolysis units, **lower costs** for gasification

System requirements – medium scale

- CFB (Circulating Fluid Bed) gasifiers have less limitations on feed size than entrained flow
  - Limited experience with biomass
  - Lower feed preparation requirements than entrained flow
- Pressure = high cost
- Oxygen for nitrogen free gas = high cost + high energy
- Indirect gasifiers give nitrogen free gas but are not large scale
- Multiple units are possible
- BFB (Bubbling Fluid Beds) are similar to CFB in most respects but will tend to have lower capacities but greater flexibility.
- **Medium scale** is OK for electricity, needs synthesis technology modification for biofuels

System requirements – small scale

- Fluid bed (Bubbling Fluid Bed) gasifiers have less limitations on feed size than entrained flow
  - Limited experience with biomass
  - Lower feed preparation requirements than entrained flow
- Pressure is not viable
- Oxygen is not viable
- Multiple units are possible
- Fixed beds have feed size limitations. Updraft give very high tars and downdraft require multiple units for even small commercial applications
- **Small scale** operation gives lower efficiencies, higher specific costs and poor economy of scale for electricity and biofuels

Gasifiers

Guessing Austria
2 MWe indirect

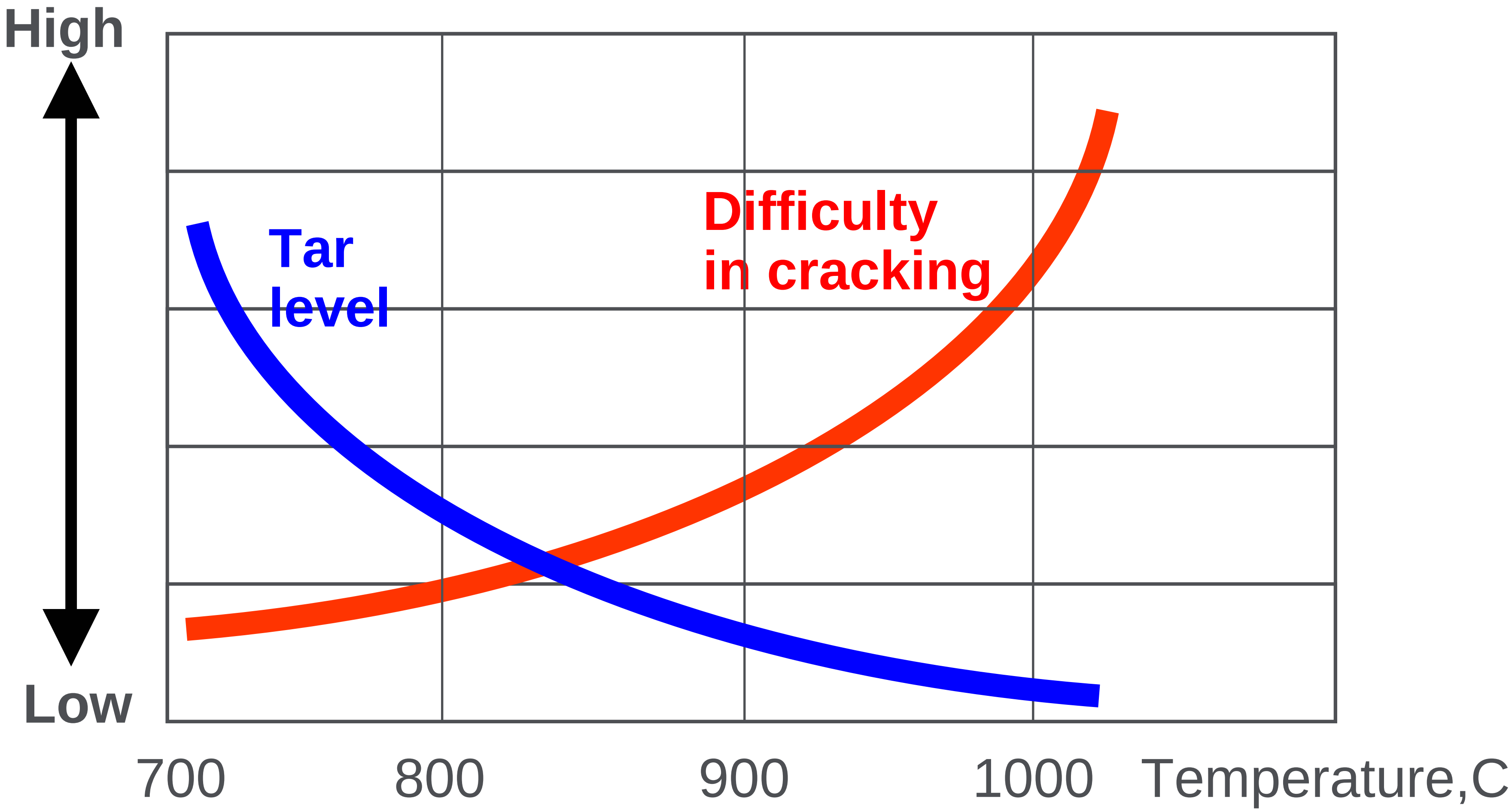
Lahti Finland
15 MWe CFB

Vermont USA 15 MWe indirect

Gas clean-up

Contaminant	*Examples*	*Solution*
Tars	**Refractory aromatics**	**Cracking, removal,**
Particulates	Ash, char, fluid bed material	Cyclone, filter
Alkali metals	Na, K compounds	Temperature control, filter
Fuel nitrogen	Ammonia, HCN	Washing
Sulphur, chlorine	HCl, H_2S	Capture, washing
Other	To be determined	
Generally		Much experience is needed

Tar reduction



Gas conditioning

Requirement	*Solution*
Nitrogen	OK for electricity Avoid for fuel synthesis (unless for ammonia). Use oxygen gasification or indirect gasification
Pressure	Fischer Tropsch and alcohol synthesis requires high pressure = pressure gasification or syngas compression
$CO:H_2$ ratio	Adjust with shift reaction
CO_2 removal	Variety of proprietary processes are available
Generally	Established technology

Gasification for biofuels

- The necessary scale of gasification and cleaning has not been demonstrated
- Gas cleaning is a major technical and economic challenge from:
  - Biomass contamination.
  - Mixed / variable feedstocks require gas cleaning for the most extreme contaminants.
  - Clean and consistent energy crops are favoured, but face increasing competition
- In all cases, economies of scale and feed costs dominate biofuel product costs
- Co-processing with coal is an interesting possibility and has been demonstrated.

Gasification conclusions

- Gasification system must be carefully matched to feed characteristics and application
- For development, large scale thermal gasification and gas cleaning & conditioning needs to be demonstrated
- For biofuels small scale hydrocarbon synthesis should be developed and demonstrated
- Develop integrated biorefineries
- Improve catalysts
- Robustly compare alternative systems
- Reduce costs

- Gasification is complementary to pyrolysis
- Economy of scale and feed cost dominate bioenergy and biofuel applications so technology and biomass cost are critical

Thank you