Aston University
Birmingham

Modularisation of Bioenergy Systems

Tony Bridgwater
a.v.bridgwater@aston.ac.uk
Aston University Bioenergy Research Group,
European Bioenergy Research Institute
Birmingham B4 7ET, UK

Technologies considered

- Biomass preparation and pretreatment
- Pyrolysis
- Pyrolysis product upgrading
- Gasification
- Gasification product upgrading
- Combustion
- End use

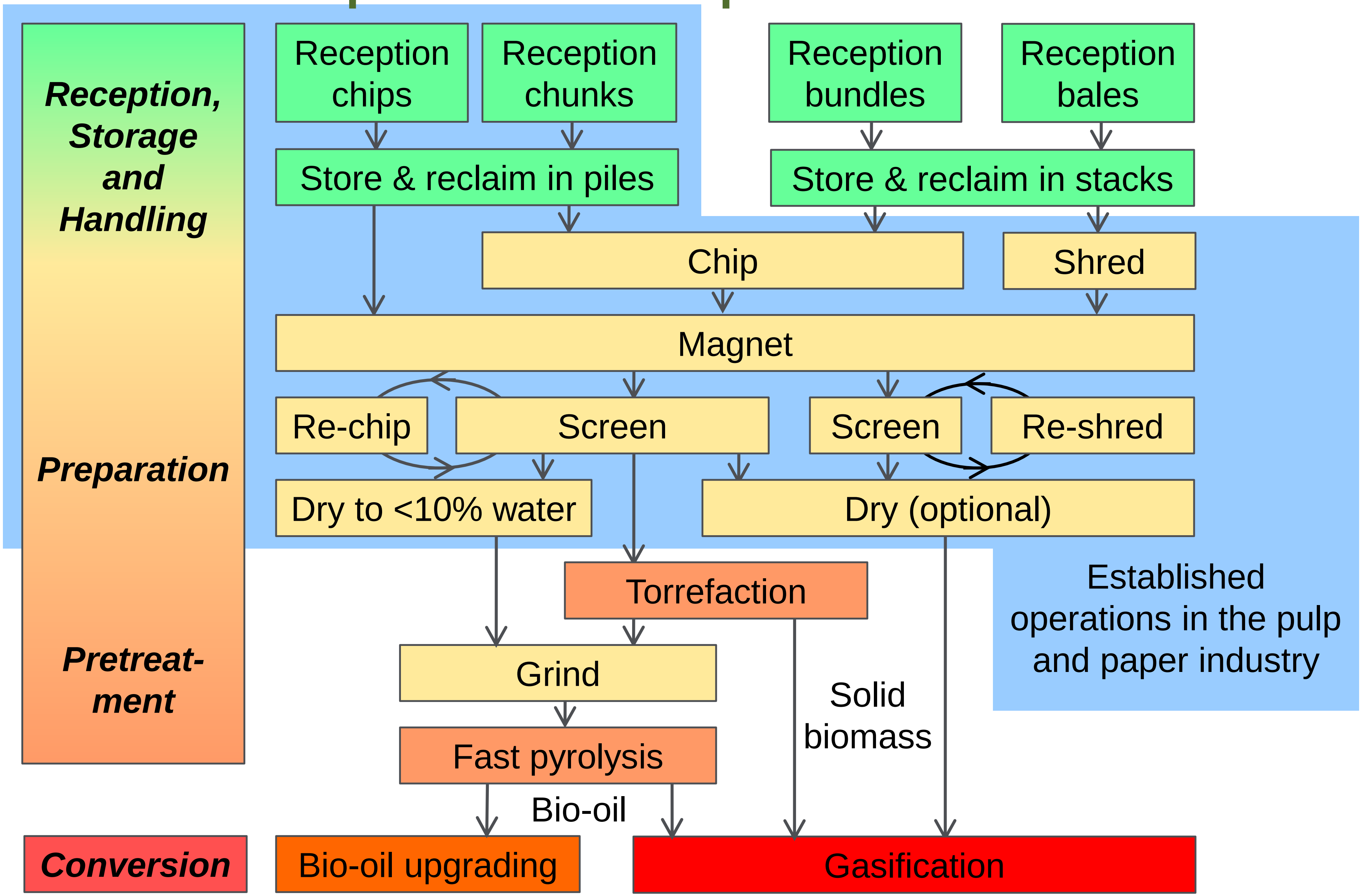
Process steps for bioenergy & biofuels

- Biomass reception storage and handling
- Biomass preparation e.g. comminution, screening, drying
- Pretreatment by torrefaction
- Fast pyrolysis
- Bio-oil upgrading including gasification
- Gasification of biomass or bio-oil
- Oxygen for gasification
- Gas cleaning for quality
- Gas conditioning for composition
- Potential for CCS
- Synthesis of biofuels (H/C or -OH)
- Conversion of alcohols to H/C
- Product refining
- Offsites including power and heat provision

Biomass preparation & pretreatment

- Converts raw biomass into a form most suitable and/or necessary for conversion
- Storage is usually required as a first step
- Properties likely to require modification include:
  - Size
  - Size range
  - Shape
  - Moisture
  - Ash
  - Contamination
- The pulp and paper industry has extensive experience with wood

Preparation & pretreatment



System design

- A biomass preparation and pretreatment system design depends on the feed material and the conversion process
- Extensive experience is available for wood, less so for other types of biomass and waste

Pyrolysis modes

Pyrolysis is anaerobic thermal decomposition. 3 products are always produced: the proportions can be controlled by the feedstock and the process.

Mode	Conditions *Wt % products*	*Liquid*	*Char*	*Gas*
Fast	**~ 500ºC; short HVRT ~1s; short solids RT**	**75%**	12%	13%
Inter-mediate	~ 500ºC; moderate HVRT ~10-30s; moderate solids RT	20% organics 30% water	30%	20%
Slow	~ 400ºC; long HVRT; very long solids RT	35% in 2 phases	35%	30%
Torre-faction	~ 300ºC; long HVRT; long solids RT	Vapours – water and organics	85% solid	15% vapours
Gasif-ication	~ 800-900ºC; short HVRT; short solids RT	1-5%	<1%	95-99%

Pyrolysis status

Mode	Status
Fast	Demonstration at up to 150 t/d in progress. Competing technologies Performance is unaffected by scale
Intermediate	Under development at laboratory scale
Slow	Well established for charcoal, especially Brazil.
Torrefaction	Several processes under development. Competing technologies.
Gasification	Limited large scale development, relatively poor history, gas cleaning challenges. Guessing (see later) is an exception.

Fast pyrolysis requirements

- The aim is to maximise the organics as liquids. These can be directly use or converted to fuels and chemicals.

Fast pyrolysis requires:

  - High heating rates: Small particle sizes < 3-4 mm are needed as biomass has low thermal conductivity
  - Dry biomass (<10wt.% water): Water in feed goes into bio-oil product plus reaction water
  - Carefully controlled temperature: ~500°C is optimum for maximising liquid yield, (but not necessarily quality)
  - Rapid and effective char removal: Char and alkali metals are catalytic and reduce liquid yield
  - Short hot vapour residence time: Thermal cracking reduces liquid yield
  - Rapid vapour cooling to minimise secondary reactions

- These specifications dictate the design

Typical reaction system

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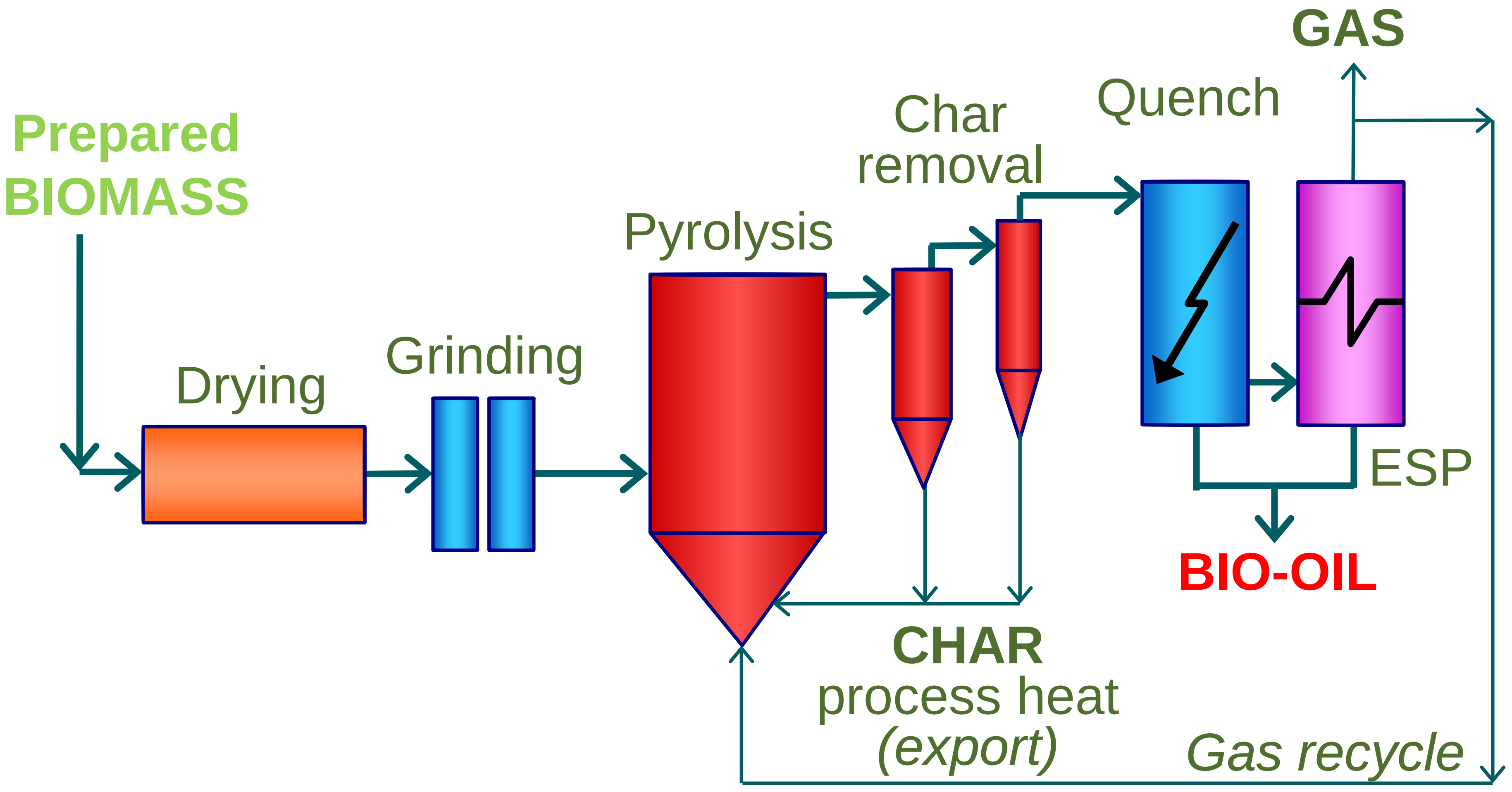

There is not a best or preferred technology, with a number of proprietary systems being demonstrated and considerable R&D focus on technology development

Variables in reaction system

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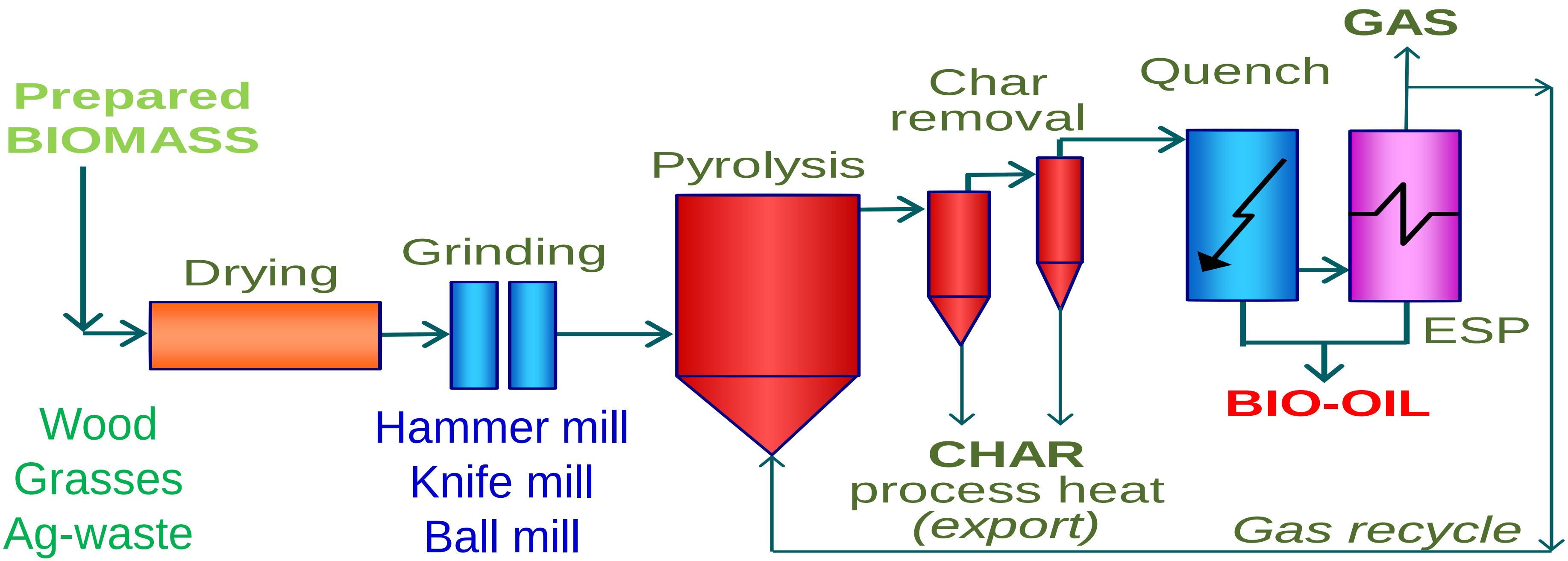

Wood
Grasses
Ag-waste
MSW
etc.

Hammer mill
Knife mill
Ball mill
etc
+combinations

Rotary kiln
Moving bed
Silo
Steam
etc

Fluid bed
Transported bed
CFB
Ablative
etc

Cyclone(s)
HV Filter
+combinations

ESP
Coalescer
Demister
Centifugal s'tor
+combinations
Or none

Quench
Heat exchanger
etc

Reaction system choice

- The choice of reaction system depends on:
  - Feed material(s)
  - Preparation method(s)
  - Choice of (proprietary) pyrolysis processes
  - Application(s) for the product and product use(s)
  - Product upgrading requirement(s)
  - The interactions between these factors X

- Modularisation is currently limited to components
- An exception is Ensyn technology for liquid smoke production in Wisconsin. This might be considered modularisation as several plants of similar design have been supplied to a dedicated application. √

Bio-oil yield

There are two dominant factors that determine the quality and quantity of bio-oil vapours and resultant liquid:

- Biomass feedstock quality:
  - Ash is catalytic. Ash (from biomass or contaminants) causes vapour cracking, giving lower organic liquid yields, higher water yields and hence potential phase separation
  - Water. High feed water gives high water content liquid and potential phase separation
- Reactor technology:
  - Thermal vapour cracking gives lower organic liquid yields and potential phase separation
  - Catalytic cracking is caused by ash and char,
  - Higher temperatures causes thermal vapour cracking which is useful for gasification but not for liquids
- This shows the interactions between feed, technology and product

X

Bio-oil for energy densification

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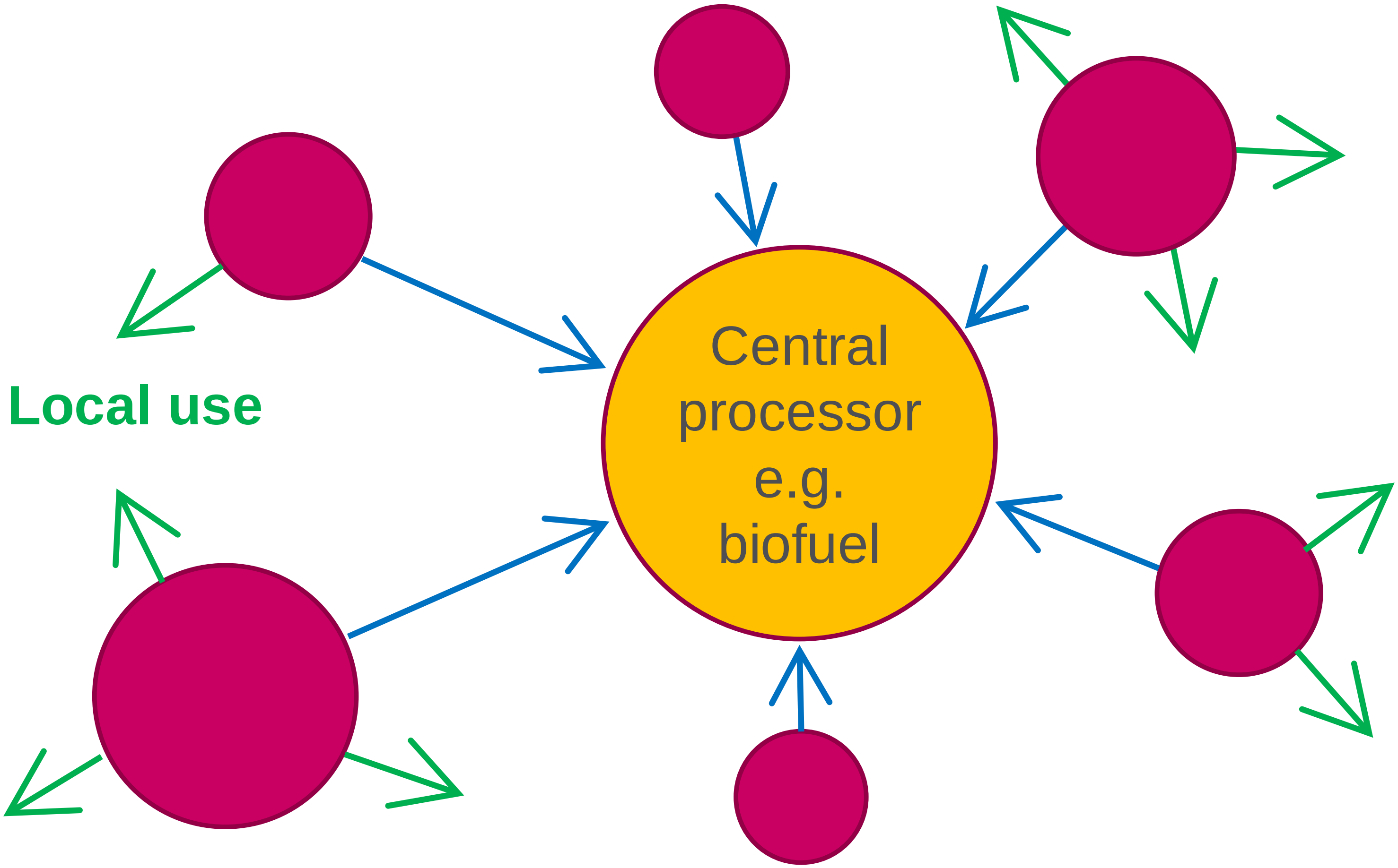
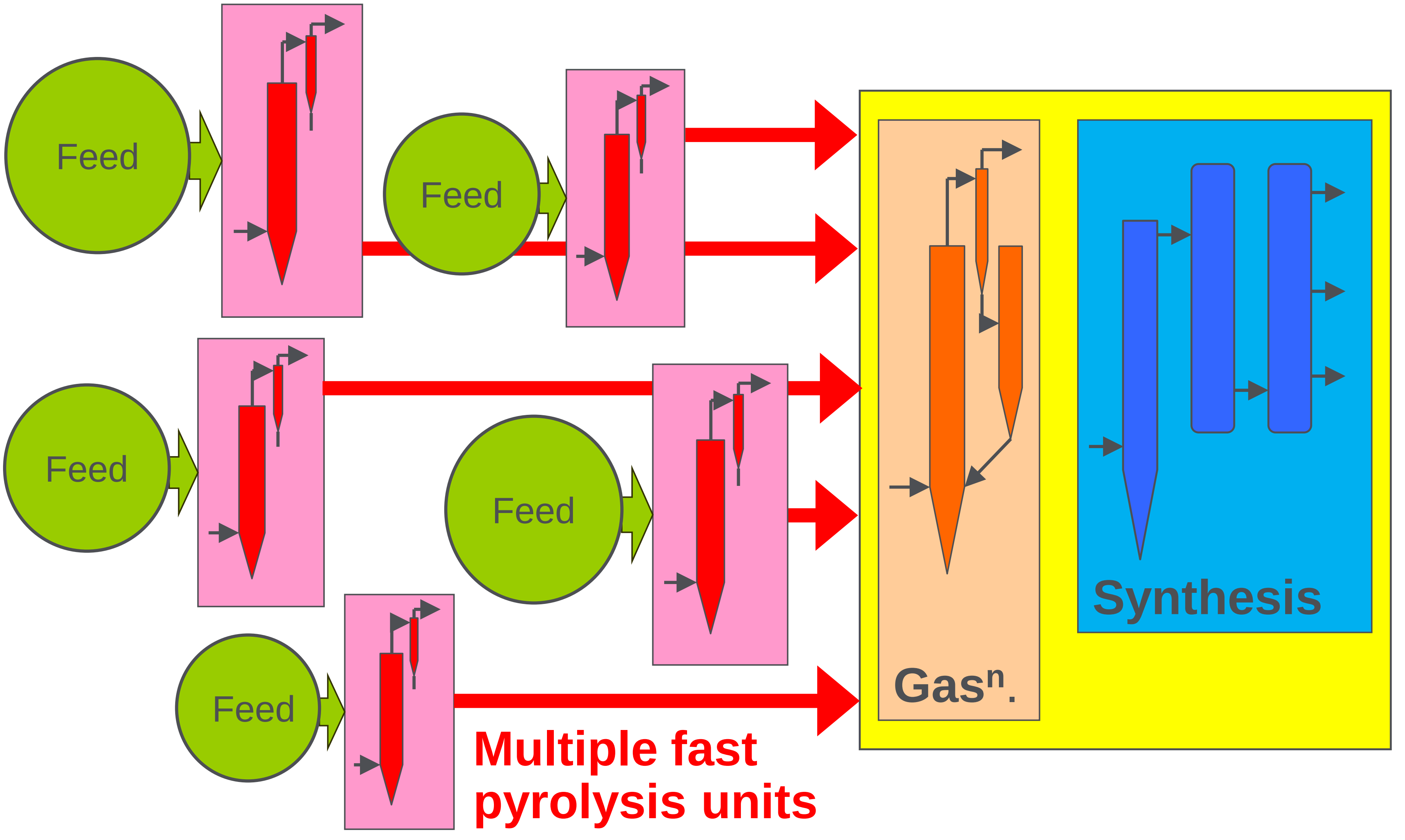
- Bulk density
  - Biomass density down to 100 kg/m^3. Bio-oil density is 1200 kg/m^3
- Bio-oil liquid storage
  - Tanks and pumps; No windblown refuse; No vermin; No mechanical handling
- Liquids are easier and lower cost to handle, transport and store
  - Pumps or gravity feed; No mechanical handling
  - Optimum use of loading weight restrictions on vehicles.
- Pressure gasification of liquids is lower cost than solids
- Decentralised fast pyrolysis offers logistical and environmental advantages in transporting bioenergy
- Alkali metals report to char so are mostly avoided in the gasification step giving lower cost gas cleaning.

Decentralised fast pyrolysis & local use √



Decentralised fast pyrolysis systems could use modularisation when concepts and technology are better established

Decentralised fast pyrolysis concept √



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

Routes to biofuels and chemicals

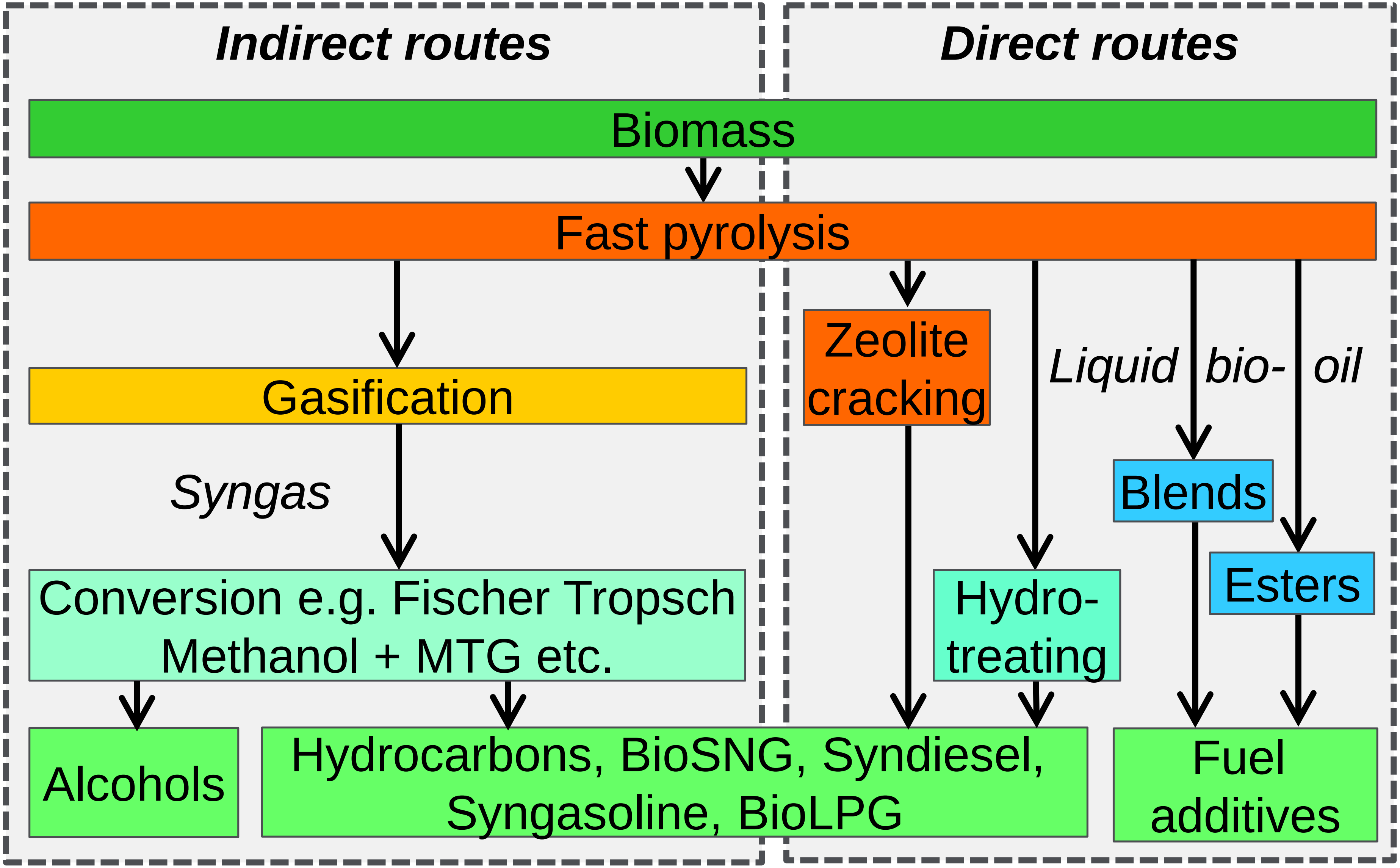
Direct production

- By catalytic upgrading of vapour. This is a further variable in the complexity of defining and hence modularising a fast pyrolysis system. X
- By hydrodeoxygenation of bio-oil. This is a decoupled operation. When sufficiently developed, offers scope for modularisation. Successful processes will need to be sufficiently flexible to be omnivorous in bio-oil feeds. √

Indirect production

- Via gasification of bio-oil followed by hydrocarbon or alcohol synthesis. There are technical and economic advantages of gasification of liquid bio-oil rather than solid biomass. Large scale inhibits modularisation X

Pyrolysis routes to biofuels



Gasification of bio-oil

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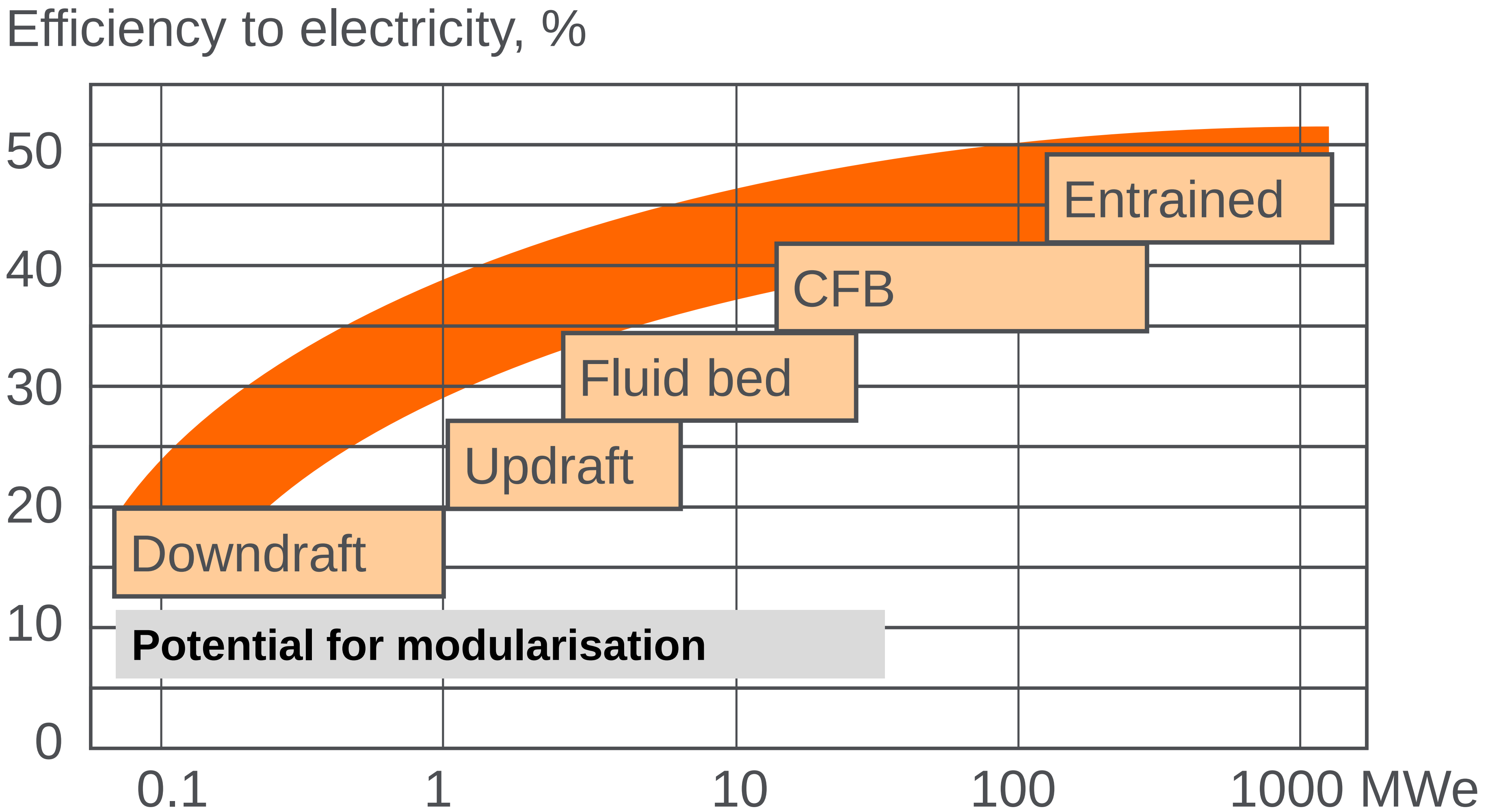
- Remote and/or decentralised fast pyrolysis considers transporting liquefied biomass as bio-oil to a central gasification plant for synthesis of hydrocarbons or alcohols
- Liquids are easier and lower cost to transport than solids
- Liquids can be more easily and economically gasified than solid biomass (e.g. no lock hoppers) i.e. lower cost
- Absence of ash reduces slagging and corrosion/erosion in gasifier i.e. lower cost
- Subsequent biofuel synthesis is based on conventional technology

- The downside is lower efficiency and higher cost of multiple fast pyrolysis processes

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 See Guessing later
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 beds √
  - Downdraft limited to <6 t/d each unit (~250 kWe)
  - Updraft limited to ~70 t/d each unit (~2.5MWe). Significant tars.
- Fluid beds √
  - BFB limited to ~200 t/d (~10MWe)
  - CFB less constrained on size, limited to ~500 t/d (50-100MWe)
- Entrained flow X
  - 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

Twin fluid bed ?

Austrian Energy at Guessing Austria. 1.5 t/h; 2 MWe indirect twin fluid bed (allothermal)

- > 50000 h operation
- > 90% availability
- Replicated 2x
- Economically viable under Austrian support policies
- Replications employed lessons learned from the Guessing plant, so limited modularisation

Downdraft

√

- **Biomass engineering, UK**, developed a suite of downdraft gasifiers from 50 to 250 kWe, with simple gas cleaning coupled to an engine
- Projects up to 2 MWe were supplied based on 8 individual gasifier – gensets coupled together
- The most common problem was understood to be a failure of the purchasers to control feedstock quality resulting in poor control and dirty gas.

- This is close to modularisation.
- Biomass Engineering currently do not offer biomass gasifiers.

Biofuels via thermal gasification

- The minimum economic size of Fischer Tropsch is widely considered to be 20,000 bbl/day or nearly 1 million t/y biofuels requiring nearly 5 million t/y biomass.
- There are several proprietary FT processes. Designs will depend on scale, syngas composition, contaminants and product spectrum
- Commercial plants will be purpose designed and built and a modular approach seems unlikely

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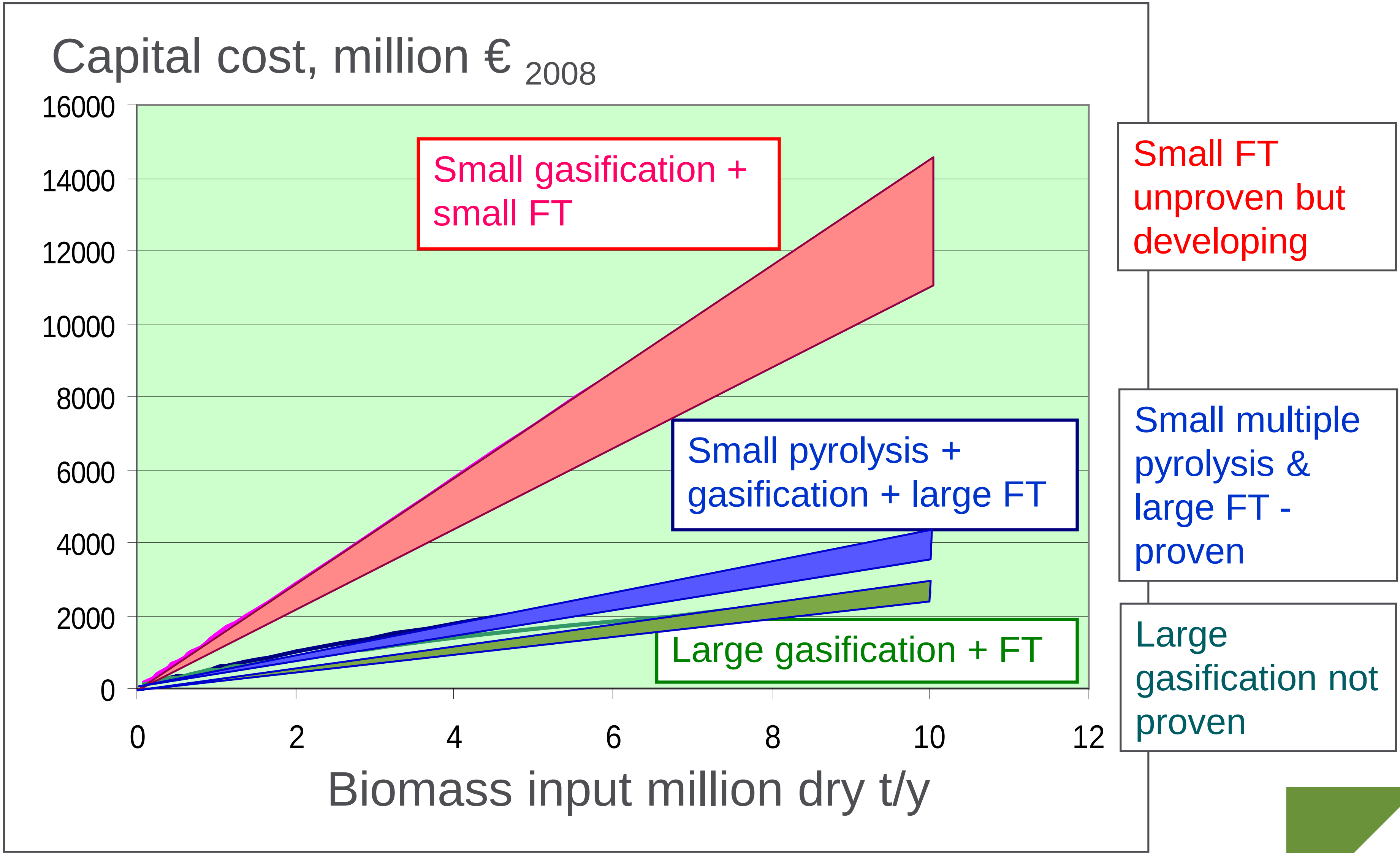
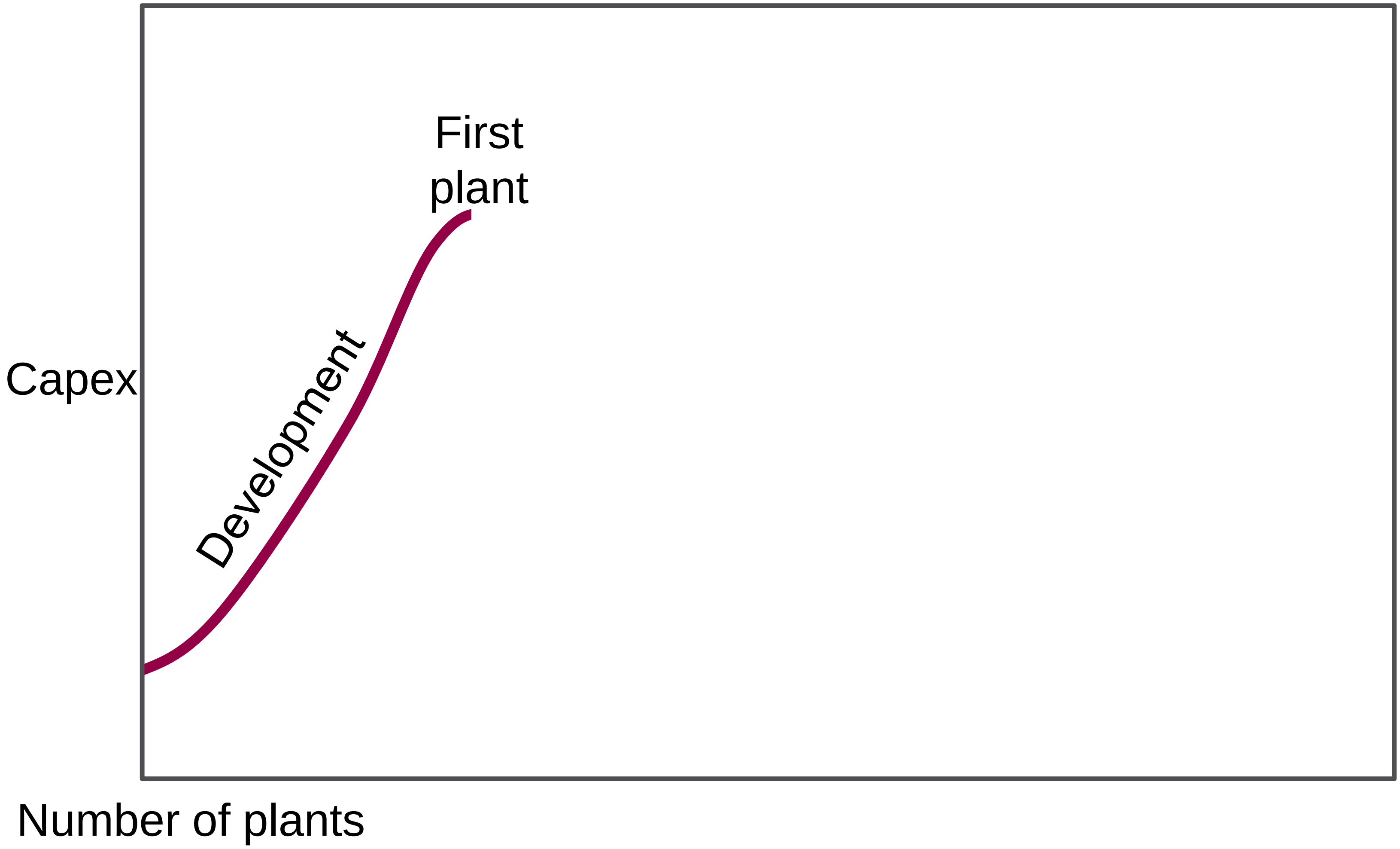
Capital costs

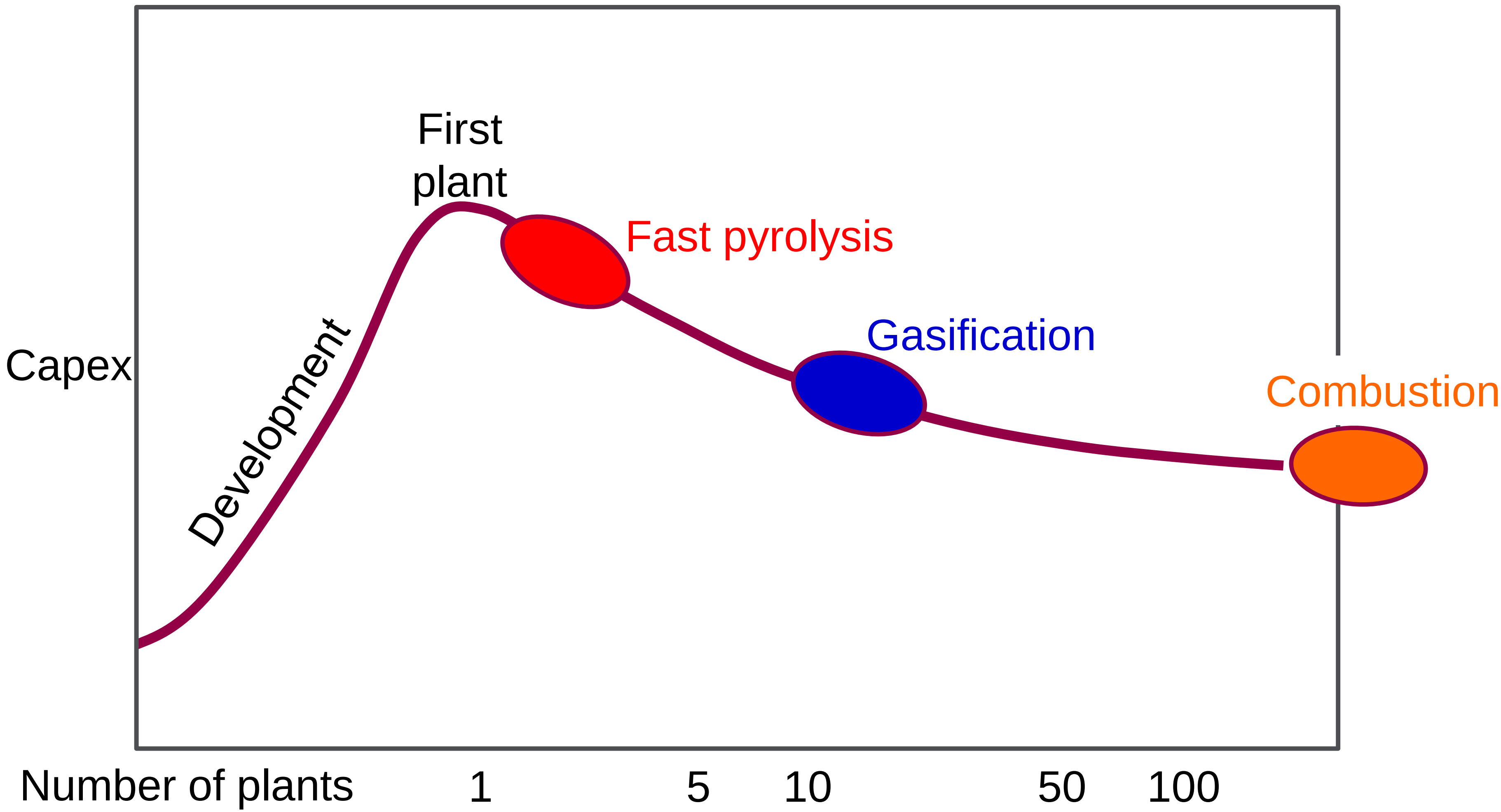
(√)



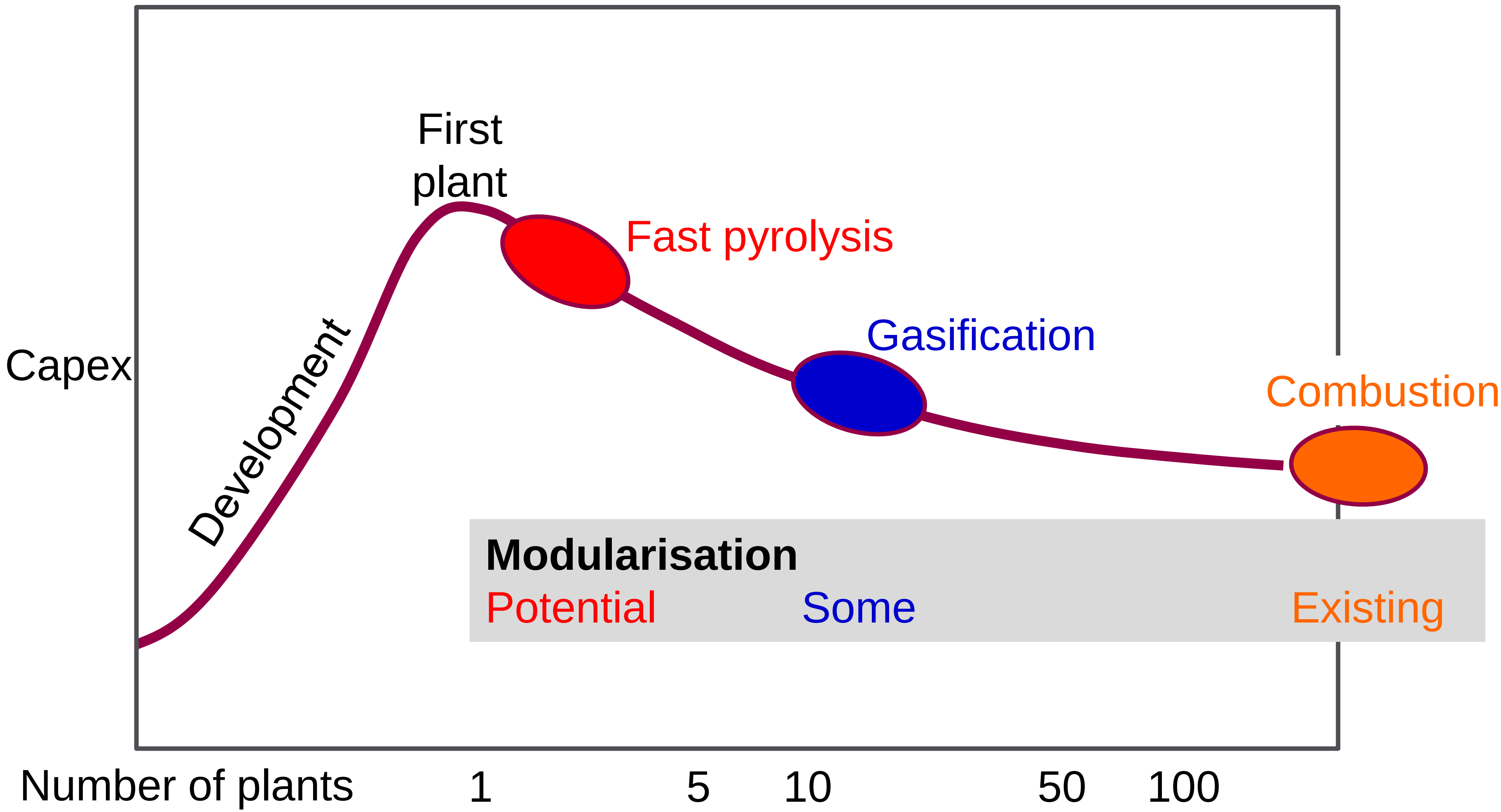
Learning



Learning


First
plant
Fast pyrolysis
Gasification
Combustion
Capex
Development
Number of plants
1
5
10
50
100

Learning



Modularisation depends on technology maturity, scale of process, and complexity of process

Modularisation conclusions

- The attraction is economic, logistical and operational.
- Bioenergy is challenging because of the interactions and dependencies between feed, technology and product which can inhibit modularisation
- Modularisation is most likely for small to medium size plants
- A sufficiently mature technology is needed for modularisation. Technologies not (yet) optimised are less likely to benefit
- Modularisation offers economic and operational benefits of multiple units if appropriate circumstances arise, but should be compared with economies of scale
- Smaller scale modules are more likely to be attractive
- Modularisation offers the potential for significantly enhanced turn down capability enabling processes to better match demand, but economics are important.

Thank you