# Biomass, Bioenergy and Biofuels

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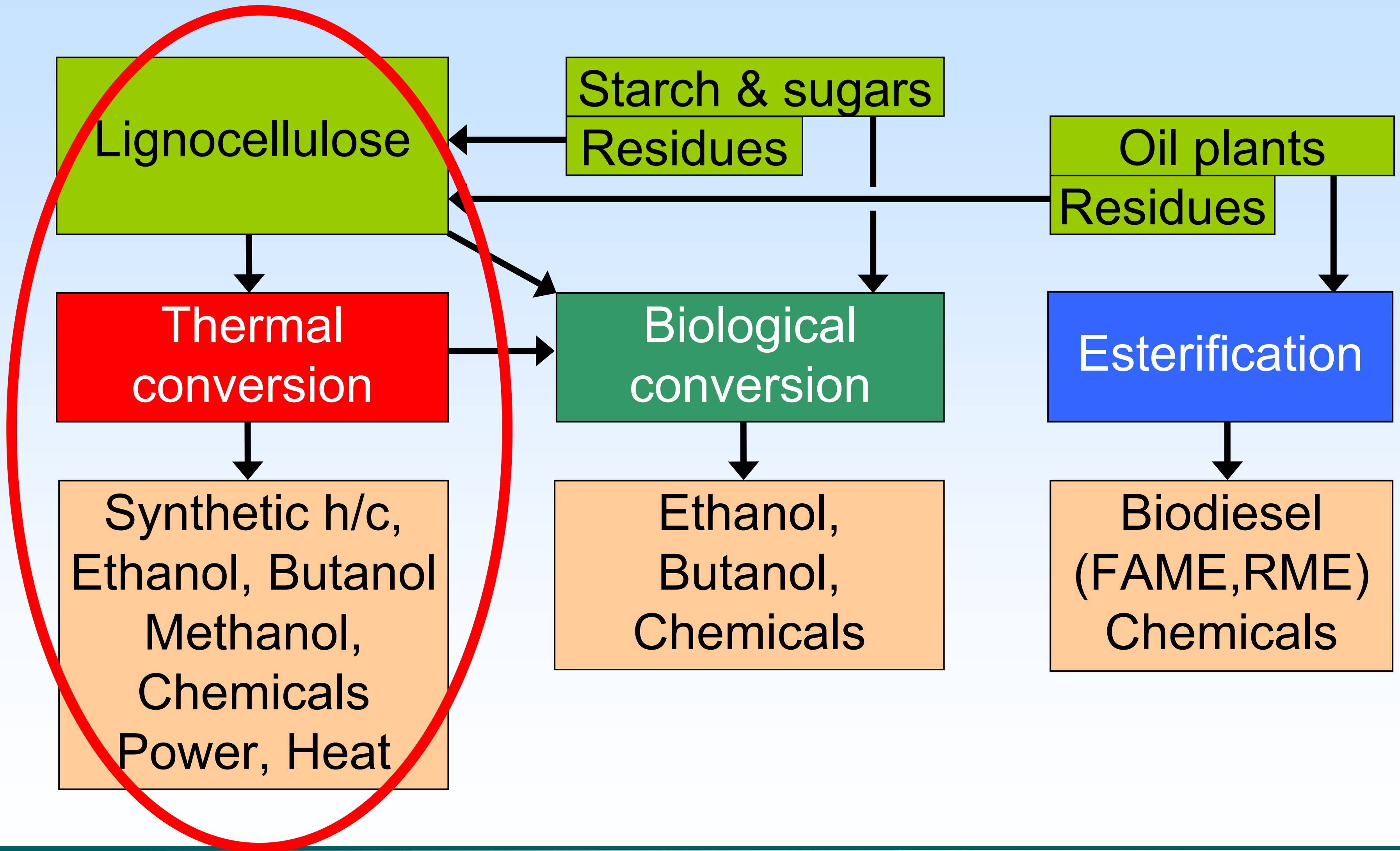
# Biomass

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

- Biomass is widely dispersed, with few sites that can sustainably produce 100,000 dry t/y, about 20-25 MWe,

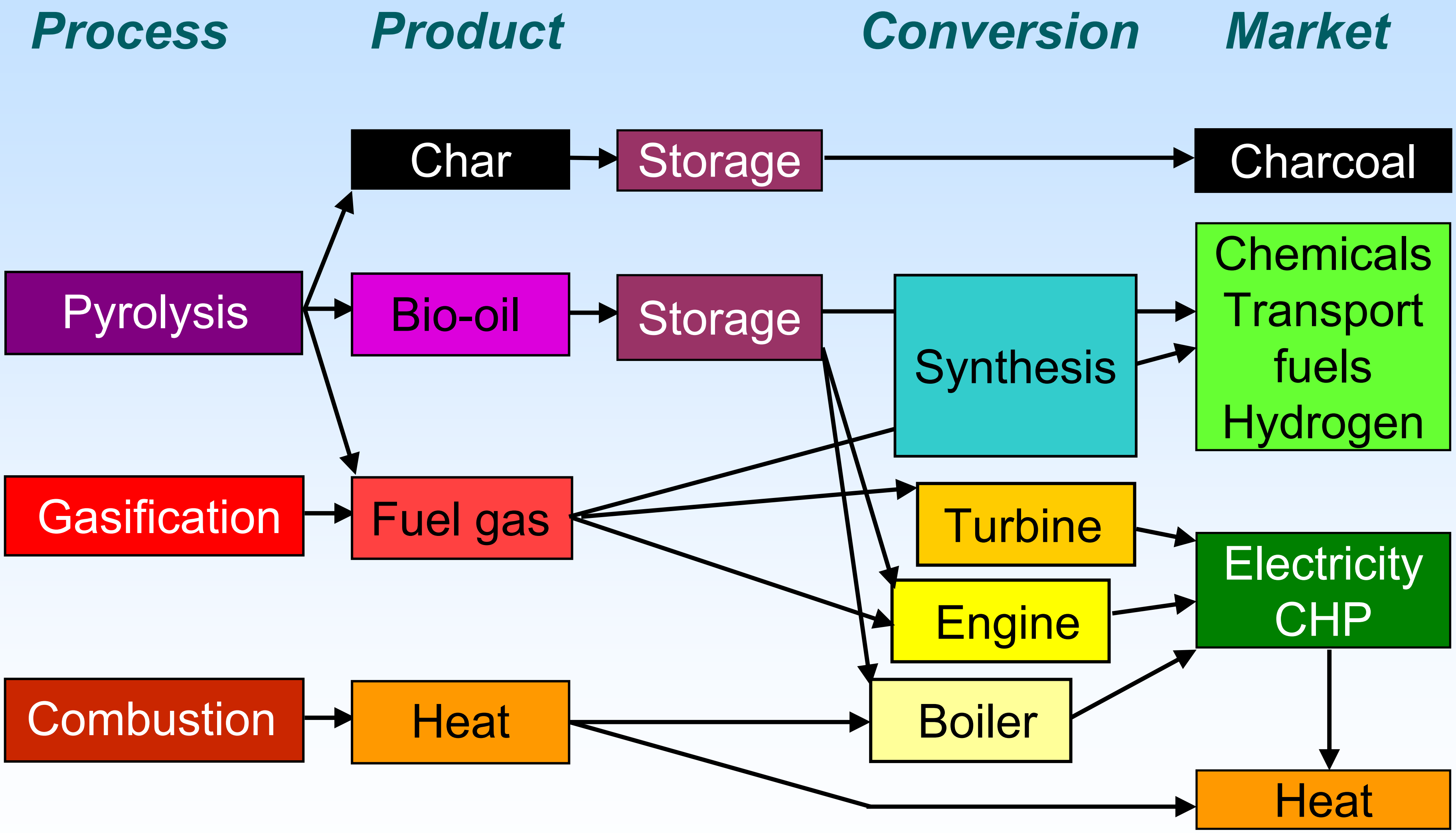
# Feeds, processes, products



# 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

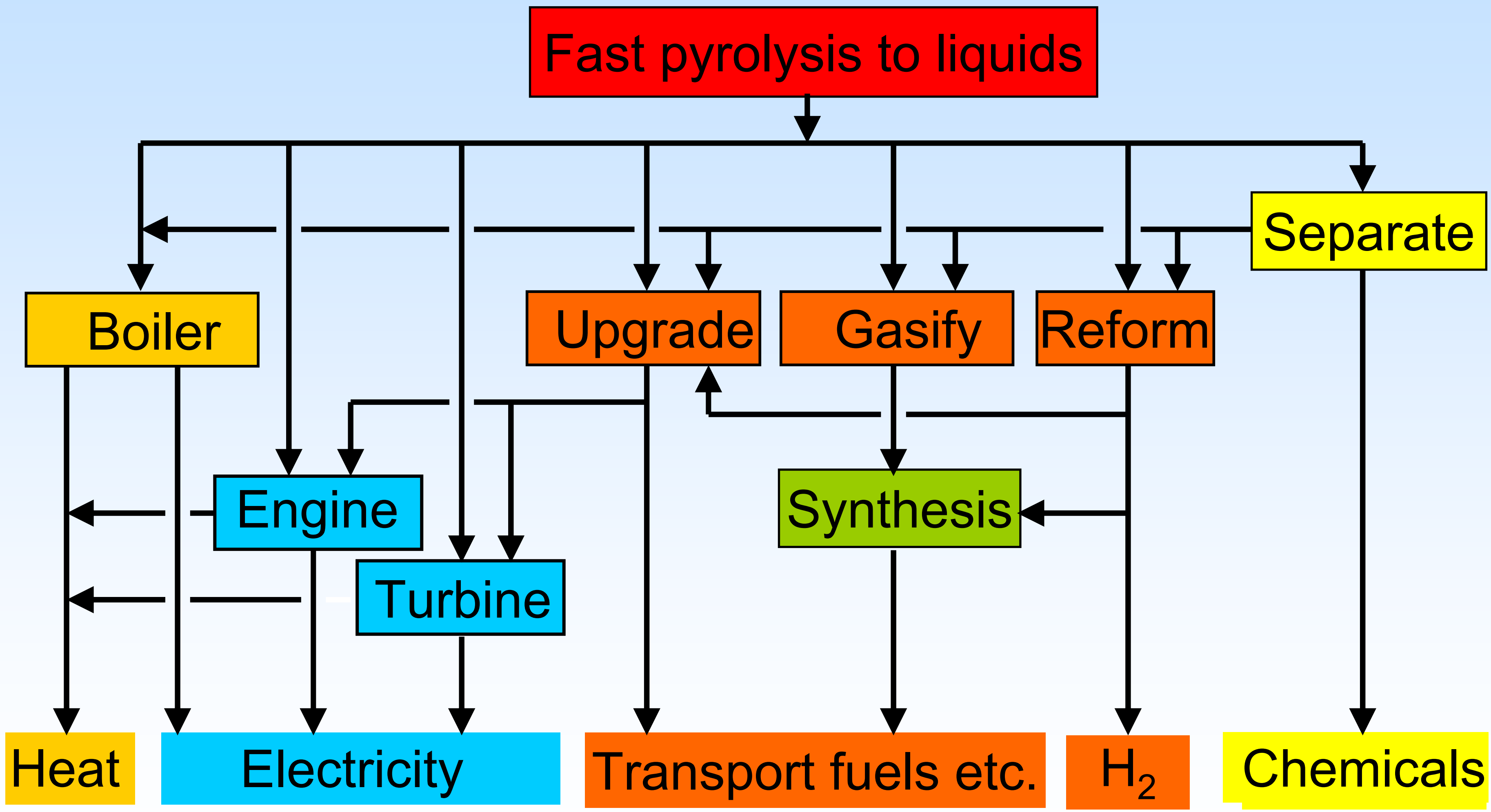
# Thermal Biomass Conversion



# Pyrolysis

| | Liquid | Char | Gas |
|---|---|---|---|
| **FAST PYROLYSIS**<br>moderate temperature (~500C)<br>short hot vapour residence time (<2 s) | 75%<br>**25% water** | 12% | 13% |
| INTERMEDIATE PYROLYSIS<br>Low-moderate temperature,<br>moderate hot vapour residence times | 50%<br>**50% water** | 25% | 25% |
| SLOW PYROLYSIS<br>Low-moderate temperature,<br>long residence times | 30%<br>**70% water** | 35% | 35% |
| GASIFICATION<br>high temperature (>800C),<br>long vapour residence time | 5% (tar)<br>**5% water** | 10% | 85% |

# Applications for bio-oil



# 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)
- The liquid has unique properties
  - Dark brown mobile liquid,
  - Combustible, but not flammable,
  - Heating value ~ 17 MJ/kg,
  - Not miscible with hydrocarbons,
  - Density ~ 1.2 kg/l,
  - Acid, pH ~ 2.5,
  - Pungent odour,

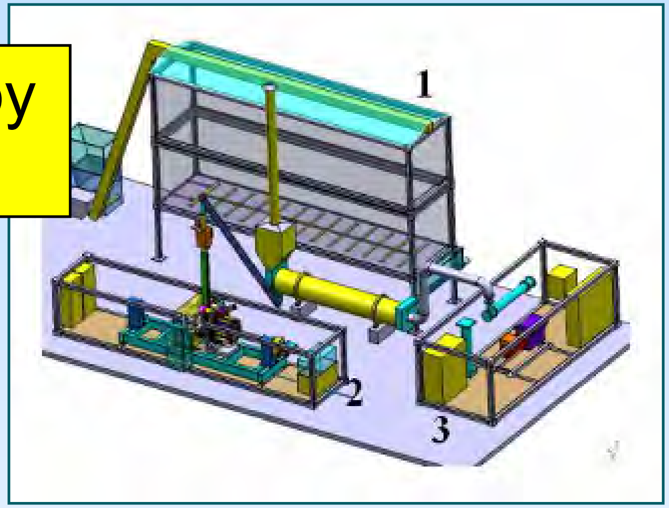
# Process requirements

| | |
|---|---|
| Drying | <10%. Feed and reaction water report to bio-oil |
| Comminution | -2mm (fluid bed), -6 mm (CFB) |
| Fast pyrolysis | high heat rate, controlled T, short residence time, |
| Char separation | Efficient char separation needed |
| Liquid recovery | By condensation and coalescence. |

# Pyrolysis examples

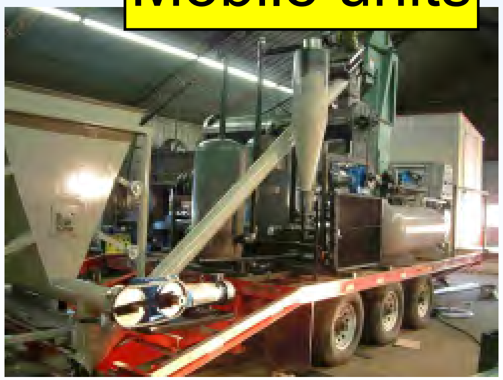

100 & 200 t/d by Dynamotive

50 t/d by Pytec




50 t/d by BTG

Mobile units



50 t/d by Ensyn

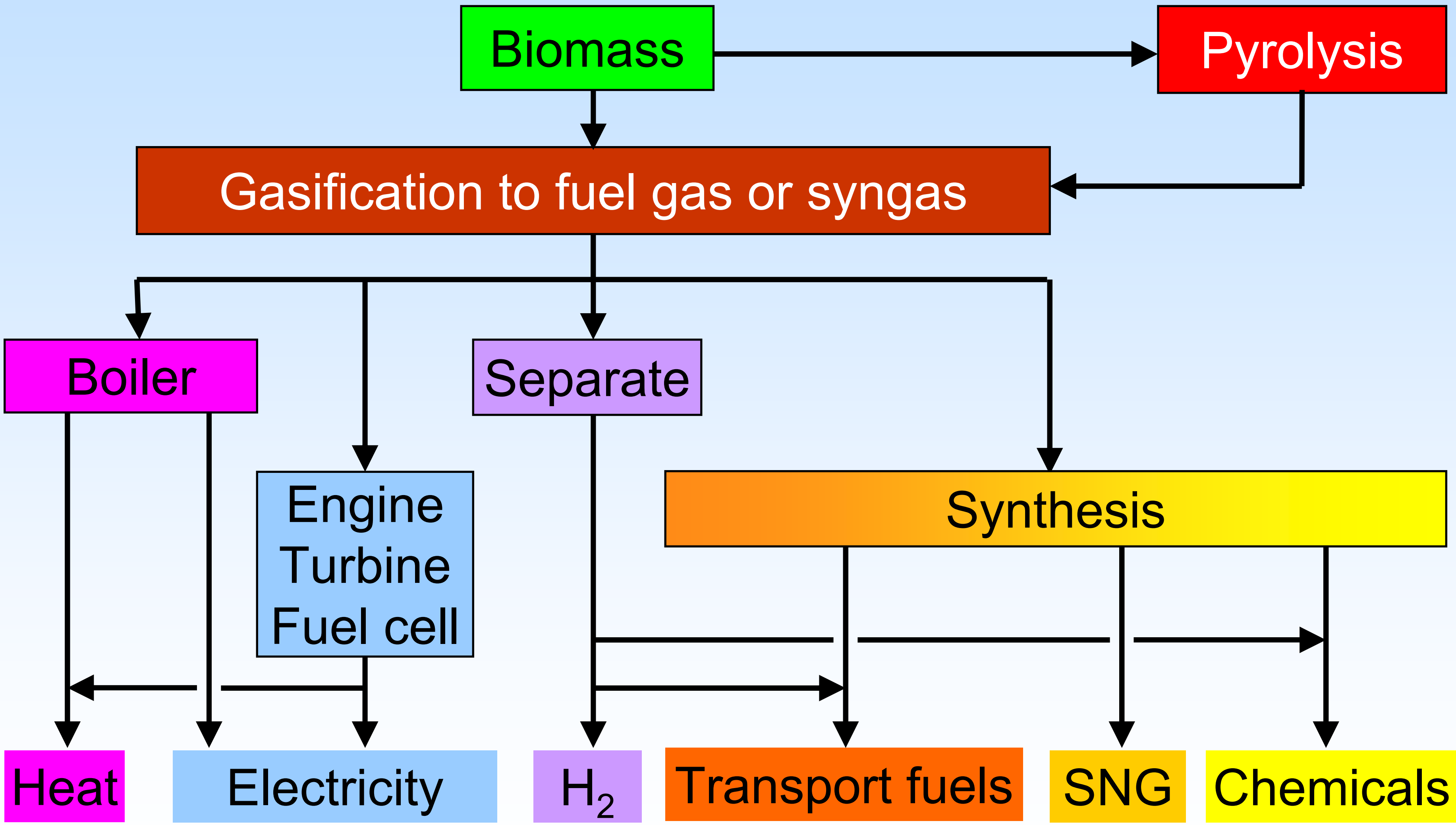
# Gasification

- Gasification is the substantial conversion of organic material into a combustible gas.
- This can be thermal:
  - Partial oxidation by incomplete combustion with air or oxygen to give a combustible fuel gas or synthesis gas. This is mostly carbon monoxide, carbon dioxide, hydrogen, and nitrogen if air is used.
  - Steam gasification or pyrolytic gasification using heat derived from combustion of byproduct char, without addition of oxygen or air. The product gas also contains significant quantities of methane.
- Or it can be biological:
  - Anaerobic digestion to methane and carbon dioxide.

# Gasification types

| *Type* | *Gas HV* | *Efficiency* | *Comments* |
|---|---|---|---|
| AIR | ~ 5 MJ/Nm$^3$ | High | Simple |
| OXYGEN | ~ 10 MJ/Nm$^3$ | Moderate | Costly |
| STEAM (PYROLYSIS) | ~ 15 MJ/Nm$^3$ | Low | Complex process, Endothermic |
| PRESSURE | | | Costly, but high IGCC potential |
| AIR | ~ 5 MJ/Nm$^3$ | High | |
| OXYGEN | ~ 10 MJ/Nm$^3$ | Moderate | |
| BIOGAS | ~ 18 MJ/Nm$^3$ | Moderate | |
| Methane for comparison | 35.5 MJ/Nm$^3$ | | |

# Applications for fuel gas or syngas



# Gasifier examples

2 MWe by Austrian Energy at Guessing

50 kWe by Biomass Eng'g in UK


45 MWe co-firing at Lahti



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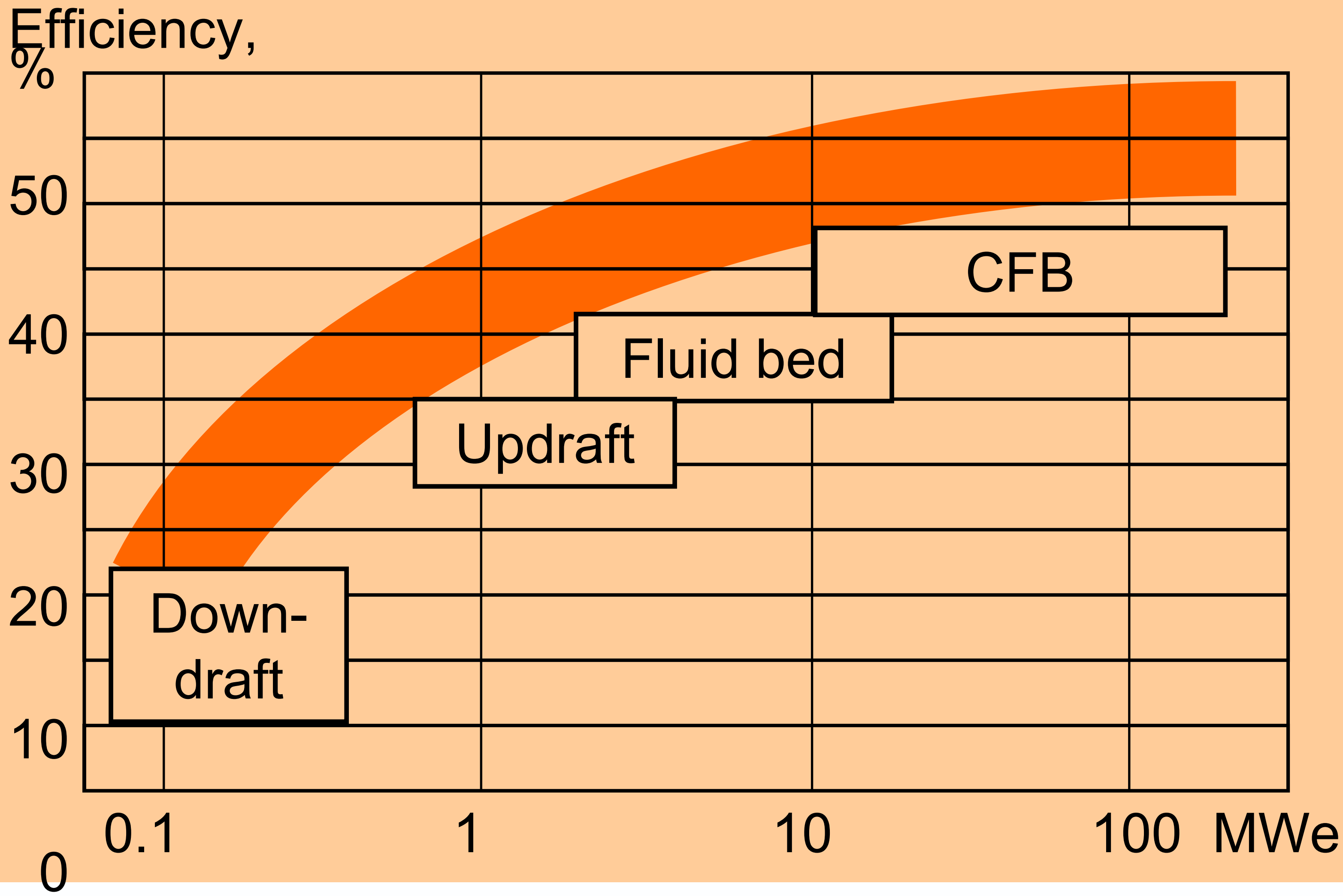
# Efficiency, technology & scale



# Main challenge - gas quality

| Contaminant | Examples | Problem | Solution |
|---|---|---|---|
| Particulates | Ash, char, fluid bed material | Erosion | Cyclone, barrier filter. |
| Alkali metals | Na, K compounds | Hot corrosion | Temperature. |
| Fuel-bound nitrogen | Ammonia, HCN | NOx | Temperature, SCR. |
| **Tars** | Refractive aromatics | Clogs filters, Difficult to burn, Deposits. | Cracking, Removal, Combustion. |
| Sulphur, chlorine | HCl, $H_2S$ | Corrosion Emissions | Capture, Washing. |

# 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 (CSNG) | 1° & 2° | Thermal |
| **Other** | | |
| • Hydrogen | 1° & 2° | Thermal or Biological |

# Synthetic hydrocarbons

- Synthetic hydrocarbons are entirely compatible with conventional crude oil–derived fuels in all proportions, but much cleaner. They include diesel, gasoline, kerosene
- The process is biomass or bio-oil gasification to a clean syngas and synthesis of hydrocarbons.
- Concept proven from coal in South Africa and from gas in Far East

- Biomass gasification technology is unproven at large scale. Gas cleaning claimed to not be a problem, but there is no evidence and no large scale experience

# Gasification + Fischer-Tropsch

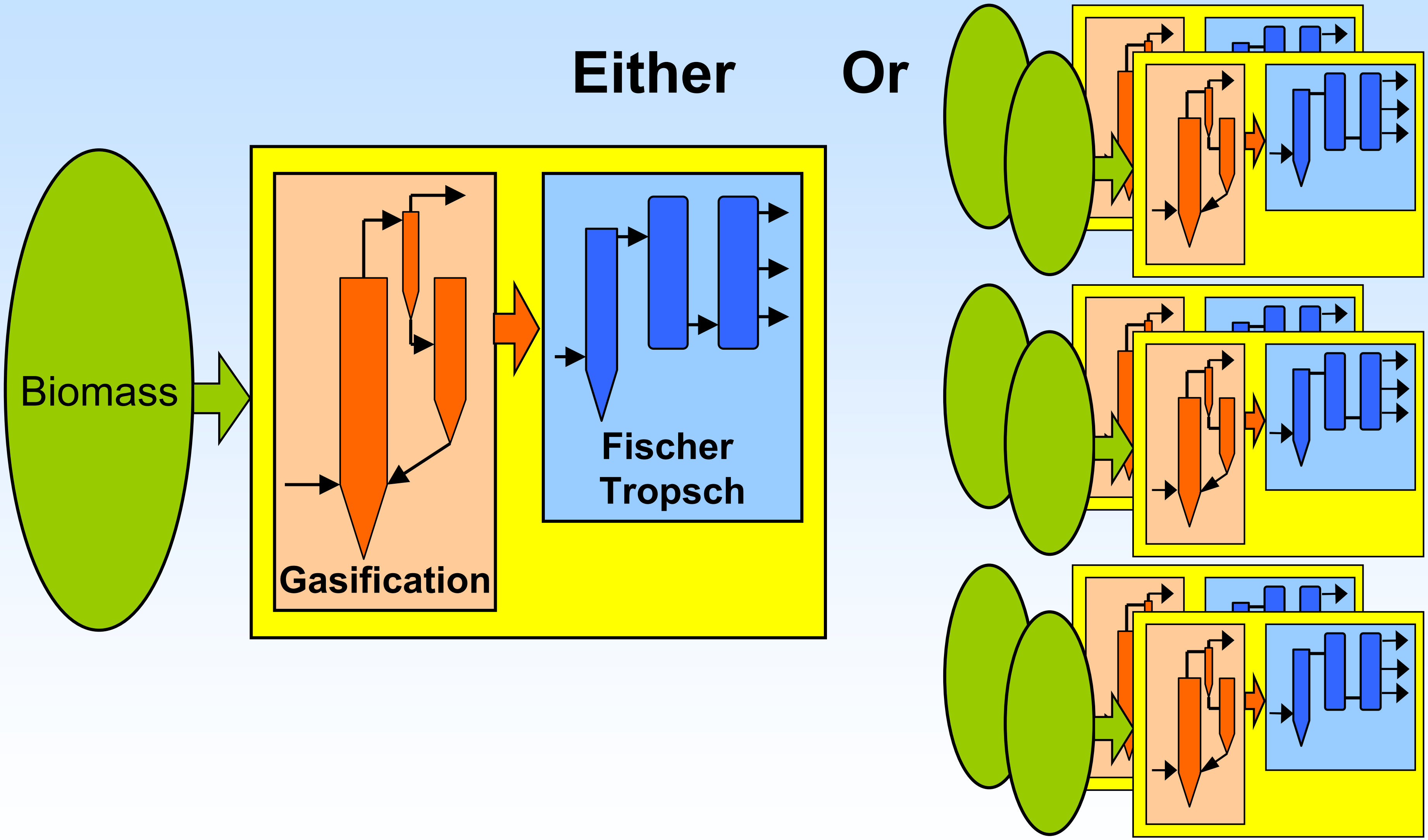
Fischer Tropsch is claimed to require a minimum size of 1 million t/y fuels to be economic

Biomass is a dispersed resource that has to be collected and transported over large distances.  There are 2 options:

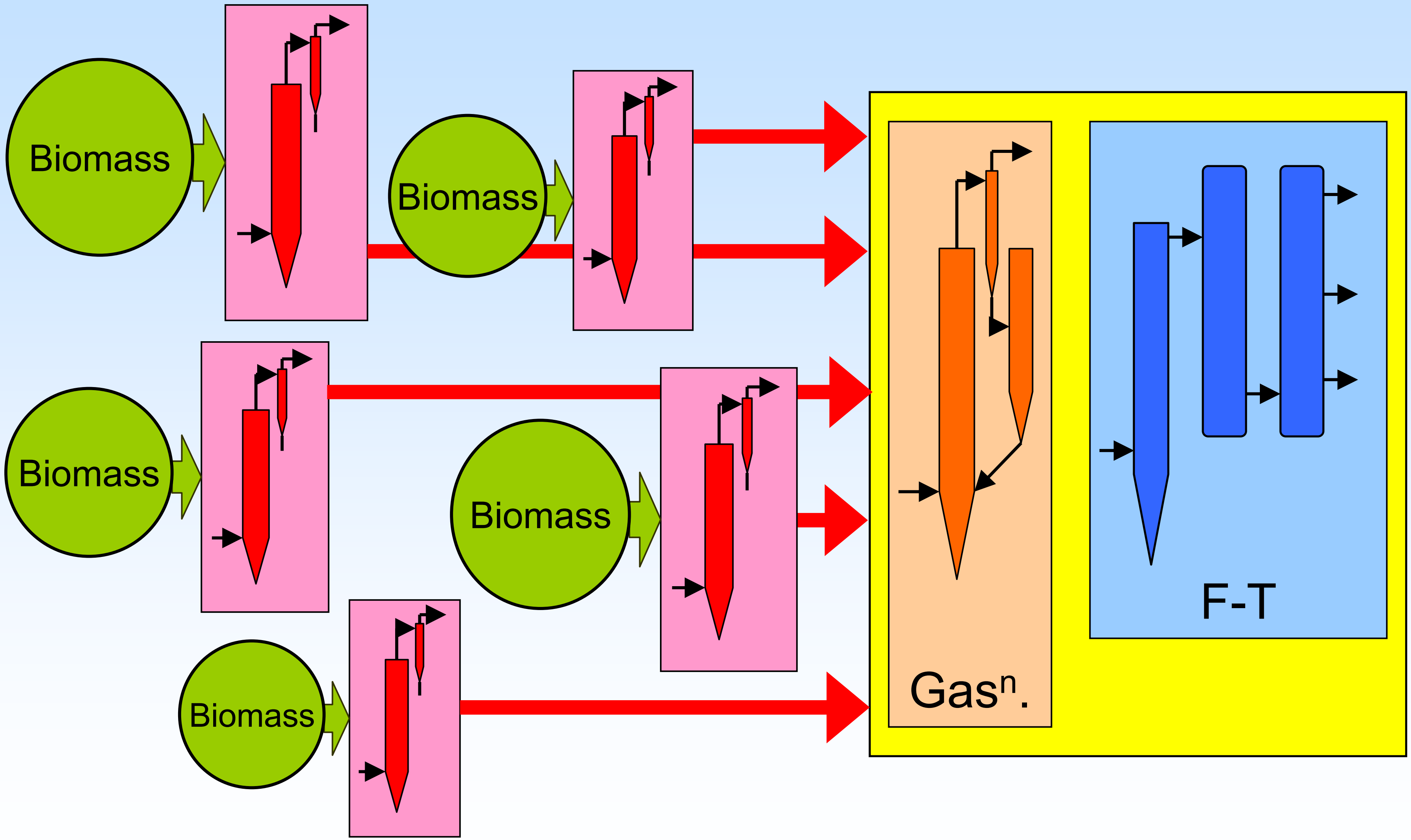
1. Large gasification plants integrated with FT synthesis. This requires delivery of very large quantities of biomass – around 5 million t/y to meet current views on economies of scale for FT plants.
2. Small multiple gasification plants integrated with downscaled Fischer-Tropsch (FT) hydrocarbon synthesis. This is costly due to absence of economies of scale and downscaling is unproven.

# Gasification + Fischer-Tropsch

Either Or



# Pyrolysis + Fischer Tropsch



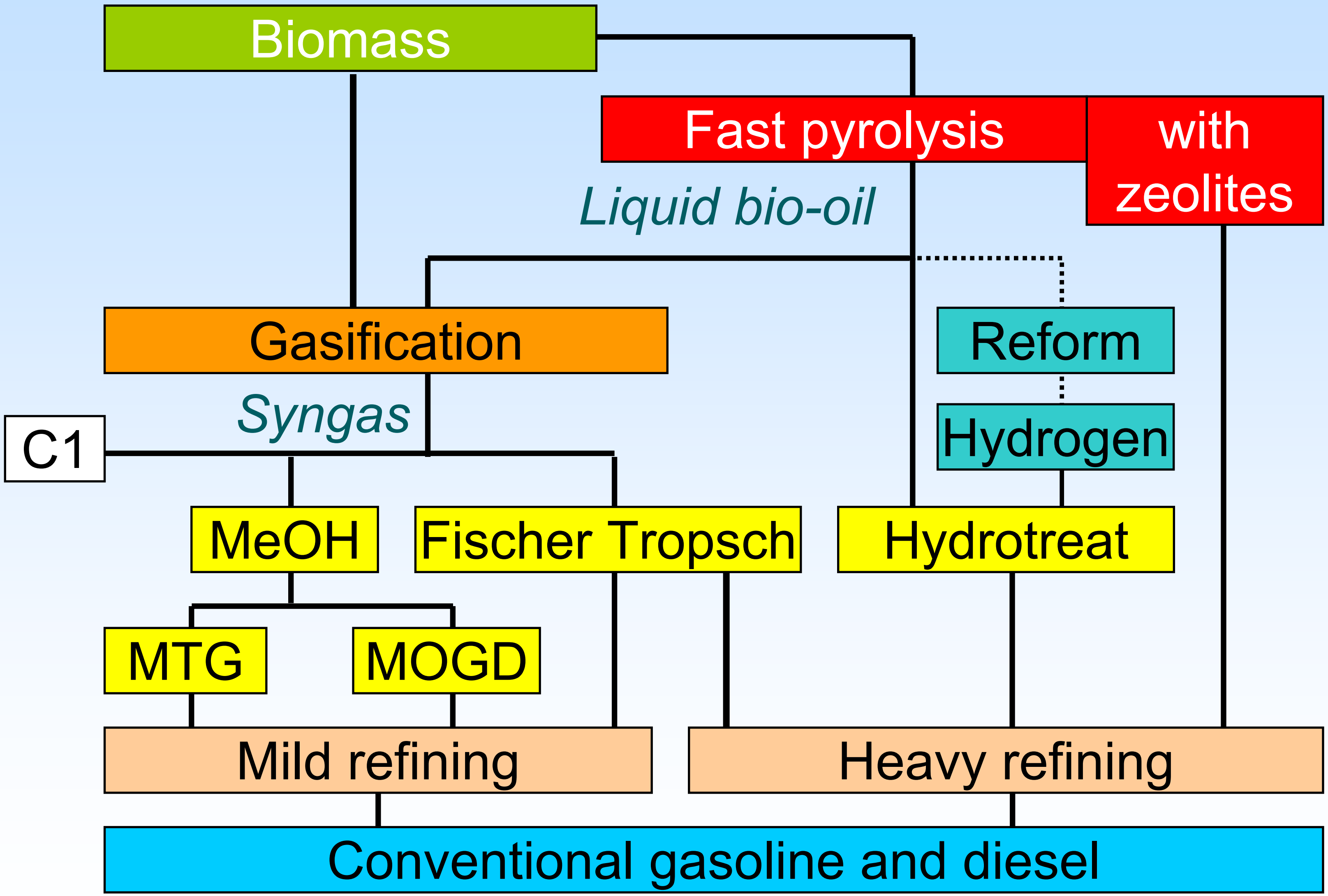
# Comparison liquid vs solid feed

- Capital cost **increase** of ~10% due to diseconomies of scale in small pyrolysis plants
- Capital cost **reduction** of ~8% due to lower raw material handling costs
- Capital cost **reduction** of ~12% due to lower gasification costs in feeding a liquid at pressure compared to solid biomass
- Efficiency **loss** of ~6% due to additional processing step

# Routes to bio-hydrocarbon fuels

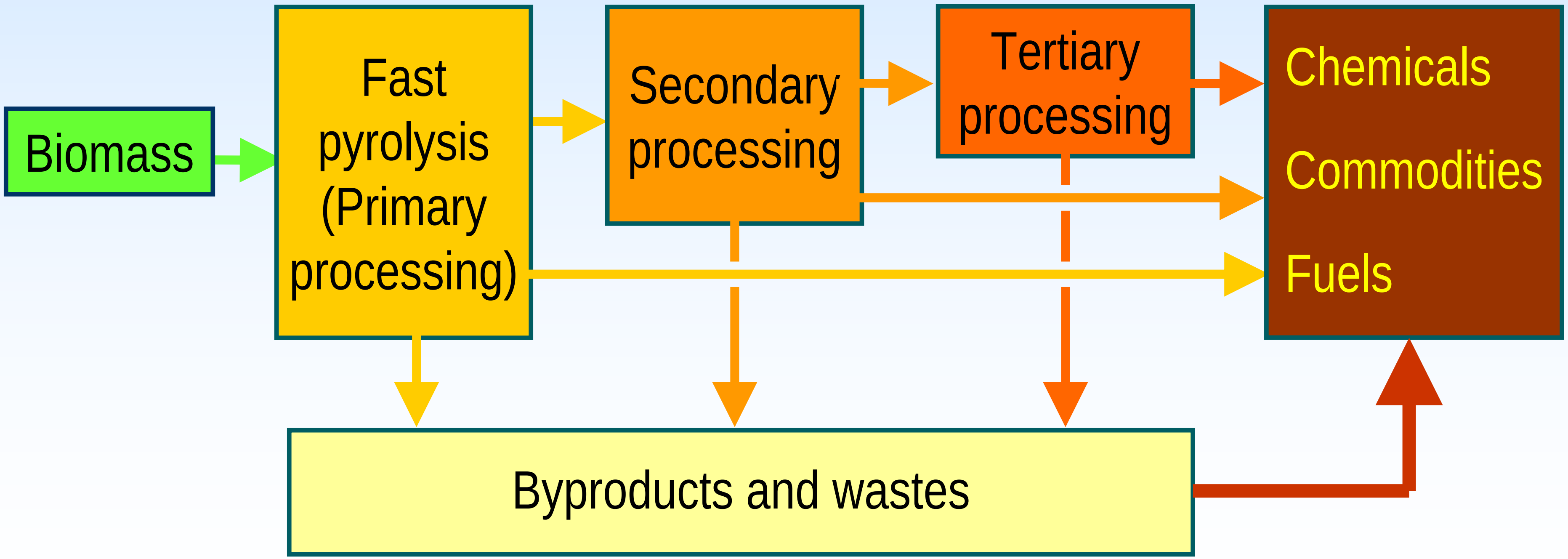
1. Thermal gasification + Fischer Tropsch
   - Solid biomass
   - Pyrolysis liquid as a preparation step
2. Thermal gasification + Methanol synthesis + upgrading by MTG or MOGD
3. Pyrolysis + upgrading by hydro-processing
4. Hydro-processing vegetable oil

# Transport fuels from biomass



# Biorefinery concept

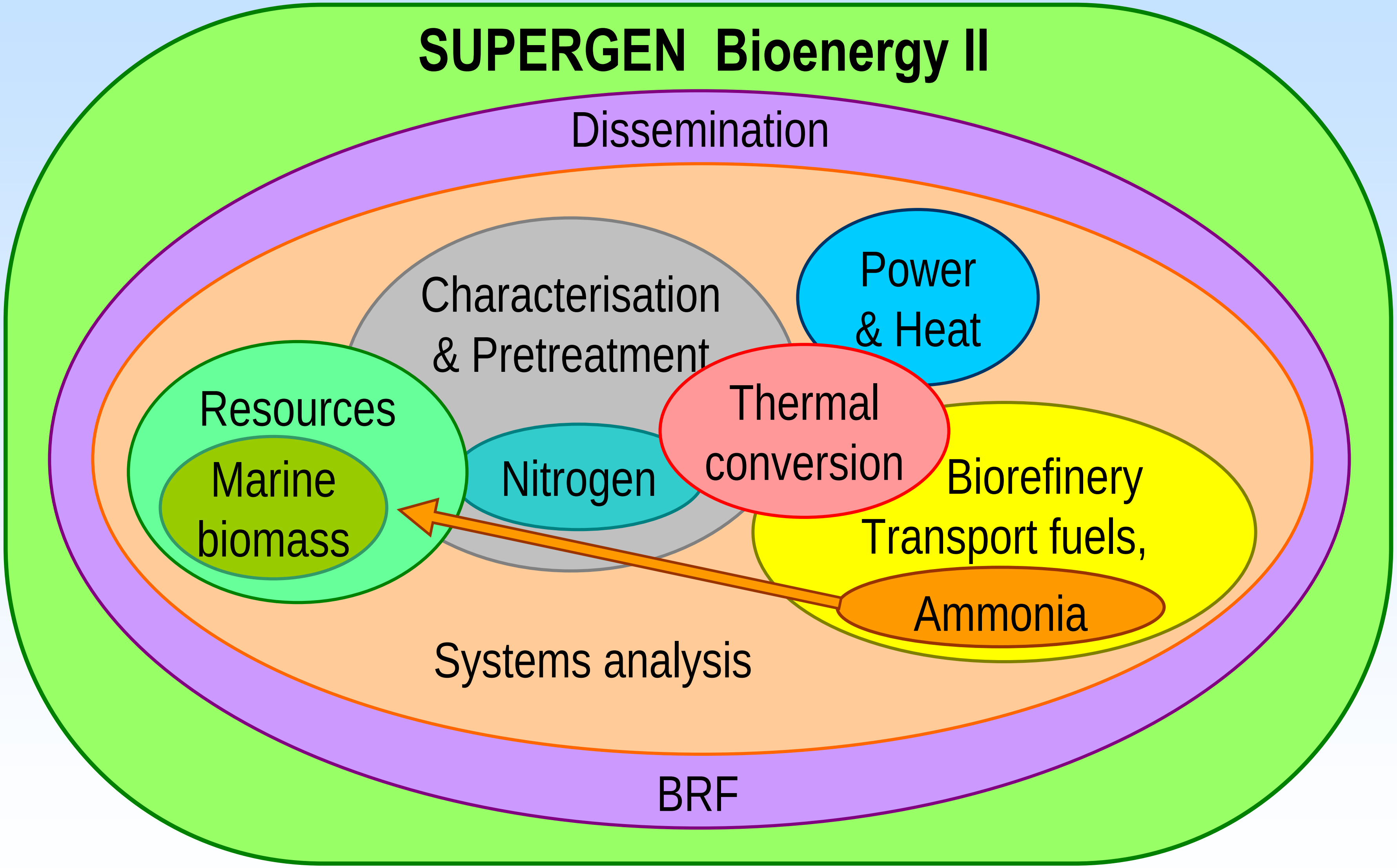
- Integrate production of higher value chemicals and commodities, as well as fuels and energy,
- Optimise use of resources, maximise profitability, maximise benefits, minimise wastes



# SUPERGEN Bioenergy

- SUPERGEN Bioenergy is one of 13 academically led consortia funded by EPSRC researching renewable energy
- A consortium of 14 research organisations and 11 companies
- Continuation of a 4 year phase 1 project with a second 4 year term and a £6.35 million budget
- Continuation of the focus on interfaces between biomass production, thermal conversion and product utilisation with added activities on:
  - marine biomass as a new resource,
  - nitrogen as a significant component of biomass,
  - second generation biofuels,
  - biorefineries and fertilisers

# SUPERGEN Bioenergy structure



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# Partners

ACADEMIC

- Aston (Management)
- Cranfield
- Forest Research
- Imperial College
- IGER
- Leeds (Finance)
- Manchester
- Policy Studies Institute
- Rothamsted Research
- Sheffield

ASSOCIATE PARTNERS

- Irish Seaweed Centre, Oxford, SAMS, Ulster

INDUSTRIAL INVITATIONS

- Alstom
- AMEC
- Bical
- BIFFA
- Biomass Engineering
- BP
- Coppice Resources
- E.On
- Johnson Matthey
- RWE
- Rural Generation

# Overall conclusions

- Bio-oil from fast pyrolysis:
  - Storable and transportable
  - Successfully used in boilers, gas turbines, diesel engines, and for chemicals,
  - Good economics and efficiency as an energy carrier for synthesis of transport fuels etc.
- Gasification
  - More developed commercially,
  - Successfully used for heat and power production, but has to be close coupled to applications,
- Biorefineries
  - Opportunity to improve costs and performance
- SUPERGEN Bioenergy is contributing to all aspects of the work described here