Microwave treatment of biomass

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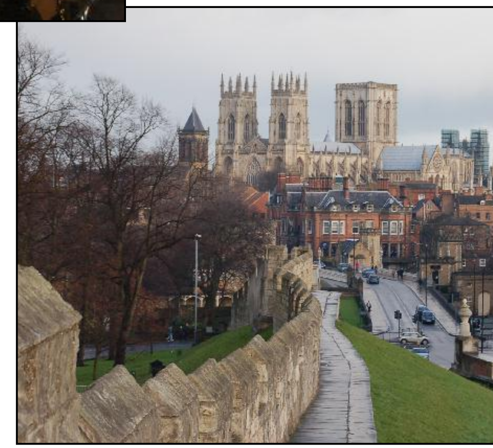
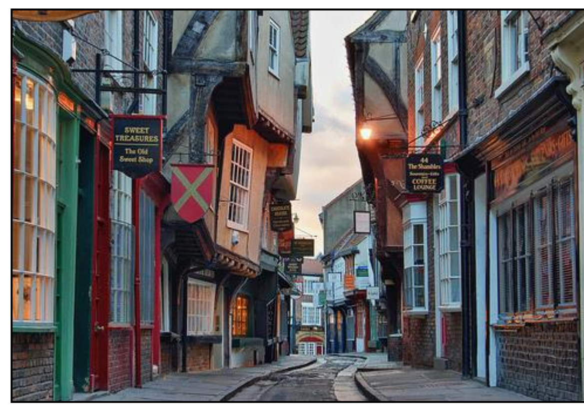
Green Chemistry
Centre of Excellence

York
One of Europe's most beautiful and historic cities






GREEN CHEMISTRY CENTRE OF EXCELLENCE
Renewable Materials
Clean Synthesis & Platform Molecules
Training, Education and Networks
Natural Solvents & Biolubricants
Microwave Processing

Excellence and innovation in Green Chemistry research across the bio-based economy.

Pre-treatment and extraction

EUBIS
Chemicals from Food Waste

Bulk components

High-value components

Conversion and separation technologies

Biomass to Chemicals
Microwave, Catalysis and Flow (EPSRC)

Materials Substitution:
Biobased polymers

Clean chemical synthesis

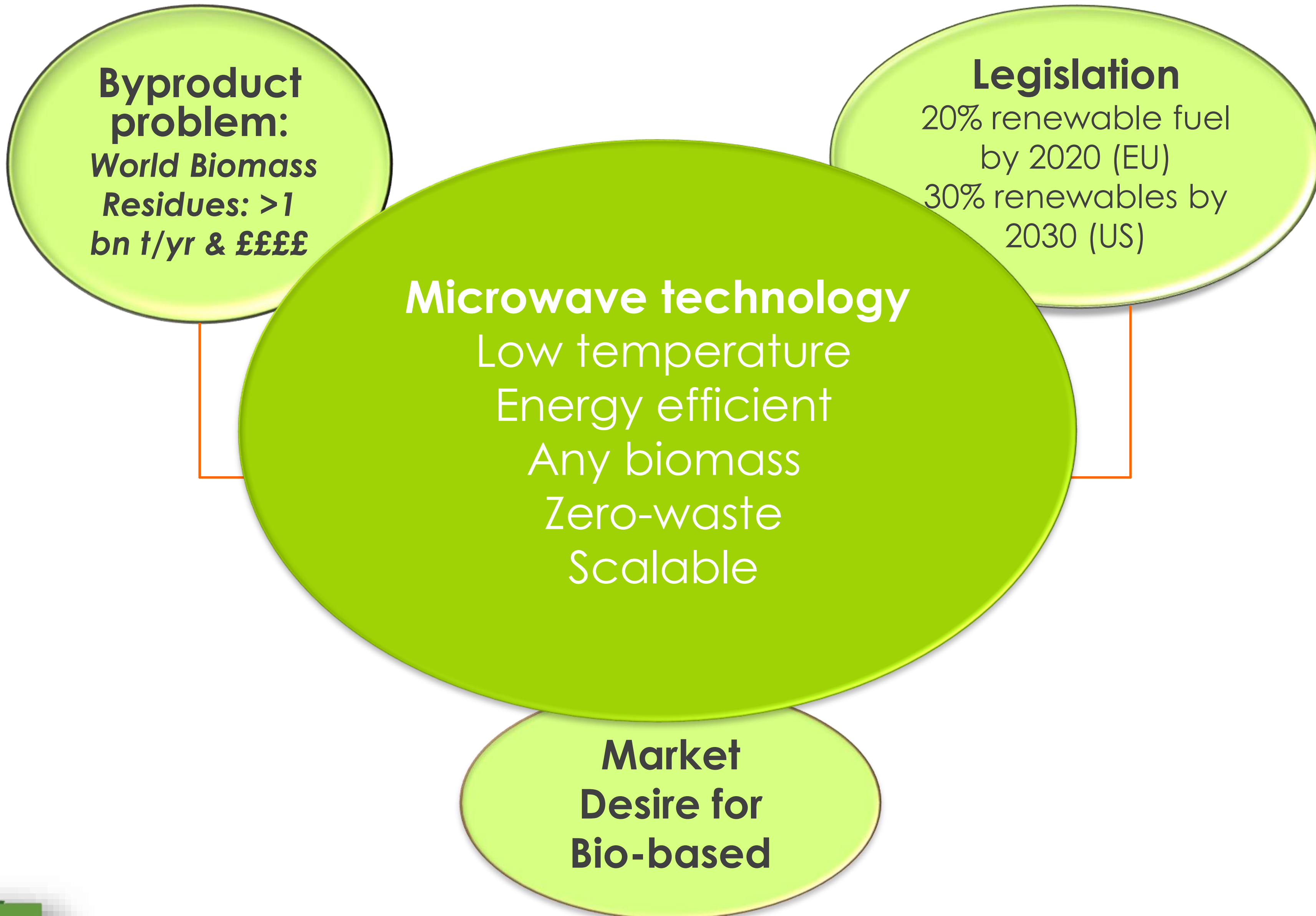
Application testing

Scale-up

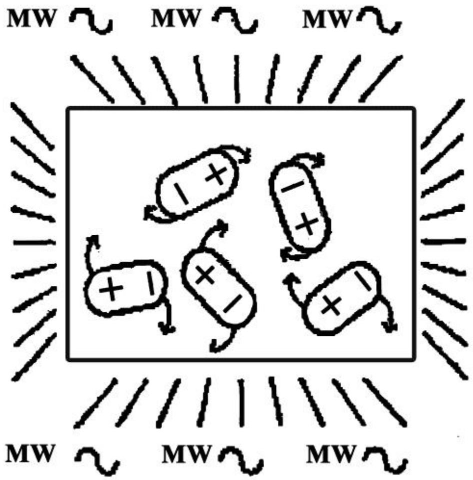
Biorenewables Development Centre

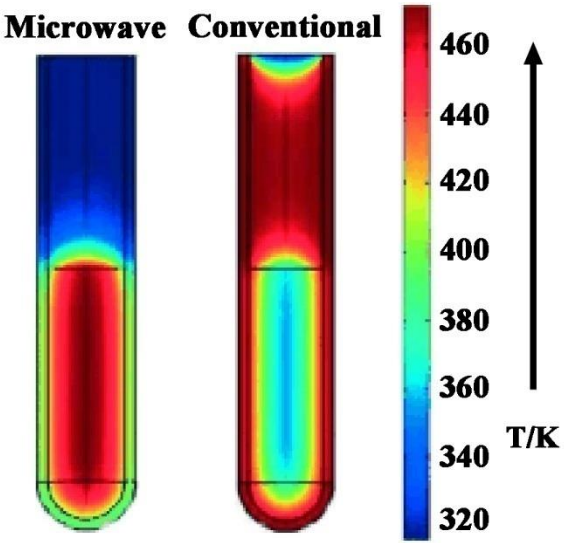
End-of-life evaluation

KBBPPS
Pre-Standardization Research for Bio-based Products


Byproduct problem:
World Biomass Residues: >1 bn t/yr & ££££
Legislation
20% renewable fuel by 2020 (EU)
30% renewables by 2030 (US)
Microwave technology
Low temperature
Energy efficient
Any biomass
Zero-waste
Scalable
Market
Desire for
Bio-based

Why microwaves?





- ✓ Rapid internal heating
- ✓ Uniform heating
- ✓ Instant control
- ✓ Acceleration of reaction rate
- ✓ Selective interaction with active groups

Versatile platform technology with two key approaches:

Pyrolysis

Microwave treatment under inert atmosphere (140 – 300 ˚C)

Key benefits:

- All biomass
- One-step formation of biofuels
- *In-situ* fractionation → **low-acidity stable bio-naptha**
- Target biomass components

Char for Gasification

Hydrothermal

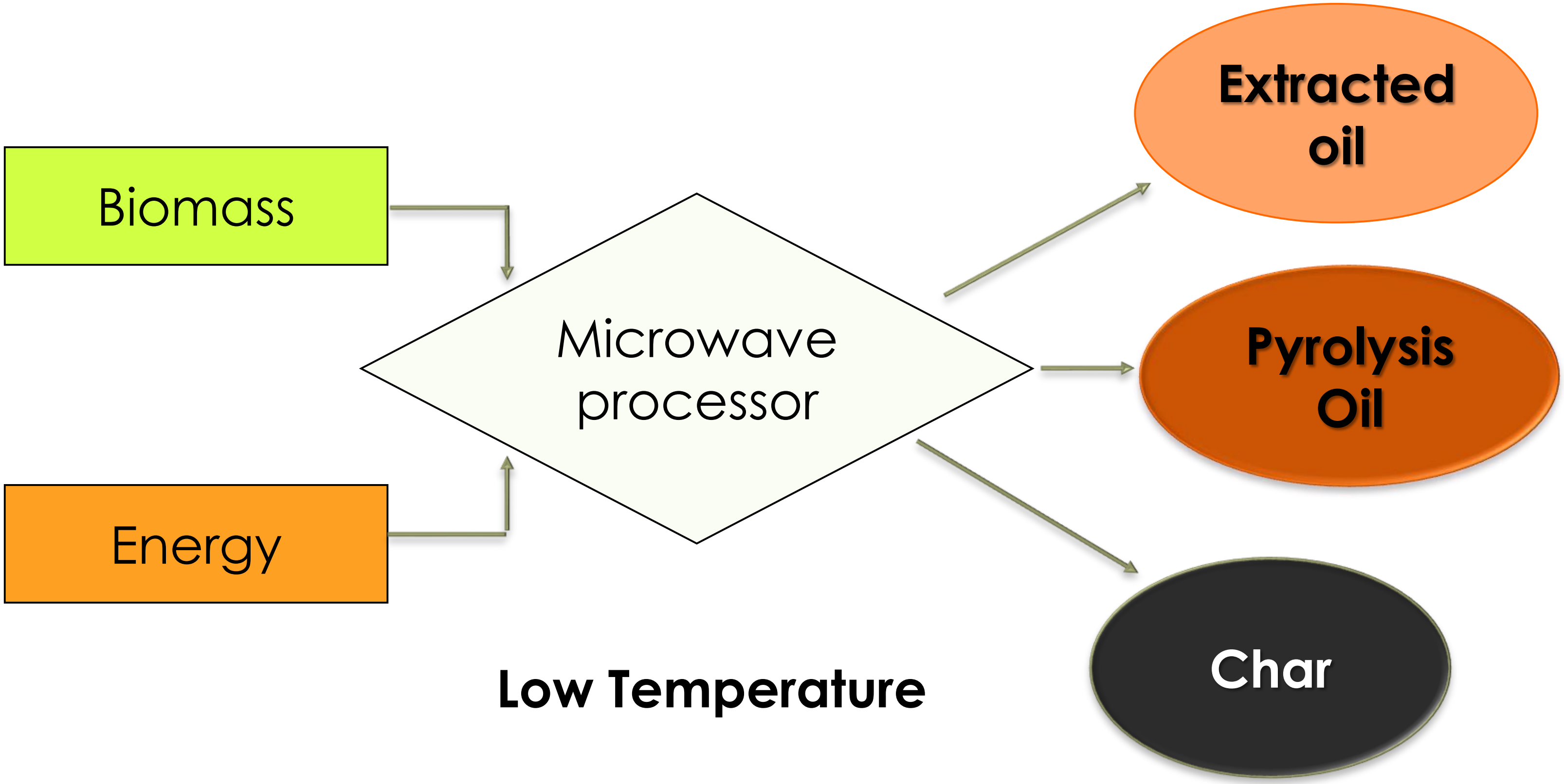
Microwave treatment in water (100 – 260 ˚C)

Key benefits:

- All biomass, especially wet
- Hydrolysis of polysaccharides to fermentable sugars
- Extraction of polysaccharides (e.g. pectin)

Fermentation pretreatment

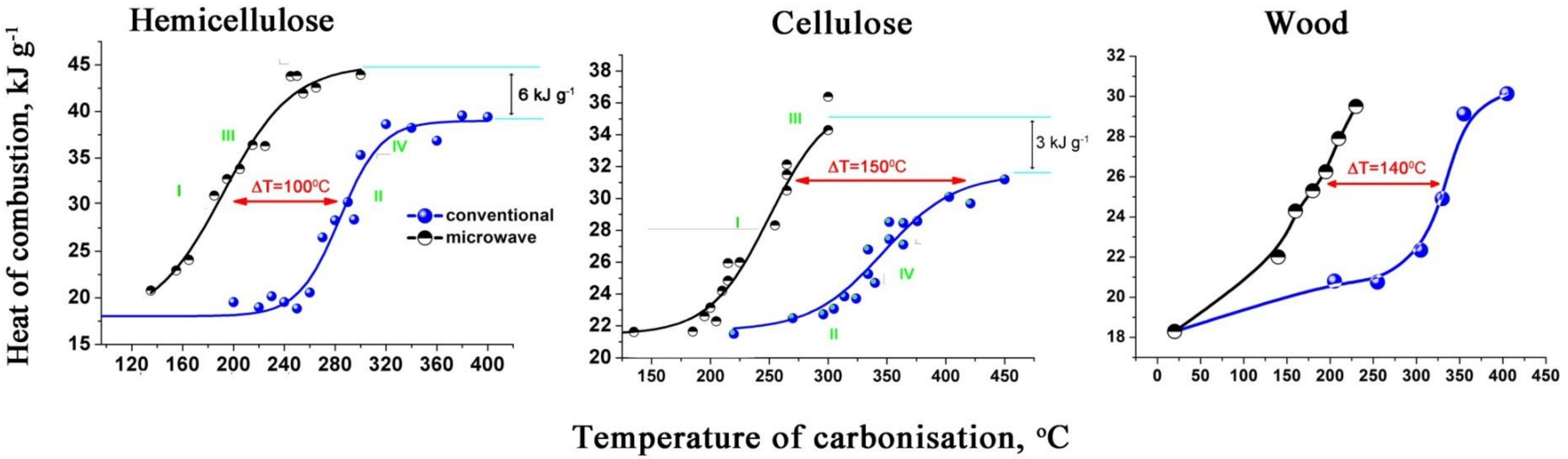
Microwave Pyrolysis Treatment of Biomass



Wide range of feedstock + Flexibility of Microwave Parameters (time, temperature, power) = Wide range of products

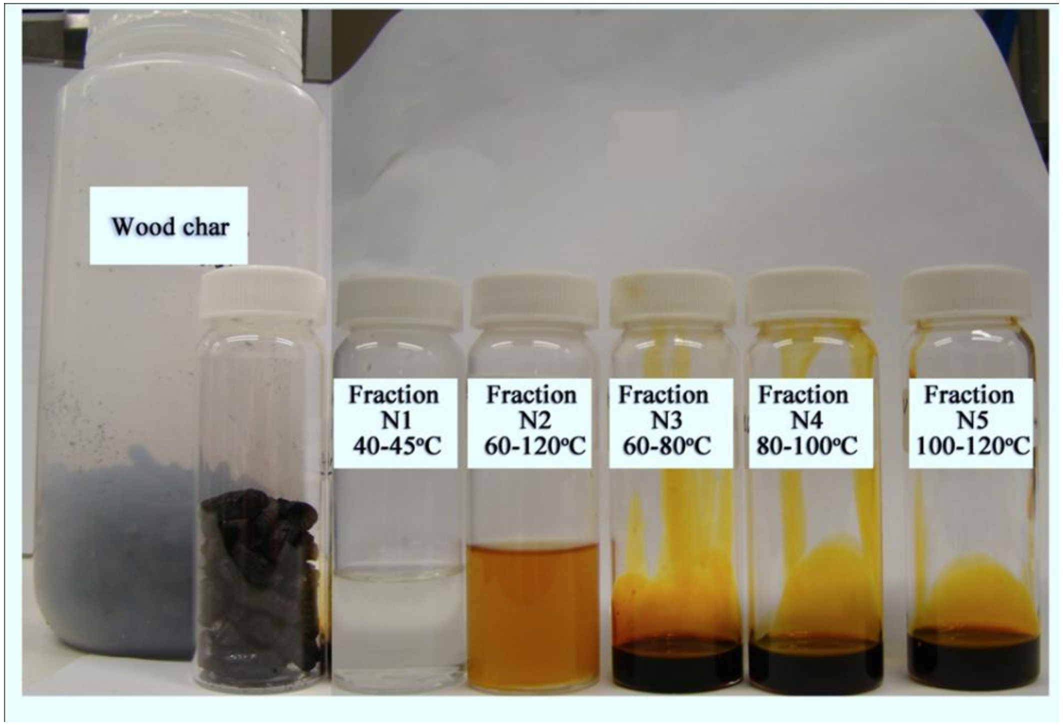
Microwave pyrolysis

Microwave results in pyrolysis at lower temperature for all biomass and biomass components studied → reduced energy



Biomass	Temperature of Microwave decomposition, °C	Temperature of Conventional decomposition °C
Hemicellulose	160	280
Cellulose	180	320
Wheat straw	160	341
Wood	164	371
Paper	200	420

MW pyrolysis enables *in-situ* bio-oil separation



- **Applicable to wide range of biomass** including wood, paper, sugarcane bagasse, seaweed, wheat straw, barley dust.
- **In-situ fractionation to valuable products:**
  - Fraction 2 (acid, water) source of acids for bio-surfactants
  - Fraction 4 (sugars) basis for platform molecules
  - Fractions 3 & 5 (Phenols, furans) drop-in replacements for petrochemical industry

Characteristics of MW Bio-Char

- High calorific value ~30kJ/g
- Good grindability
- Good hydrophobicity
- Co-firing with coal
- Ideal for gasification

Semi-scale microwave trials(30 kg/h)

12 trials

5 types of biomass

Temperature: 110-190^{0}C

18 kg of wheat straw

↓

6.7 kg of char + 5.7 kg of oil

Benefit of Microwave Hydrolysis

- ✓ High efficiency of heating: water is the best microwave absorber
- ✓ Saving energy of water vaporisation
- ✓ Direct solubilisation of biomass due to hydrolysis of polysaccharides

Bio-Waste

Acid Hydrolysis

Problems:
- ✓Salt Waste
- ✓Low value Lignin
- ✓Corrosion/Safety

Microwave technology

Benefits:
- ✓Acid free
- ✓Waste agnostic
- ✓Tunability
- ✓Specific activation

Faster, energy efficient

Sugars

Fermentation

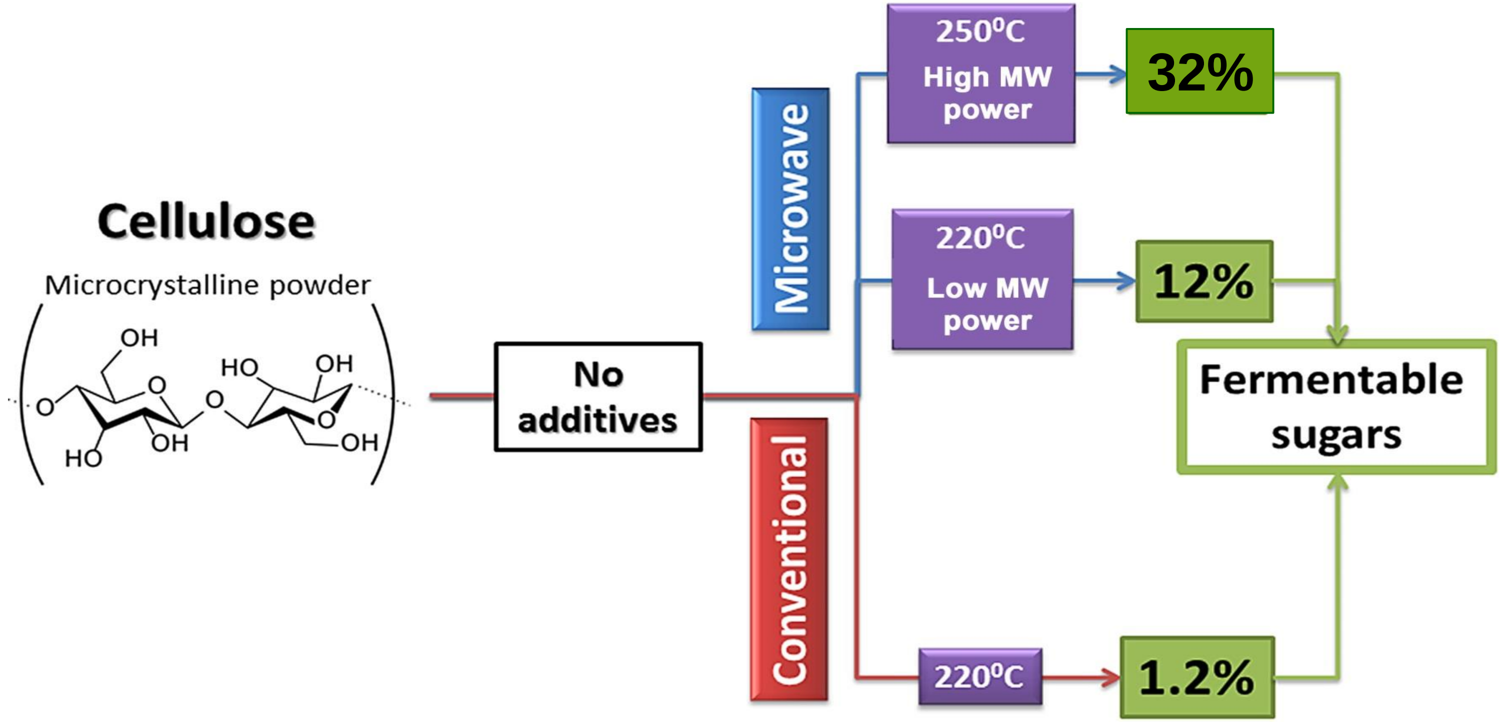
Existing market

Fuels	Bio-ethanol (£4bn)
Polymer	Butanol (£3.6bn)
Pharmaceutical	Succinic acid (£0.7bn)
Food	Lactic acid (£2.7bn)
	Citric acid (£3.5bn)

Additional products & market opportunity

Wax (>£3.0bn)
Limonene (>0.2bn)
Phenols (£2.4 bn)
HMF (1.5MT)
Levoglucosenone (?)

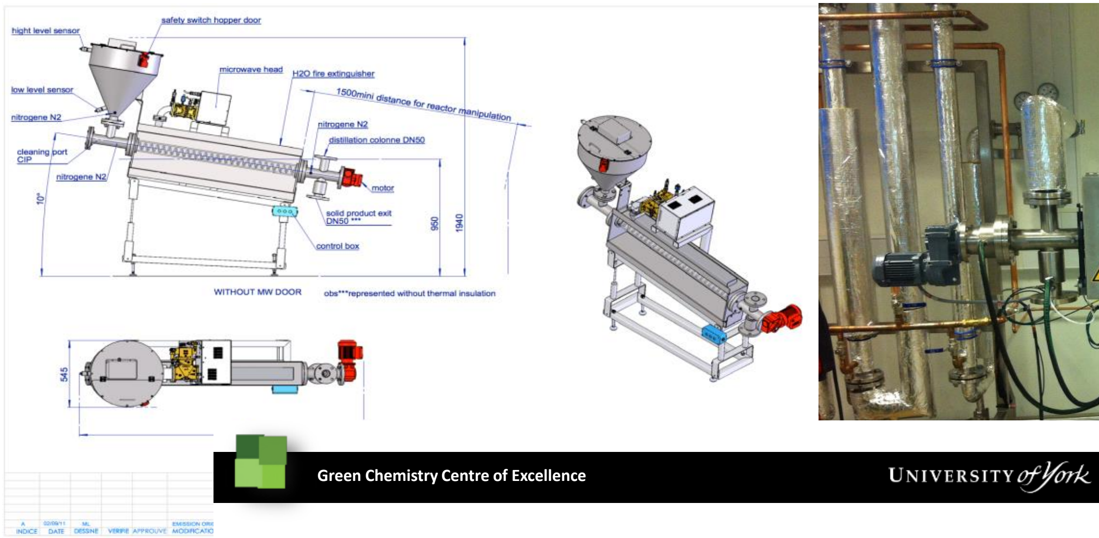
Microwave Assisted Cellulose Hydrolysis

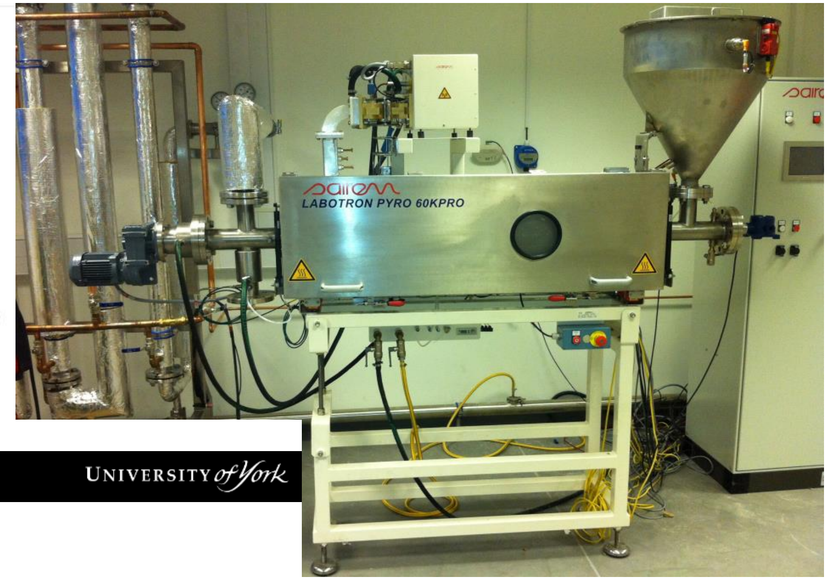


- ➢ **Sugars yield increases x20 in the presence of microwave irradiation**
- ➢ **High selectivity toward glucose. Repeated MW hydrolysis of solid produces up to 40% yield of sugars at 220ºC**

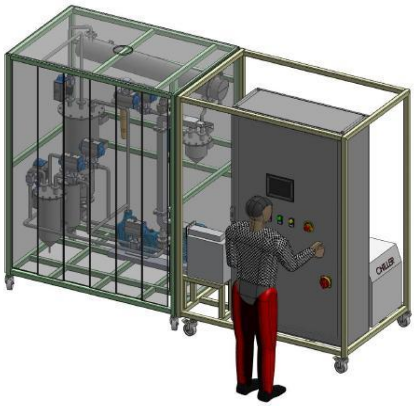
Fan et al, *JACS*, 2013, 1178

Continuous microwave processor. 30 kg/h





Getting ready for the large scale!



Extending to pressurised reactors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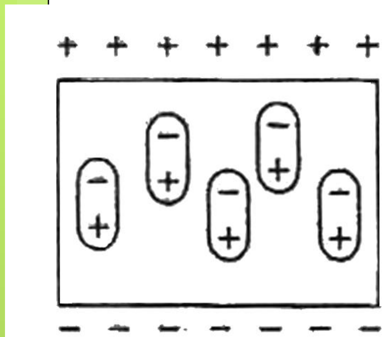
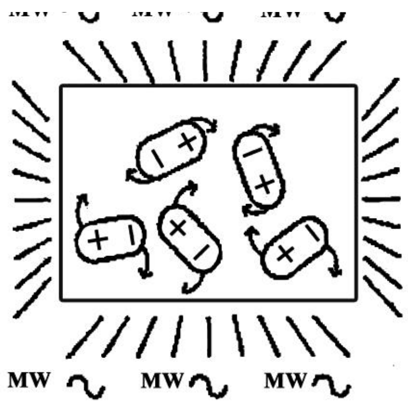
Research
Networking

MW as a heater



Continuous electric current:

•Continuous electric current of dipole is impossible

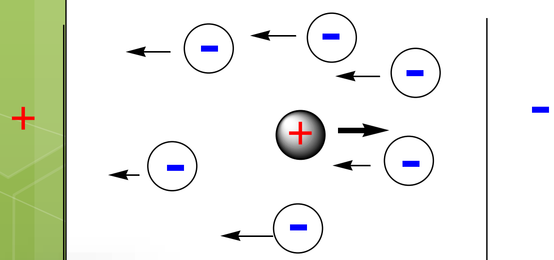


Alternative electric current (*dipolar polarization mechanism*):

•Inversion of orientation at every altrernance

•Stirring and friction of molecule

•Intenal homogeneous heating



Alternative electric current of ions (*conduction mechanism):*

•Debye effect: If $\nu > 109$ resistance decrease dramatically