Production of biochar- different aspects of pyrolysis

Biochar production, from lab to deployment; overview of challenges and opportunities in scaling-up biochar production

Ondřej Mašek
University of Edinburgh, UKBRC

Groningen, Netherlands
10.12.2013

The Interreg IVB North Sea Region Programme
Investing in the future by working together for a sustainable and competitive region

UK Biochar Research Centre

EPSRC
Engineering and Physical Sciences Research Council

Scottish Funding Council
Promoting further and higher education

Pyrolysis/ torrefaction and biochar production research at UKBRC

UKBRC

Scale

STAGE III

Pilot-scale continuous pyrolysis unit with capacity of up to 50 kg of biomass per hour, mean residence time 5-60 min., and temperature range up to 850 °.

STAGE II

Continuous pyrolysis unit with capacity of up to 2 kg of biomass per hour, mean residence time 5-60 min., and temperature range up to 850 °.

STAGE I

Bench-scale batch pyrolysis with capacity of up to 100g, operating temperature range up to 1100 °C and heating rate from <1°C/min to >100 °C/s.

TGA/ DSC

Automated TGA/DSC instrument for biomass pyrolysis and biochar characterisation

The Interreg IVB North Sea Region Programme

From lab to deployment - Key challenges

Two different ways to think about scale-up

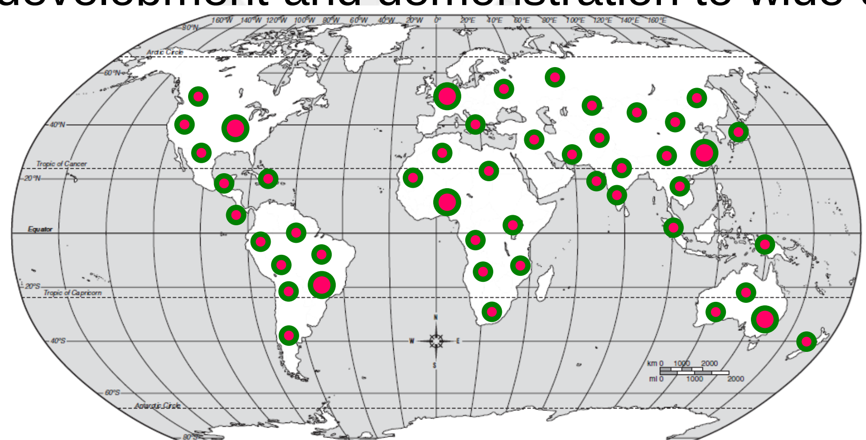
1) Move from test tubes and laboratory units to industrial processing

- Equipment capacity

Main

2) Move from development and demonstration to wide deployment

- Sustain
- Resour eyond heat and electricity)
- Econon o-products)



Source: www.eduplaces.com

Pyrolysis

Which parameters matter

Feedstock related

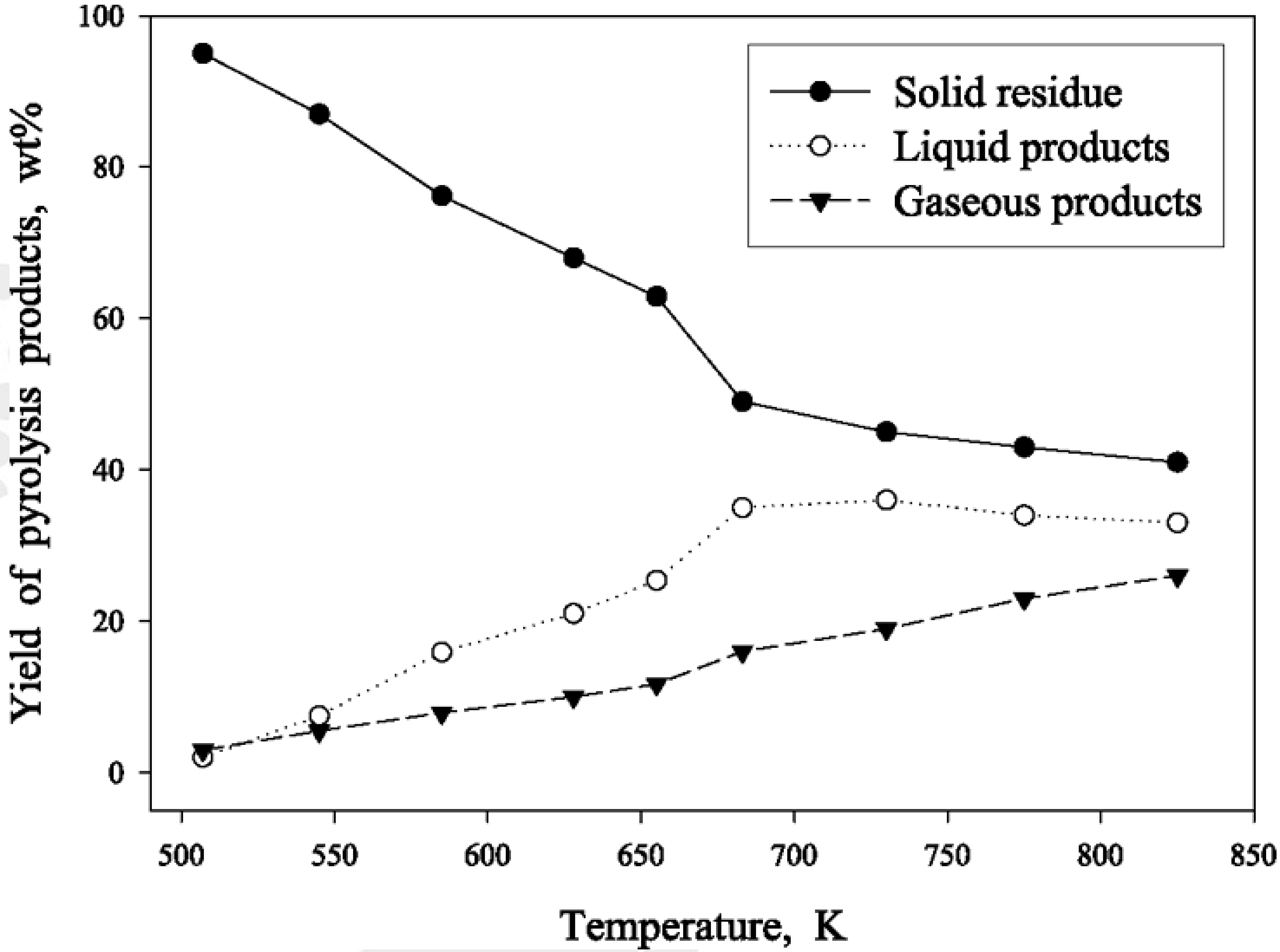
- particle size and shape
- physical properties (e.g., density)
- composition (lignin, cellulose, etc.)
- ash content and composition
- moisture content
- …

Process related

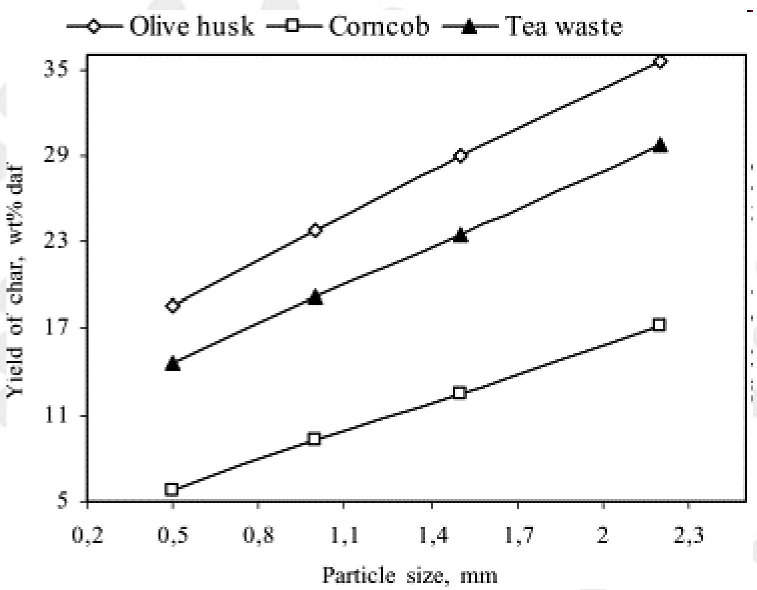
- peak temperature
- pressure
- heating rate
- residence time
- heat transfer
- vapour/ solid interaction
- …

Most of these parameters are interconnected, so it is not possible to change one parameter without affecting all/ some of the others.

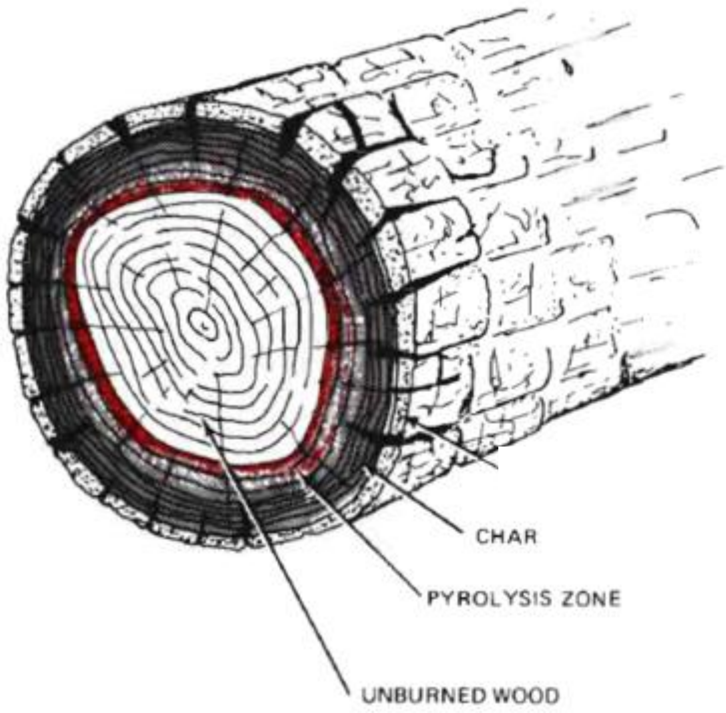
Effect of temperature



Effect of particle size



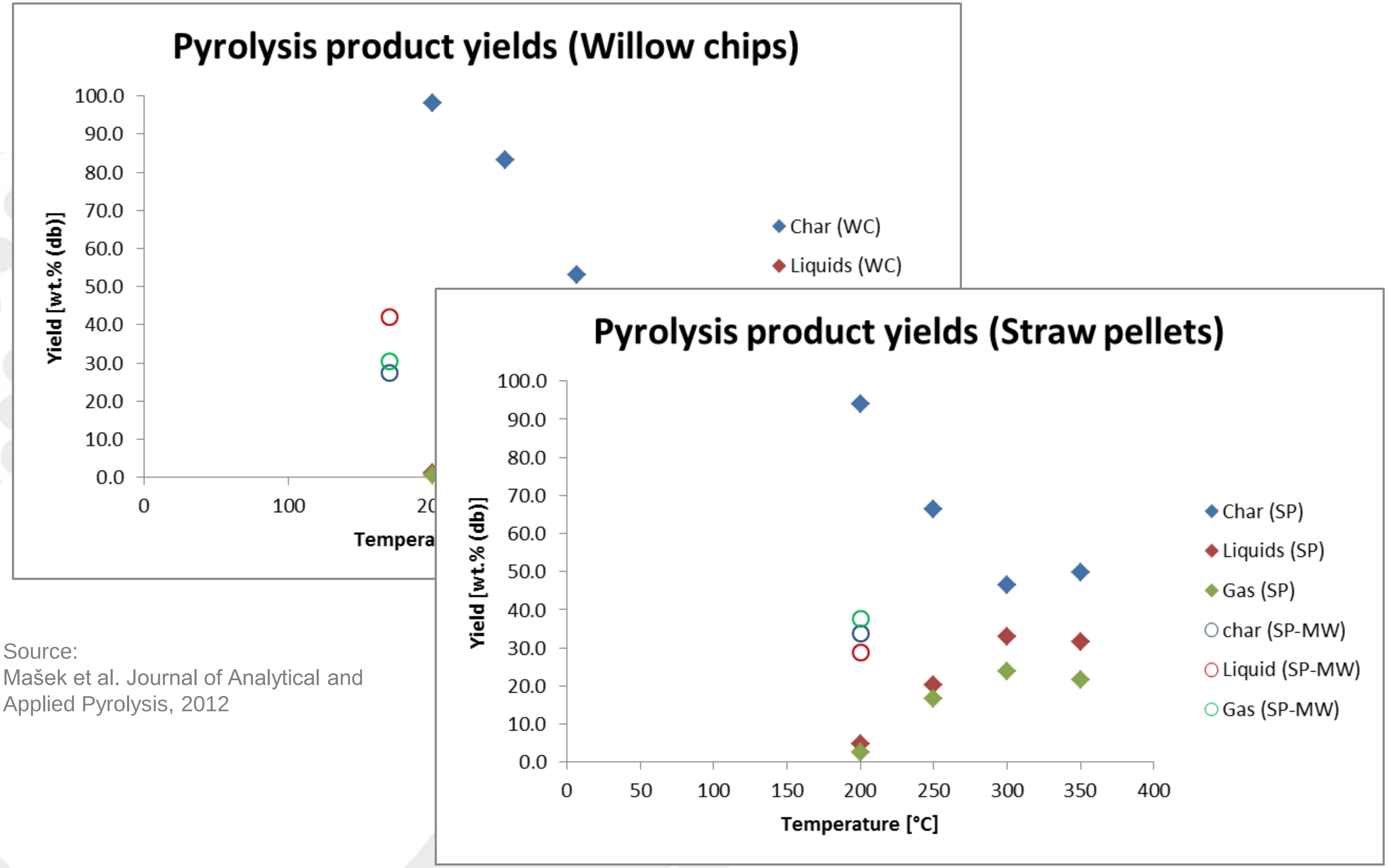
slow pyrolysis at 677 °C



Effect of heating mode

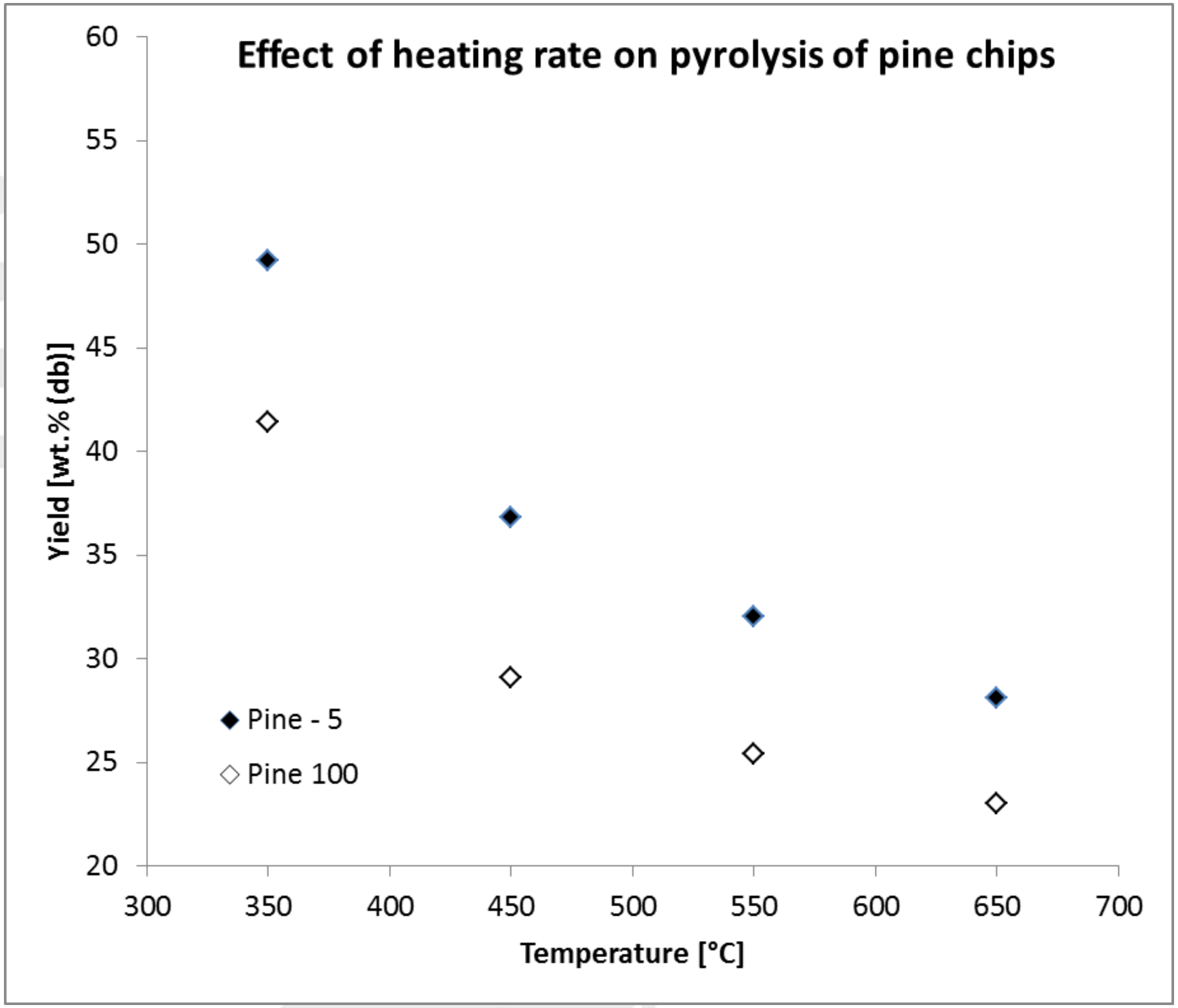
Microwave vs. conventional slow pyrolysis

UKBRC



Source:
Mašek et al. Journal of Analytical and Applied Pyrolysis, 2012

Effect of heating rate

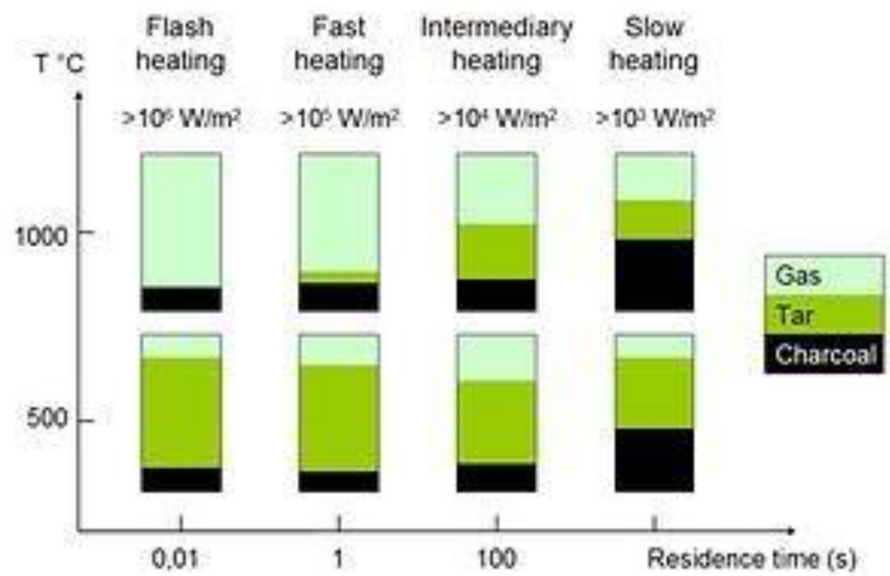


Source:
Crombie and Mašek. Environmental Science and Technology

Effects of heating rate – types of pyrolysis

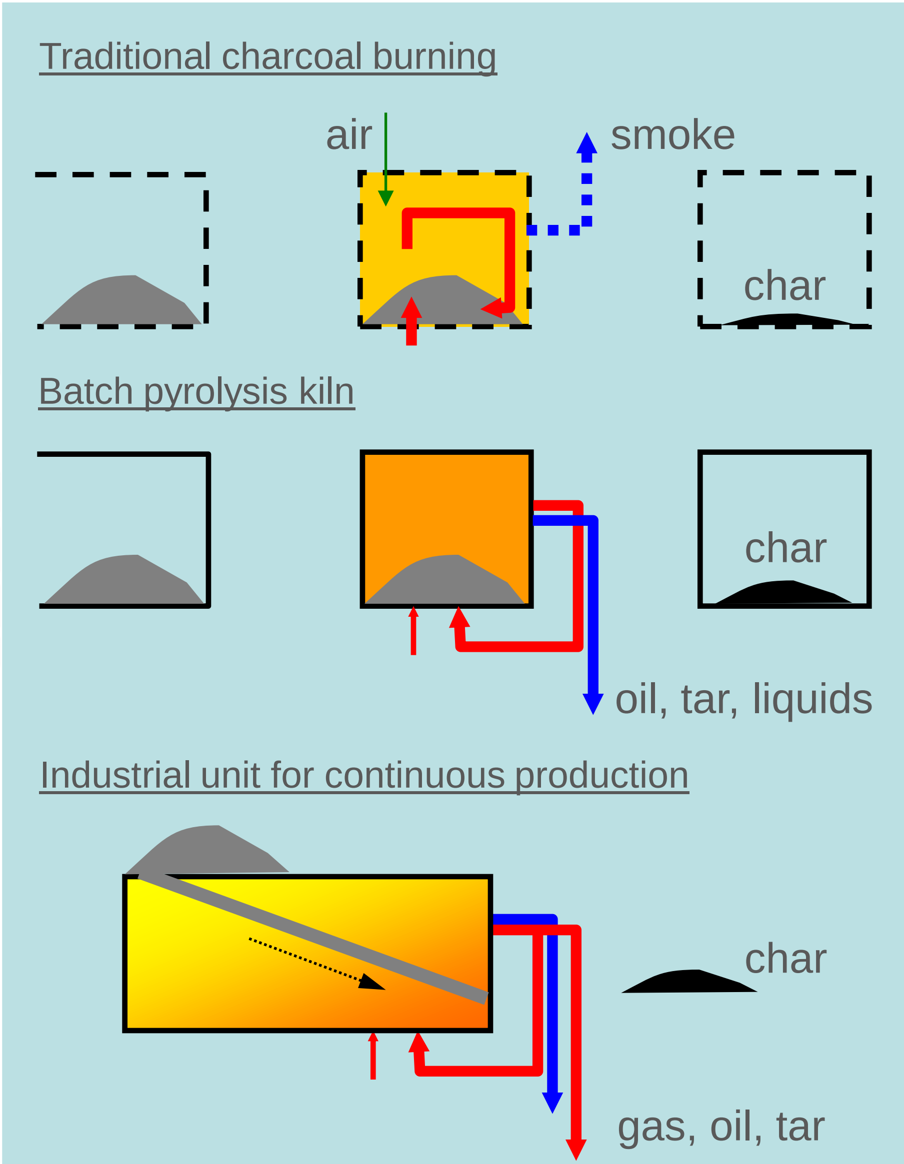
UKBRC

Mode	Conditions Wt %	Liquid	Char	Gas
Fast	~ 500°C, short hot vapour residence time ~ 1 s	75%	12%	13%
Intermediate	~ 500°C, hot vapour residence time ~ 10-30 s	50%	25%	25%
Slow - Torrefaction	~ 290°C, solids residence time ~30 mins	-	82% solid	18%
Slow - Carbonisation	~ 400°C, long vapour residence time hrs → days	30%	35%	35%
Gasification	~ 800°C	5%	10%	85%



The Interreg IVB North Sea Region Programme

Slow pyrolysis/ carbonisation



Source: Dr. Saran Sohi

Source: Ondřej Mašek

From lab to deployment - Key challenges

Move from test tubes and laboratory units to industrial processing

- Equipment capacity
- Energy balance
- Product quality
- Product consistency
- Control and monitoring
- Reliability
- Economics

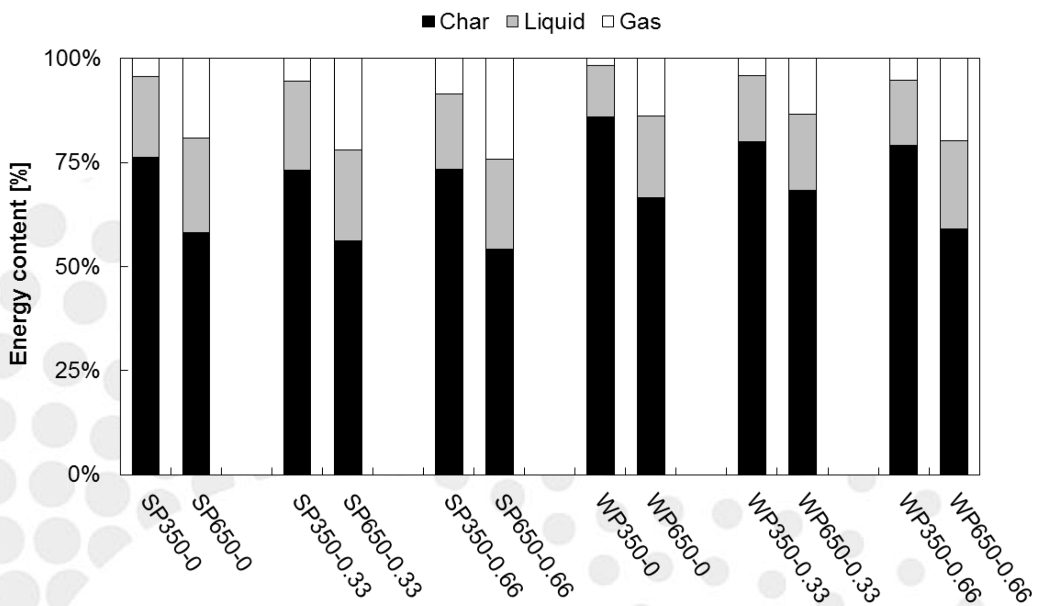
Technical challenges – Equipment capacity

Limitations on pyrolysis equipment size

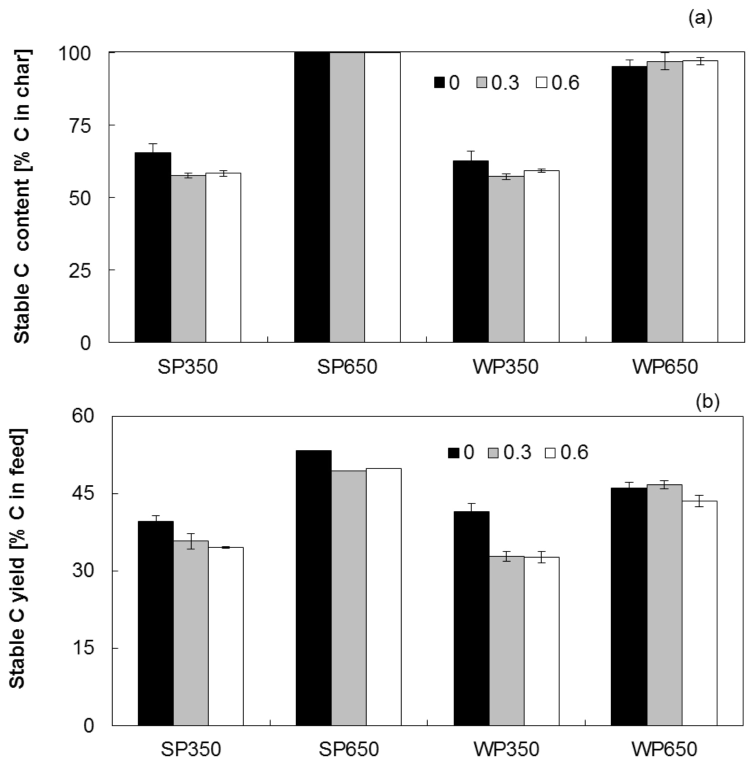
- Construction material
- Mechanical stability
- Heat transfer
- Material flow
- …

Some technologies/ pyrolysis unit designs are more scalable than others.

Technical challenges – Energy balance

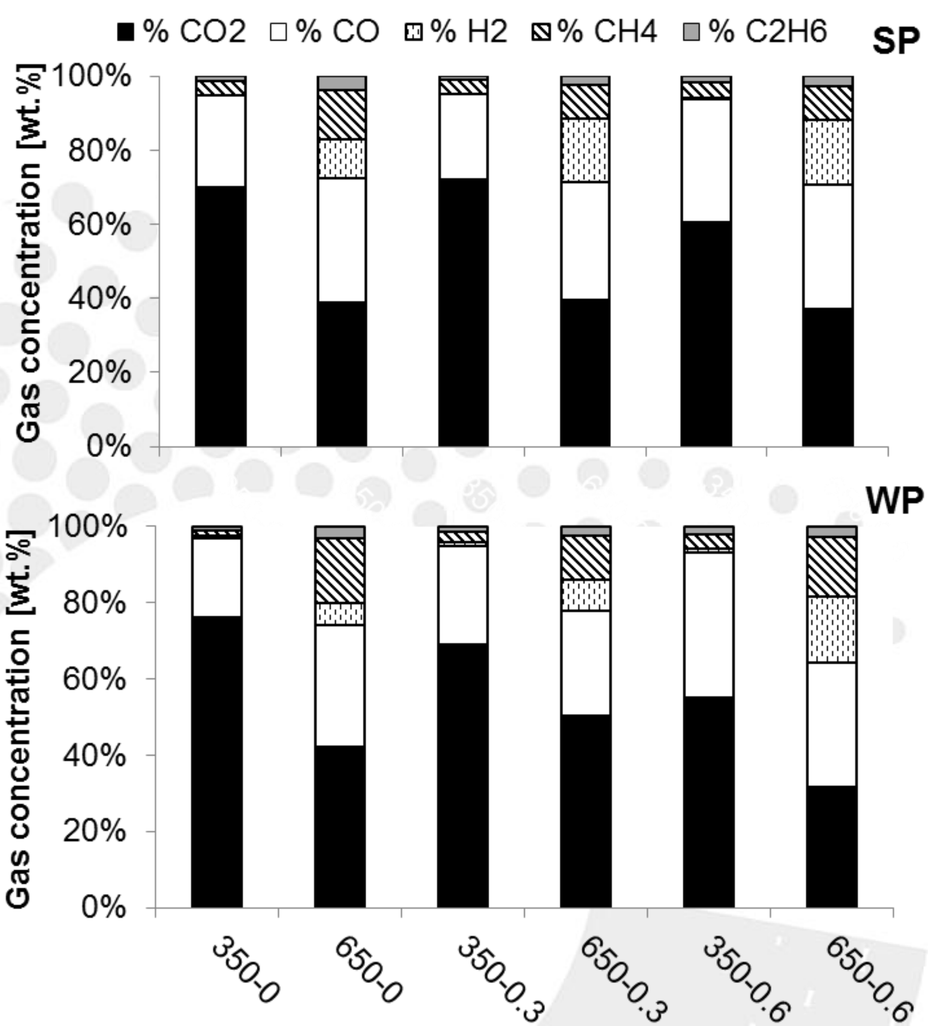


Source:
Crombie and Mašek. Global Change Biology Bioenergy, 2013



Higher temperature slow pyrolysis/ carbonisation (at around 650°C) combines high yield of stable carbon with good recovery of energy in form of gases and pyrolysis liquids.

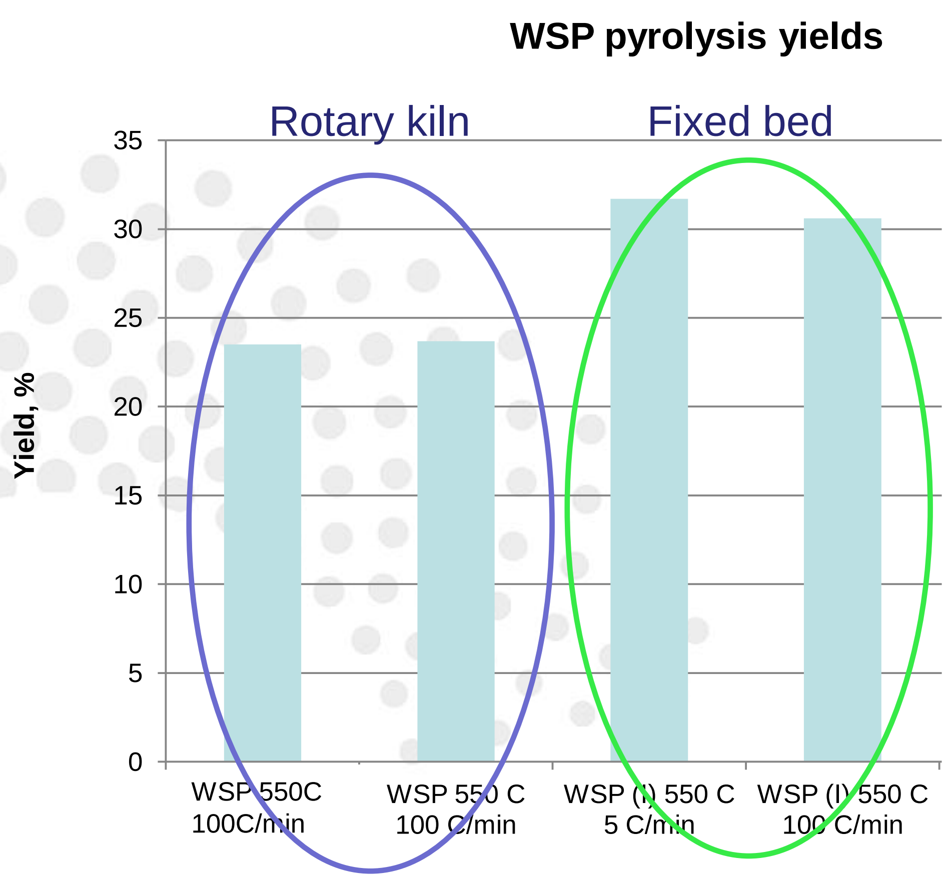
Technical challenges – Energy balance



Energy contained in the gas is sufficient to sustain the pyrolysis process (assuming dry feedstock) and in case of pyrolysis at 650°C, excess energy is available for feedstock pre-drying.

Source:
Crombie and Mašek. Global Change Biology Bioenergy, 2013

Technical challenges – Effect of unit arrangement



Pyrolysis temperature, heating rate and residence time are important parameters, but not the only key factors affecting product yields and properties

Technical challenges – Process operation, controll and monitoring

UKBRC

Operation

- material feeding
- exclusion of O_2
- tar condensation
- blockage
- corrosion

Control

- temperature measurement
- gas flow rate measurement
- particle temperature history

Use of by-products

- low pH of pyrolysis liquids
- low heating value
- high water and oxygen content

Operational challenges

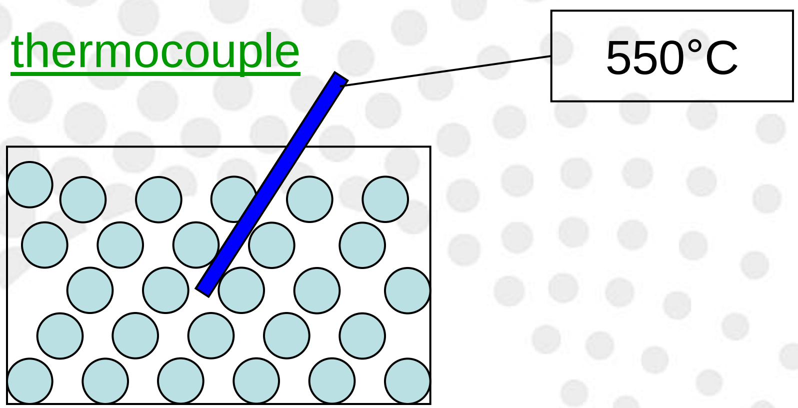
Process monitoring and control

Temperature measurement

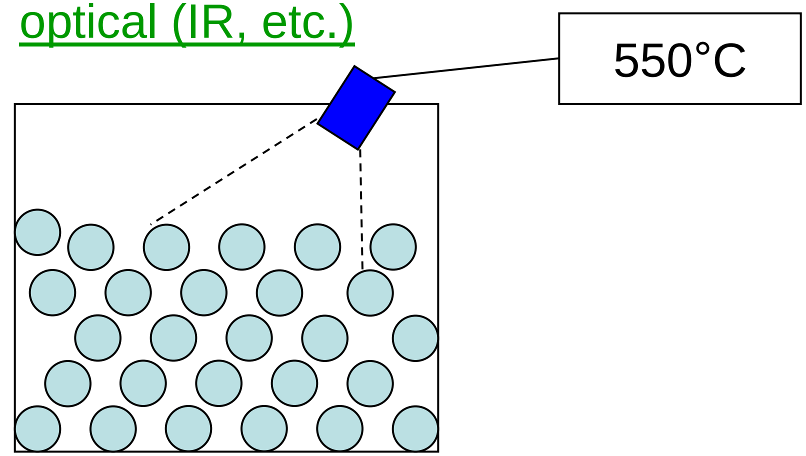
- Where ? (gas phase, particle bed, …)

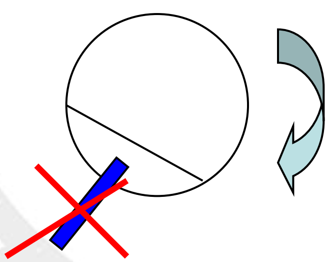
- How? (aggressive environment, difficult access, …)

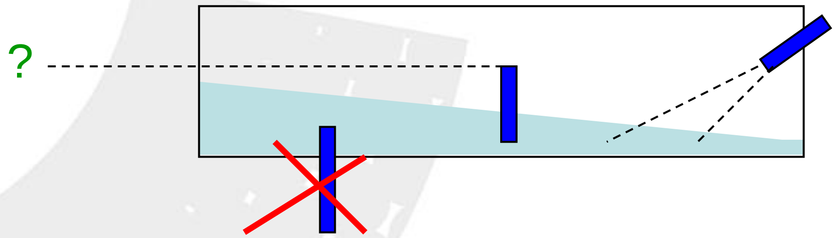
thermocouple



optical (IR, etc.)







Complicated by the presence of gases and vapours from pyrolysis

Technical challenges - Product quality

UKBRC

Besides effects on product yields, production conditions have a strong effect also on product properties.

•

Therefore good control/ monitoring of production conditions and their consistency is critical for high-quality / high-value products.

•

This is easier to achieve in laboratory than in industrial units.

Example - Standard Biochar

Wheat straw | Oilseed rape straw | Softwood | Miscanthus | Rice husk

550 °C

700 °C

A set of research grade biochars

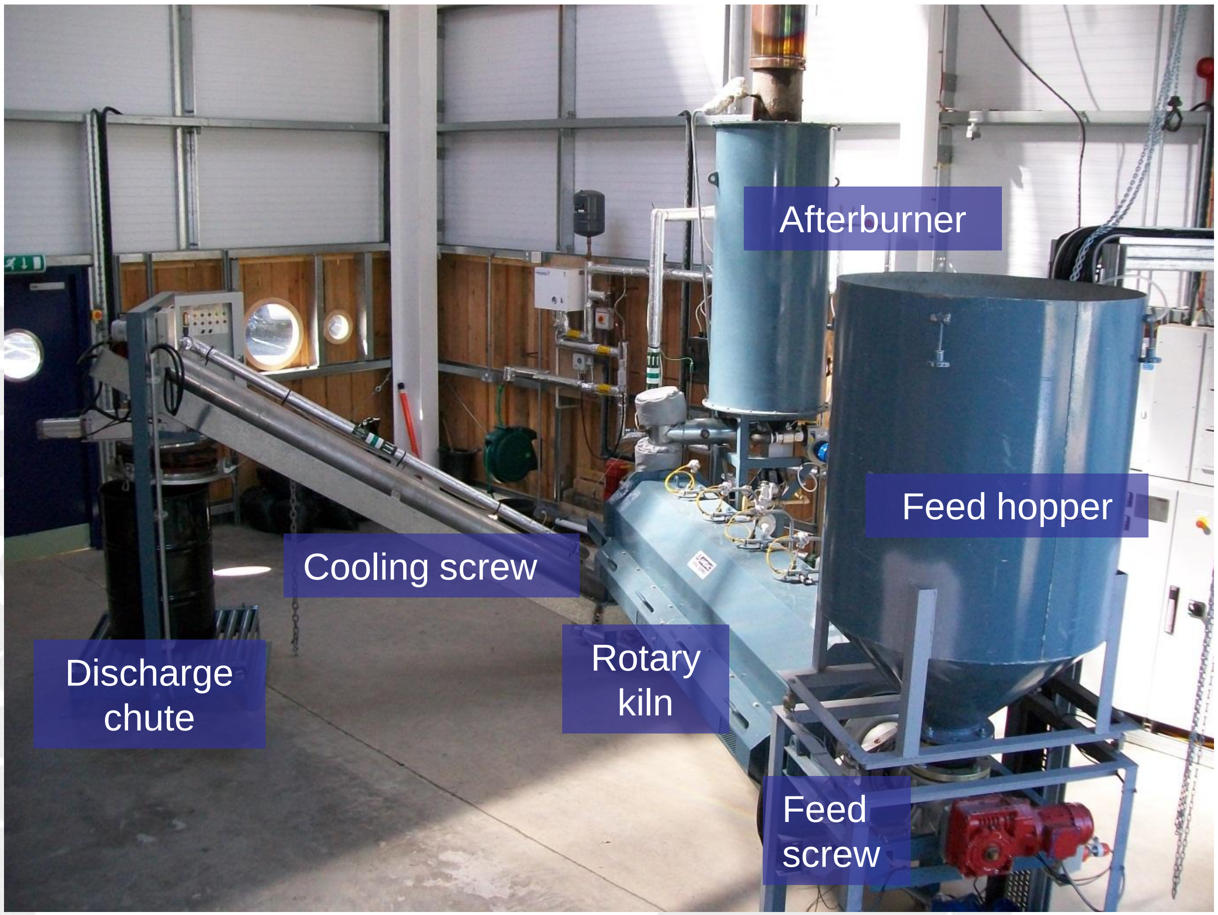
Standard Biochar specification sheets

UKBRC

Basic Utility Properties (Category A)		Mean Value (n=4)	SD (n)
Moisture	wt.% (a.r.)	1.50	0.15 (4)
C	wt.% (db.)	48.69	2.37 (5)
H	wt.% (db.)	1.24	0.12 (5)
O (by difference)	wt.% (db.)	1.21	
Organic carbon	wt.% (db.)		
H:Corg	Molar ratio	tbd	
Total ash	wt.% (db.)	47.77	2.18 (4)
Total N	wt.% (db.)	1.094	0.11 (5)
pH	pH	9.71	0.26 (4)
Electric conductivity	dS/m	0.48	0.14 (4)
liming (if pH is above 7)	% CaCO3	tbd	
particle size distribution	% >4,000 µm;	0.00	n.d.
	% 2,000-4,000 µm;	1.62	n.d.
	% 1,400-2,000 µm;	4.94	n.d.
	% 710-1,400 µm;	39.81	n.d.
	% 350-710 µm;	36.05	n.d.
	% < 350 µm	17.58	n.d.

The Interreg IVB North Sea Region Programme

Stage III – Pilot-scale continuous unit



UKBRC pilot-scale pyrolysis unit

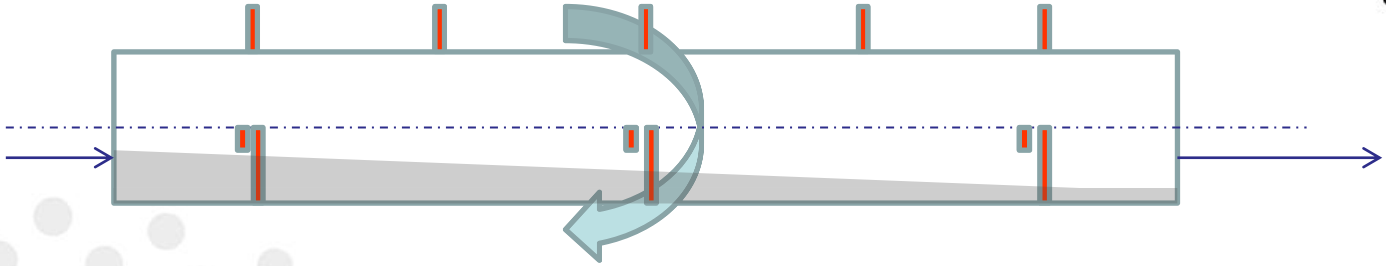
Stage III – control and monitoring

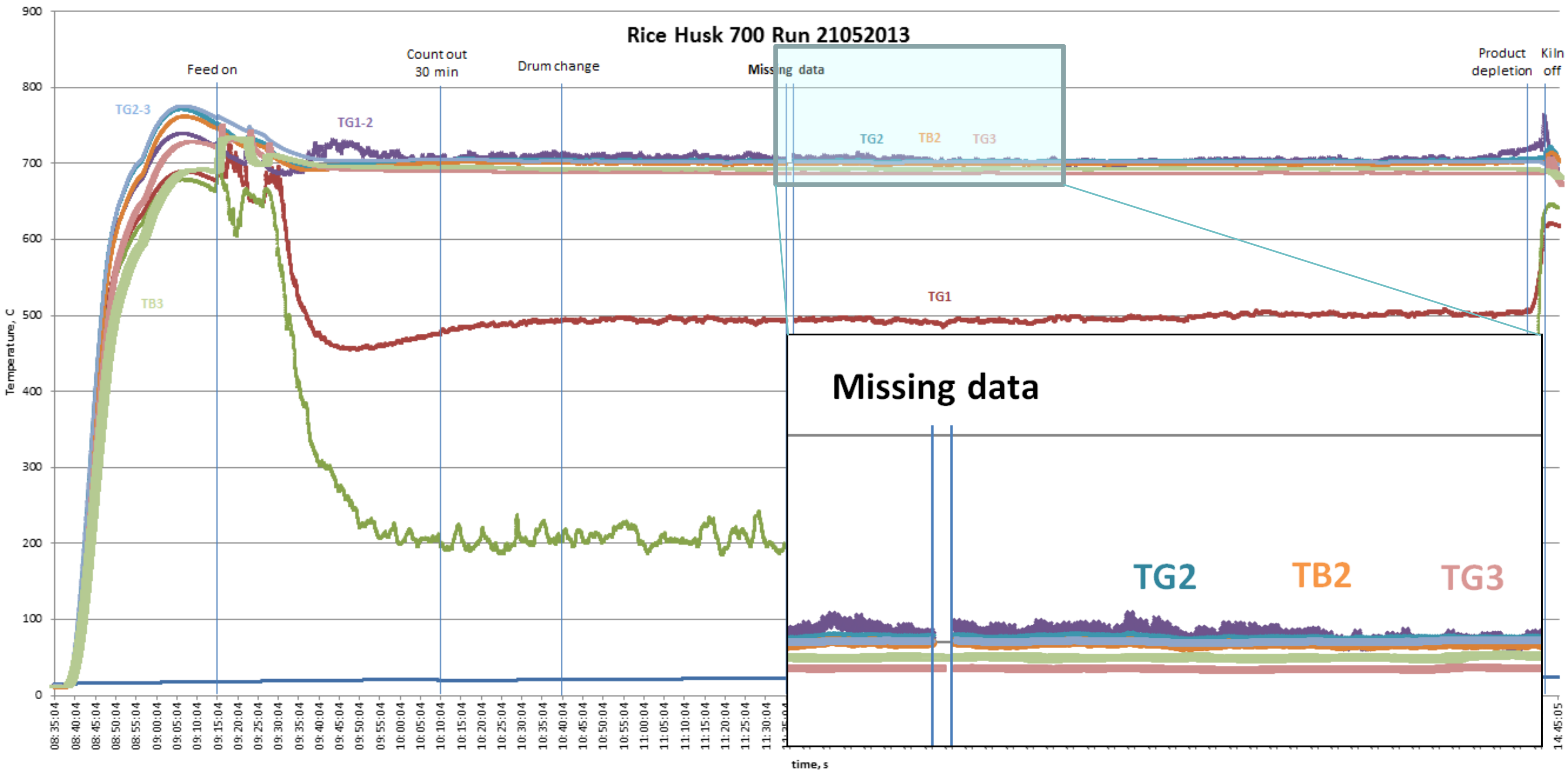
UKBRC

Feed Reference	Kiln Temp (°C)	Zone 1 (°C)	Zone 2 (°C)	Zone 3 (°C)	Feed Temp (°C)	Nominal Residence Time (mins)	Storage Location	Feed Screw	Feed Hz	Feed % VSD	Nominal Feed Rate kg/hour	Kiln VSD Hz	Kiln % VSD	Gear Box
Jun-13	550	550	550	550	400	20		120		15	34		34	200
Jun-13	550	550	550	550	400	20		120		15	34		34	200
Jun-13	550	550	550	550	400	20		120		15	34		34	200
Jun-13	700	600	700	700	400	20		120		15	34		34	200
May-13	700	650	700	700	400	20		120		30	12		34	200
May-13	700	650	700	700	400	20		120		30	12		34	200
May-13	550	550	550	550	400	20		120		30	12		34	200
May-13	700	650	700	700	400	20		120		30	12		34	200
Mar-13	450	450	450	450	300	20		120		15	36		34	200
May-13	450	450	450	450	300	20		120		30	12		34	200
Mixed	450	450	450	450	300	20		120		25	20		34	200
Mixed	700	650	700	700	300	20		120		25	20		34	200

There are many operating parameter to control/ monitor

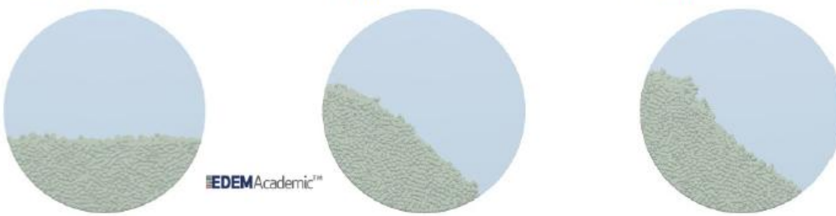
Stage III – control and monitoring





Modelling and simulation – an important step for scale-up

Stationary 4 rpm 12.5 rpm



$$\frac{dX}{dt} = k(T)f(X) = A\exp\left(-\frac{E}{RT}\right)(1-X)$$

$$\frac{dx_{plastic}}{dt} = -(k_{gas} + k_{liq} + k_{char})(1-x)\varphi^{o,1}$$

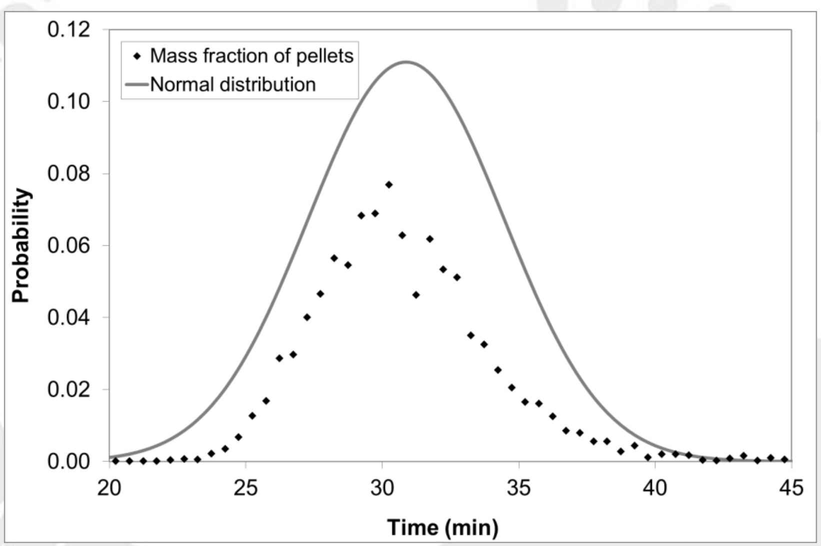
$$\frac{dX_{Gas}}{dt} = k_{Gas}\,(1-X)\varphi^{o,1}$$

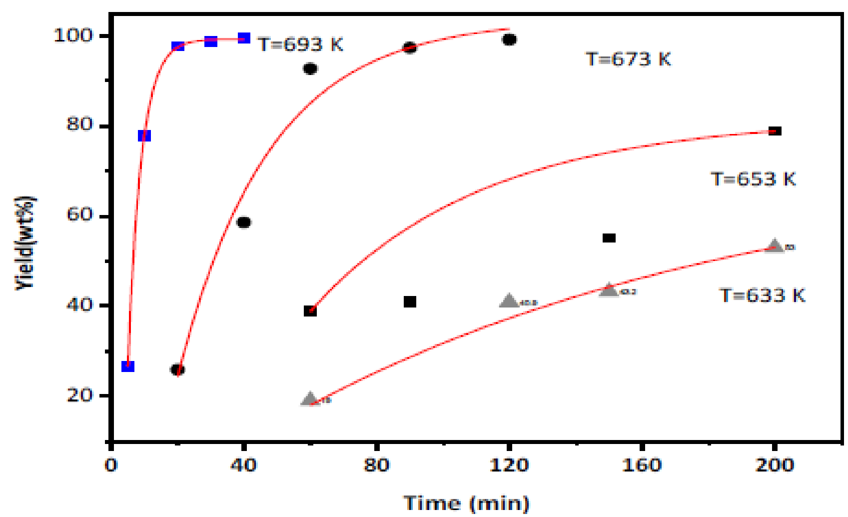
$$\frac{dX_{Liquid}}{dt} = k_{Liquid}\,(1-X)\varphi^{o,1}$$

$$\frac{dX_{Char}}{dt} = k_{Char}\,(1-X)\varphi^{o,1}$$

$$\frac{dX_{WP}}{dt} = \frac{dX_{Gas}}{dt} + \frac{dX_{Liquid}}{dt} + \frac{dX_{Char}}{dt}$$

$$\varphi = \exp(\alpha \cdot r \cdot M_0 \cdot X_c/\mathrm{W})$$



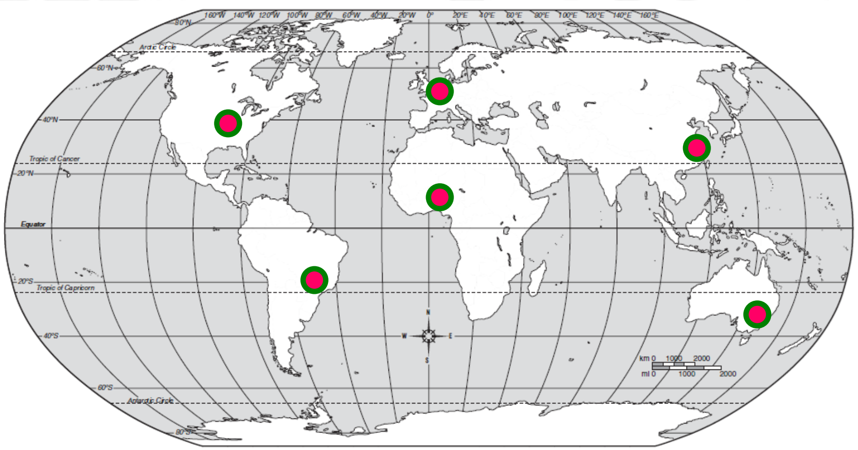


From lab to deployment - Key challenges

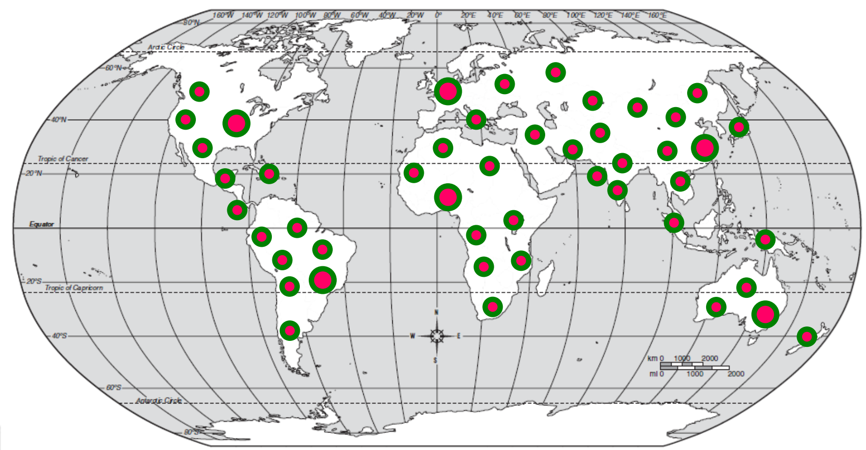
UKBRC

Move from development and demonstration to wide deployment

- Sustainability (resource use, residues management, etc.)
- Resource use efficiency (there are many uses for biomass beyond heat and electricity)
- Economics (high value co-products vs. relatively low-value co-products)



Source: www.eduplaces.com



Source: www.eduplaces.com

The Interreg IVB North Sea Region Programme

Biochar in bio-energy systems

Key areas of relevance

Carbon footprint
- From close to carbon-neutral to carbon-negative

Feedstock supply
- Increased yields
- Reduced input requirements
- Improved environmental performance

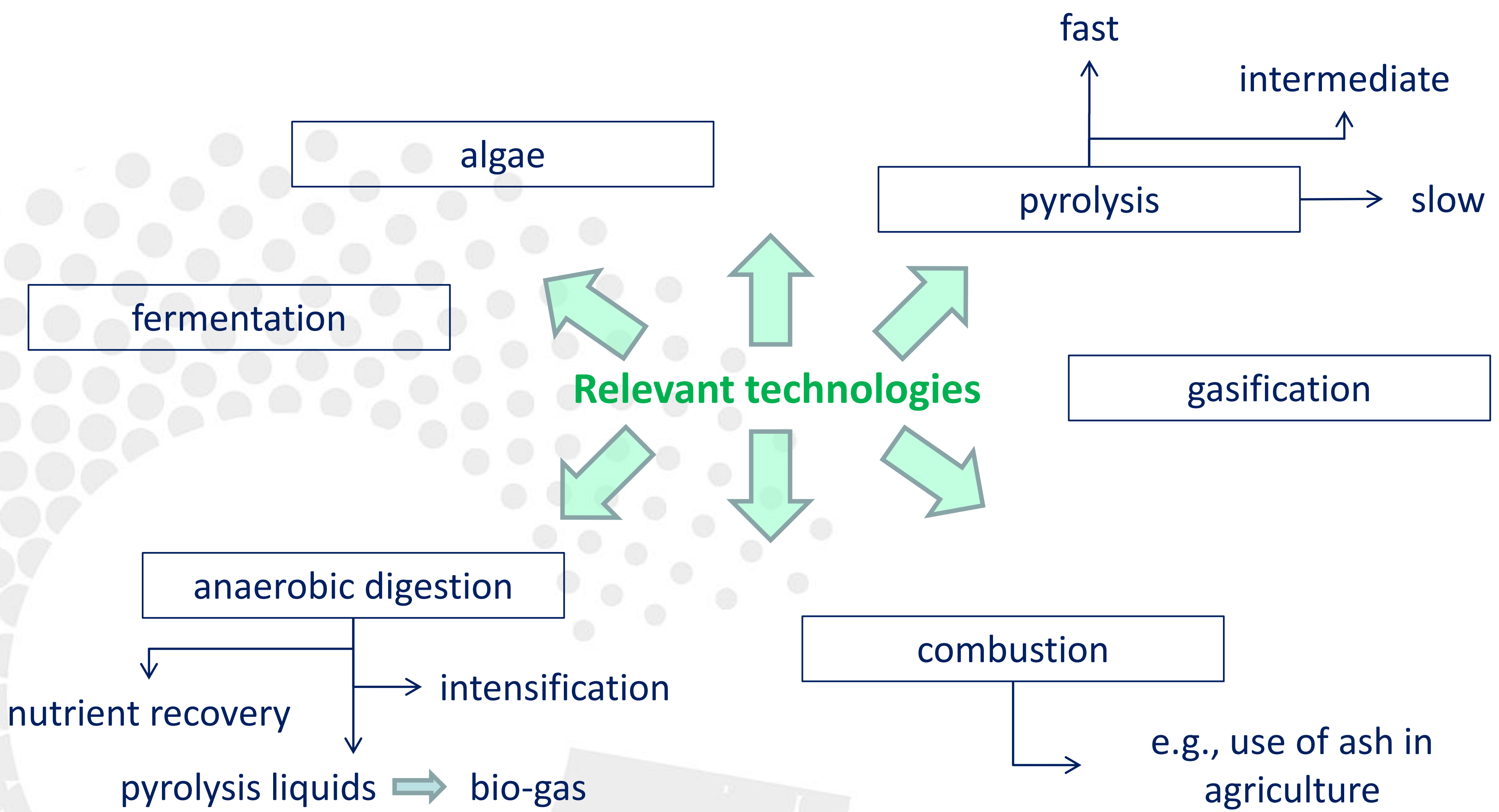
Sustainability

Nutrient cycling
- Return of nutrients removed with harvested biomass
- Improved release dynamics

GHG balance
- Reduction of soil GHG emissions
- Reduction of GHG's associated with inputs for biomass production (fertiliser, …)

Resource use efficiency
- Suitable for poly-generation

Biochar in bio-energy systems



Biochar production

Biochar as the main product

- Slow pyrolysis (biochar yield 20-35 wt.%)

Choice of feedstock and operation conditions can be selected to tune the yield and properties of biochar to suit particular application; also yields other co-products

↓

Most likely to achieve high-grade "engineered" biochar with high-value applications, and predictable function

Biochar as a by-product

- Fast pyrolysis (biochar yield 10-15 wt.%)
- Gasification (biochar yield <10 wt.%)

Choices of feedstock and operation conditions are dictated by the needs of the main product, i.e. liquids (fast pyrolysis) and gases (gasification)

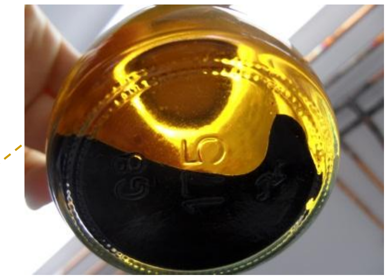
↓

Mostly use of solid by-products, and therefore the char is unlikely to be engineered for specific application. However, based on understanding of relationships between biochar, soil and crops, its use can be successfully prescribed to achieve safe use and good performance.

Pyrolysis for carbon sequestration and production of added-value products

biomass

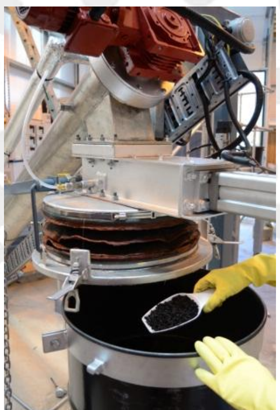
pyrolysis



solids (biochar)

gases

liquids



soil

growing media

?

?

fuel

power and heat generation

heat and electricity

processing

chemical

biological

?

fine chemicals

Agro-chemicals

?

Conclusions

- There are many **technical and non-technical** challenges in scaling-up biomass slow pyrolysis/ carbonisation
- These need to be considered when translating research results **from laboratory conditions to industrial applications**
- **Whole system assessment** is necessary to decide on priorities for use of biomass as fuel or feedstock for poly-generation technologies.
- **High value products** (whether solid, liquid or gaseous) can make biomass utilisation more economically viable

Thank you!

Dr. Ondřej Mašek

Tel. +44 131 650 5095

Skype: ondrej.masek-ukbrc

Email: ondrej.masek@ed.ac.uk

Web: http://www.geos.ed.ac.uk/homes/omasek

Web: www.biochar.ac.uk