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Devon Barry, Cedric Briens, and Franco Berruti, "Pyrolysis of residues from well-established biochemical processes for the production of biochar" in "Biochar: Production, Characterization and Applications", Franco Berruti, Western University, London, Ontario, Canada Raffaella Ocone, Heriot-Watt University, Edinburgh, UK Ondrej Masek, University of Edinburgh, Edinburgh, UK Eds, ECI Symposium Series, (2017). <http://dc.engconfintl.org/biochar/74>

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Pyrolysis of Sewage Sludge for the Production of Biochar

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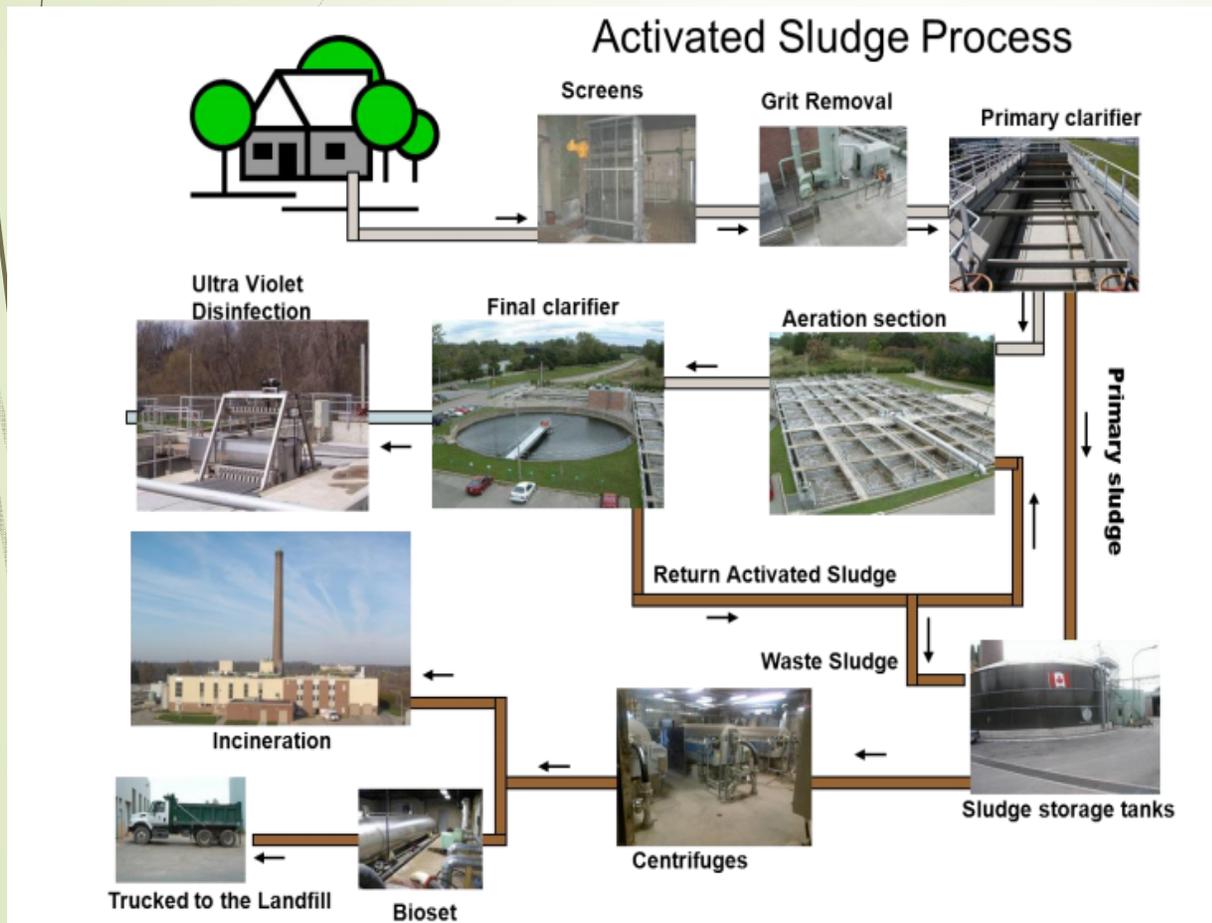
Overview

- Background and Objectives
- Feedstock Characterisation
- Overview of Reactors
- Pyrolysis results and product characterisation
- Energy Balance of Process
- Ongoing and Future Work
- Conclusions

Motivation and Background

- ▶ The disposal and treatment of sewage sludge is a problem faced by every modern city
- ▶ Global estimates for sewage sludge production are over 50 Million Tonnes of dry solids per year
- ▶ Current Technologies for sludge disposal are:
 - ▶ Landfilling
 - ▶ Soil application for agriculture
 - ▶ Anaerobic digestion
 - ▶ Incineration

Current Sludge Production and Treatment in London, Ontario



- 60% Primary Sludge
- 40% Waste Activated Sludge
- Thickening with polymer addition
- Dewatered using centrifuge to 72% moisture
- Produced 16,000 dry tonnes in 2015

Pyrolysis as an Alternative

Incineration Pyrolysis

► Pros:

- Process can run autogenously
- Destruction of pathogens and odours
- High reduction in waste volume

► Cons:

- Negative public perception
- Highest GHG emissions
- Heavy metals concentrated in ash
- High disposal costs of ash (\$70/ton)

► Goals of pyrolysis:

- Thermally self sustainable process (production of energy)
- Destruction of pathogens and odours
- Reduction of GHG emissions (Carbon Sequestration)
- Stabilisation of heavy metals in char
- Create zero waste solution

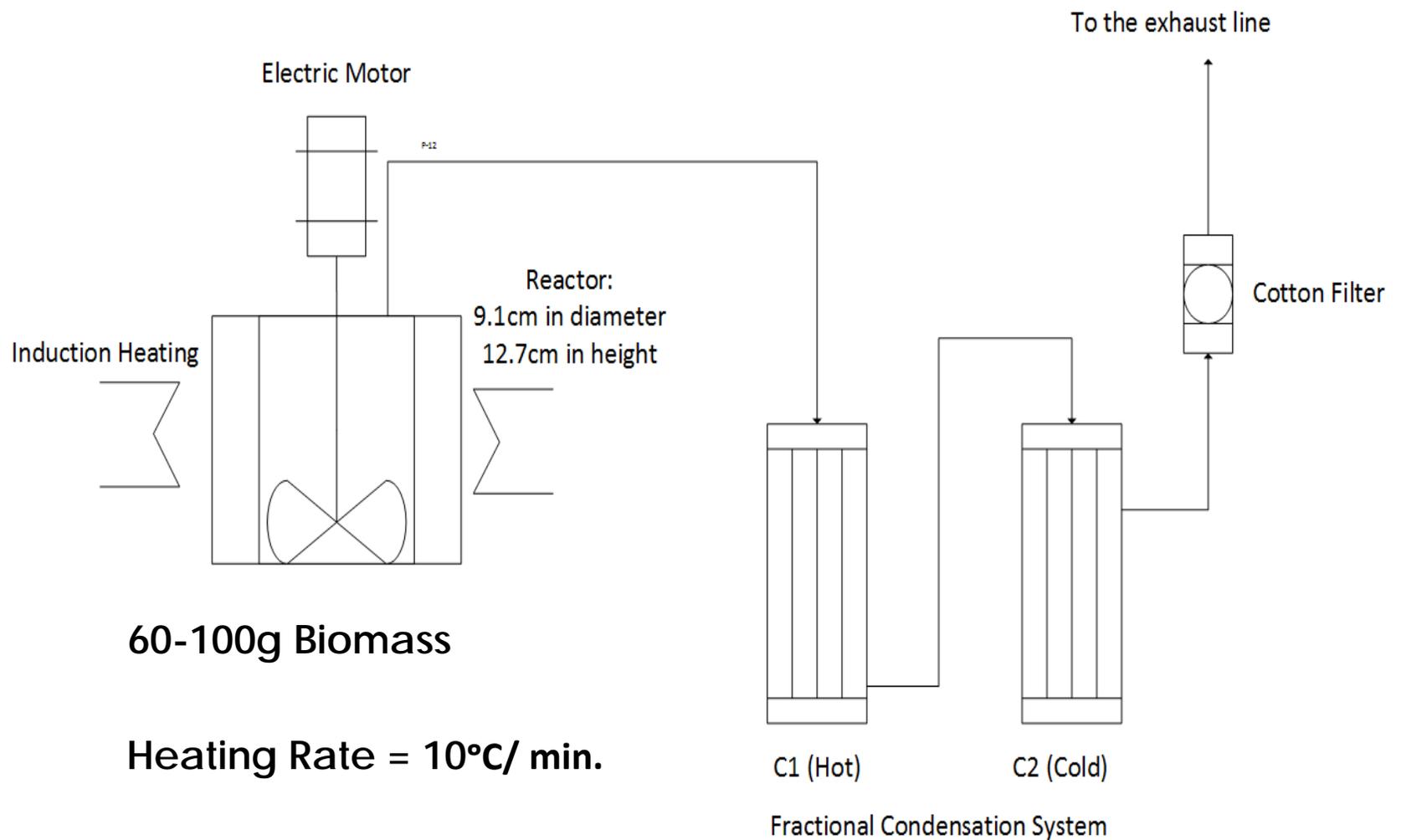
Dried Sewage Sludge Analysis

HHV (MJ/kg)	14.1
Ash Content (wt% d.b.)	16%
Elemental Composition (wt% d.b.)	
C	38.3
H	5.0
N	3.4
S	0
O	37.3

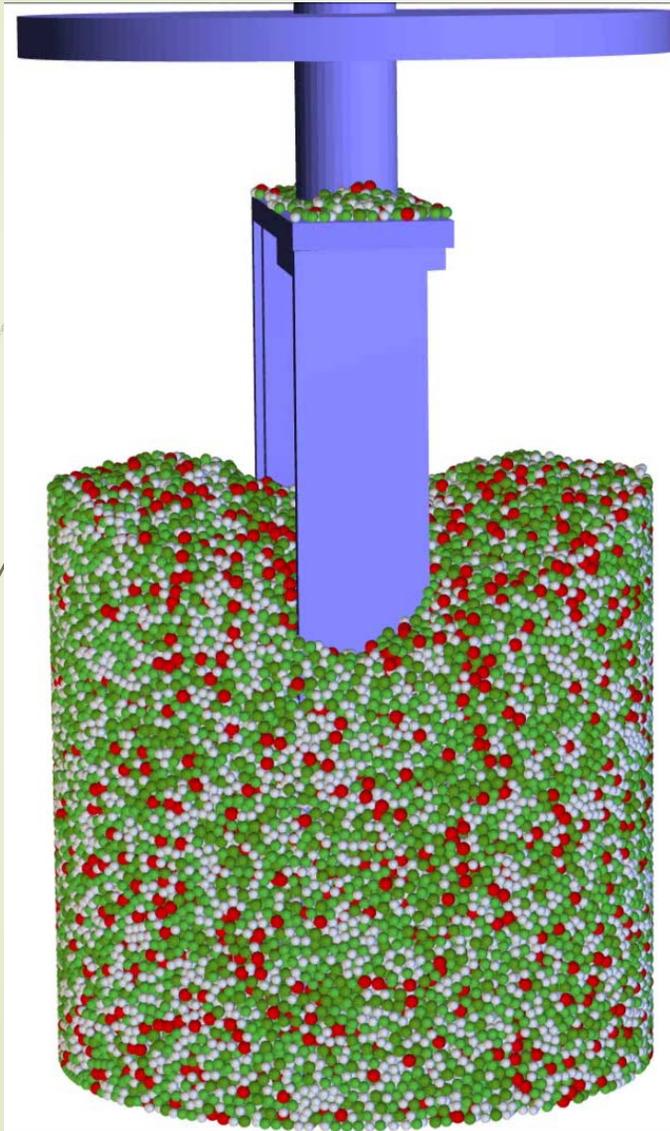
Dried Sludge ICP Analysis

Restricted Metal Analysis	(mg/kg d.b.)
As	<1.25
Cd	0.49
Co	<0.125
Cr	2
Cu	350
Mo	2
Ni	10
Pb	45
Se	<1.25
Zn	443
Other Metal Analysis	(mg/kg d.b.)
K	2,300
P	16,500
Fe	49,800

Slow Pyrolysis Mechanically Fluidized Reactor (MFR)



How The MFR Works



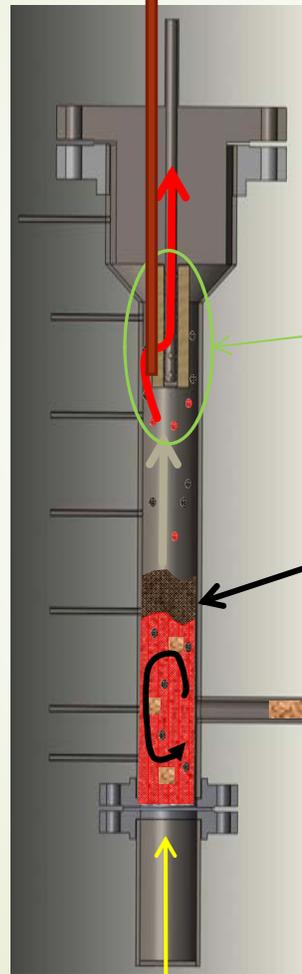
- ▶ Vertical arm mixer intimately mixes the bed
- ▶ Mechanical mixing and propagation of pyrolysis vapours equal or more effective than traditional gas fluidisation

Fast Pyrolysis Reactor

10

Char Periodically
Elutriated

To Condensers



5) Bio-oil vapours and permanent gases leave the reactor toward condensers.

4) A hot filter traps the small fraction of fine particles elutriated from the bed, avoiding contamination of the bio-oil.

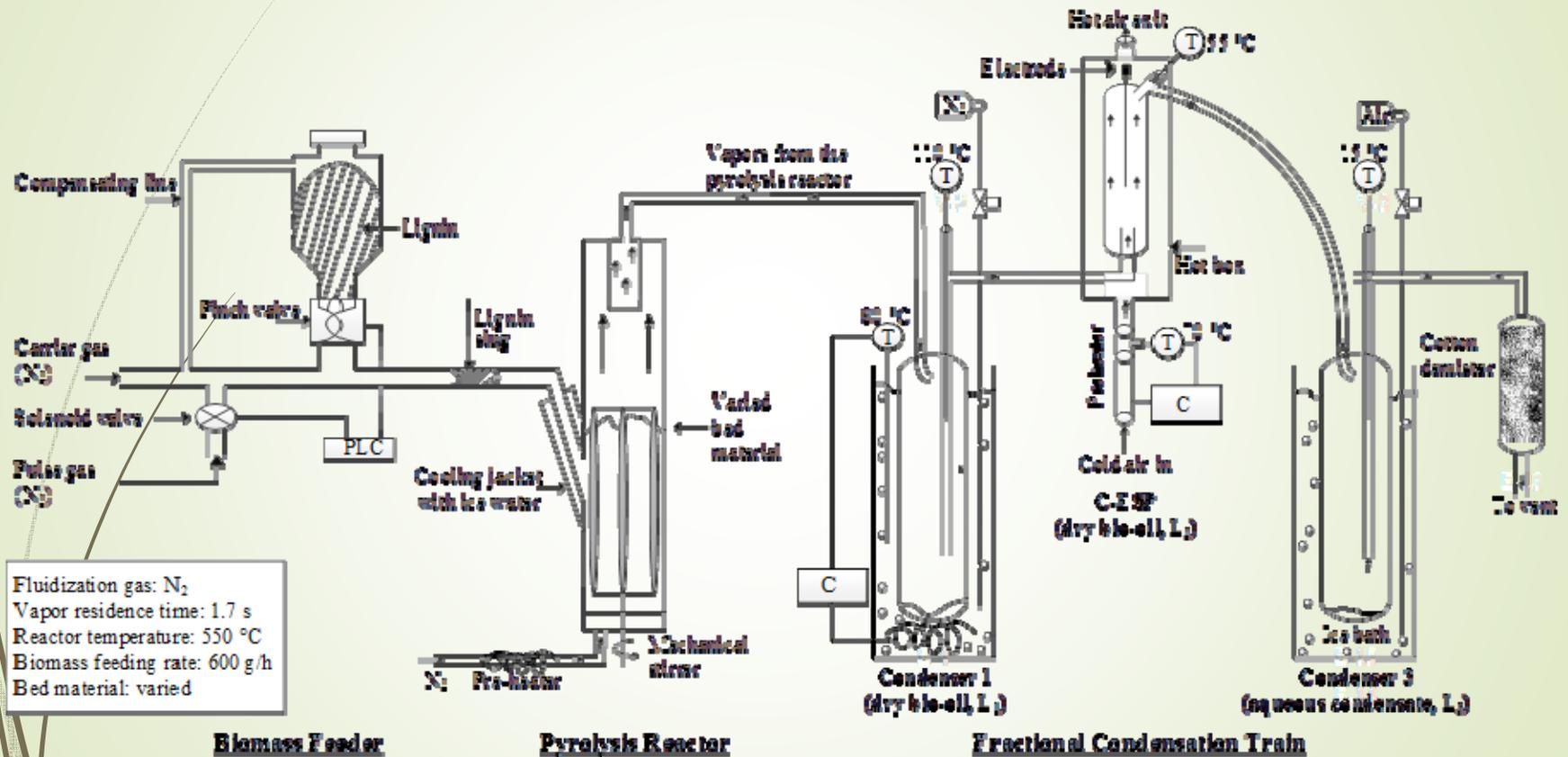
3) The char stays in the bed.

2) It mixes with the hot sand and reacts.

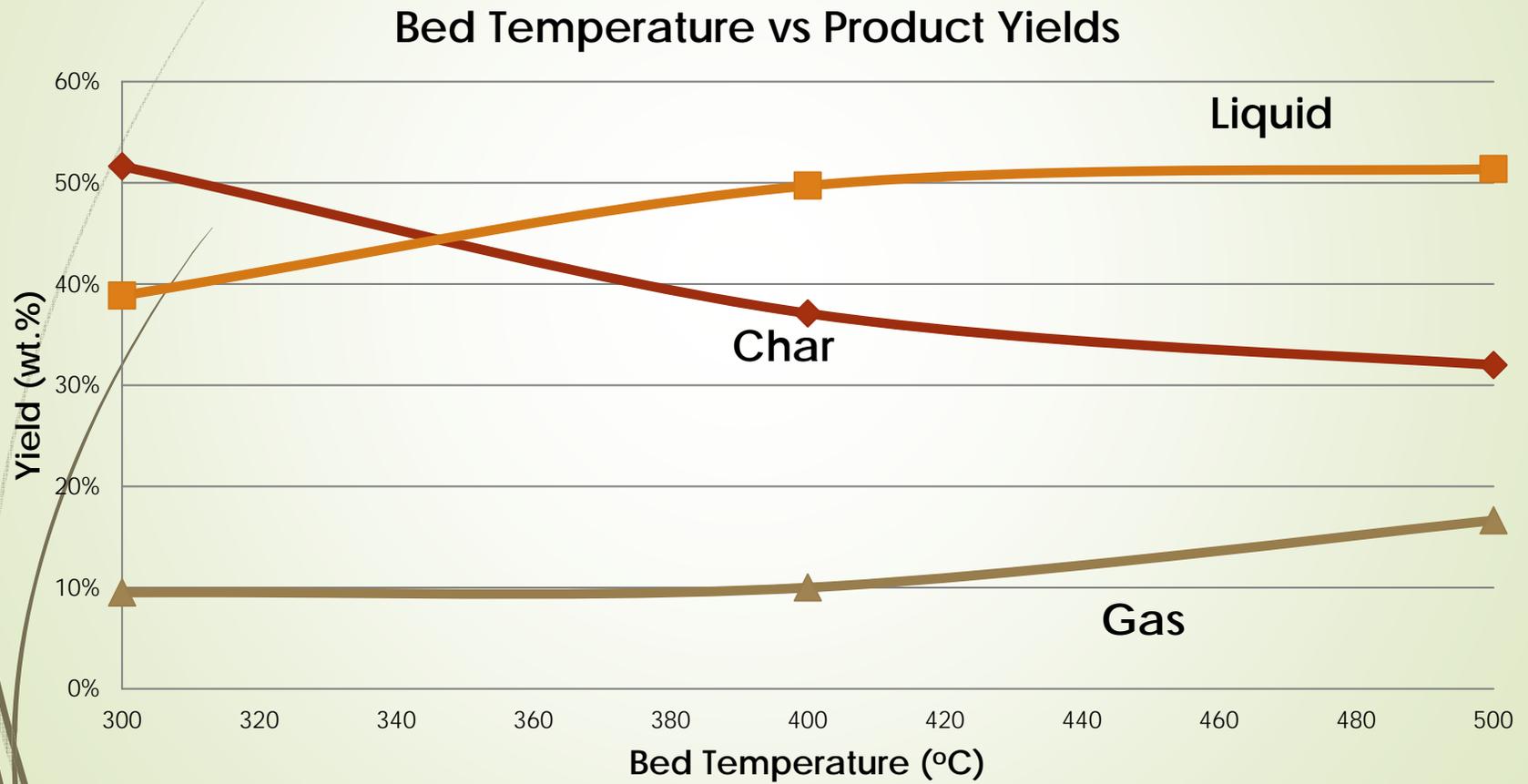
1) The biomass is injected into the bed.

N₂ for Fluidization

fast pyrolysis system overview

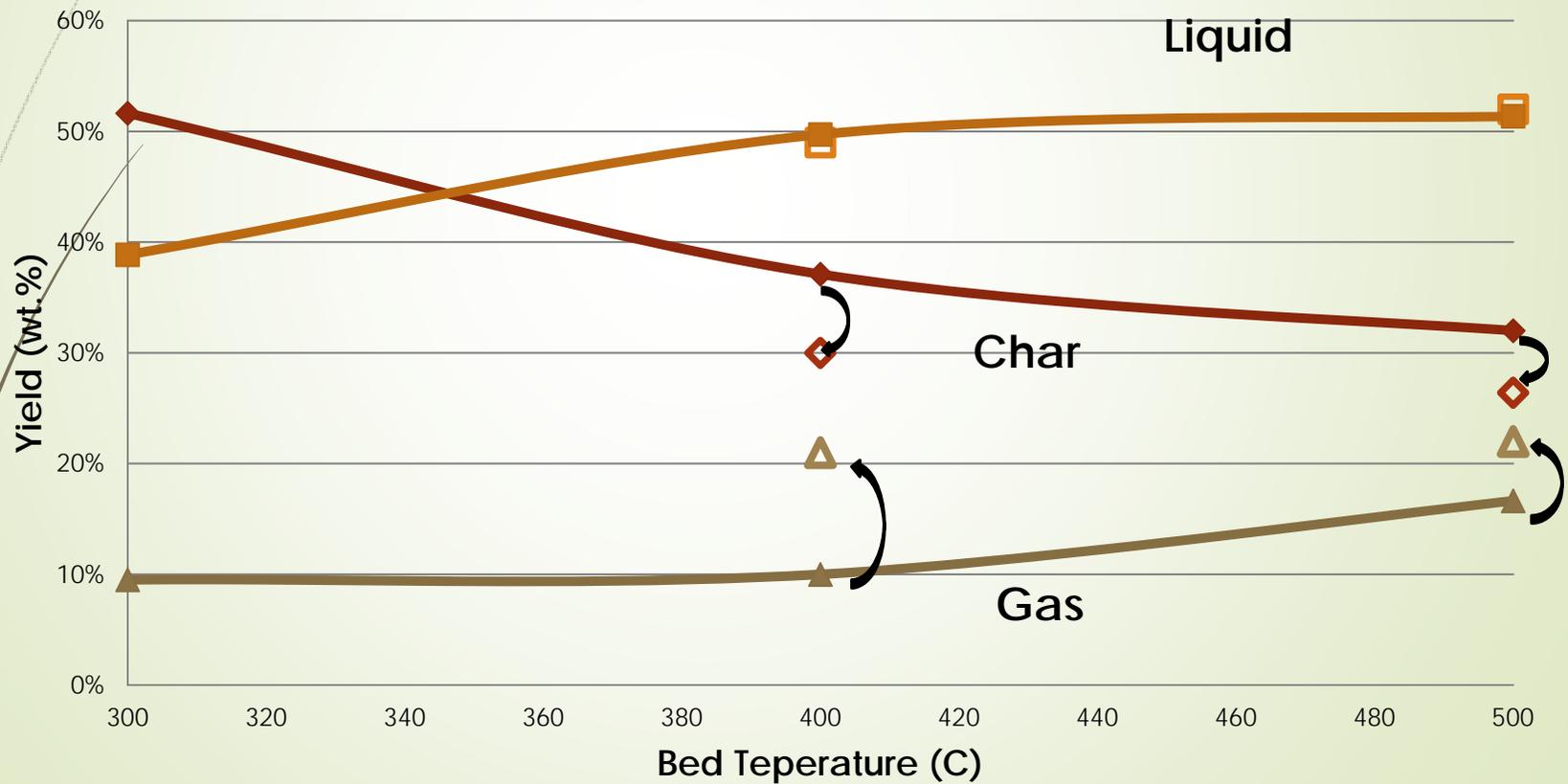


Slow Pyrolysis Yields



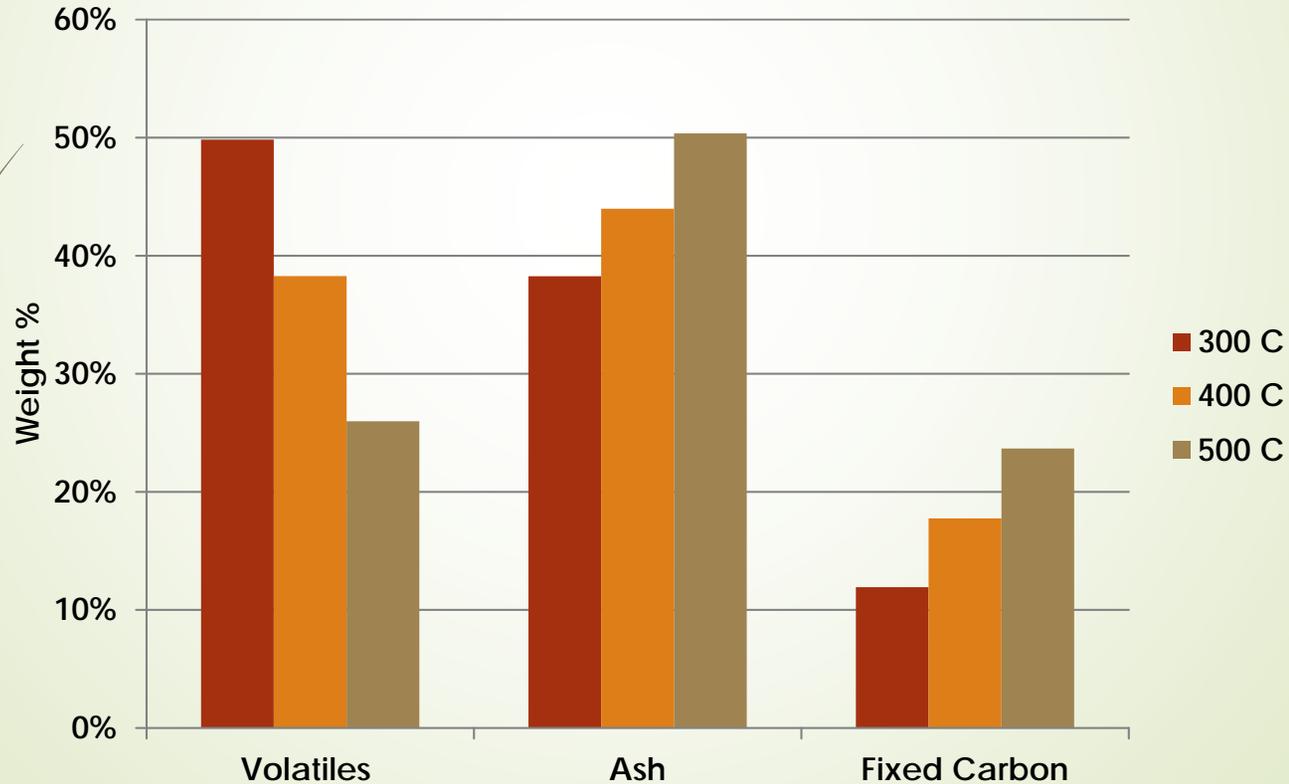
Compare With Fast Pyrolysis Yields

Bed Temperature vs Product Yields



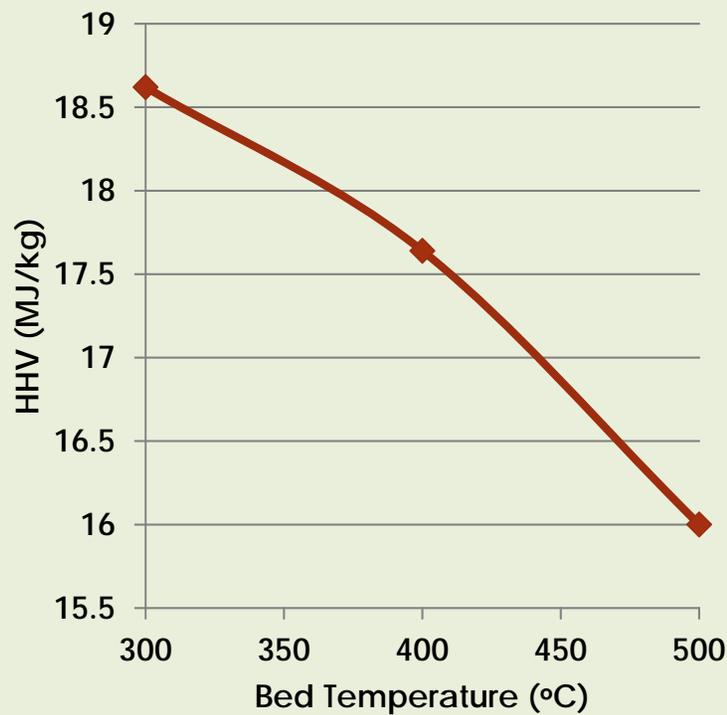
Slow Pyrolysis Char Analysis

Effect of Pyrolysis Temperature on Volatile, Ash, and Fixed Carbon Content on Slow Pyrolysis Chars

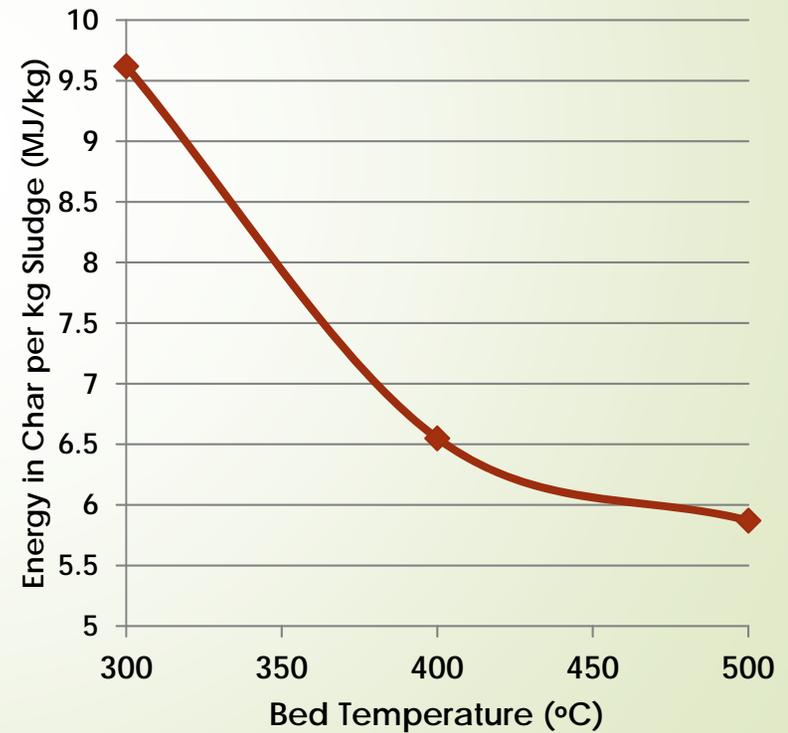


Slow Pyrolysis Char Energy Analysis

Char HHV vs Bed Temperature

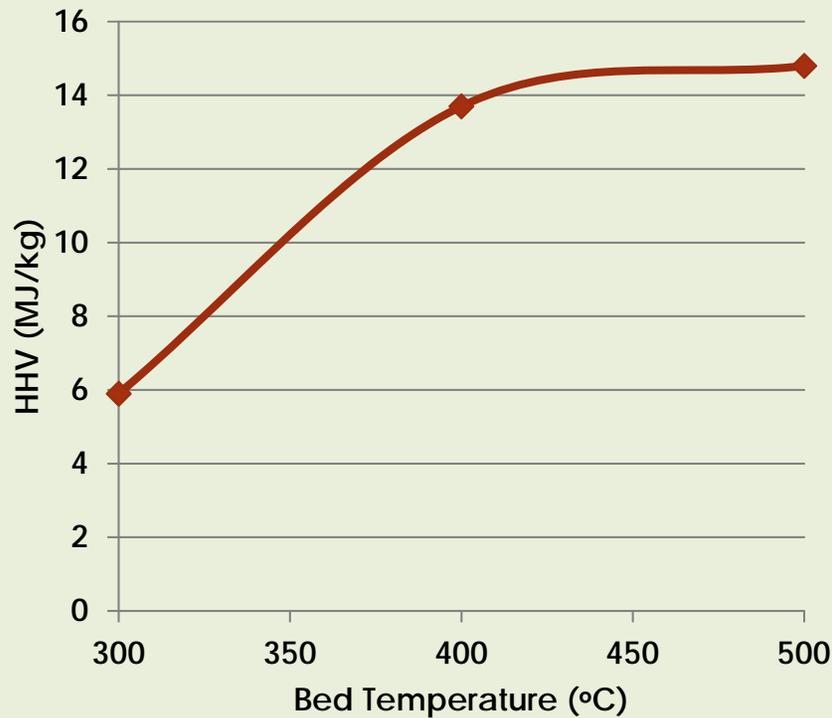


Energy in Char per kg Dry Sludge Feed vs Bed Temperature

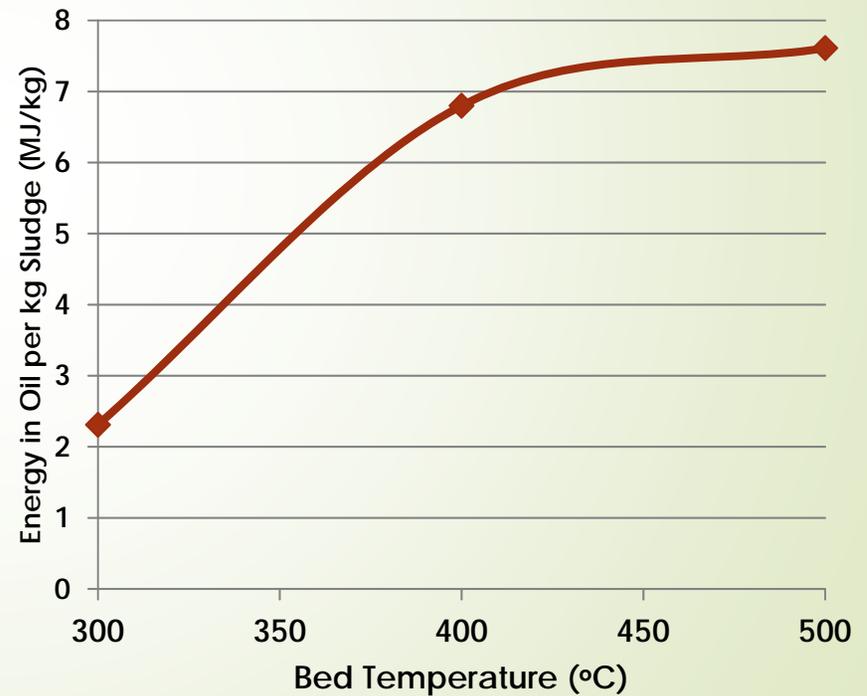


Slow Pyrolysis Oil Analysis

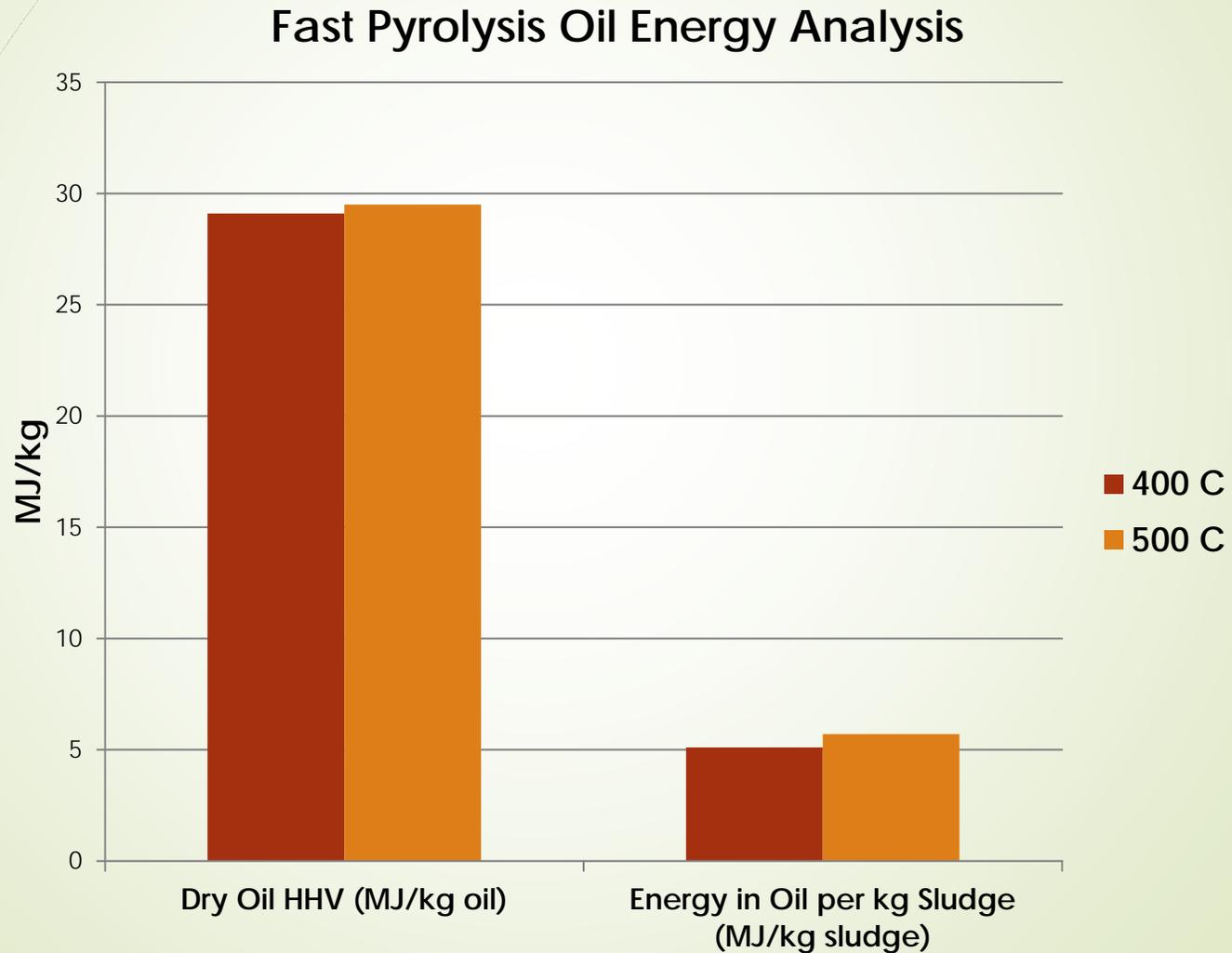
Oil HHV vs Bed Temperature
HHV (MJ/kg)



Energy in Char per kg Dry
Sludge Feed vs Bed
Temperature



Fast Pyrolysis Oil Energy Analysis



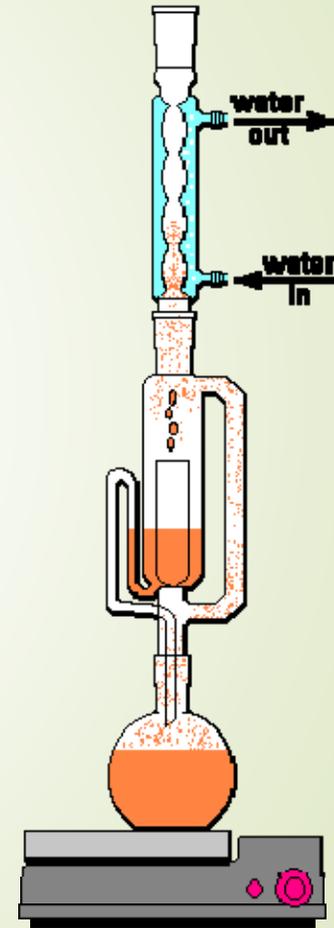
Fast Pyrolysis Gas Analysis (500°C)

Gas Component	Weight %
CO*	43.4%
C ₂ H ₄	37.5%
CO ₂	13.9%
C ₃ H ₈	3.9%
C ₄ H ₁₀	1.3%

Total Gas Yield	Heating Value (MJ/kg)	Energy in Gas per kg Dry Sludge (MJ/kg)
22%	24.7	5.4

Char Heavy Metals Leaching

- ▶ Leaching experiments performed using soxhlet extractor
- ▶ Water used as solvent
- ▶ Extraction temperature = 70 °C
- ▶ 72 hr extraction time



Leaching results

Restricted Metals	Slow Pyrolysis Char 500 °C	Fast Pyrolysis Char 500 °C
Cd	0%	0%
Cr	0%	0.7%
Cu	1.1%	1.5%
Ni	0%	2.4%
Pb	0%	0%
Zn	0.2%	0.4%
Other Metals		
P	0.2%	0.5%
K	29.0%	66.0%

Enthalpy of Pyrolysis Method

- Enthalpy of pyrolysis was determined by analysing the power applied to heat the reactor during biomass feeding, and again while injecting a known flowrate of water
- The energy balance of the reactor can be expressed as:

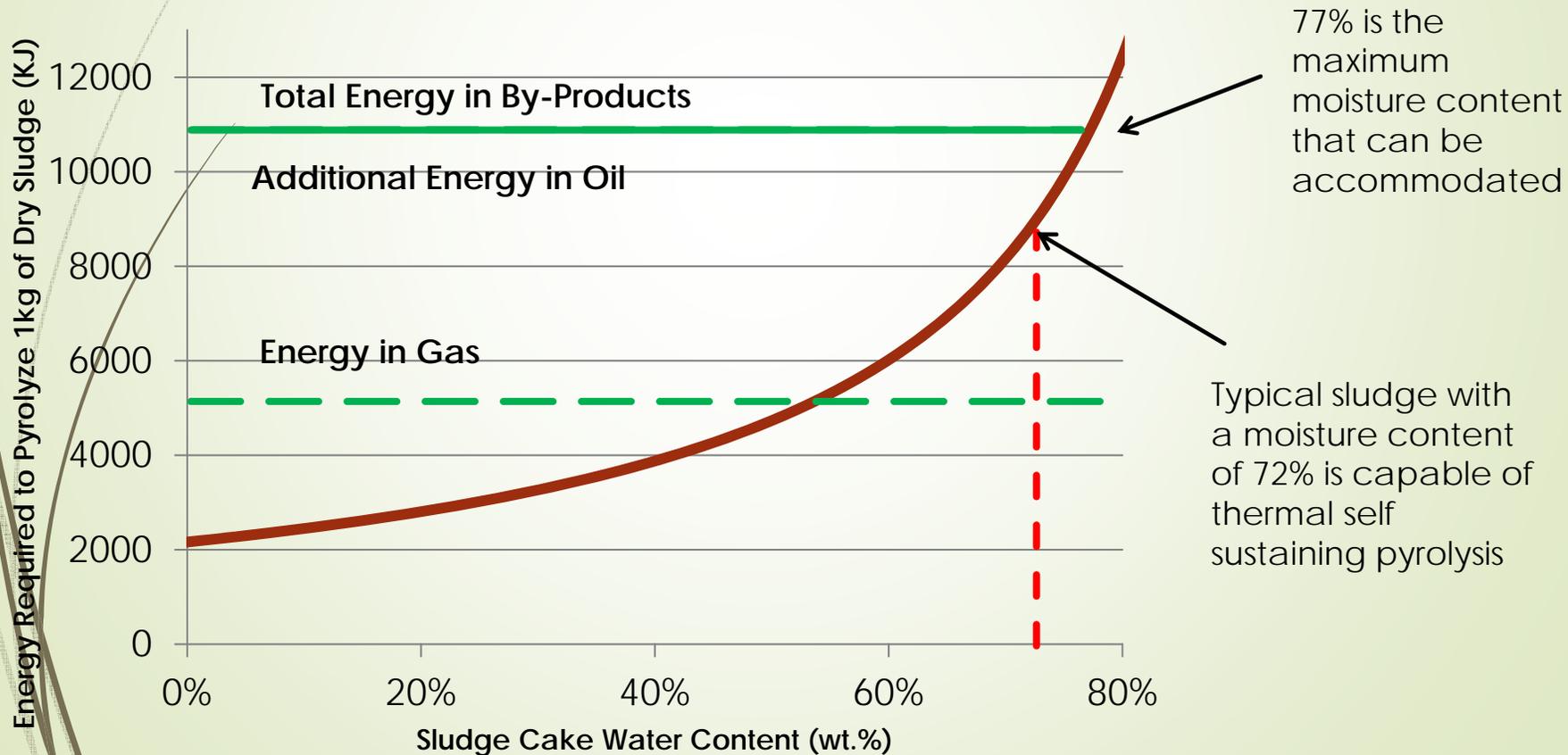
$$E_{R,pyrolysis} = Q_{Loss,pyrolysis} + H_{Pyrolysis}$$
$$E_{R,water\ injection} = Q_{Loss,water} + H_{Water}$$

Vary water flow rate

$$H_{Pyrolysis} = 2.16 \text{ MJ/kg}$$

Energy Balance of Pyrolysis at 500°C

Energy Required to Pyrolyze 1kg of Dry Sludge vs Sludge Cake Water Content



Ongoing and Future work

- Autothermal pyrolysis of sewage sludge
- Economic analysis of commercial scale sewage sludge pyrolysis
- Life Cycle Analysis of commercial scale sewage sludge pyrolysis
 - Global warming potential
 - Acidification potential
 - Human health effects

Conclusions

- Pyrolysis is viable as a thermally self sufficient process to transform sewage sludge into biochar
- Good recovery and stabilisation of heavy metals in the biochar.
- Likely to be economically and environmentally favourable to incineration
- Increases in dewatering efficiencies will allow for excess energy generation from products.

Acknowledgements

The logo for iocfar features a stylized flame icon in orange and green to the left of the lowercase text "iocfar".

iocfar

The logo for Western University includes the word "Western" in a large, purple, serif font, with "UNIVERSITY • CANADA" in a smaller, purple, sans-serif font below it. To the right is the university's crest, a purple shield with a sunburst at the top, a book, and a maple leaf.

Western
UNIVERSITY • CANADA

The logo for TROJAN UV features the word "TROJAN" in black, uppercase, sans-serif font, followed by "UV" in red, uppercase, sans-serif font. Above the "UV" is a cluster of red dots of varying sizes.

TROJAN UV™

The logo for Réseau Biofuelnet Canada features a stylized leaf icon on the left, composed of two overlapping shapes in green and orange. To the right, the text "RÉSEAU BIOFUELNET" is in a large, grey, sans-serif font, with "CANADA" in a smaller, grey, sans-serif font below it.

RÉSEAU
BIOFUELNET
CANADA

The logo for London Canada features a stylized tree icon in green on a grey square background. Below the square, the word "London" is in a large, green, sans-serif font, and "CANADA" is in a smaller, green, sans-serif font below it.

London
CANADA

Questions?