Western
Institute for Chemicals and Fuels from Alternative Resources (ICFAR)

icfar

The Production of Pyrolytic Biochar for Value-Added Building Materials

Franco Berruti[1] Douglas Matthew Cuthbertson[1],
Umberto Berardi[2] and Cedric Briens[1]

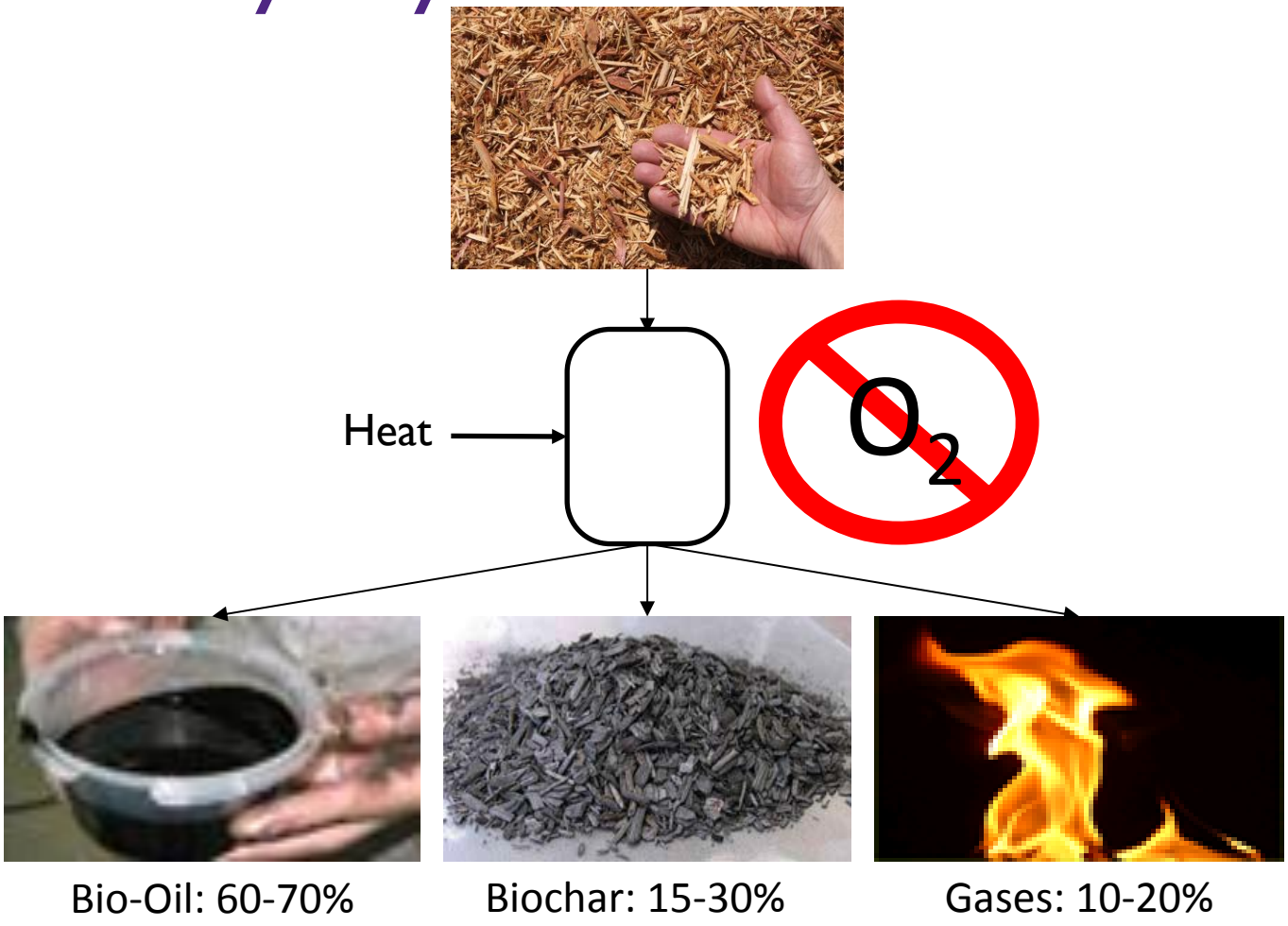
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OVERVIEW

- Introduction
- Biochar Production
  - Reactor Technology
  - Characterization
- Epoxy Composites
  - Electrical Properties
- Biochar + Concrete (Charcrete)
  - Production Methods
  - Results

INTRODUCTION:
Pyrolysis and Biochar

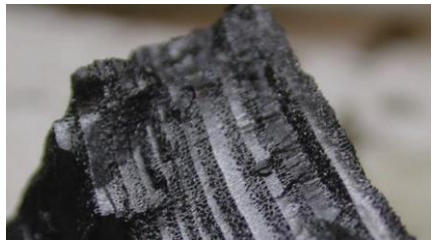


Bio-Oil: 60-70%

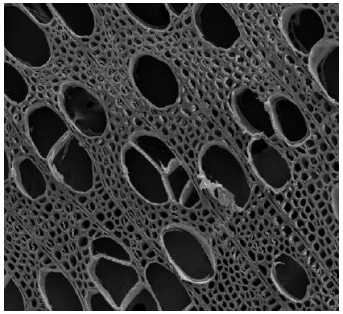
Biochar: 15-30%

Gases: 10-20%

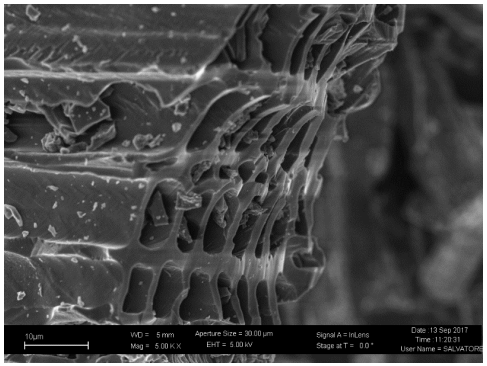
INTRODUCTION: Pyrolysis and Biochar



- **Biochar**
  - Condensed, aromatic carbon; Repolymerized volatiles
  - Ash content from feedstock
  - Wide range of surface functional groups

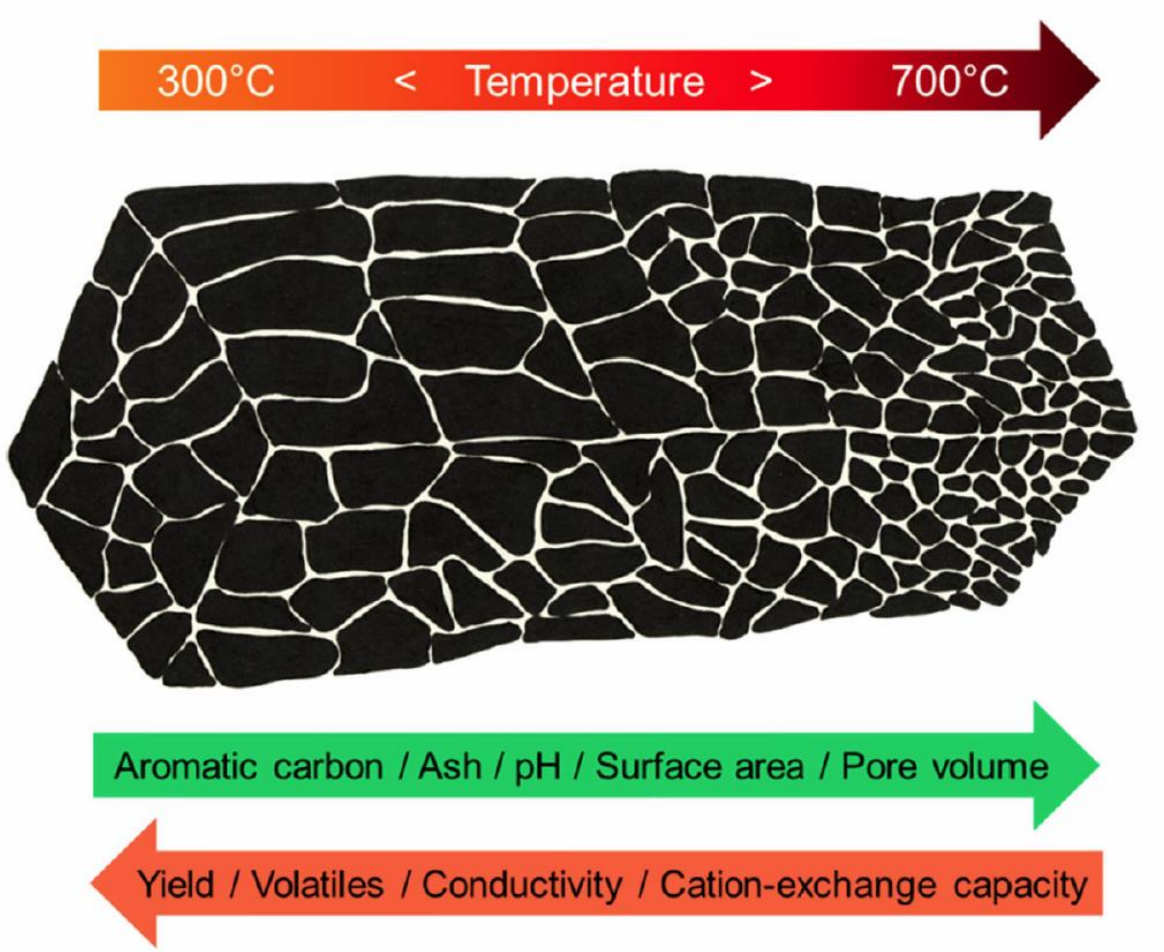


- **Why biochar?**
  - Typically considered a by-product of bio-oil production
  - Can be produced from waste materials
  - Applications:
    - Soil Amendment and Carbon Sequestration
    - Activated Carbon



Could there be more valuable applications?

INTRODUCTION:
Biochar Characteristics



Sonil Nanda, Ajay K. Dalai, Franco Berruti, and Janusz A. Kozinski: Biochar as an Exceptional Bioresource for Energy, Agronomy, Carbon Sequestration, Activated Carbon and Specialty Materials. *Waste Biomass Valorization*, Volume 7, **2016,** pp 201-235

INTRODUCTION:
Biochar in Building Materials

- Reduced Carbon Footprint
- Chemically and Thermally Stable
- Lightweight
- Insulation
- Improved stability and strength
- Buffering humidity
- Electrical conductivity, permittivity
- Noise protection
- High Frequency Radiation shielding
- Deodorizing
- Toxins binding (VOCs)
- Fungicide
- Replacement for carbon black, graphene, and carbon nanotubes (CNT)
- Black Colour

Biochar-Clay-Plaster for optimal indoor climate

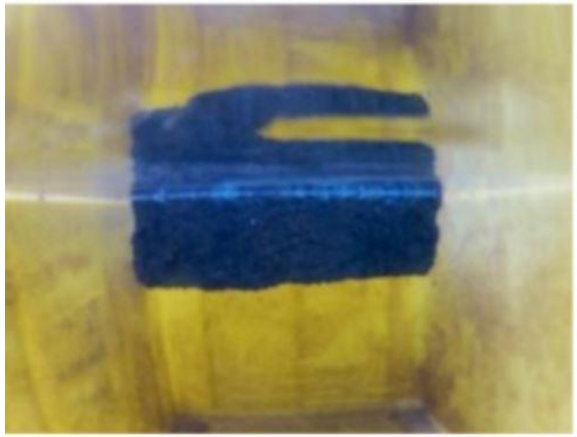




humidity control, thermal insulation, toxin fixation, electro-magnetic shielding

Hans-Peter Schmidt, Ithaka Institute, 2017

light weight Biochar Bricks swim







Hans-Peter Schmidt, Ithaka Institute, 2017

RESEARCH OBJECTIVES

1) **Produce biochar** from different Canadian waste and industrial by-products
2) **Characterize** the physical, chemical properties and the electrical characteristics when added to a composite
3) **Investigate** the effects of biochar addition to concrete (charcrete)

FEEDSTOCKS

Feedstock	Source	Volatile Matter (%)	Fixed Carbon (%)	Ash Content (%)
Miscanthus	Agriculture	86.6	11.4	2.2
Wood Chips	Construction	75.1	12.9	12.0
Dried Distiller's Grain (DDG)	Corn Ethanol By-Product	82.0	12.6	5.2



Miscanthus



Wood Chips



Distiller's Grain

BIOCHAR PRODUCTION: Reactor Technology

Pyrolysis Pilot Plant (1 kg/h):

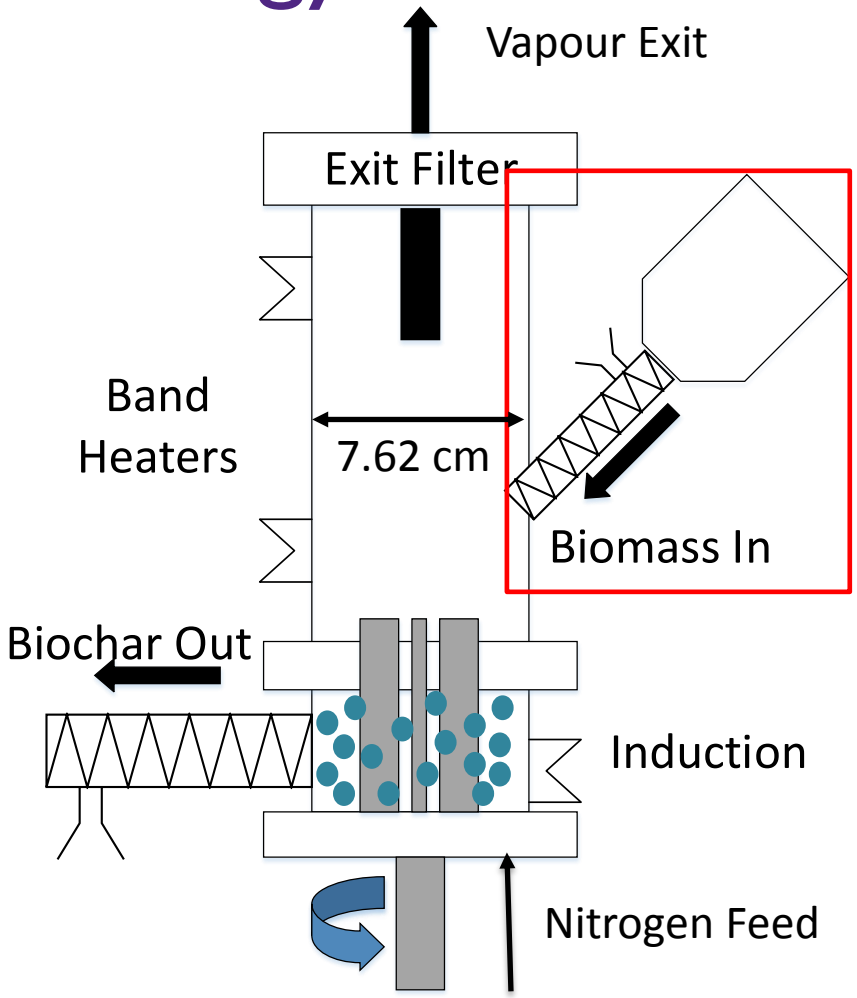
- 3.5 L Reactor
- Gas Fluidized
- Mechanically Fluidized
- Two Feed Methods
  - Side Mounted Screw Feeder
  - ICFAR "Slug Injection" Feeder
- Continuous solid extraction



BIOCHAR PRODUCTION: Reactor Technology

Pyrolysis Pilot Plant (1 kg/h):

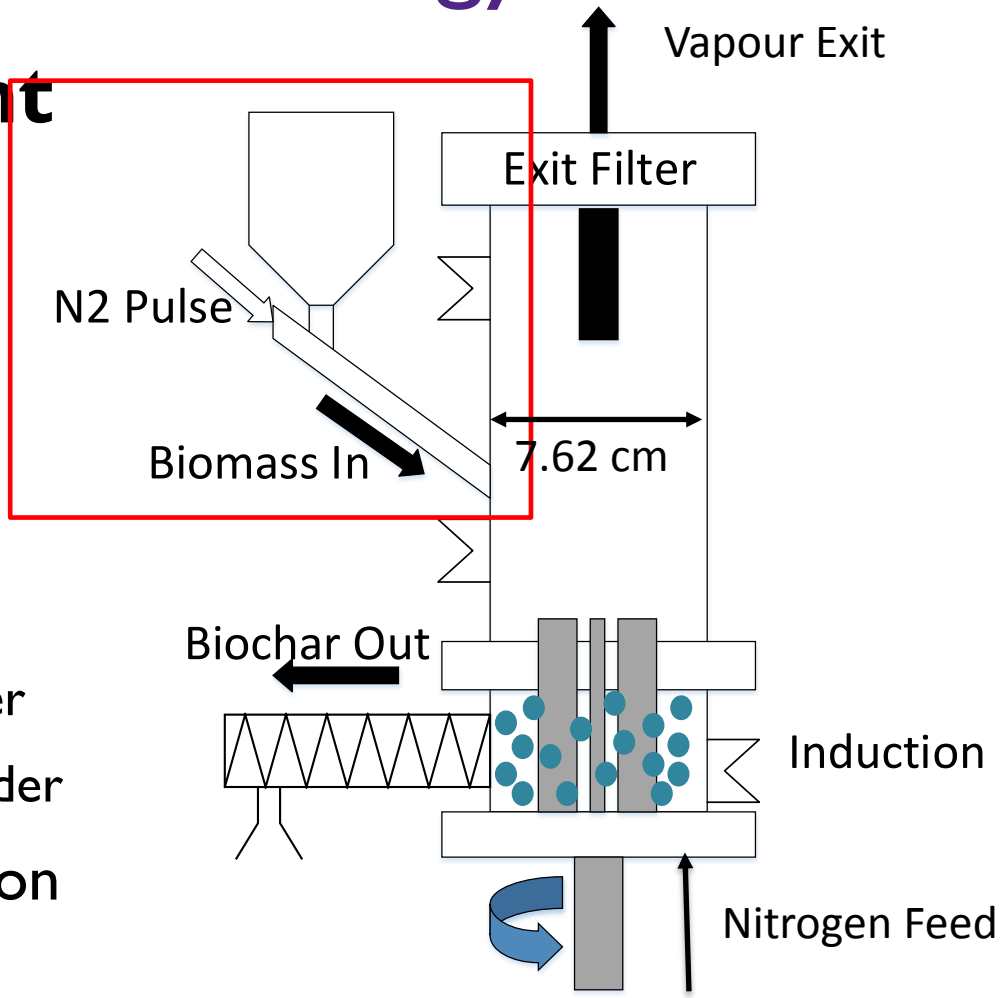
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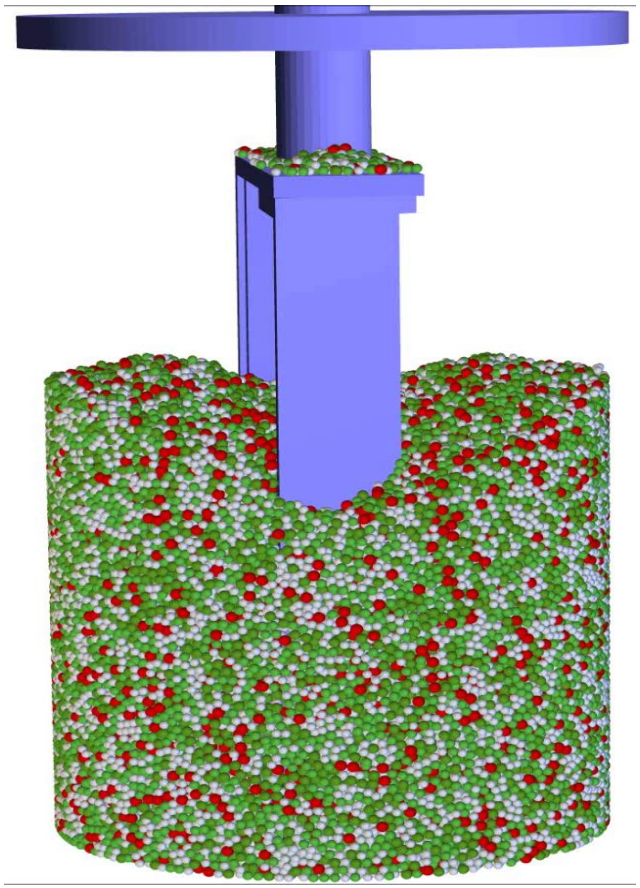
BIOCHAR PRODUCTION: Reactor Technology

- Fast pyrolysis experiments between **350 °C and 550 °C**
- Vapour residence time of **3 to 5 seconds**

BIOCHAR PRODUCTION: Reactor Technology

The Small Batch Mechanically Fluidized Reactor (MFR):

- 1 L Batch Reactor
- Heated by induction system
- Mechanically Mixed
- Allows for **intermediate or slow pyrolysis**
  - 12-14 °C/minute heating
  - 2 hour experiments



BIOCHAR PRODUCTION: Reactor Technology

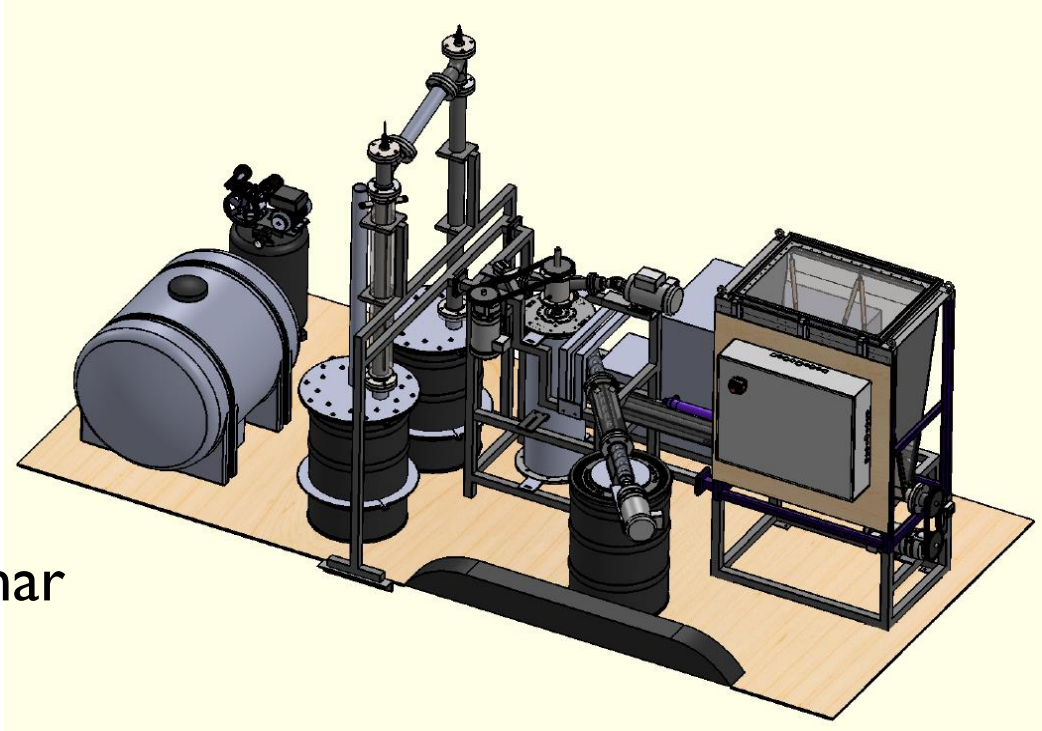
Horizontal Mixed Batch Reactor (25 L) for slow pyrolysis



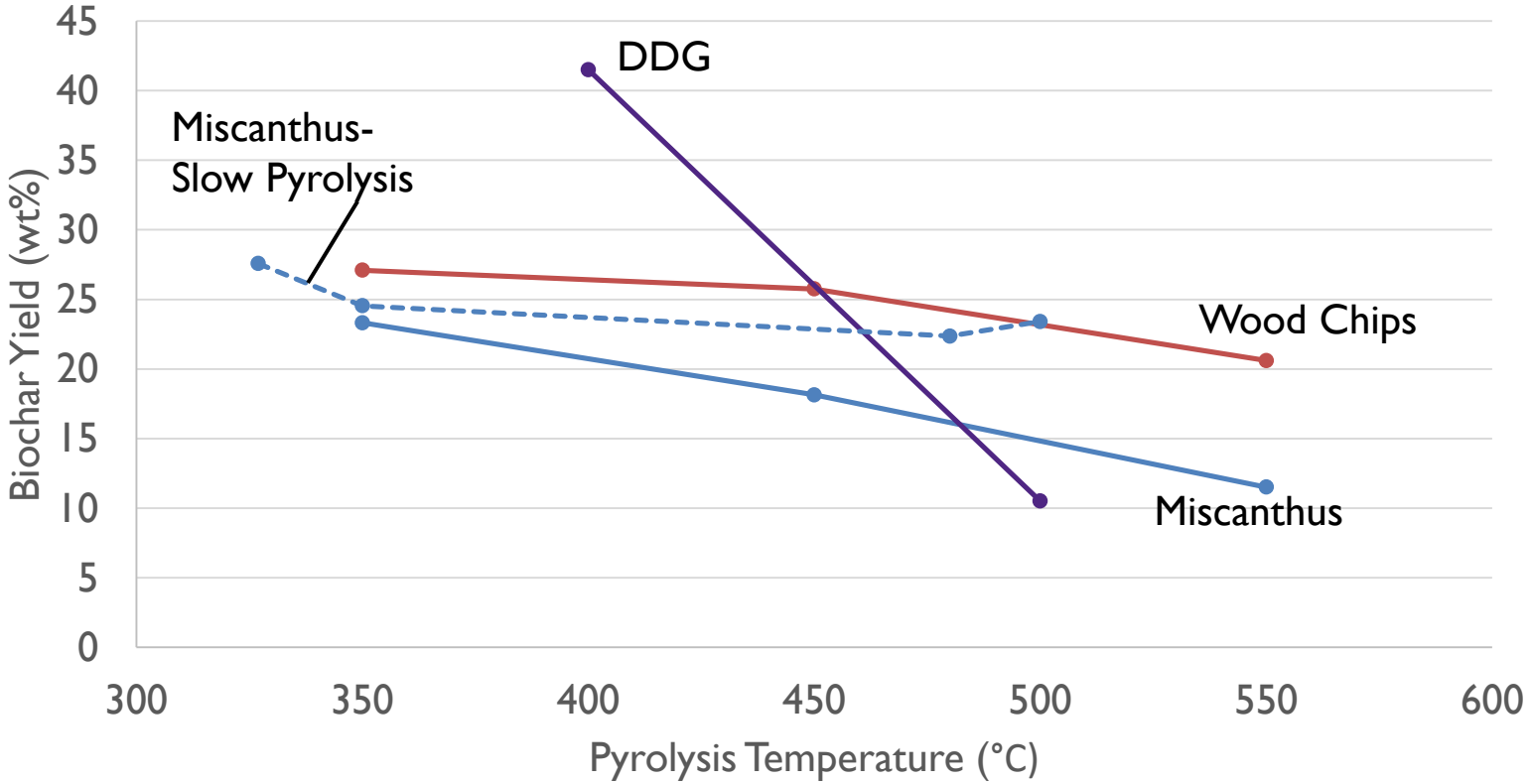
BIOCHAR PRODUCTION: Reactor Technology

The MFR 100:

- Large scale technology
- 100 kg/h processing
- Mechanically fluidized
- Used to produce large quantities of DDG biochar

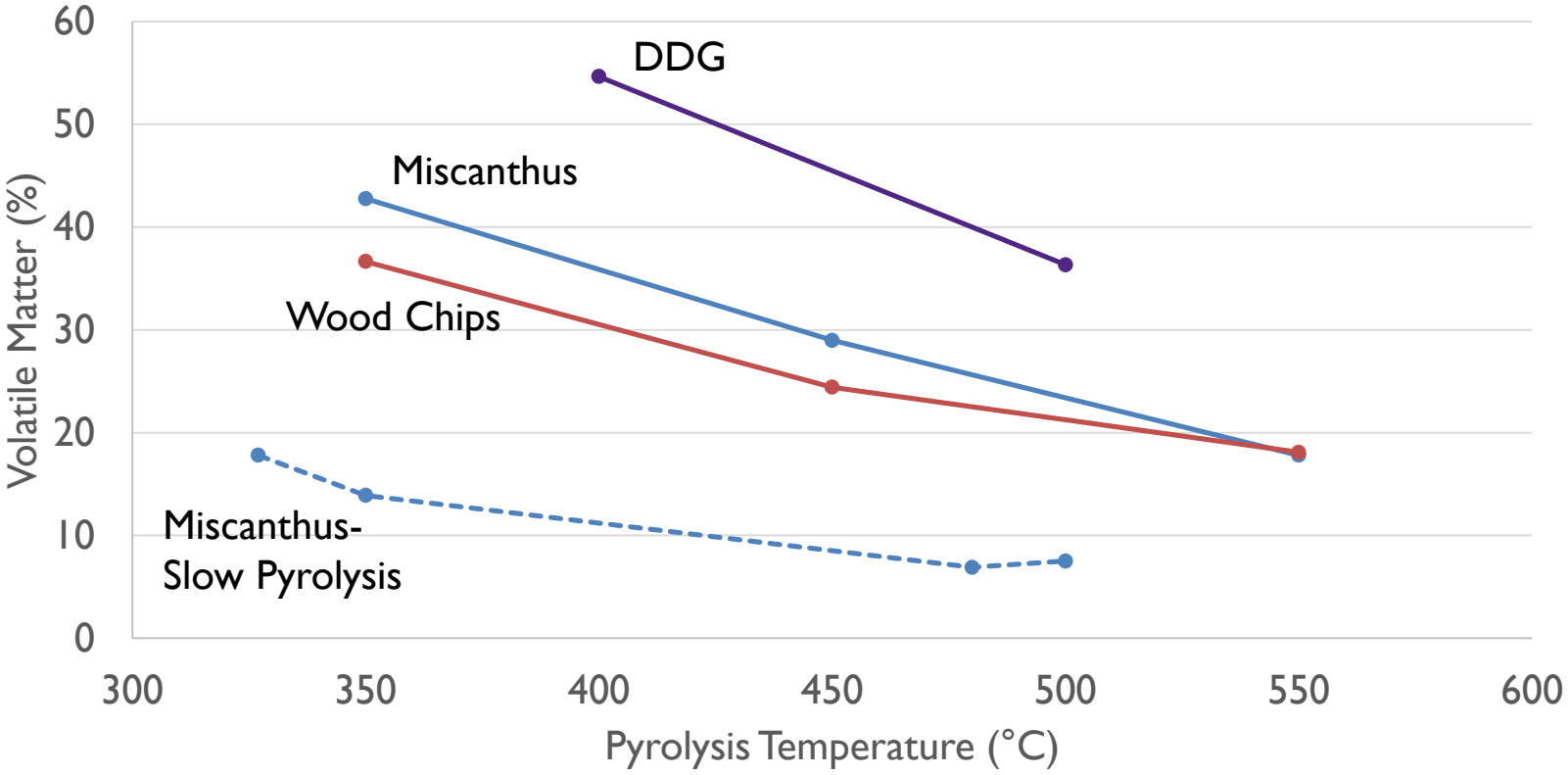


BIOCHAR PRODUCTION: Characterization



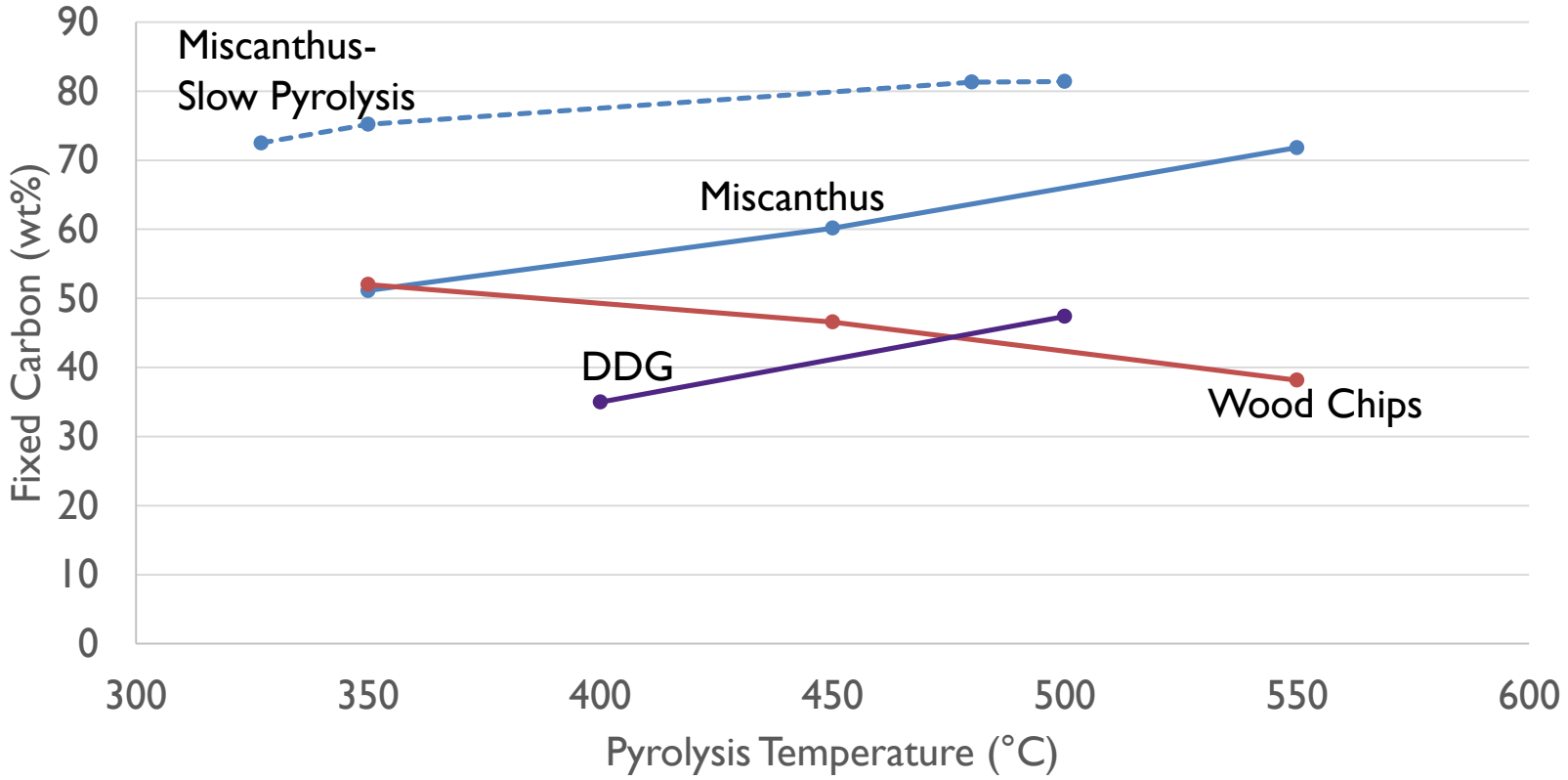
Biochar Yield as a Function of Pyrolysis Temperature

BIOCHAR PRODUCTION: Characterization



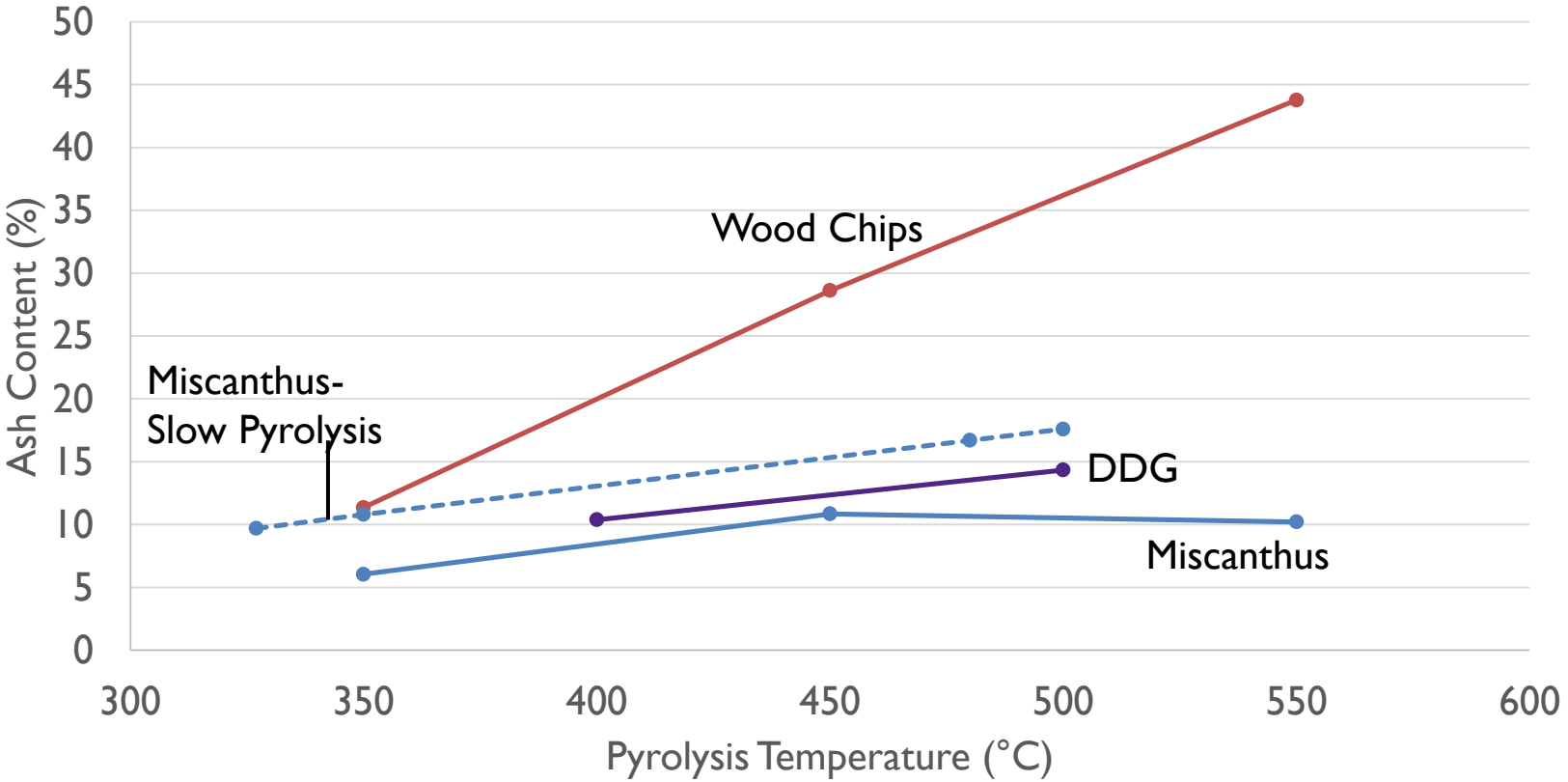
Biochar Volatile Matter as a Function of Pyrolysis Temperature

BIOCHAR PRODUCTION: Characterization



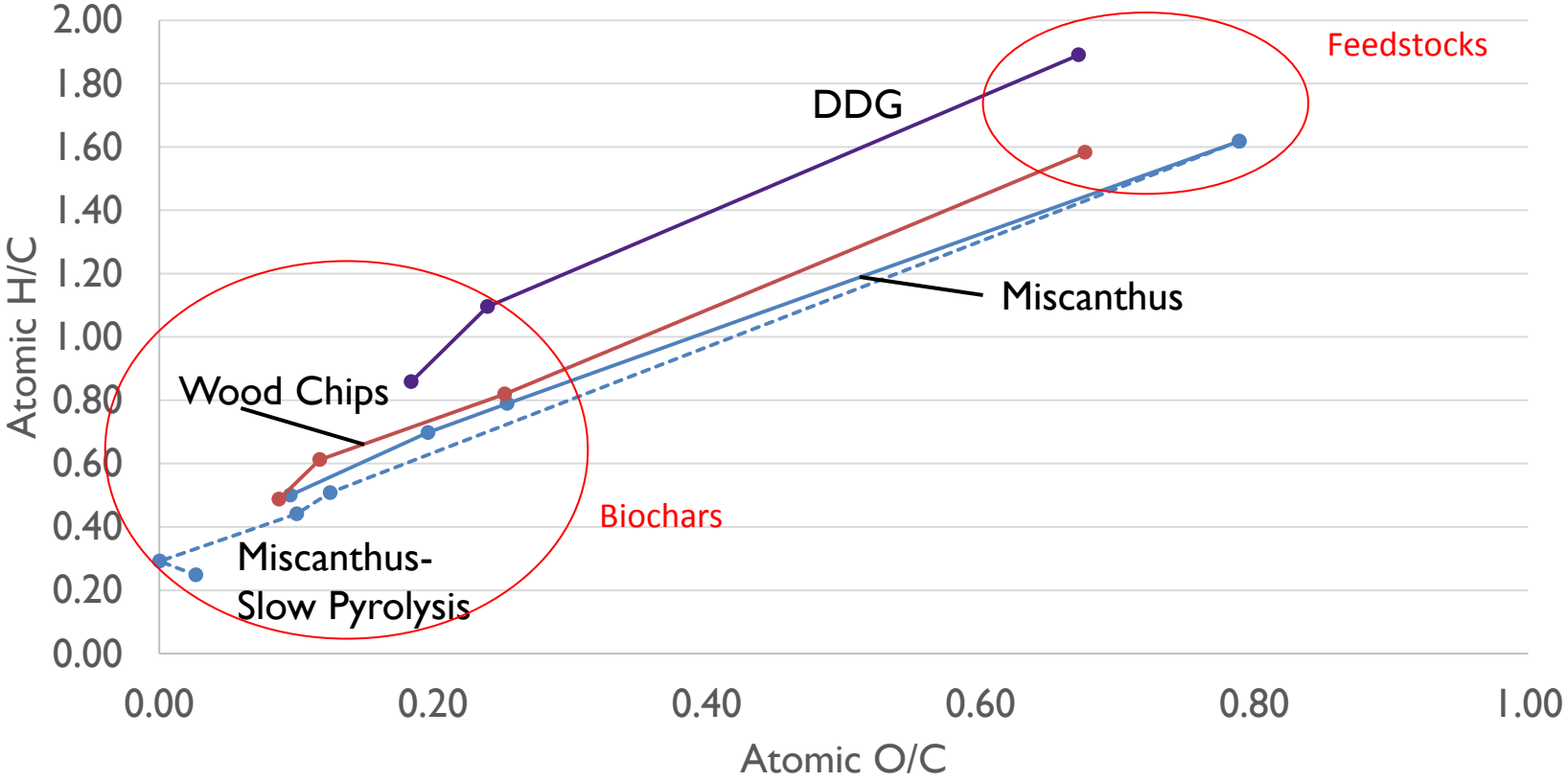
Biochar Fixed Carbon as a Function of Pyrolysis Temperature

BIOCHAR PRODUCTION: Characterization



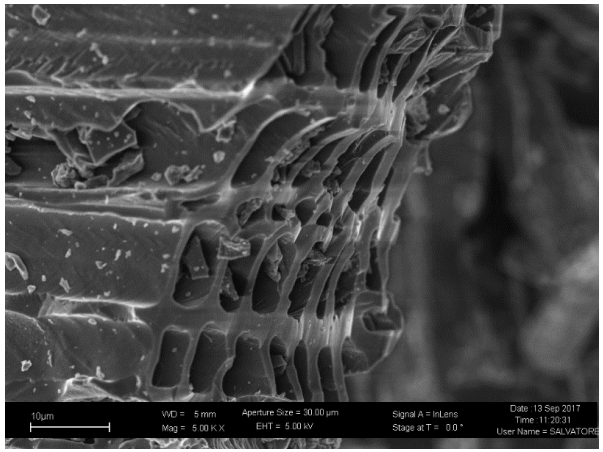
Biochar Ash Content as a Function of Pyrolysis Temperature

BIOCHAR PRODUCTION: Characterization

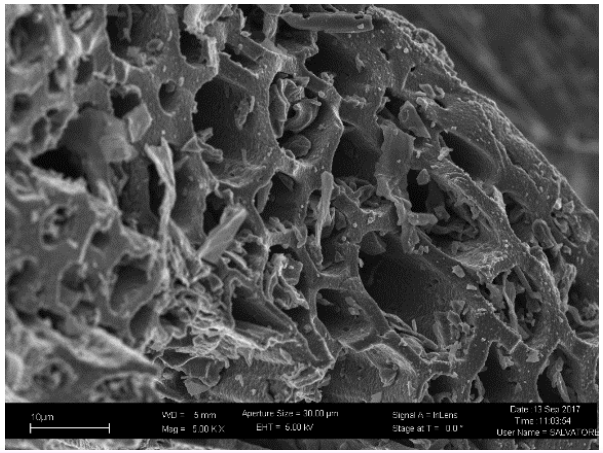


Van Krevelen Diagram for Biochar

BIOCHAR PRODUCTION: Scanning Electron Microscopy

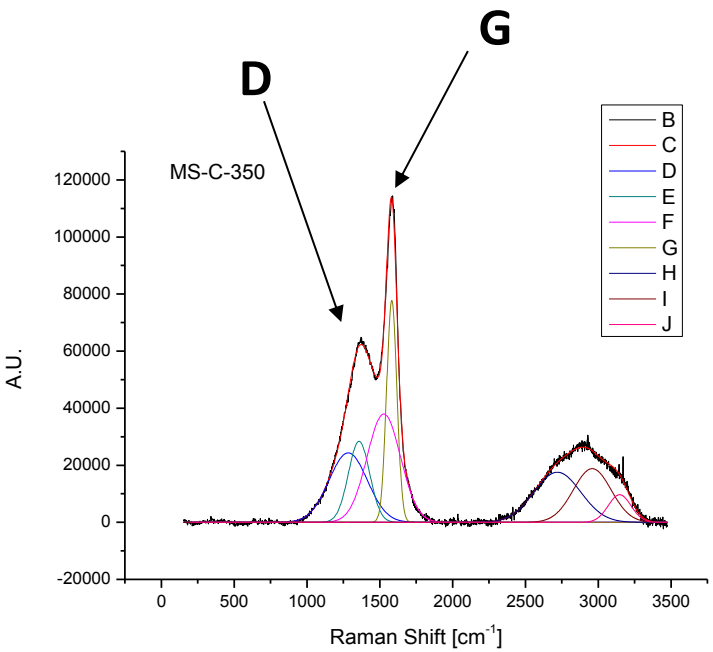


WOOD CHIPS BIOCHAR, 5000x
550 °C



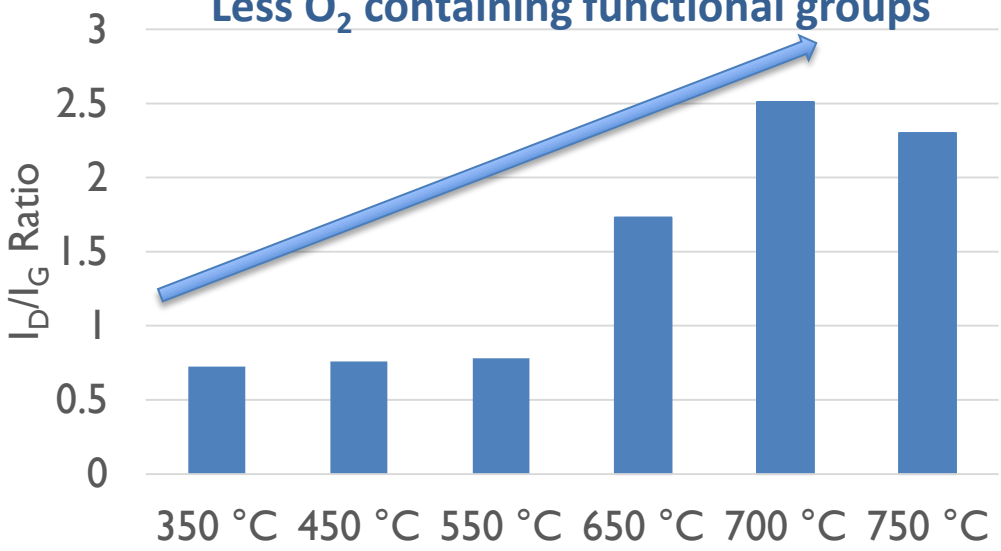
MISCANTHUS BIOCHAR, 5000x
550 °C

BIOCHAR PRODUCTION: Raman Spectroscopy



Example of a Raman shift for carbon based material

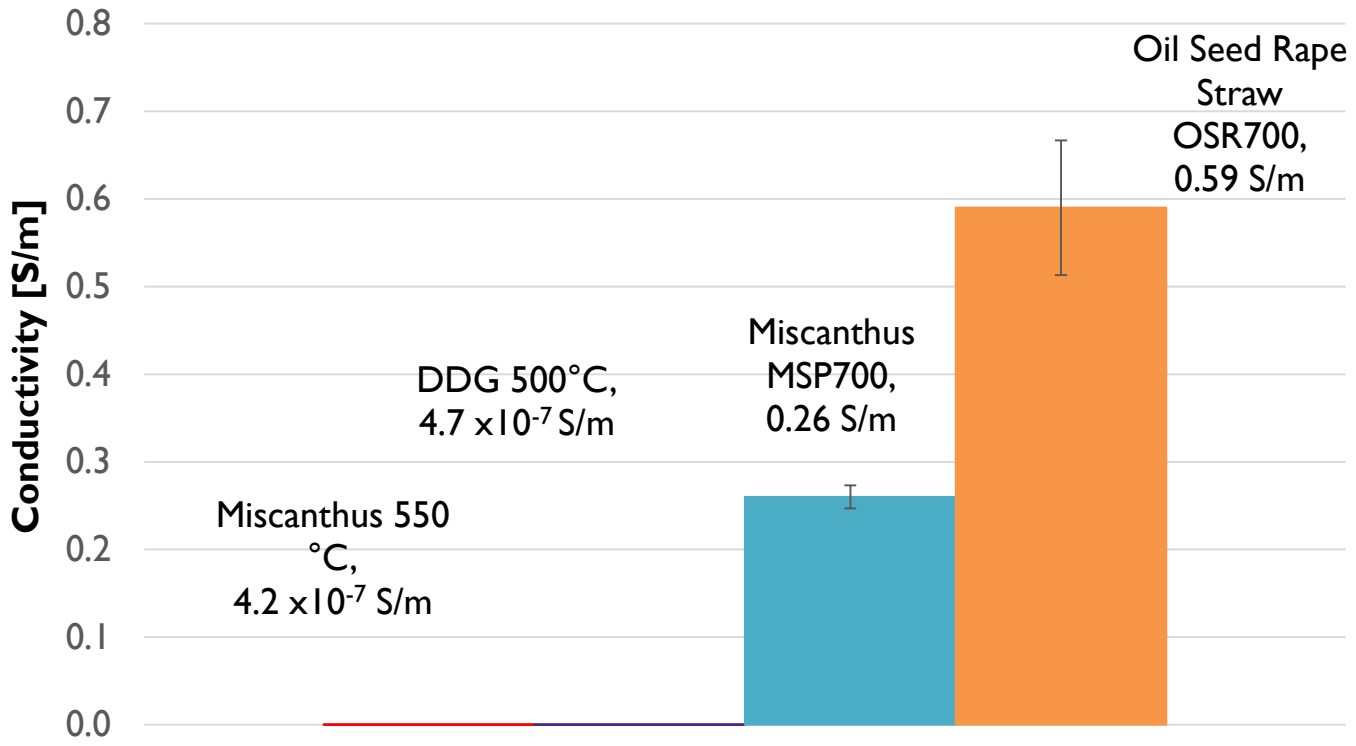
More disordered carbon
More aromaticity
Less O_2 containing functional groups



Ratio of D and G band intensity for Miscanthus biochar

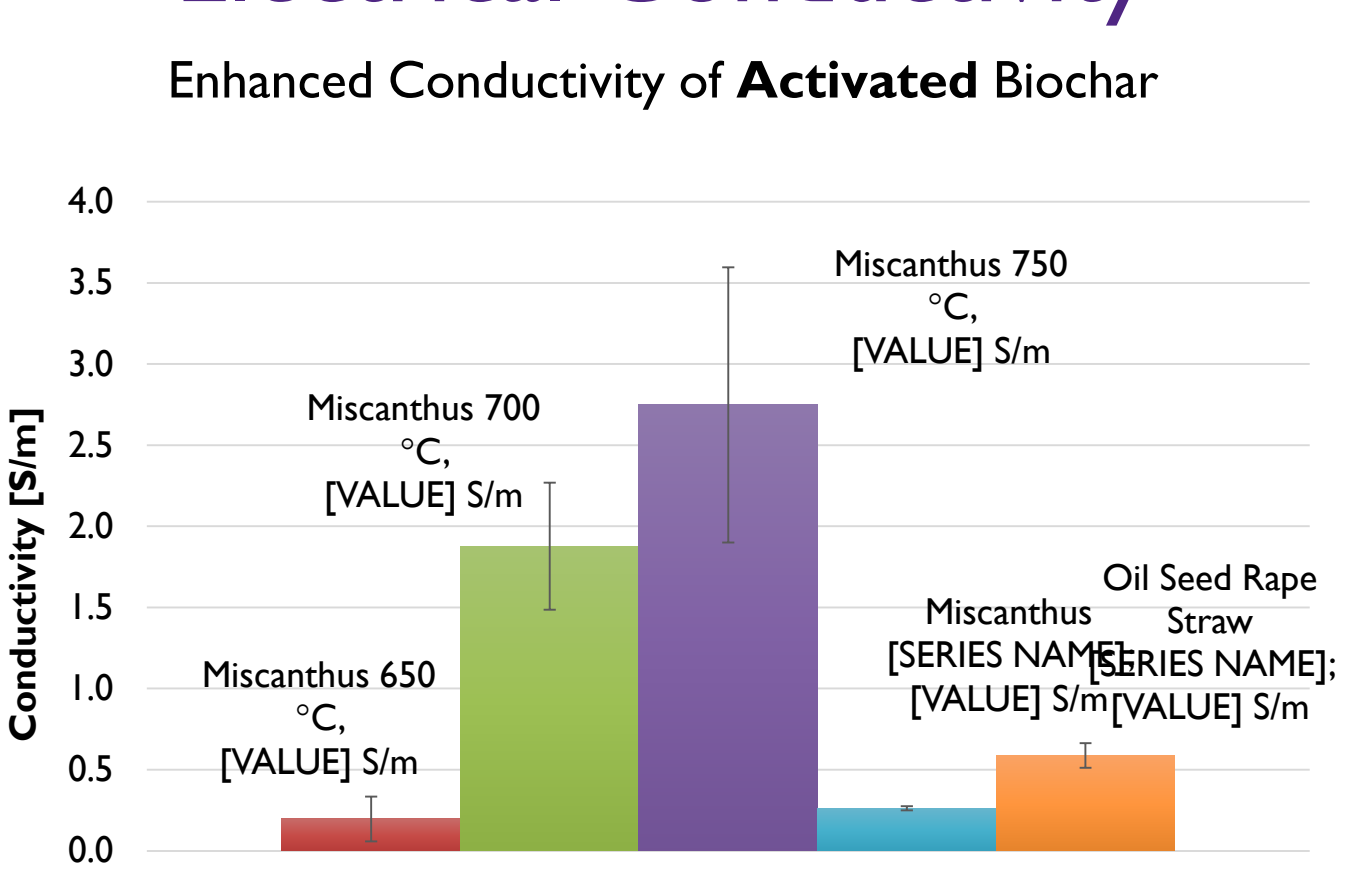
BIOCHAR PRODUCTION: Electrical Conductivity

Biochar Conductivity and temperature effects



Our produced biochars showed very little conductivity!

BIOCHAR PRODUCTION: Electrical Conductivity



Activated biochars showed much higher conductivity!!

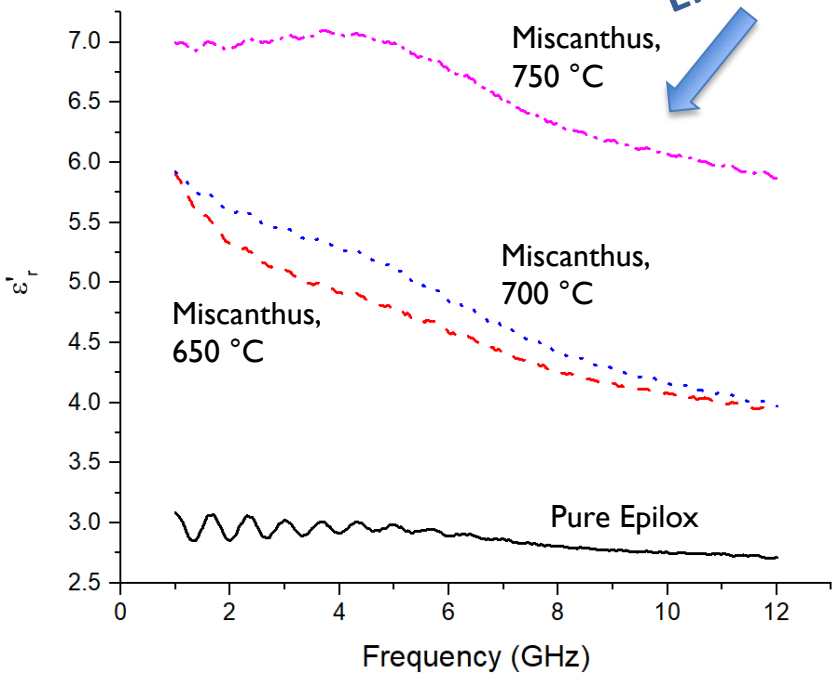
EPOXY COMPOSITES: Electrical Properties

- **Conductive biochar (activated)** was added to Epoxy Resin (Epilox) at **20% by weight**
- Electrical permittivity and conductivity of composites were measured
- Testing to determine the electromagnetic shielding effectiveness

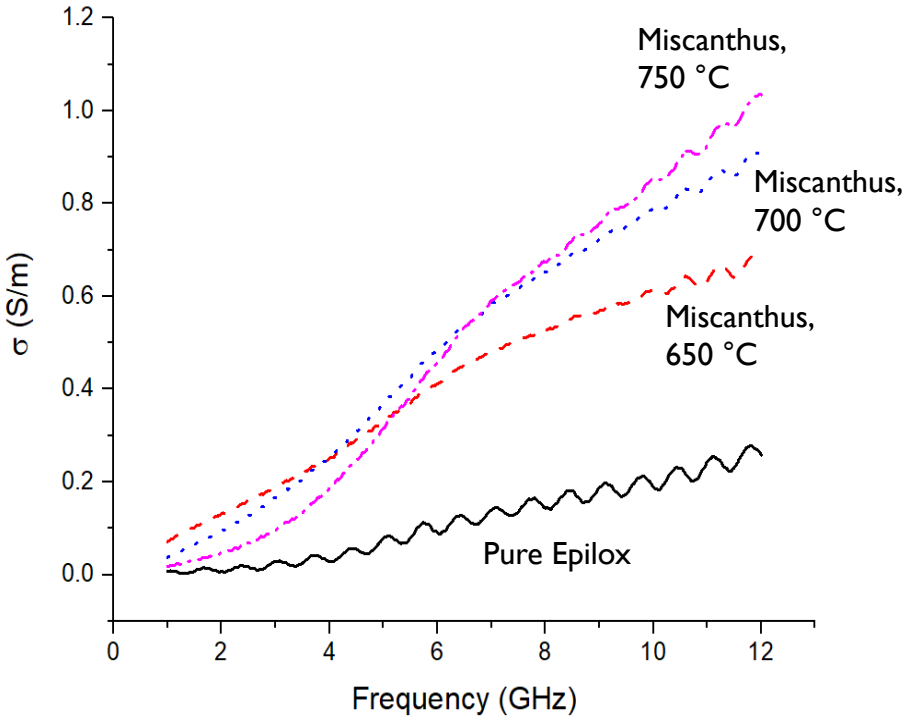


EPOXY COMPOSITES: Electrical Properties

Real part of **permittivity**



Conductivity



…about ½ of that achieved with 5% CNT

CHARCRETE: Production

- **Portland Cement**
  - 3:1 Sand Ratio
  - 3:1 Aggregate Ratio
- **DDG Biochar/ activated carbon added in place of sand or aggregate**
- Four different moulds (in cm)
  - 30 x 30 x 5 -Thermal Testing
  - 10 x 10 x 2 -Thermal Testing
  - 10 cm diameter x 2 -Acoustic Testing
  - 5 x 5 x 5 -Mechanical Testing
- Cured for minimum 28 days



CHARCRETE: Production

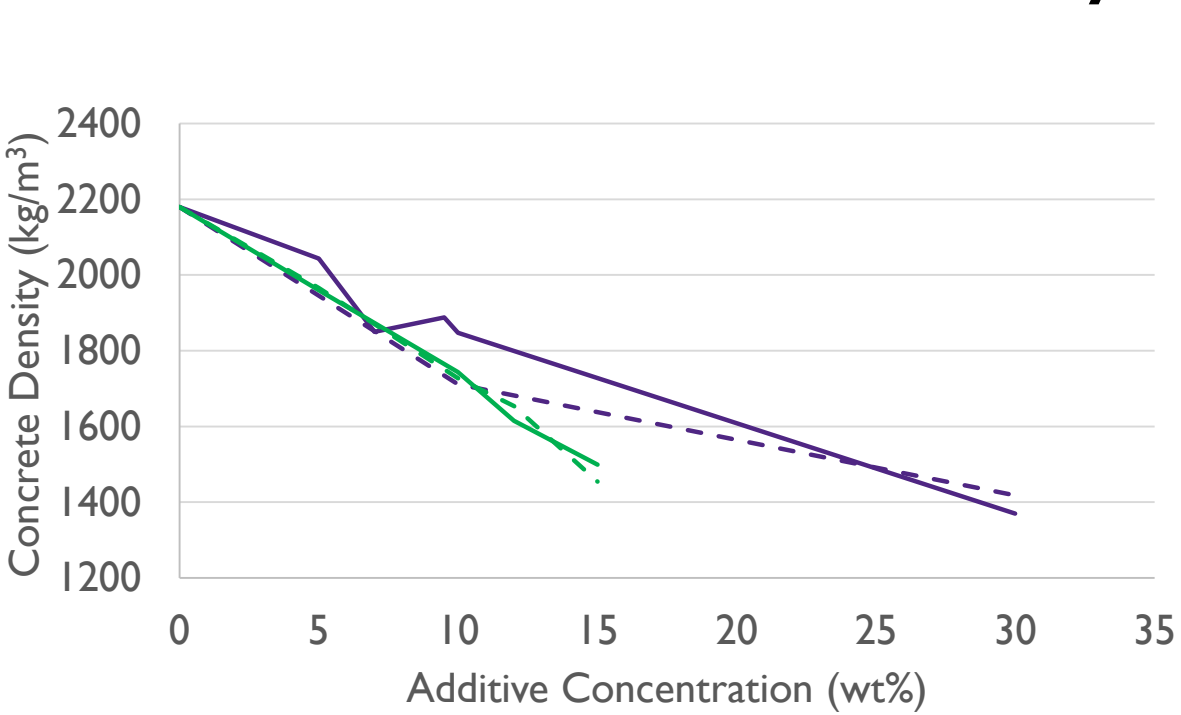
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CHARCRETE: Results

Biochar decreases density of concrete!

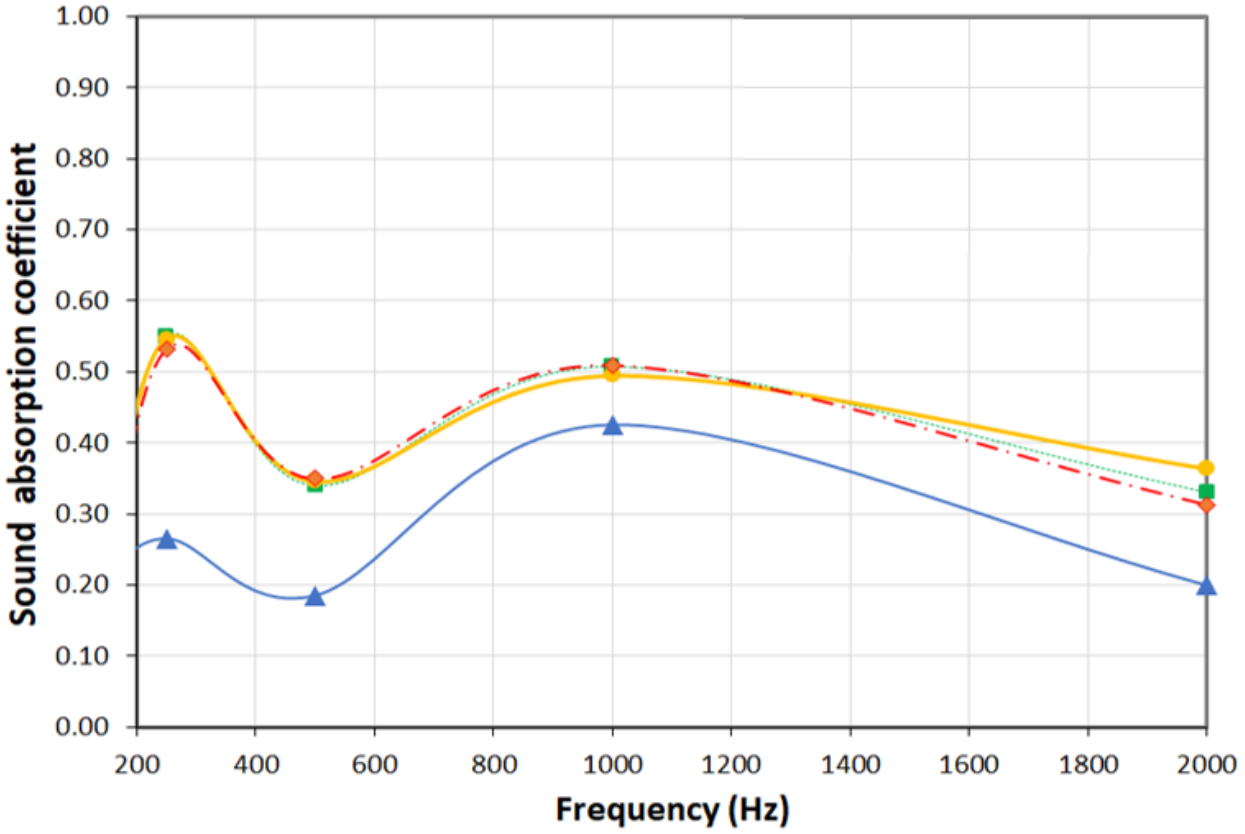


Legend		
	Material	Replacing
———	Biochar	Sand
- - -	Biochar	Aggregate
———	Activated Carbon	Sand
- - -	Activated Carbon	Aggregate

BIOCHAR DENSITY	ACTIVATED CARBON DENSITY (kg/m³)
500 kg/m³	460-530 kg/m³

CHARCRETE: Results

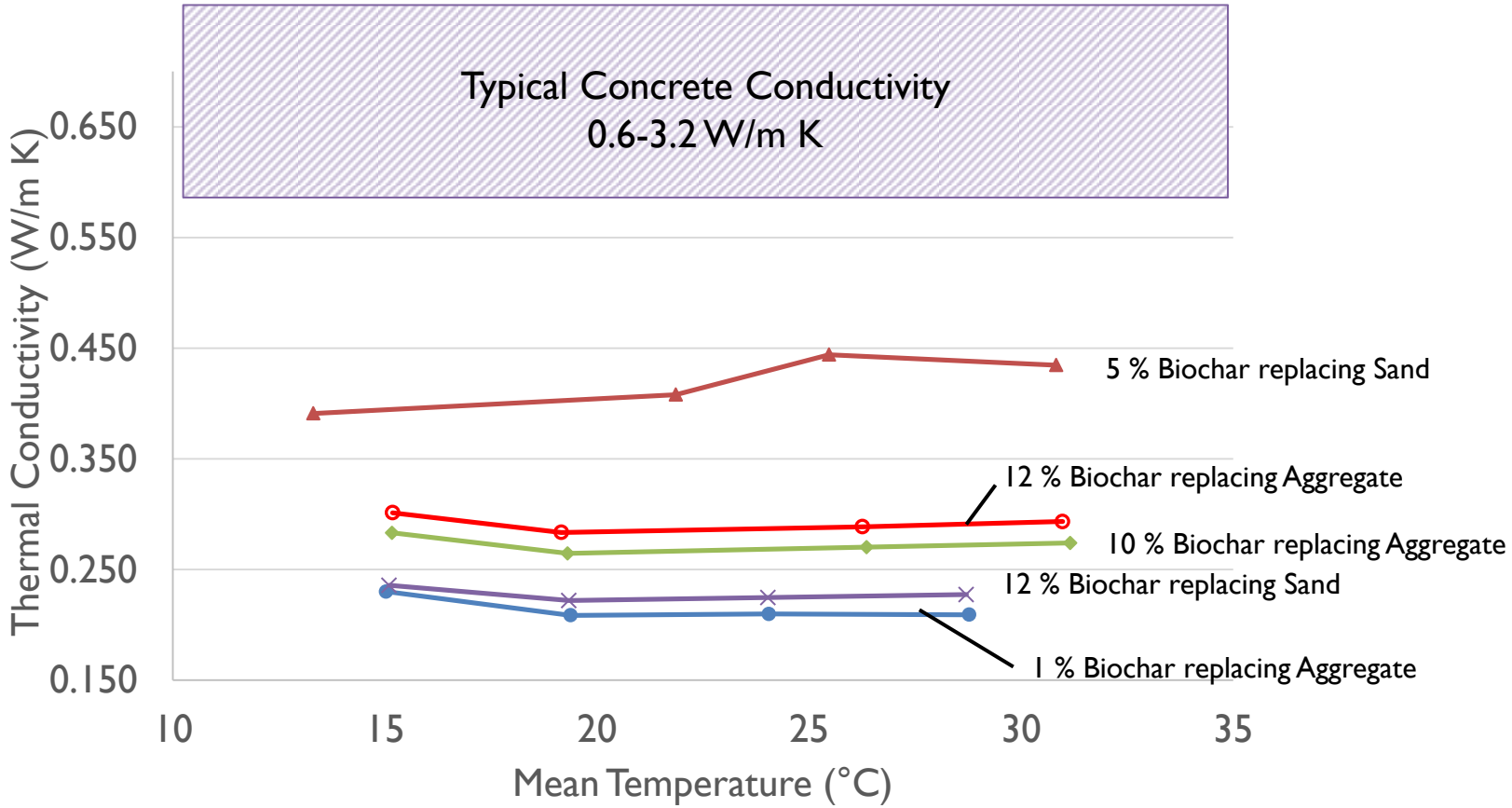
Biochar improves sound absorption of concrete!



Legend		
	Material	Replacing
	Standard	-
	7.3% Activated Carbon	Aggregate
	10 % Biochar	Sand
	15 % Biochar	Aggregate

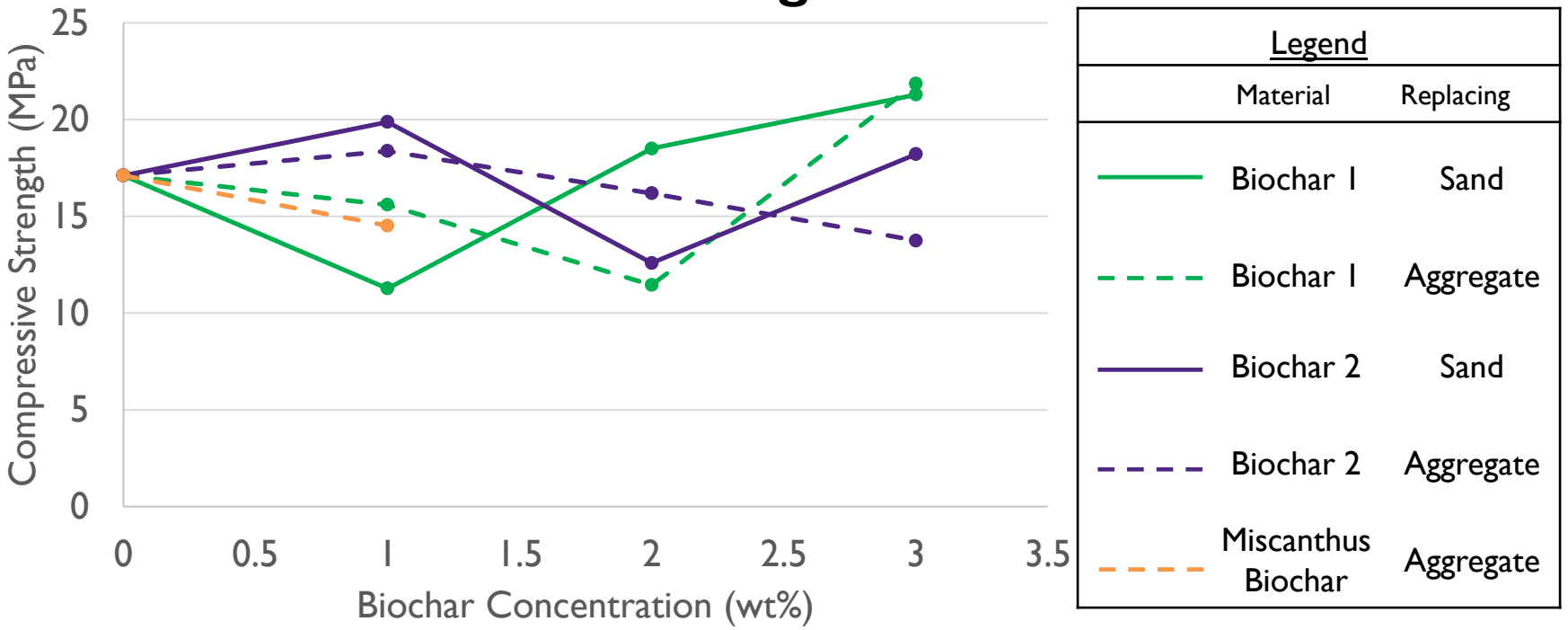
CHARCRETE: Results

Biochar improves thermal insulation of concrete!



CHARCRETE: Results

Small additions of biochar do not compromise mechanical strength!



Limited sample size and testing range

CONCLUSIONS:

- Biochar produced using different feedstocks and process conditions
- Characterization and Activation
- Utilization of Biochar in Epoxy and Cement Composites
- The experimental results show promising properties of biochar application in building materials

ACKNOWLEDGMENTS

- Special thanks to:
  - Alberto Tagliaferro, Mauro Giorcelli, Pravin Jagdale and Patricia Savi at the Politecnico di Torino
  - Natural Sciences and Engineering Research Council of Canada
  - Ontario Research Fund
  - Western SGPS and the Queen Elizabeth II Graduate Scholarship







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FEEDSTOCKS

Feedstock	Carbon (%)	Oxygen (%)	Hydrogen (%)	Nitrogen (%)	Ash (%)
Miscanthus	44.7	47.0	6.0	0.2	2.2
Wood Chips	43.2	39.0	5.7	0.1	12.0
DDG	43.8	39.2	6.9	4.9	5.2

Prominent Inorganic Material

Miscanthus	
Metal	mg/kg
Ca	10 315
K	4112
Mg	1263

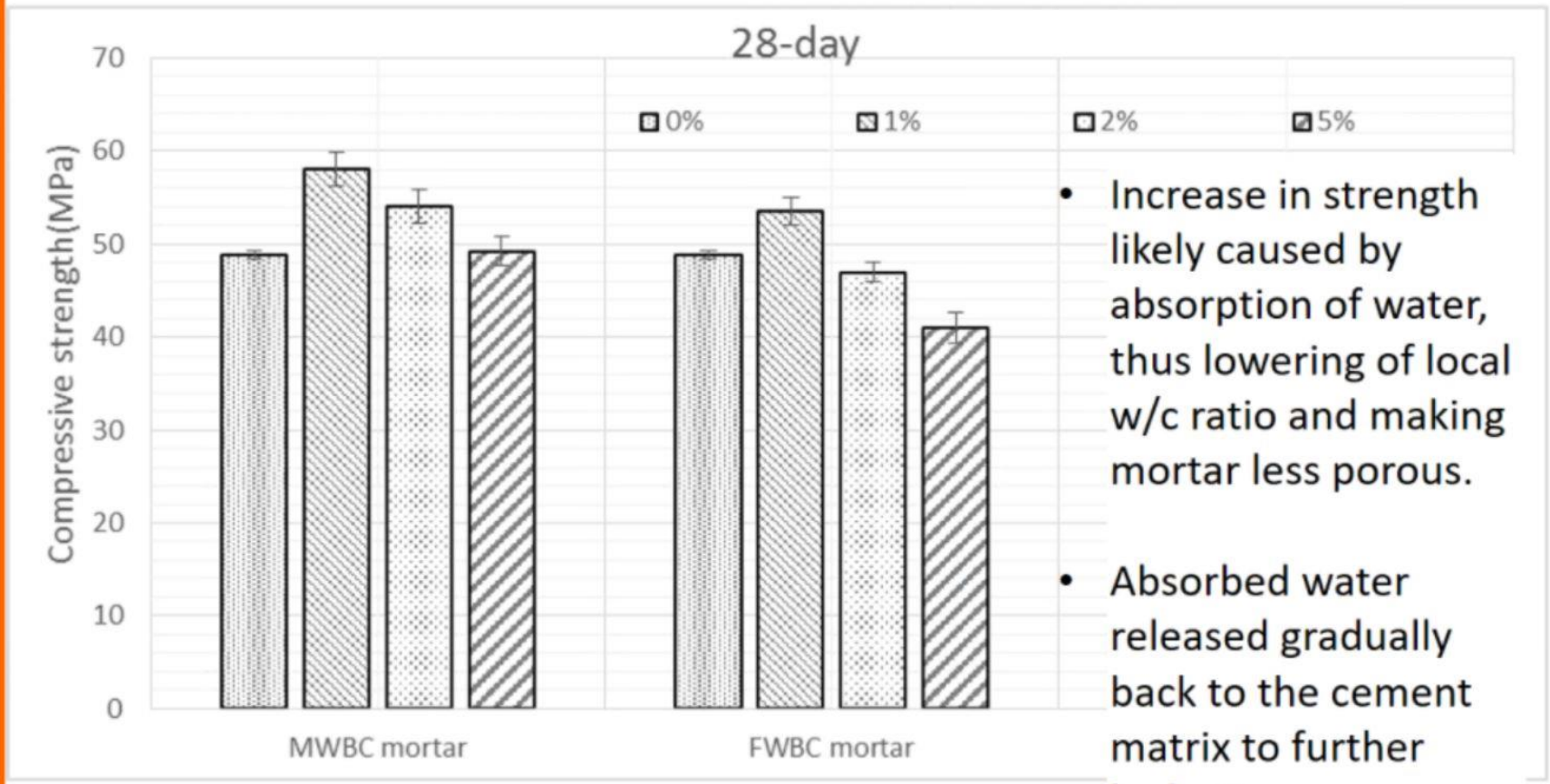
Wood Chips	
Metal	mg/kg
Ca	12 791
Fe	2010
Insolubles	92 316

DDG	
Metal	mg/kg
K	8716
P	8405
S	7287

RESULTS

28-day Compressive Strength

MWBC: mixed wood biochar **FWBC: food waste biochar**



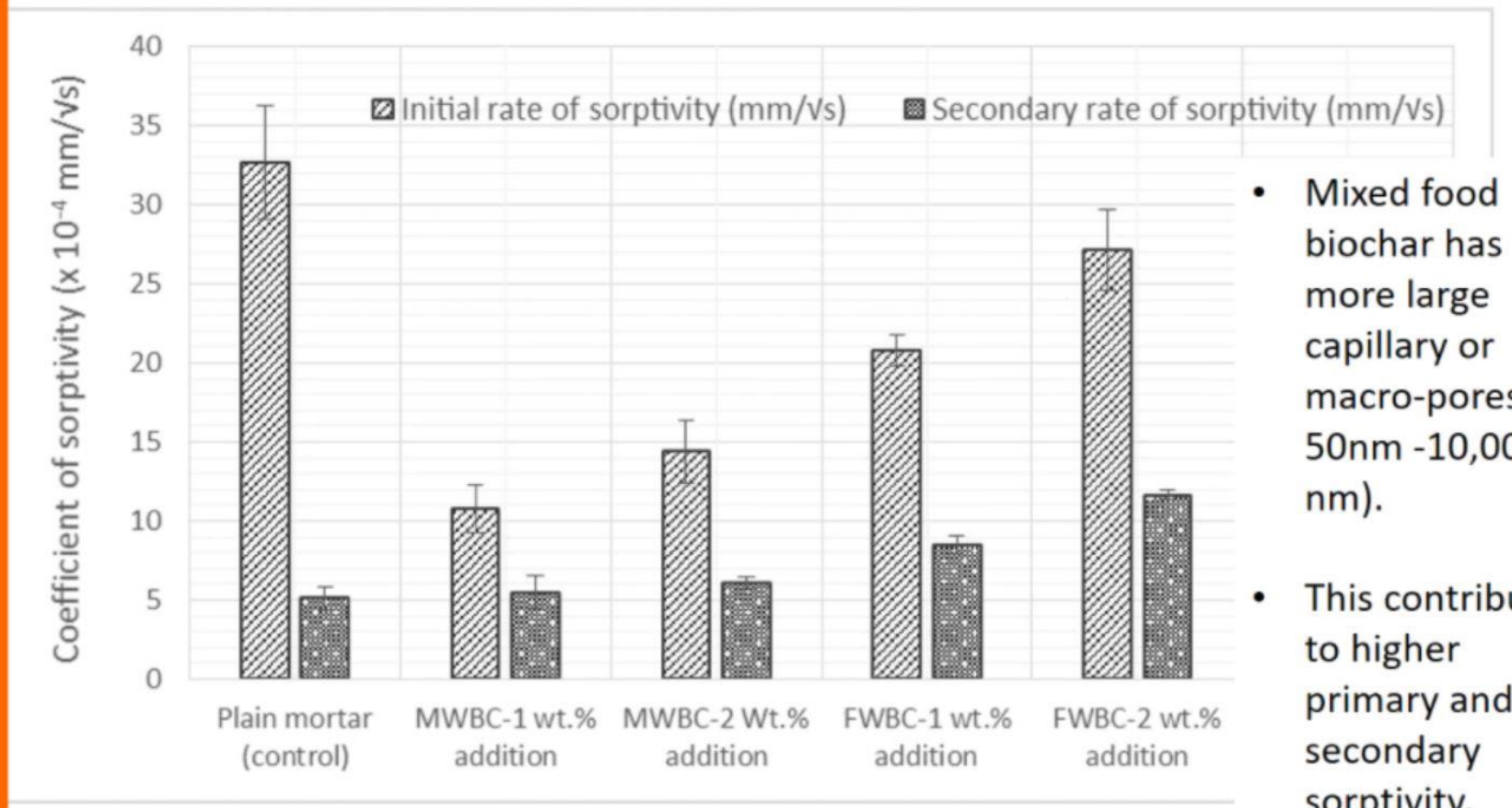
- Increase in strength likely caused by absorption of water, thus lowering of local w/c ratio and making mortar less porous.
- Absorbed water released gradually back to the cement matrix to further hydration.

HarnWei KUA, Souradeep Gupta, Hui Jun Koh, May, Shuan Koh, Kenny Ong (2017)

RESULTS

Water Sorptivity

MWBC: mixed wood biochar **FWBC: food waste biochar**



- Mixed food biochar has more large capillary or macro-pores (50nm -10,000 nm).
- This contributes to higher primary and secondary sorptivity.

HarnWei KUA, Souradeep Gupta, Hui Jun Koh, May, Shuan Koh, Kenny Ong (2017)