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Biochar from microwave pyrolysis of selected feedstocks

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Biochar from Microwave Pyrolysis of Selected Feedstocks

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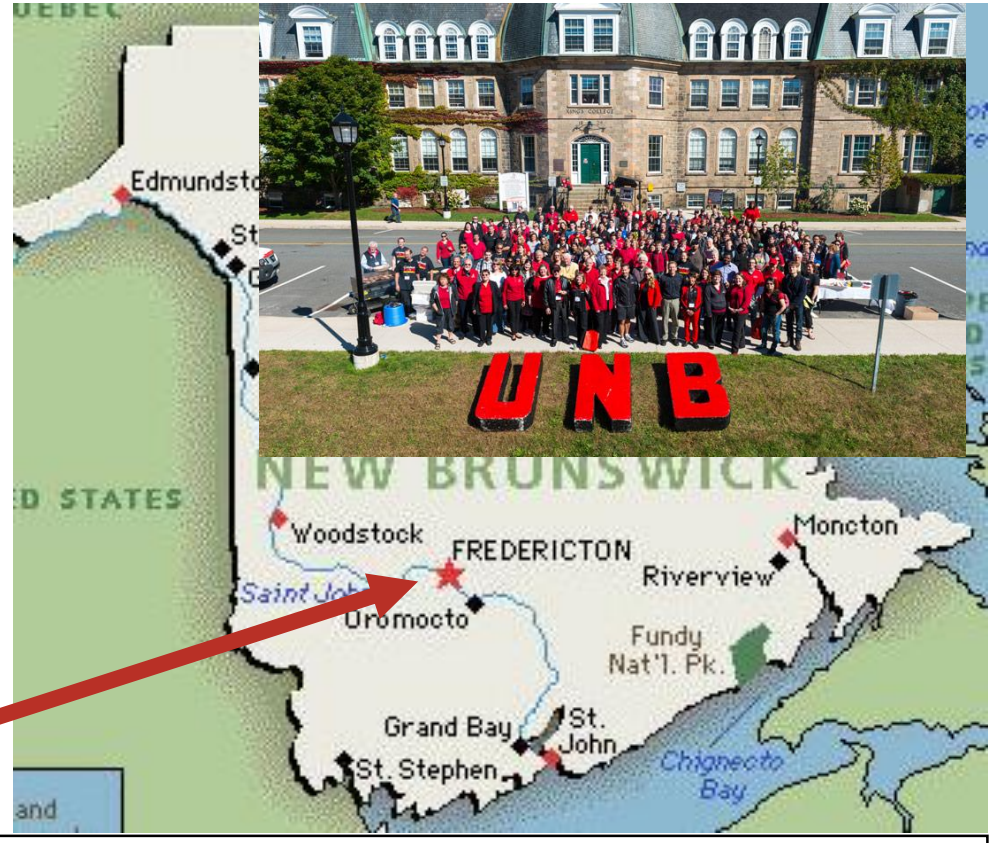
Biochar: Production, Characterization and Applications

An ECI Conference

August 20-25, 2017, Alba, Italy

Where is UNB located?

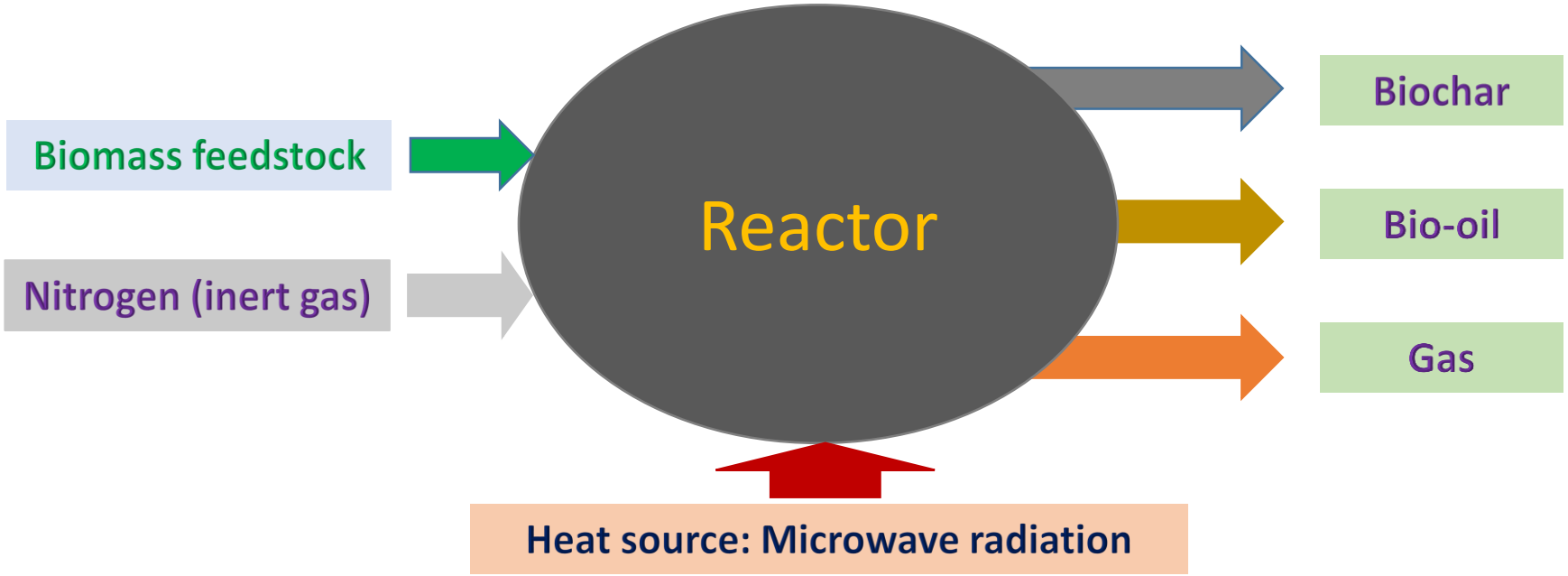


Population: 58,000; Area: 133 km^2

Summary of Microwave Pyrolysis Work Conducted at Bioenergy and Bioproducts Research Lab (BBRL), Mechanical Engineering, UNB, Canada

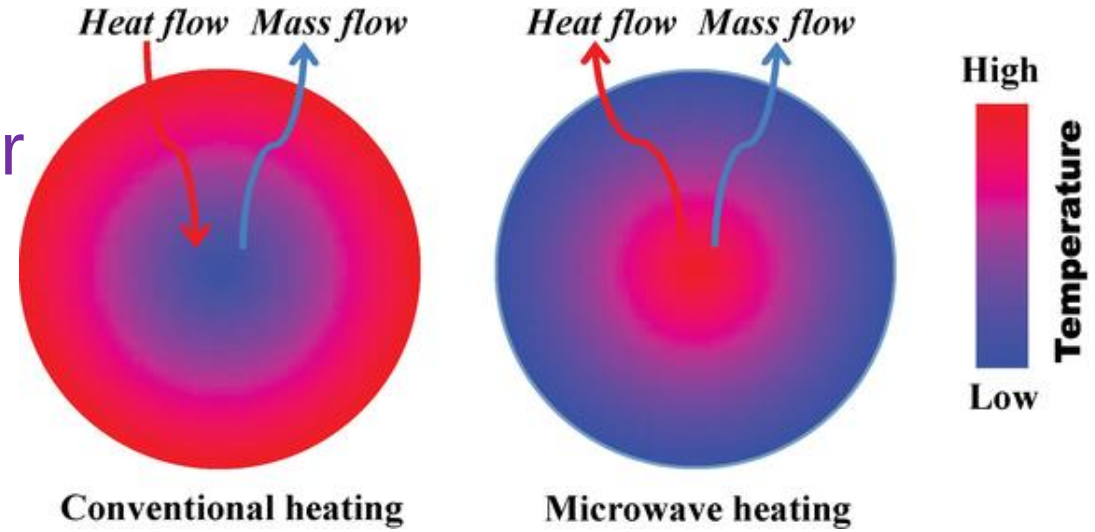
What is microwave pyrolysis?

- Thermal degradation of biomass in the absence of oxygen
- Results in **solid biochar, liquid bio-oil, and gas**
- Uses microwave heating to accomplish pyrolysis



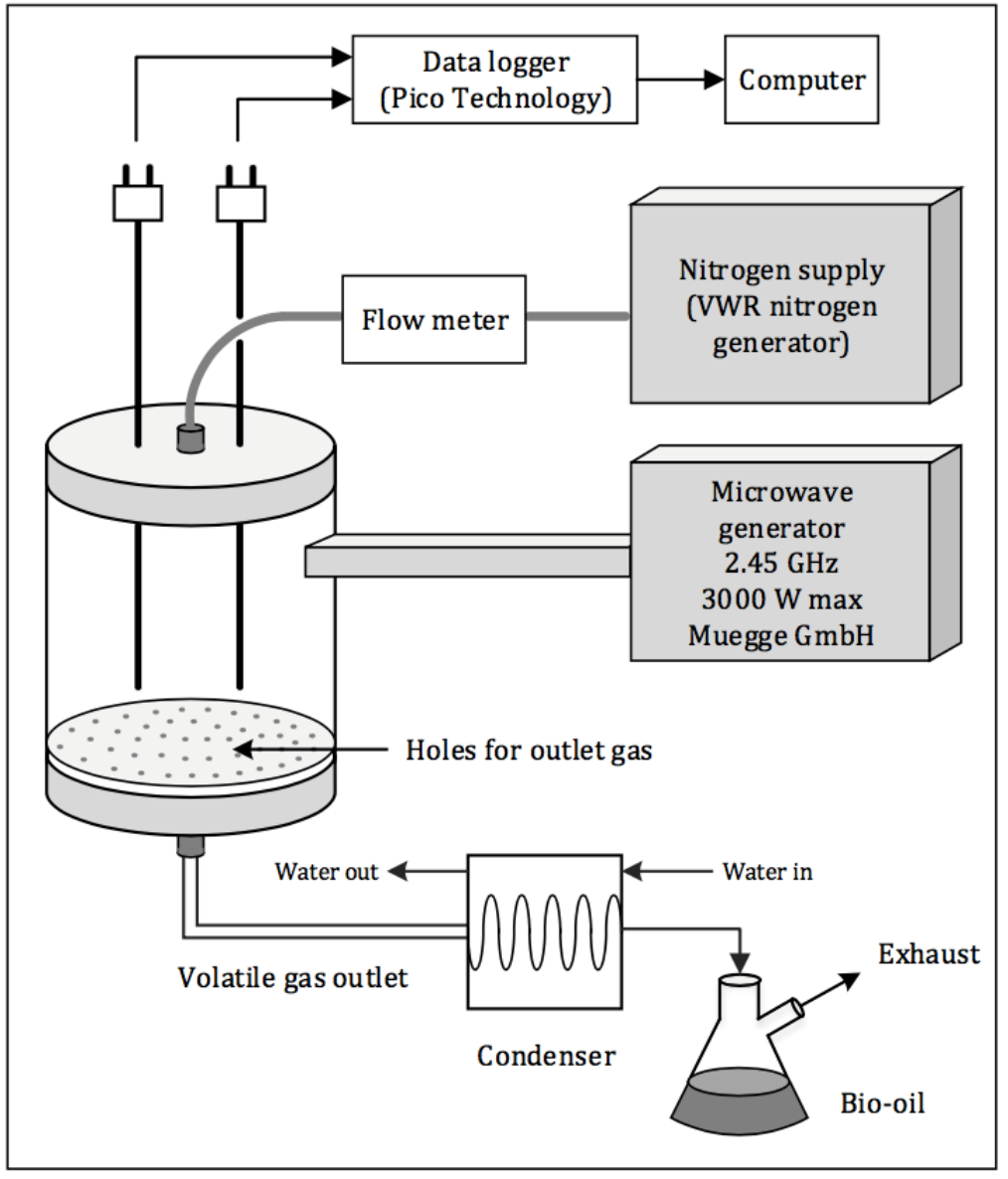
Advantages to using microwave-assisted pyrolysis (MAP)

- More controllable
- Higher energy efficiency
- Energy transfer rather than heat transfer
- Non-contact and rapid heating
- Quick startup and shutdown
- Fast heating rate
- Volumetric heating



Microwave pyrolysis system at BBRL, UNB

Process layout describing MAP



Work 1: Corn stalk briquettes (CSB)

- Preprocessing
  - ✓Corn stalk chopped, shredded, dried
  - ✓Hydraulic briquetting machine
  - ✓Constant Pressure:100 MPa; Holding time: 5 s
  - ✓Briquette dimension: diameter of 0.04 m, length of 0.02 m, and weight around 30 g
- Microwave pyrolysis using briquettes

Salema A A., M.T. Afzal, and L. Bennamoun. 2017. Pyrolysis of corn stalk biomass briquettes in a scaled-up microwave technology. Bioresource Technology 233: 353-362.

Proximate and ultimate analysis of corn stalk

Proximate analysis	Weight %
Moisture content	6.8
Volatile matter	76.2
Fixed carbon	17.0

Ultimate analysis	Weight %
Carbon	46.67
Hydrogen	6.01
Nitrogen	0.02
Sulphur	0.02
Oxygen	47.28

Salema A A., M.T. Afzal, and L. Bennamoun. 2017. Pyrolysis of corn stalk biomass briquettes in a scaled-up microwave technology. Bioresource Technology 233: 353-362.

Experimental procedure

- Microwave power input: 900 W, 1200 W, and 1500 W
- Biomass loading: 0.5 kg and 1 kg
- 75 g of biochar used as a microwave absorber (fixed amount)
- Duration: 1 hour

Product yield from CSB pyrolysis

Product yield	Weight %
Bio-oil	13.4 – 19.6
Biochar	30.9 – 41.1
Gas	41.6 – 54.0

- Most briquettes retained their original shape after pyrolysis

Salema A A., M.T. Afzal, and L. Bennamoun. 2017. Pyrolysis of corn stalk biomass briquettes in a scaled-up microwave technology. Bioresource Technology 233: 353-362.

Elemental analysis of CSB biochar

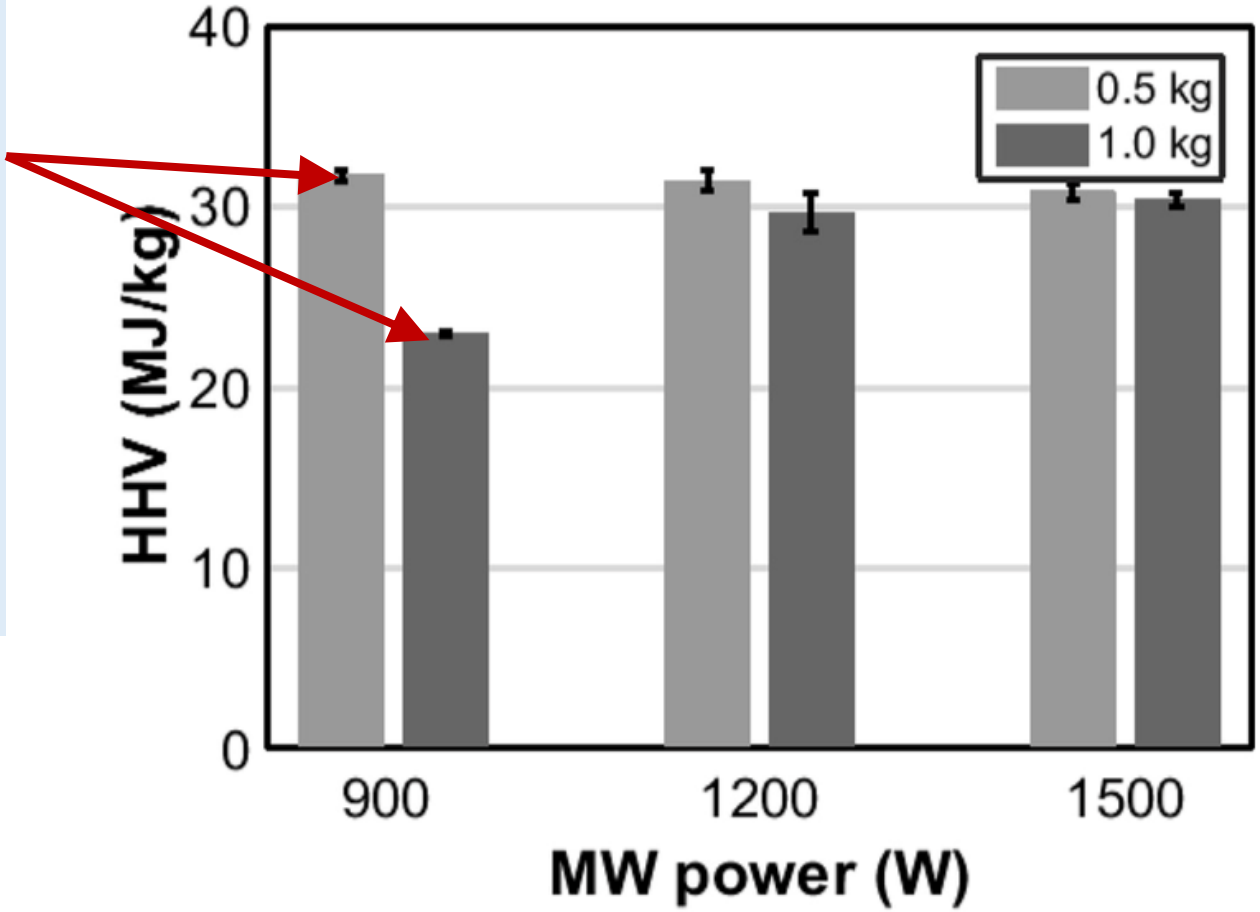
Biochar	Weight %
Carbon	63.05 – 74.33 (raw 47%)
Hydrogen	1.49 – 2.91
Nitrogen	0.14 – 0.48
Oxygen	23.45 – 35.31

Salema A A., M.T. Afzal, and L. Bennamoun. 2017. Pyrolysis of corn stalk biomass briquettes in a scaled-up microwave technology. Bioresource Technology 233: 353-362.

Higher heating value (HHV) of biochar

Significant difference in HHV at Low power level and high loading condition

Min~max: 23~32MJ/kg



Work 2: MAP of spruce, maple and switchgrass

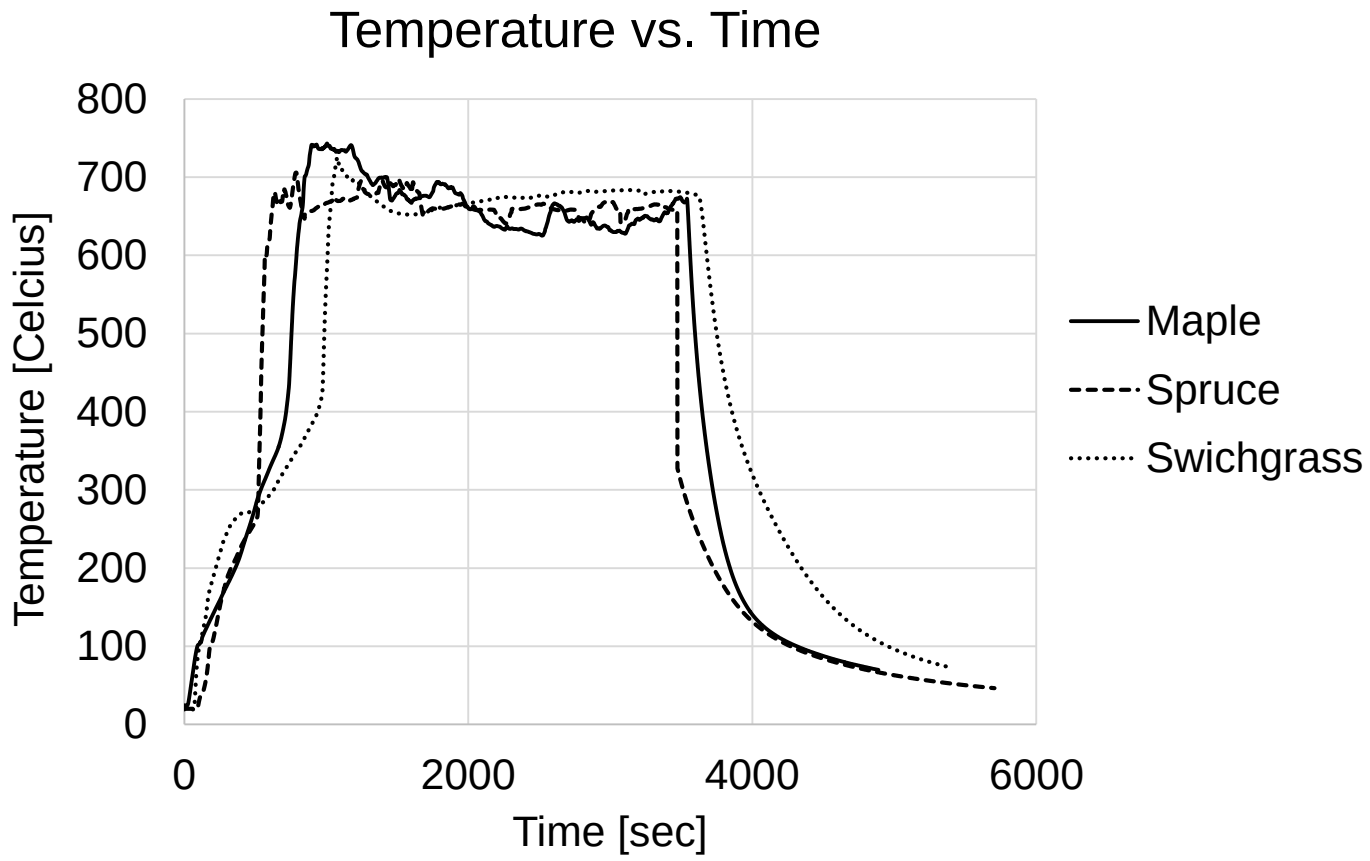
Maple Spruce Switchgrass

Bowlby, L., G. Saha., and M. T. Afzal. 2017. Synthesis of high-surface area biochar particles using microwave pyrolysis technique. CSBE17-164; CSBE/SCGAB AGM and Technical Conference, Winnipeg, MB. August 6-10.

Experimental conditions

- Microwave power input: 500 W
- Biomass loading: 100 g
- 10 g of biochar used as a microwave absorber
- Time: 1 hour

Reaction temperature



- Reaction temperatures in the vicinity of 700˚C, maintained for the duration of the conversion process

Bowlby, L., G. Saha., and M. T. Afzal. 2017. Synthesis of high-surface area biochar particles using microwave pyrolysis technique. CSBE17-164; CSBE/SCGAB AGM and Technical Conference, Winnipeg, MB. August 6-10.

Reaction temperature and biochar yield

Biochar Feedstock	Reaction Temperature (˚C)	Avg. Biochar Yield (wt.%)
Spruce	670	22.2
Maple	680	22.0
Switchgrass	690	24.4

Bowlby, L., G. Saha., and M. T. Afzal. 2017. Synthesis of high-surface area biochar particles using microwave pyrolysis technique. CSBE17-164; CSBE/SCGAB AGM and Technical Conference, Winnipeg, MB. August 6-10.

Elemental analysis of biochar

Biochar Feedstock	Carbon (wt.%)	Hydrogen (wt.%)	Nitrogen (wt.%)	Oxygen (wt.%)	Ash content (wt.%)
Spruce	80.1	2.90	0.03	16.0	0.98
Maple	79.5	3.37	0.04	15.5	1.56
Switchgrass	69.6	2.36	0.05	18.5	9.50

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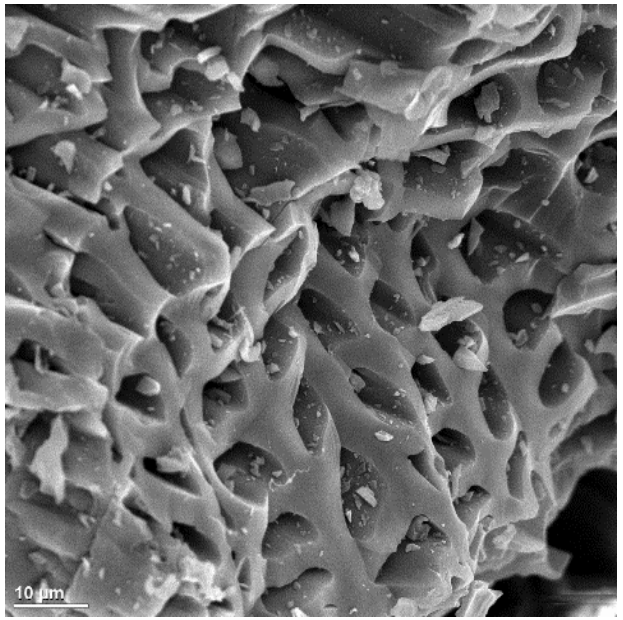
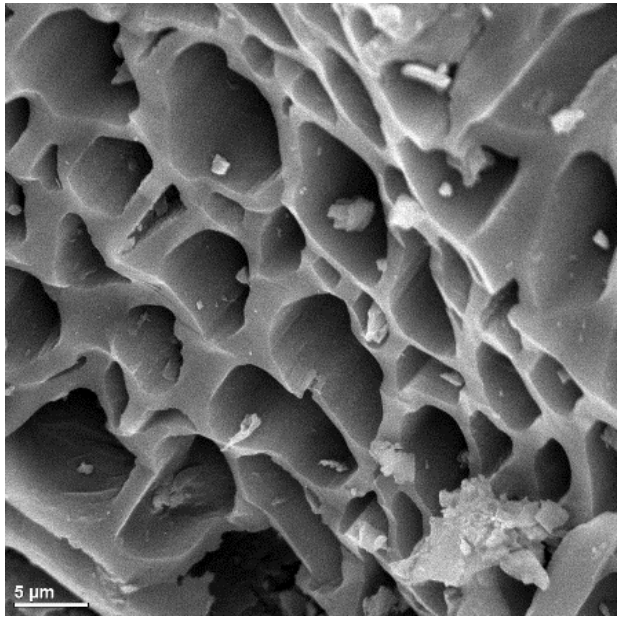
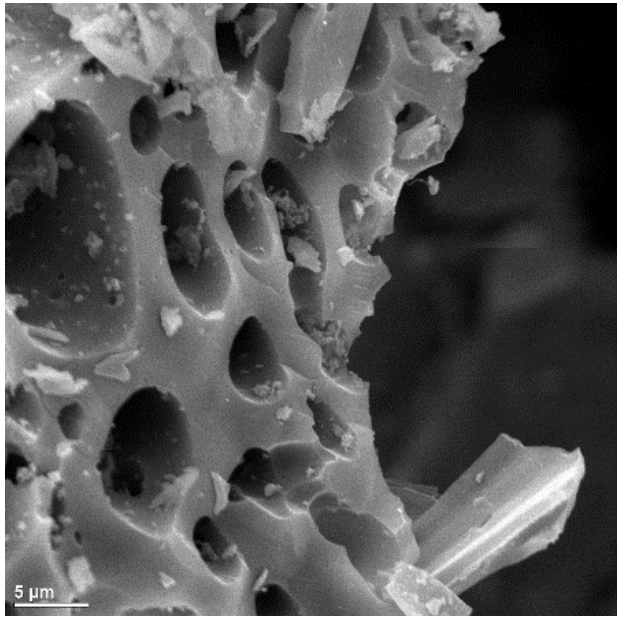
SEM analysis of biochar



Spruce



Maple



Switchgrass

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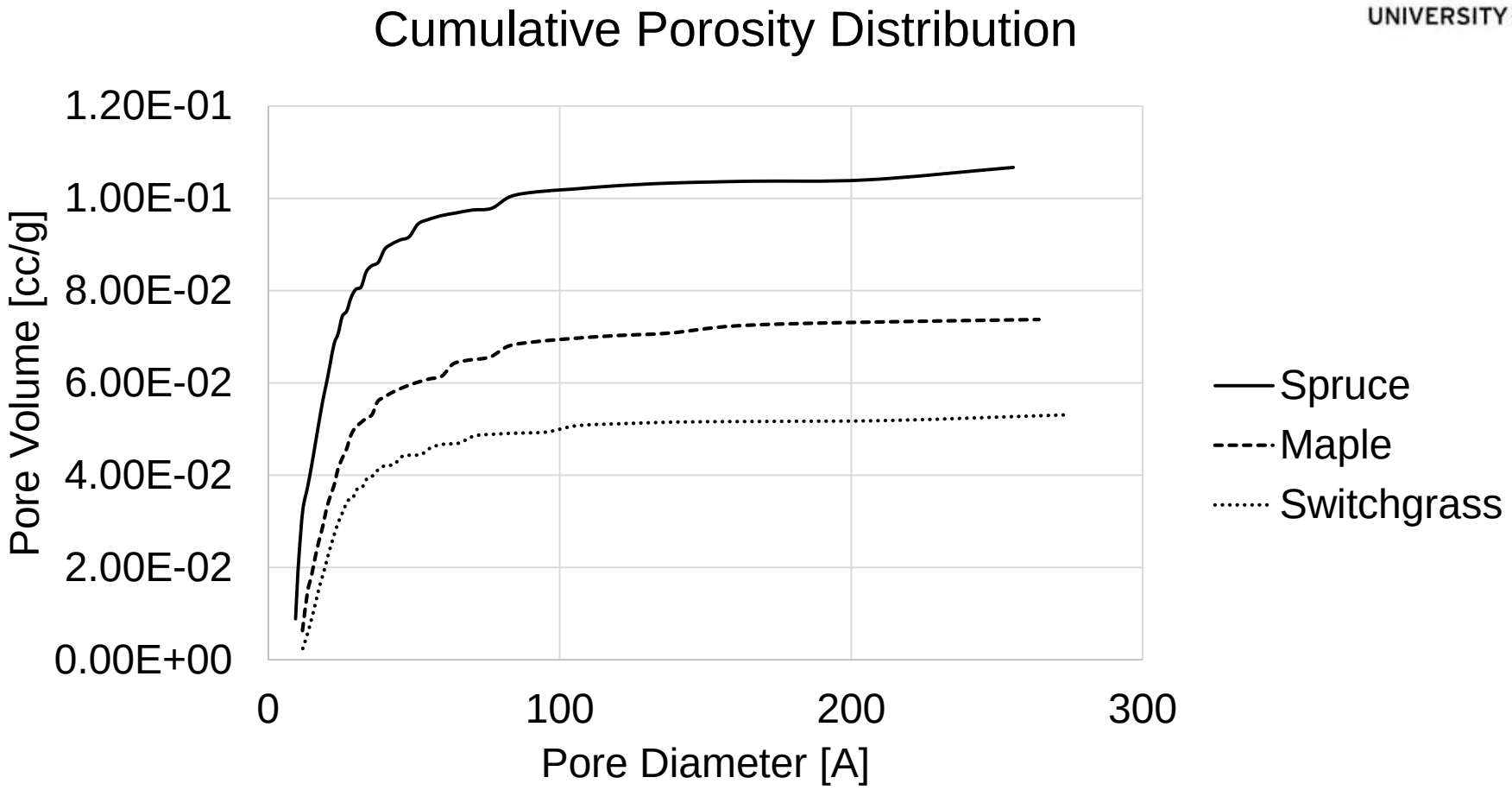
BET analysis

Biochar feedstock	Pore volume ($x10^{-2}$ cc/g)	BET surface area (m^2/g)
Spruce	12.12	203.9
Maple	7.712	155.7
Switchgrass	5.394	116.5

Bowlby, L., G. Saha., and M. T. Afzal. 2017. Synthesis of high-surface area biochar particles using microwave pyrolysis technique. CSBE17-164; CSBE/SCGAB AGM and Technical Conference, Winnipeg, MB. August 6-10.

Porosity distribution



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Work 3: MAP of wood pellets

Wood pellets

Microwave Pyrolysis

Biochar

Wood pellets

- Eastern Embers Premium Wood Pellets used as feedstock
- 100% softwood
- Manufactured from spruce sawdust

Experimental procedure

- Microwave power input: 2000 W, 2500 W, and 3000 W
- Biomass loading: 1.5 kg, 2.5 kg, and 3.5 kg
- 10% biochar used as a microwave absorber
- Time: 1 hour

Product yield distribution

Test conditions	Biochar (%)	Bio-oil (%)	Gas (%)
2500 W, 1.5 kg	26.03	44.33	29.64
2500 W, 2.5 kg	27.56	40.25	32.18
2500 W, 3.5 kg	28.26	38.57	33.17
2000 W, 2.5 kg	32.36	36.54	31.10
2500 W, 2.5 kg	28.55	41.25	30.20
3000 W, 2.5 kg	26.19	46.01	27.80

BC and gas yield Increasing biomass loading

Biooil yield Increasing power level

Elemental analysis

Weight %	Wood pellets	Biochar
Carbon	41.19	69.58 – 85.66
Hydrogen	5.01	2.44 – 3.28
Nitrogen	0.02	0.04 – 0.05
Ash	0.29	0.97 – 1.44
Oxygen	53.49	10.44 – 26.32

Bulk density of biochar and wood pellets

Test conditions	Bulk density (kg/m^3)
Raw wood pellets	650.1
2500 W, 1.5 kg	359.7
2500 W, 2.5 kg	373.1
2500 W, 3.5 kg	384.5
2000 W, 2.5 kg	386.7
2500 W, 2.5 kg	373.3
3000 W, 2.5 kg	371.2

increased with biomass loading

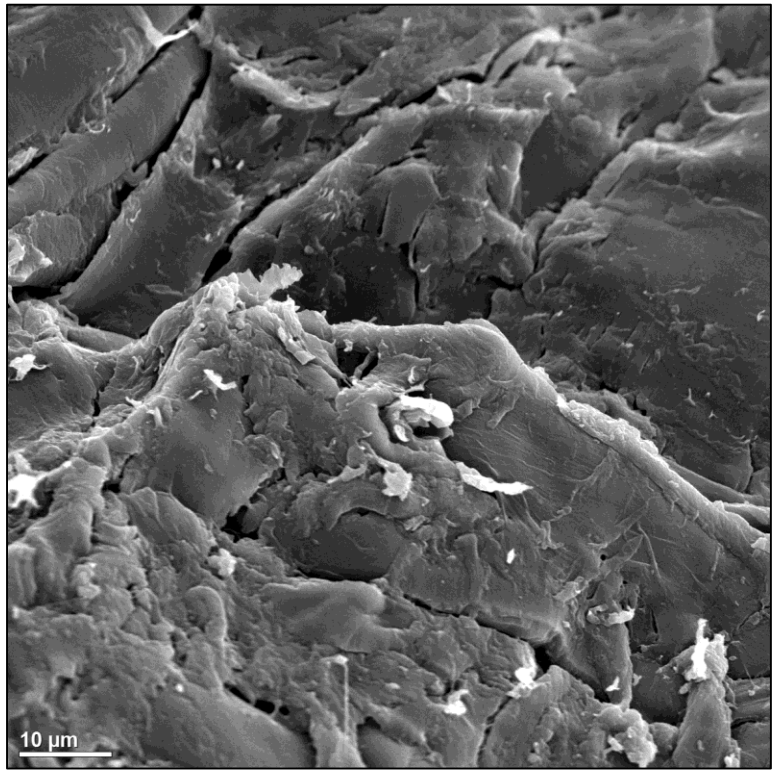
decreased with power level

Higher heating value (HHV) of biochar

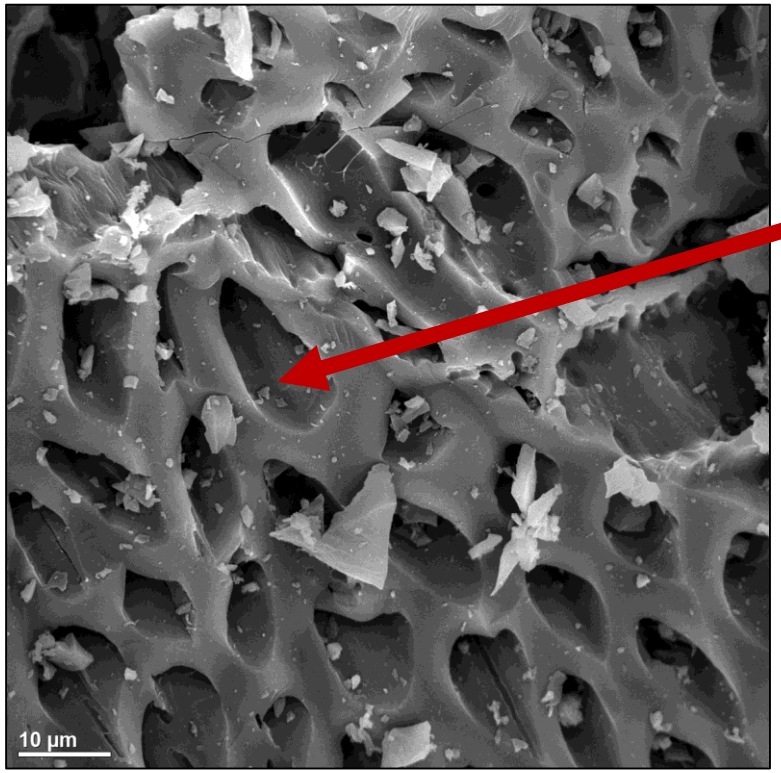
Test conditions	HHV of biochar (MJ/kg)
2500 W, 1.5 kg	30.8911
2500 W, 2.5 kg	31.2055
2500 W, 3.5 kg	31.8091
2000 W, 2.5 kg	30.5528
2500 W, 2.5 kg	31.8411
3000 W, 2.5 kg	31.5416

HHV increased by 54-60% compared that to raw wood pellets (raw 20 MJ/kg)

SEM analysis



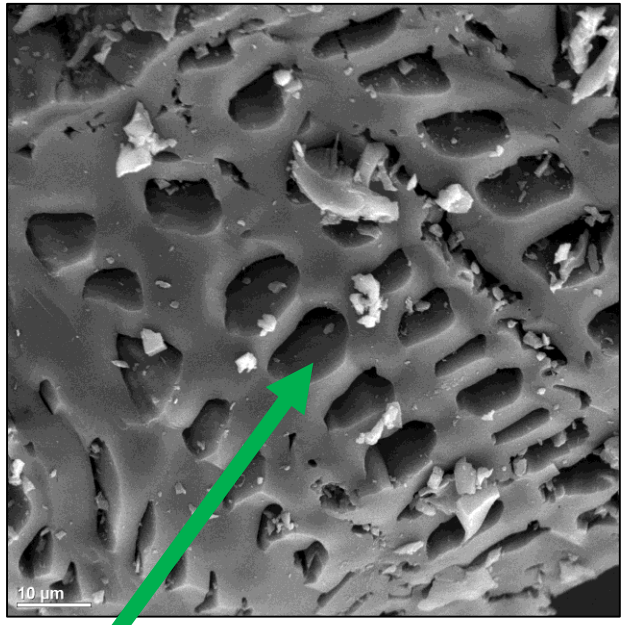
Wood pellets



Biochar

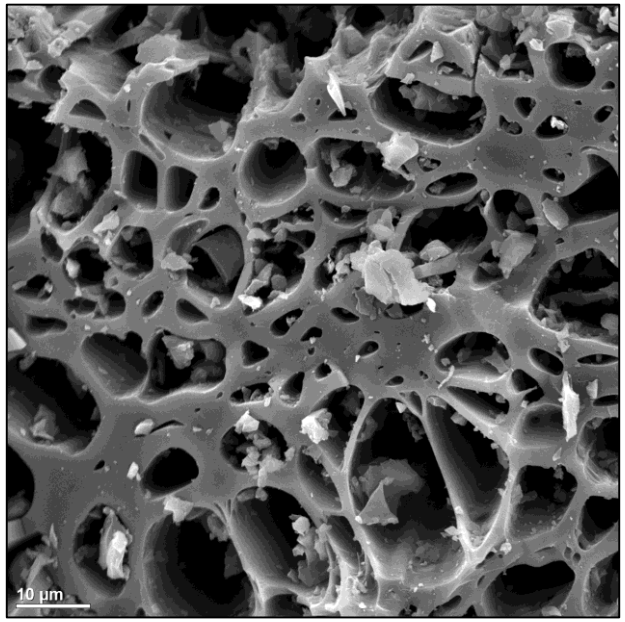
Porous structure

SEM analysis of biochar

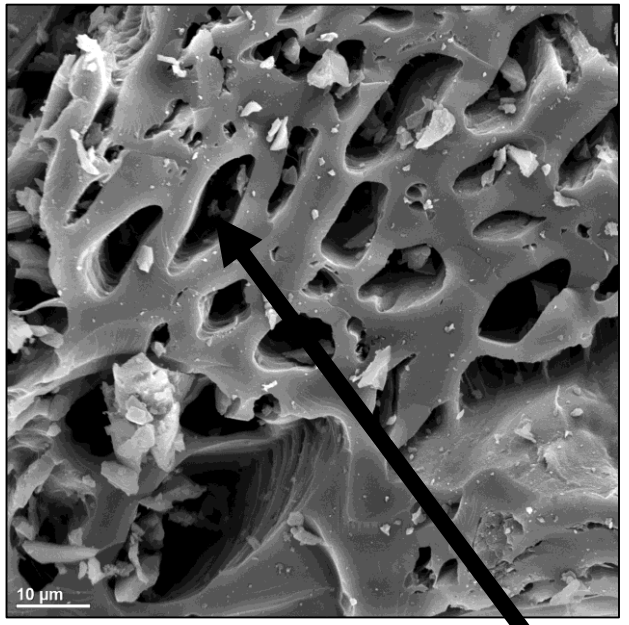


2000 W and 2.5 kg

Circular, uniformly distributed pores



2500 W and 2.5 kg



3000 W and 2.5 kg

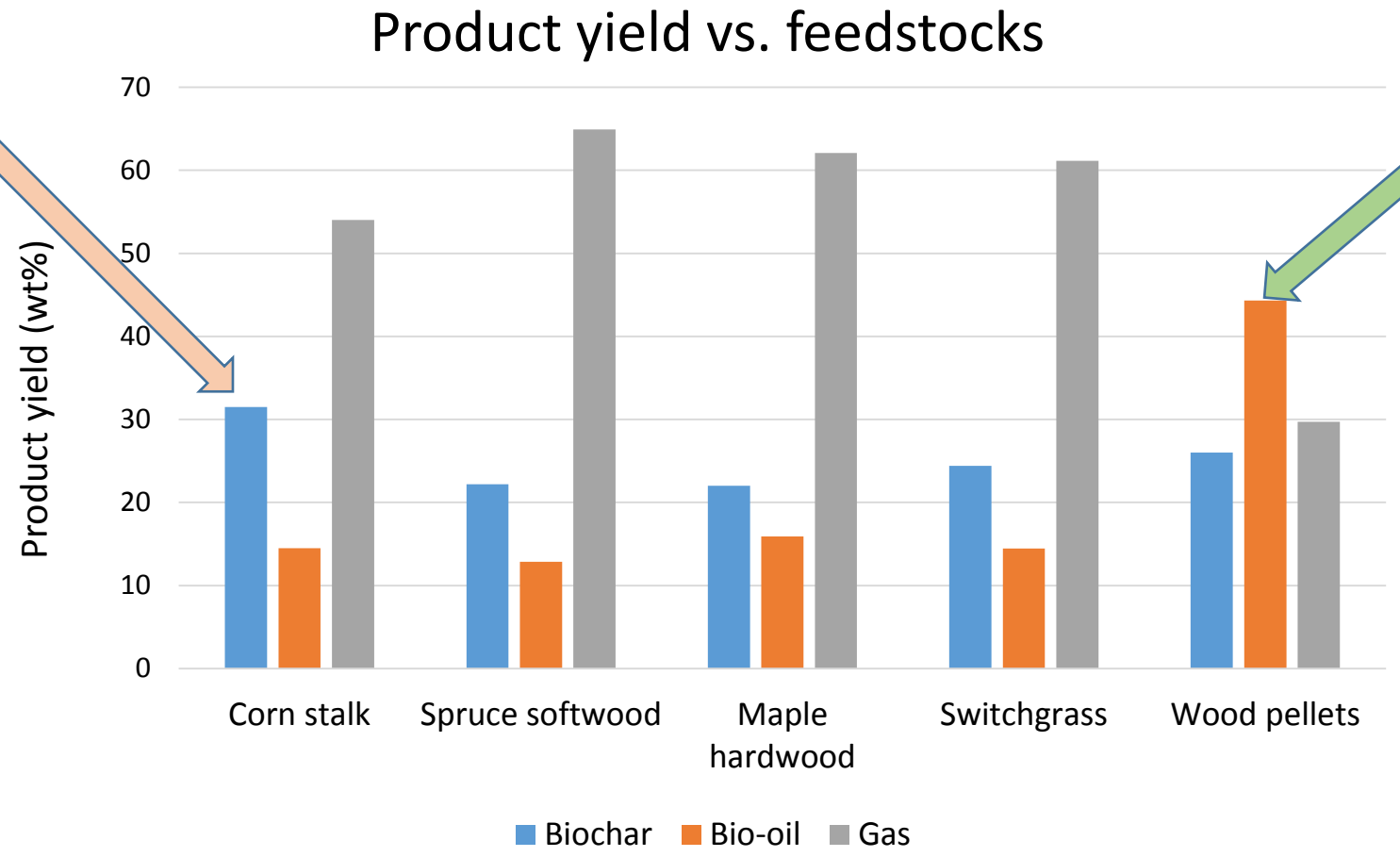
Narrow, less structured pores

BET analysis of biochar

Test conditions	Surface area (m^2/g)	Mean pore size (nm)
2500 W, 1.5 kg	180.12	0.69
2500 W, 2.5 kg	122.65	0.71
2500 W, 3.5 kg	129.35	0.71
2000 W, 2.5 kg	366.51	0.94
2500 W, 2.5 kg	108.91	0.74
3000 W, 2.5 kg	131.77	0.81

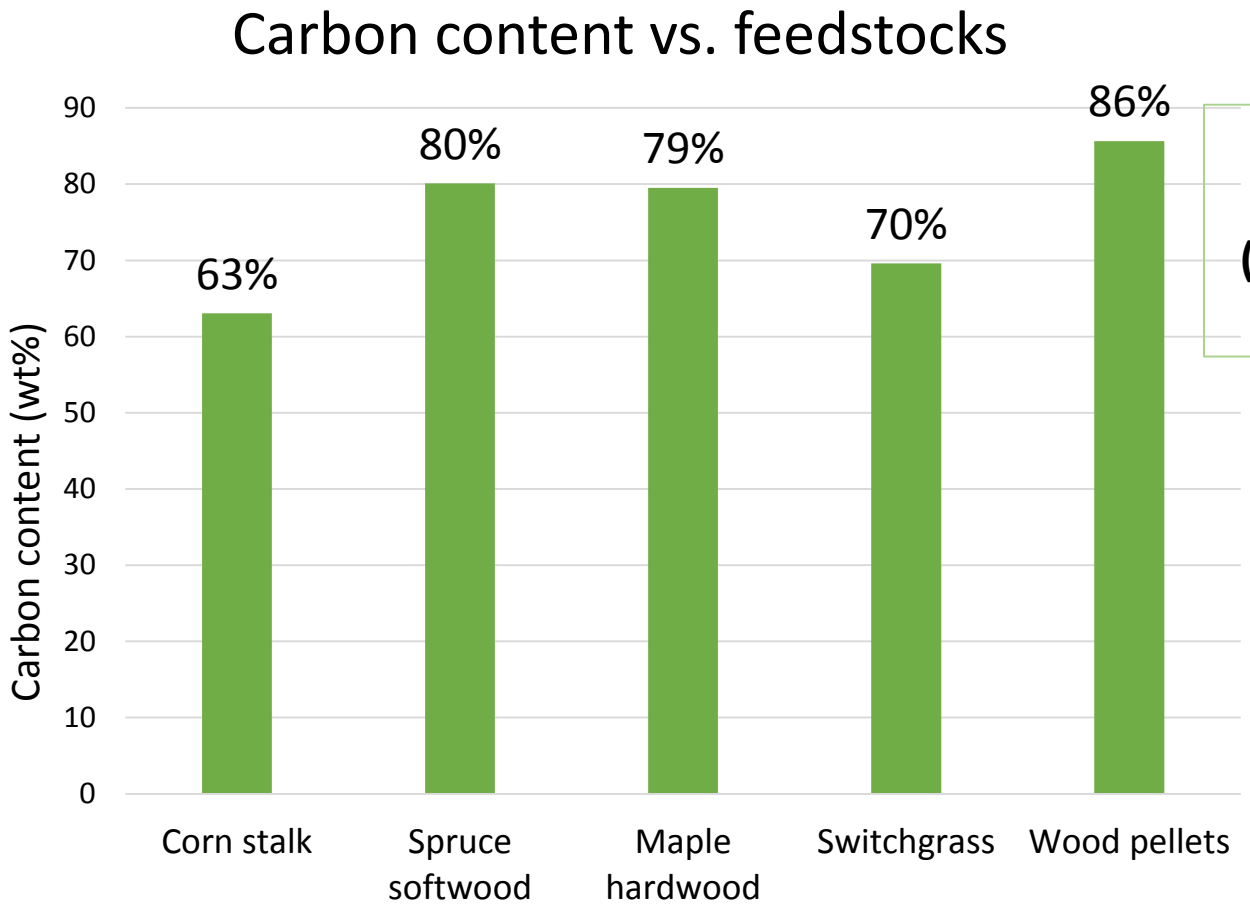
Summary of results

Corn stalk briquette
32% biochar
Highest biochar yield



Wood pellets
44% bio-oil
Highest bio-oil yield

Summary of results



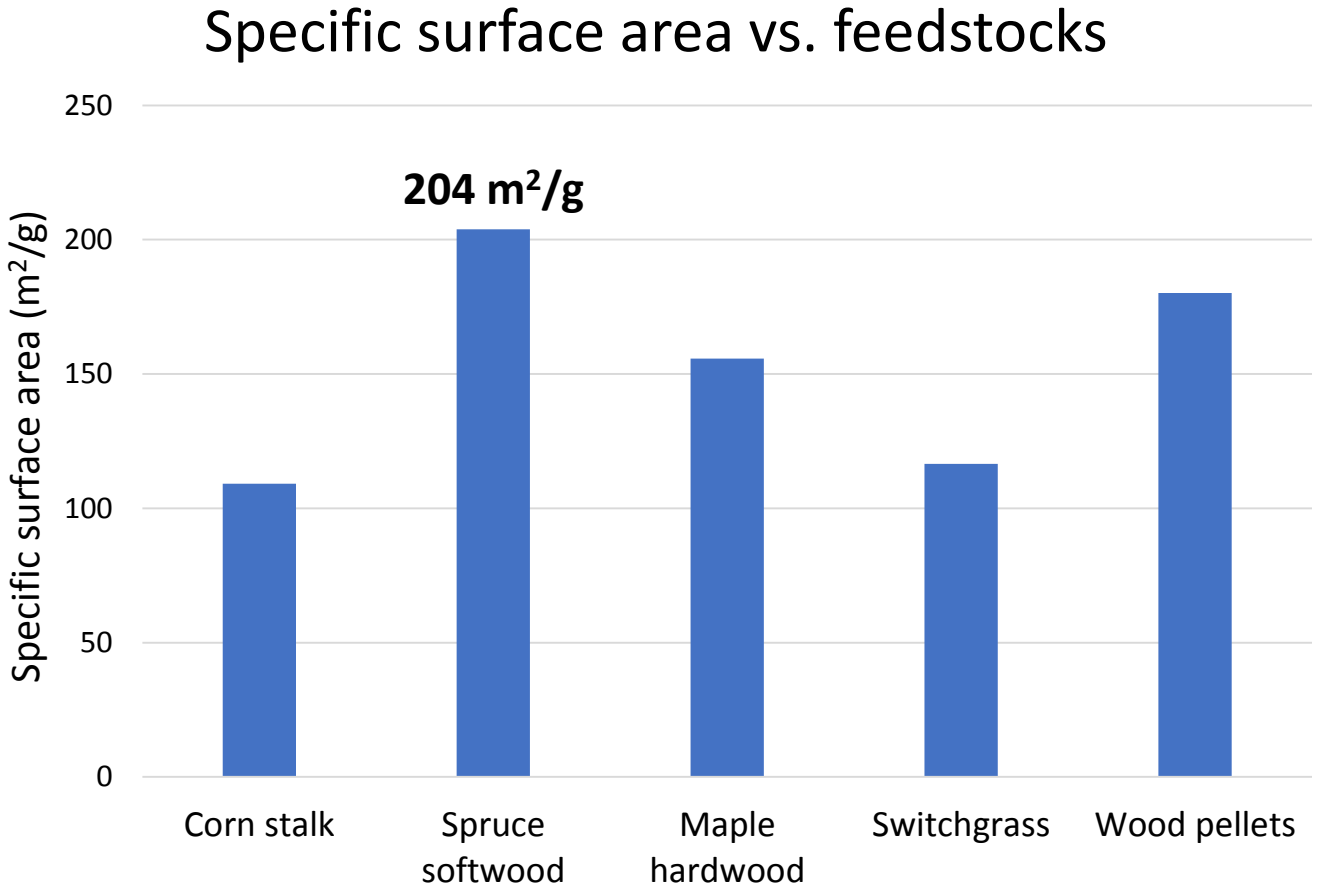
Wood pellets

Highest carbon content (%)

(more than double of that in raw wood pellets)

Summary of results

Spruce softwood
204 m^2/g
Max. BET surface area
Applicable for adsorption processes



Conclusions

- Product yield depends on the process conditions and the type of feedstocks
- Biochar produced has high porosity that could potentially be used in different adsorption processes
- Further work on biomass loading and reactor design is needed
- Additional research on the effect of scaling up microwave reactor technology on product distribution and qualities

Acknowledgements

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  - ✓ **Current and Past Research Team**
    - Dr. Muhammad T. Afzal (Professor, Team Leader)
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    - Tanisha Dreise (Research Assistant)
    - Lucas Bowlby, Noorfidza Harun (Graduate students)
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  - ✓ Natural Science and Engineering Council of Canada (NSERC)
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Thank you!

Interested in collaboration, please contact:

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