UNIVERSITY OF ALBERTA
FUTURE ENERGY SYSTEMS

Feedstock type and pyrolysis temperature drive properties of activated and non-activated biochars

Christopher Nzediegwu, M. Anne Naeth, Scott X. Chang
Department of Renewable Resources
May 3-5, 2022

Territorial acknowledgement: I respectfully acknowledge that I reside on treaty 6 territory, a traditional gathering place for diverse Indigenous people whose histories, cultures and languages continue to influence our vibrant communities

CANADA FIRST RESEARCH EXCELLENCE FUND
Research made possible in part by funding from the Canada First Research Excellence Fund

CLRA | ACRSD ALBERTA CHAPTER

www.futureenergysystems.ca

CANADA FIRST RESEARCH EXCELLENCE FUND
Research made possible in part by funding from the Canada First Research Excellence Fund

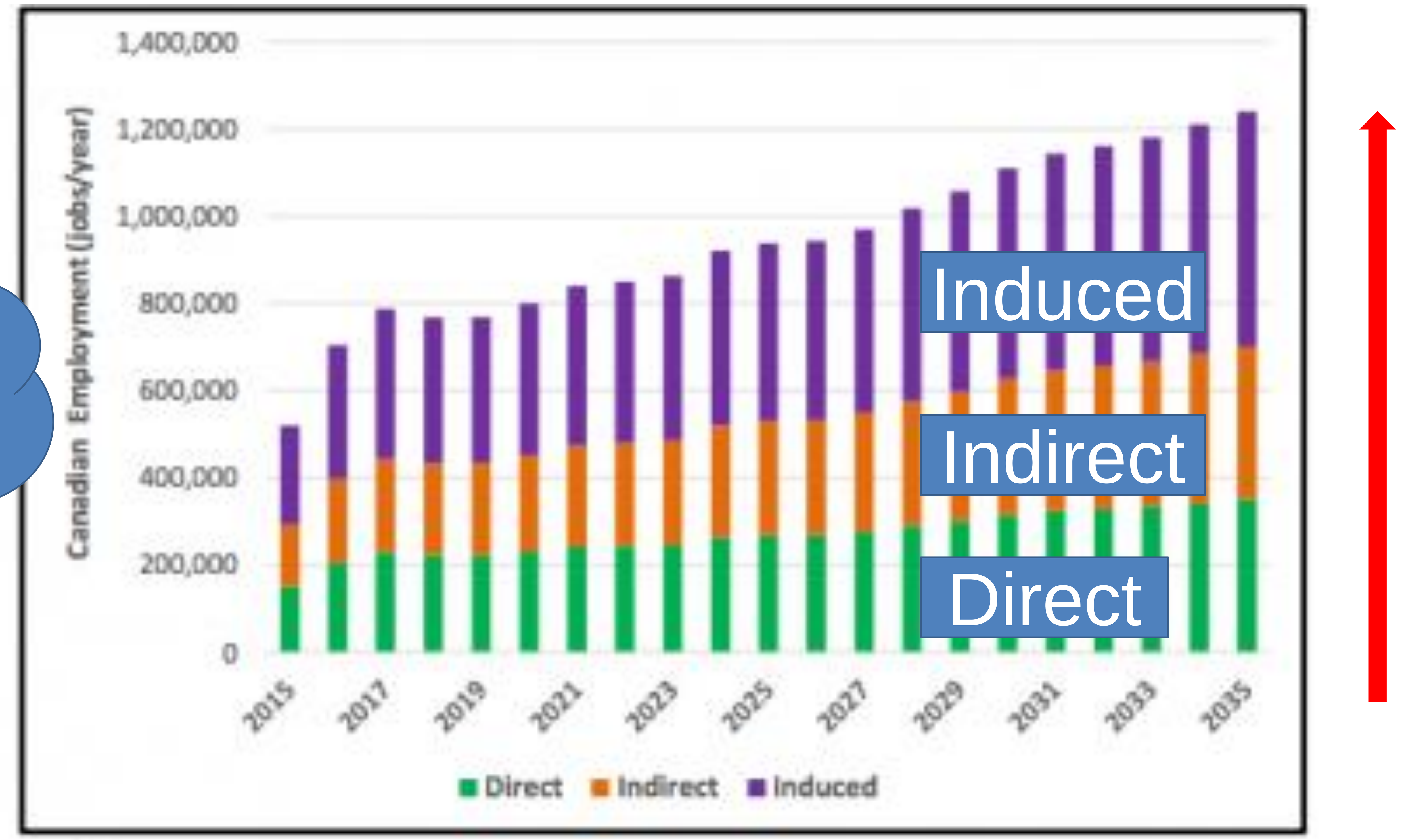
Oil sands mining: The good

Economic benefits

- Creates jobs
- Contributes to gross domestic product
- Enhances infrastructural development

~1.2 million jobs in 2035

Oil sands direct, indirect and induced employment forecast



Source: CERI

Retrieved on April 25, 2022, from http://theamericanenergynews.com

Gross domestic product (GDP) distribution of Alberta, Canada 2020

Sector	%Contribution to GDP
Mining, quarrying, and oil and gas extraction	25.87
Real estate and rental and leasing	11.36
Manufacturing	7.08
Construction	6.93
Health care and social assistance	5.81

Retrieved on April 25, 2022, from www.statistica.com

CANADA FIRST RESEARCH EXCELLENCE FUND
Research made possible in part by funding from the Canada First Research Excellence Fund

Oil sands mining: The ugly

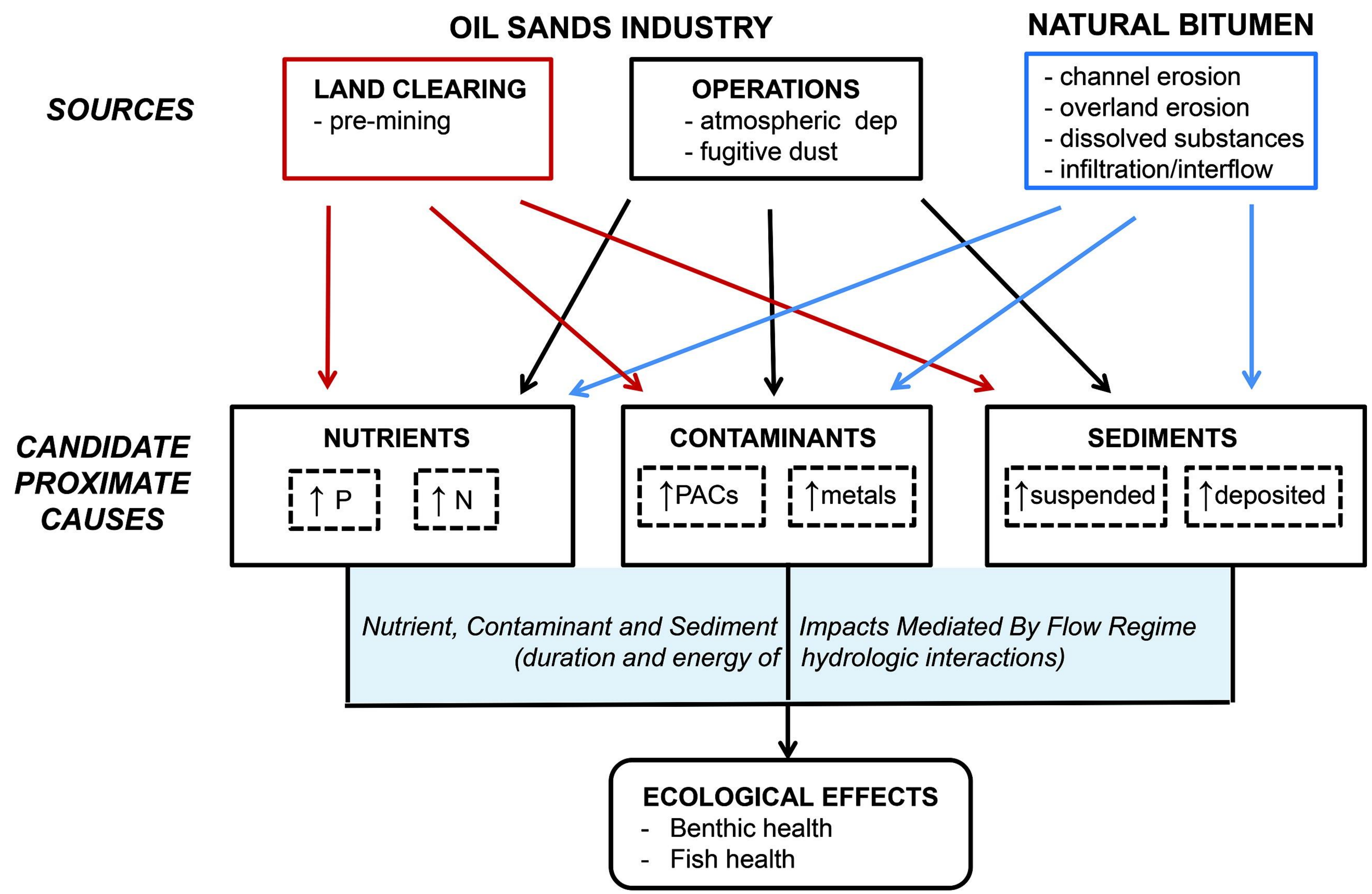
Environmental impacts

- Land fragmentation
- Soil disturbance
- Soil and water pollution

Tailings ponds

- Occupied 270 km^2 in 2020
- Stored ~1.4 trillion L of oil sands process-affected water (OSPW)

Potential Sources, Causes and Ecological Effects of Oil Sands Activity



Adapted from Culp et al. (2020). Environmental Reviews. **29**(2): 315-327. https://doi.org/10.1139/er-2020-0082

[1] Elizabeth M. Beck, Judit E. G. Smits, Colleen Cassady St Clair, Evidence of low toxicity of oil sands process-affected water to birds invites re-evaluation of avian protection strategies, *Conservation Physiology*, Volume 3, Issue 1, 2015, cov038, https://doi.org/10.1093/conphys/cov038

CANADA FIRST RESEARCH EXCELLENCE FUND
Research made possible in part by funding from the Canada First Research Excellence Fund

Toxicity and environmental pathways of OSPW

Toxic compounds in OSPW [1]

- Polycyclic aromatic hydrocarbons, 0.01 mg/L, 0.00001- 0.00006 mg/L
- Naphthenic acids, 110 mg/L
- Potentially toxic elements (arsenic, cadmium)
- Dissolved solids (salinity)

Environmental pathways [1]

- Seepage through dykes to wetlands and surface water bodies
- Direct pumping into wetlands
- Percolation to groundwater

Banned for decades, releasing oilsands tailings water is now on the horizon

Some Indigenous groups say they are stuck choosing between environmentally risky options

Kyle Bakx · CBC News · Posted: Dec 06, 2021 4:00 AM ET | Last Updated: December 6, 2021

Tailings drain into a pond at the Syncrude oilsands mine facility near Fort McMurray, Alta. on July 9, 2008. That year, some 1,600 ducks died in one of the company's toxic tailings ponds. (Jeff McIntosh/Canadian Press)

CANADA FIRST RESEARCH EXCELLENCE FUND
Research made possible in part by funding from the Canada First Research Excellence Fund

Using wetlands to intercept OSPW

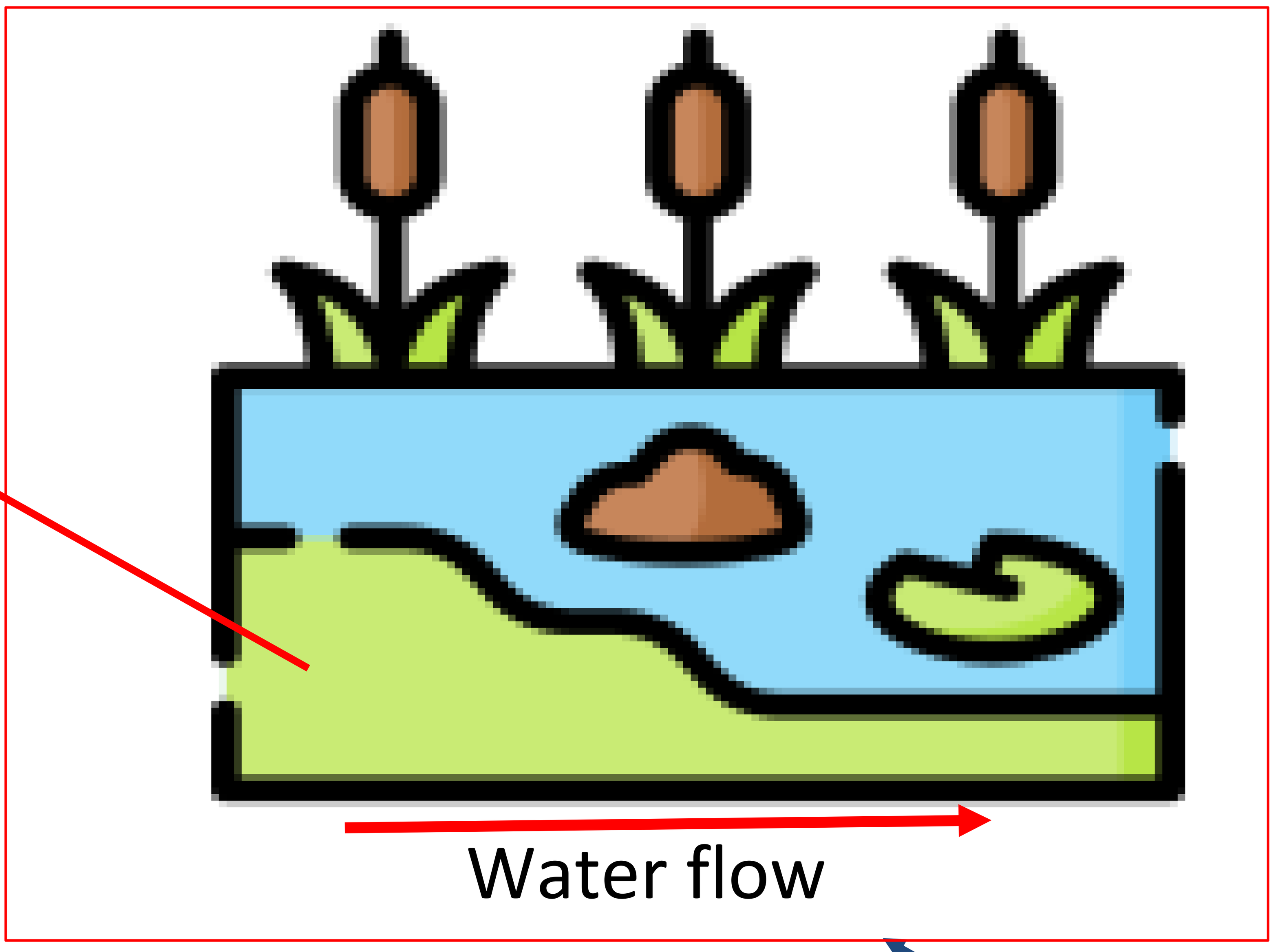
No silver bullet to treat tailings

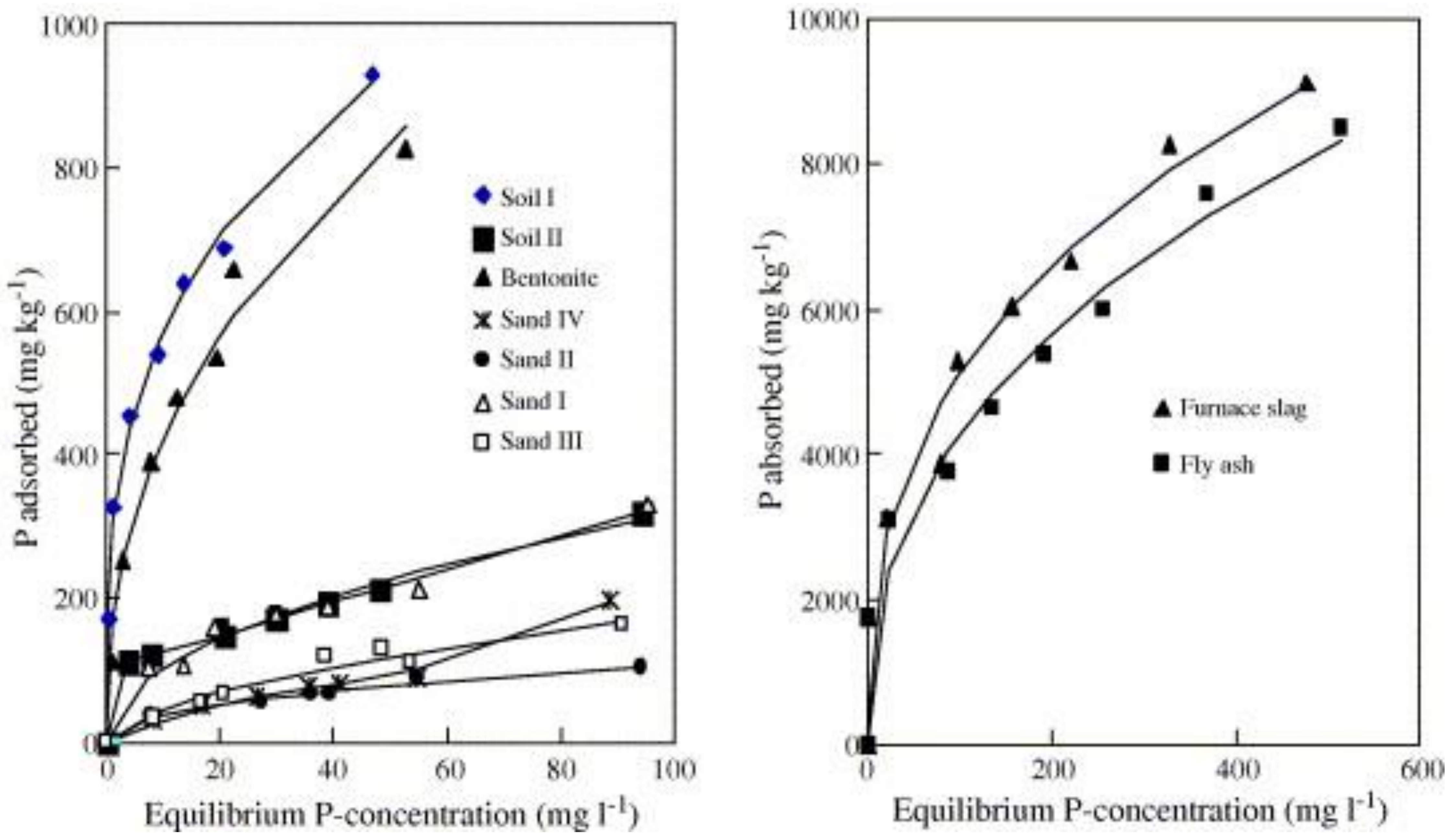
While the federal government develops regulations, the industry is testing various chemical and biological methods of treating tailings water.

The trick is to find the most effective methods that are also cost-effective and don't produce other environmental impacts, like more greenhouse gases.

Substrates

- Furnace slag
- Fly ash
- Peat
- Sand
- Bentonite
- Biochar

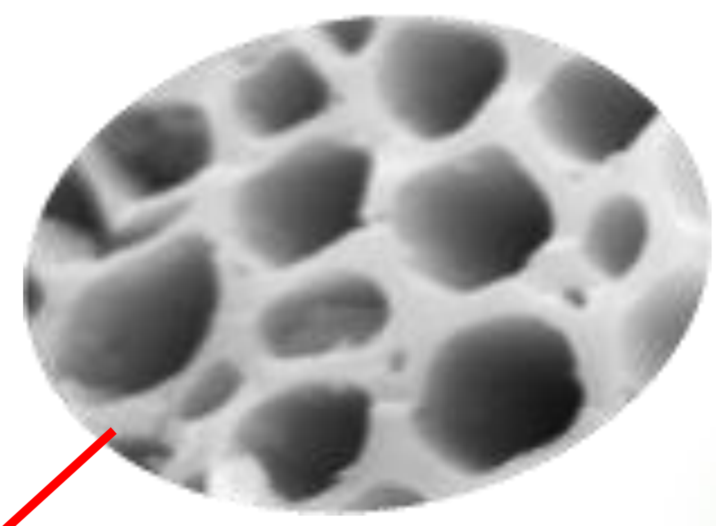


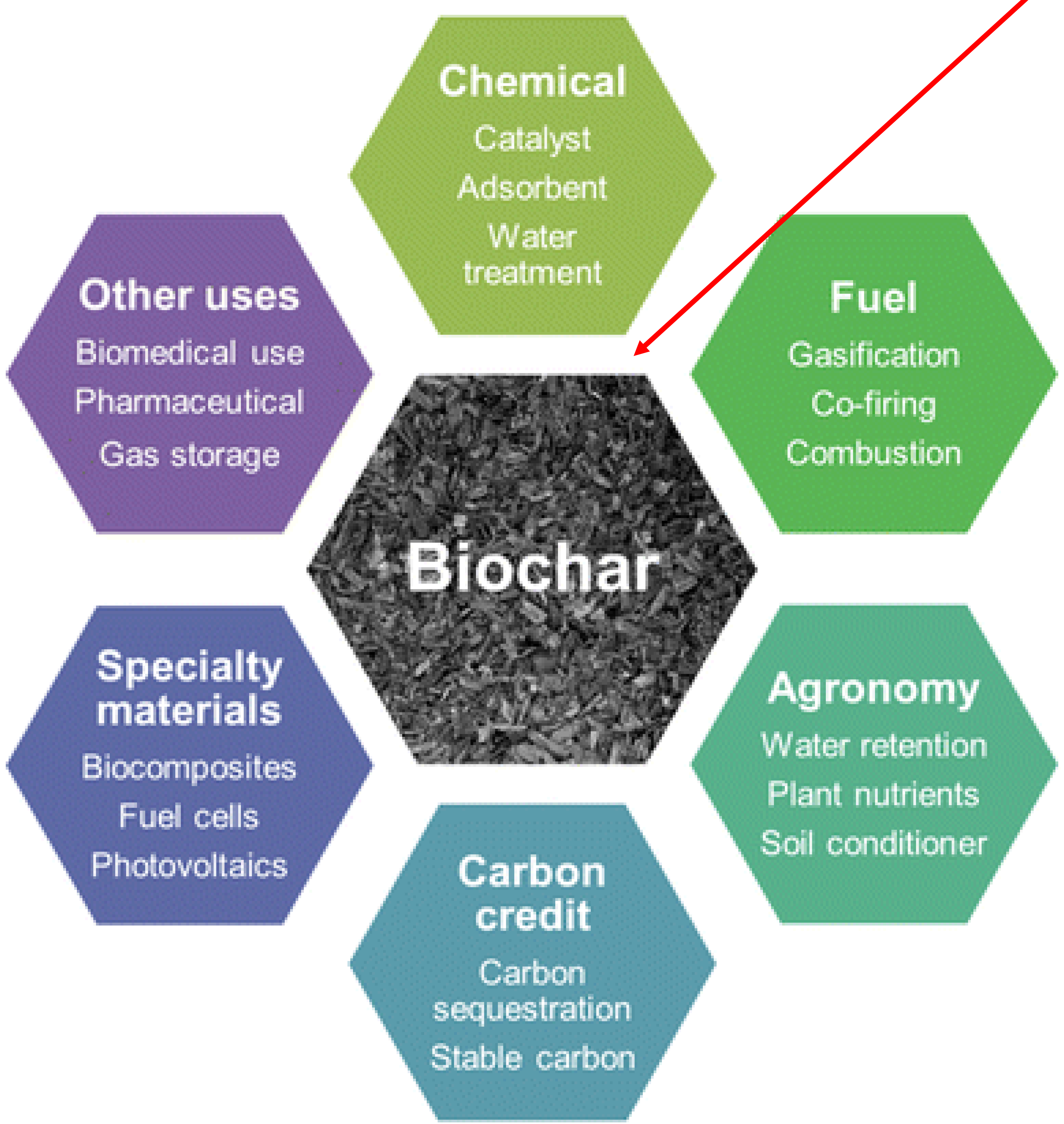


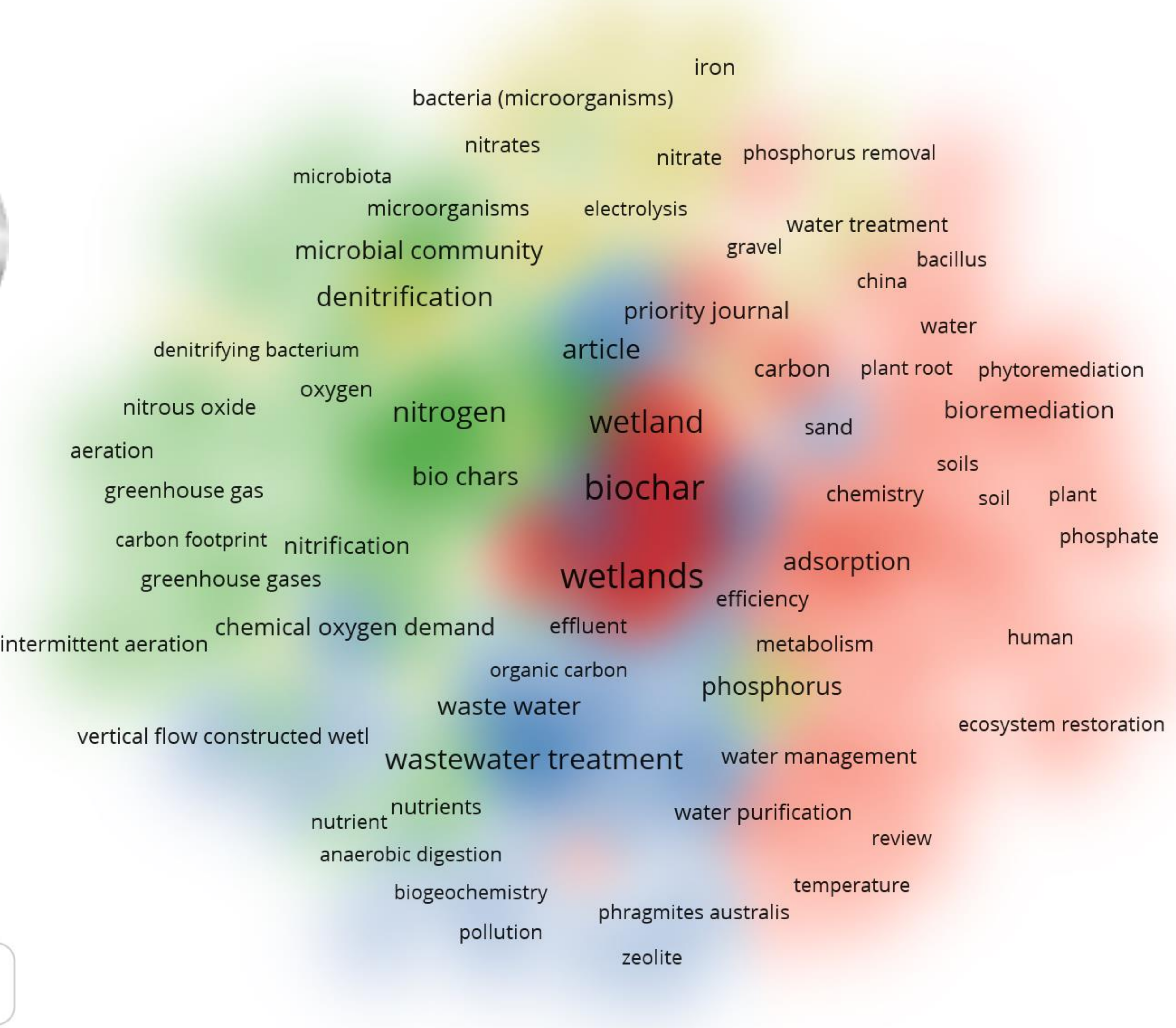
Xu et al., (2006). *Chemosphere*, *63*(2), 344-352.

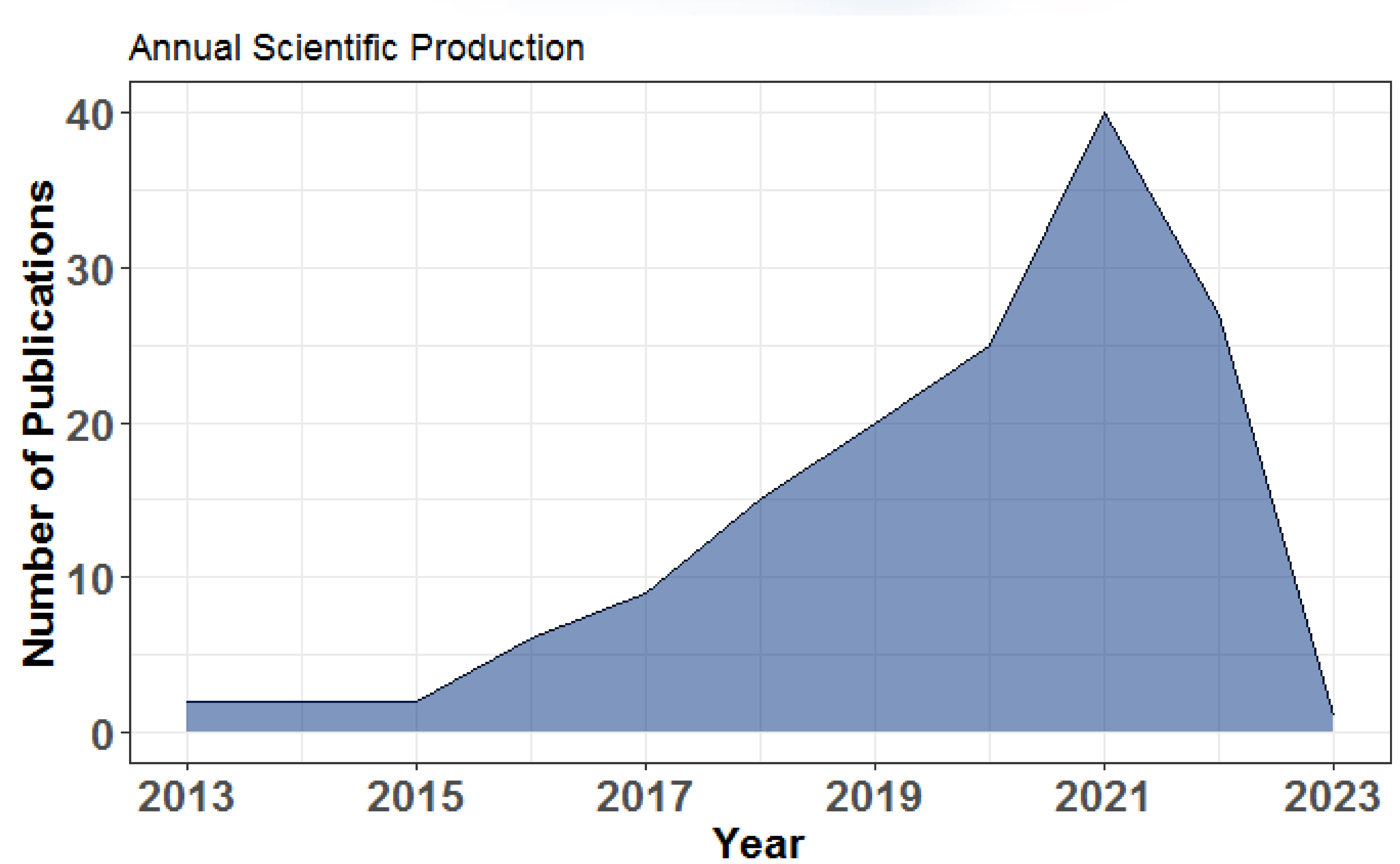
Biochar as a potential substrate for constructed wetlands

- Biochar
  - A porous carbon-rich material produced by burning waste biomass in the absence of oxygen (pyrolysis)









Nanda *et al. (2016), Waste Biomass Valor* **7,** 201–235.

Unaddressed questions and theoretical considerations

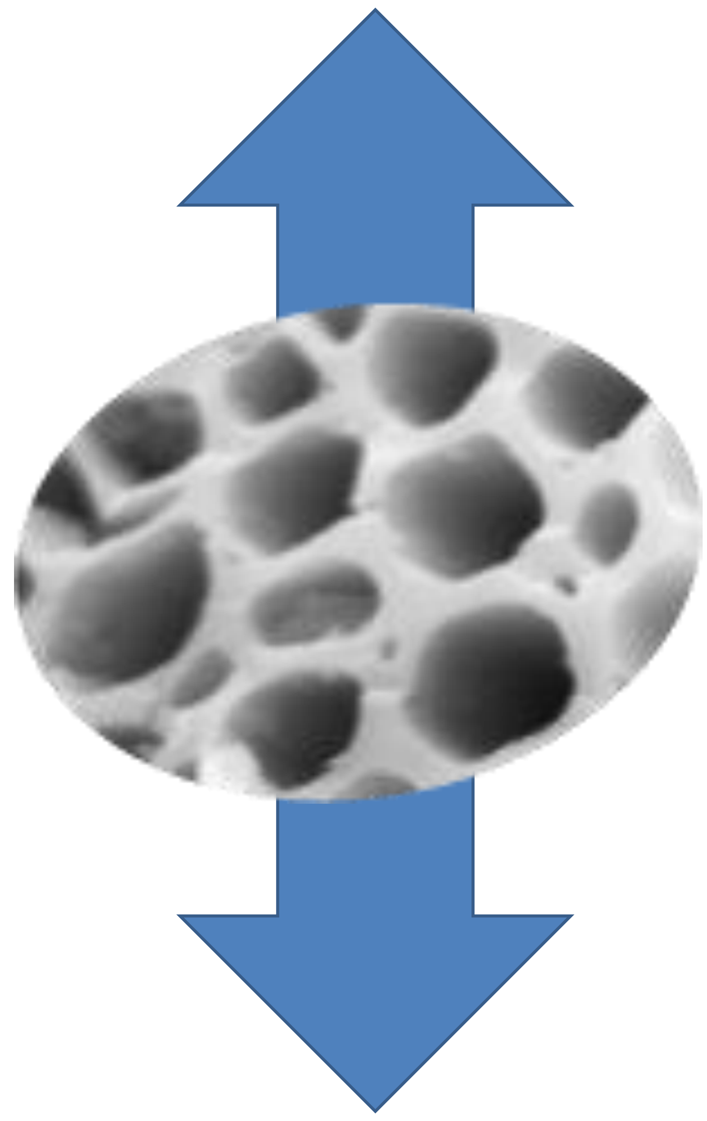
Questions

- How stable is biochar in constructed wetlands?
- How do feedstock type, production temperature and activation affect biochar stability?

Theoretical considerations

- Carbon stability
  - Carbon sequestration
  - Mineralization

- Studied by several methods
  - Lignin content
  - Carbon to nitrogen ratio
  - Oxidative recalcitrance



CANADA FIRST RESEARCH EXCELLENCE FUND
Research made possible in part by funding from the Canada First Research Excellence Fund

Objectives 1.1

- To determine the stability (oxidative recalcitrance) of activated and non-activated biochars
- To evaluate the effects of feedstock type, production temperature and activation on the oxidative recalcitrance of biochars

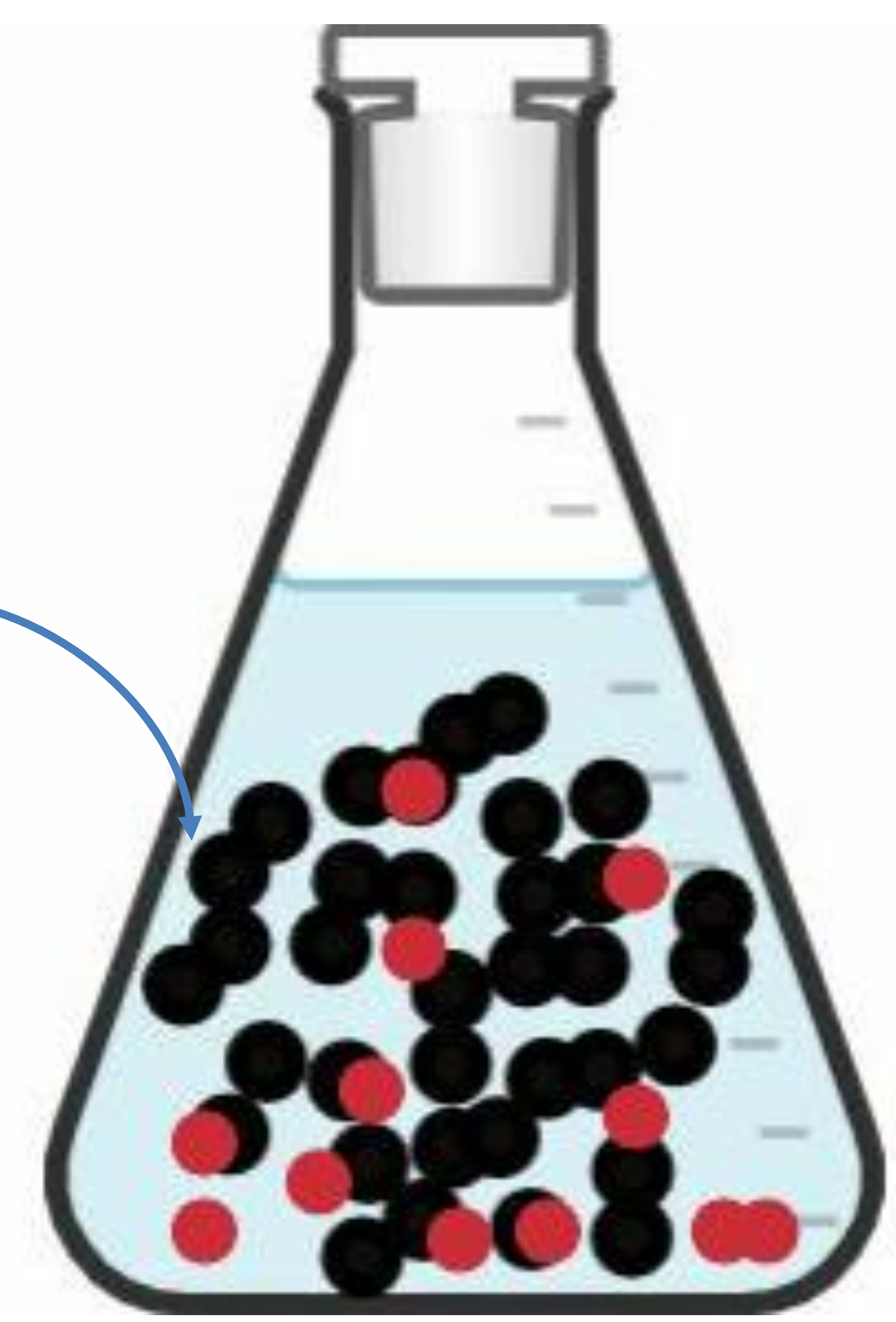
Experimental procedure 1

Biochar

- **Feedstock types (x4; canola straw, manure pellets, sawdust, wheat straw)**
- **Production temperatures (x3; 300, 400, 500 °C)**
- **Biomass residence time (20 min)**
- **Microwave-assisted heating**

Activation [2]

- **Nitric acid (3.5%)**
- **Ambient temperature (~25 °C)**
- **1:20 (w/w) solid:liquid ratio, soaked overnight**
- **Filtered and washed with deionized water**
- **Dried at 105 °C for 24 h**



[2] Nzediegwu et al. (2022), Bioresource Technology 344, 126316

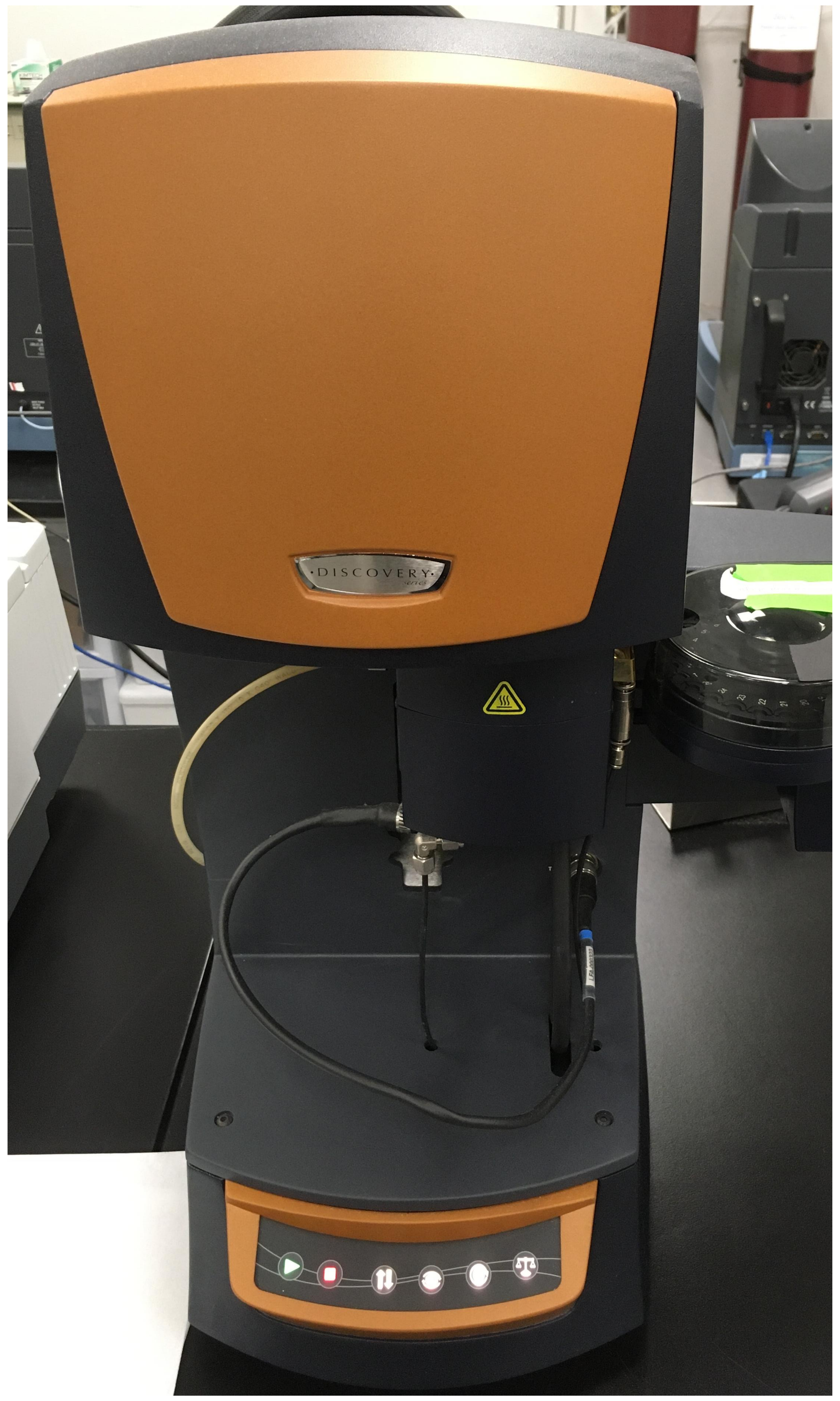
Experimental procedure 2

Characterization

- **Thermogravimetric analysis**
  - **~10 mg sample**
  - **Combusted from 25-700 °C**
  - **10 °C min^{-1} heating rate**
  - **Air-filled environment**

Properties

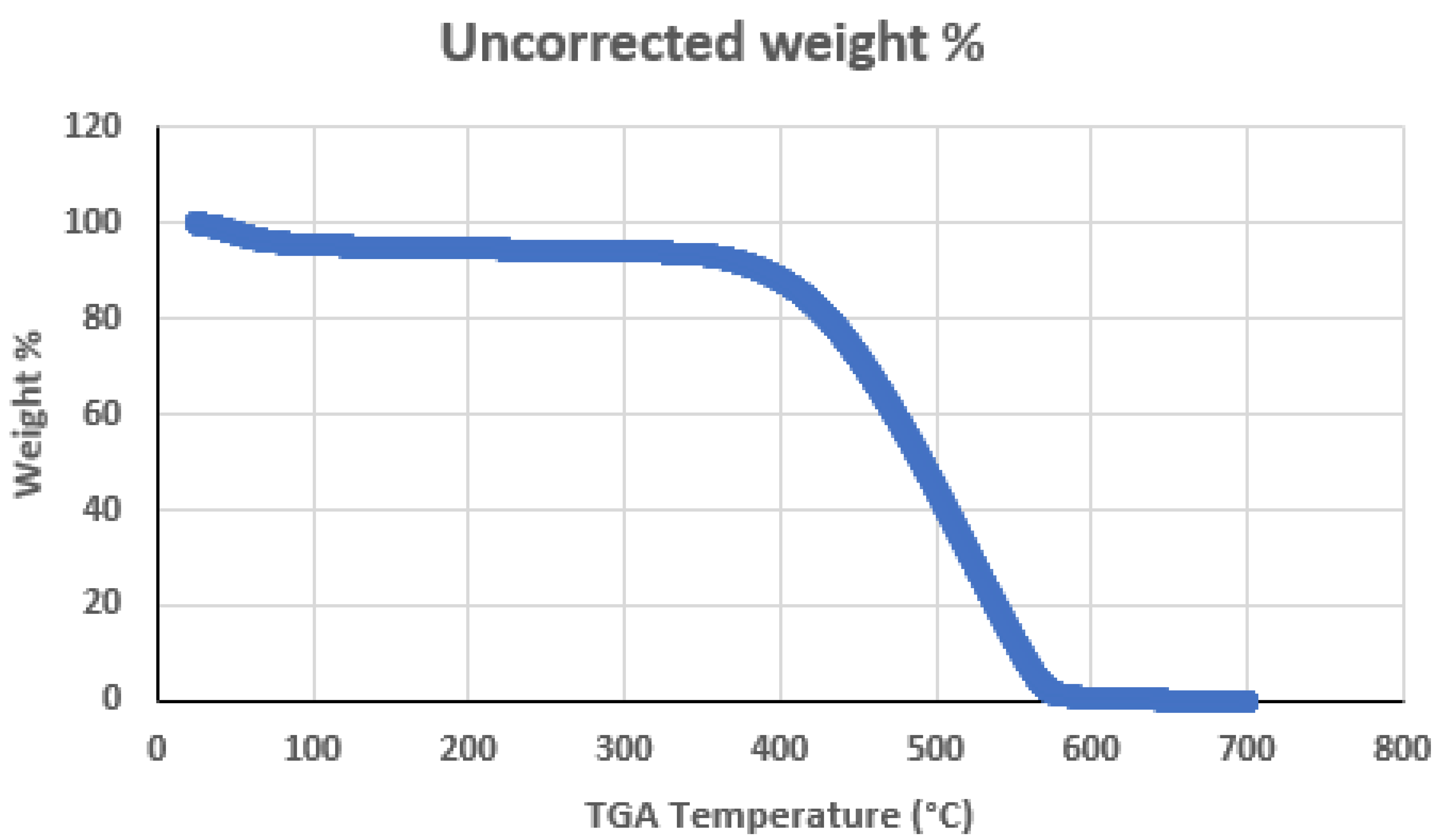
- **Thermal stability**
- **Weight loss**
- **Ash content**
- **Oxidative recalcitrance**

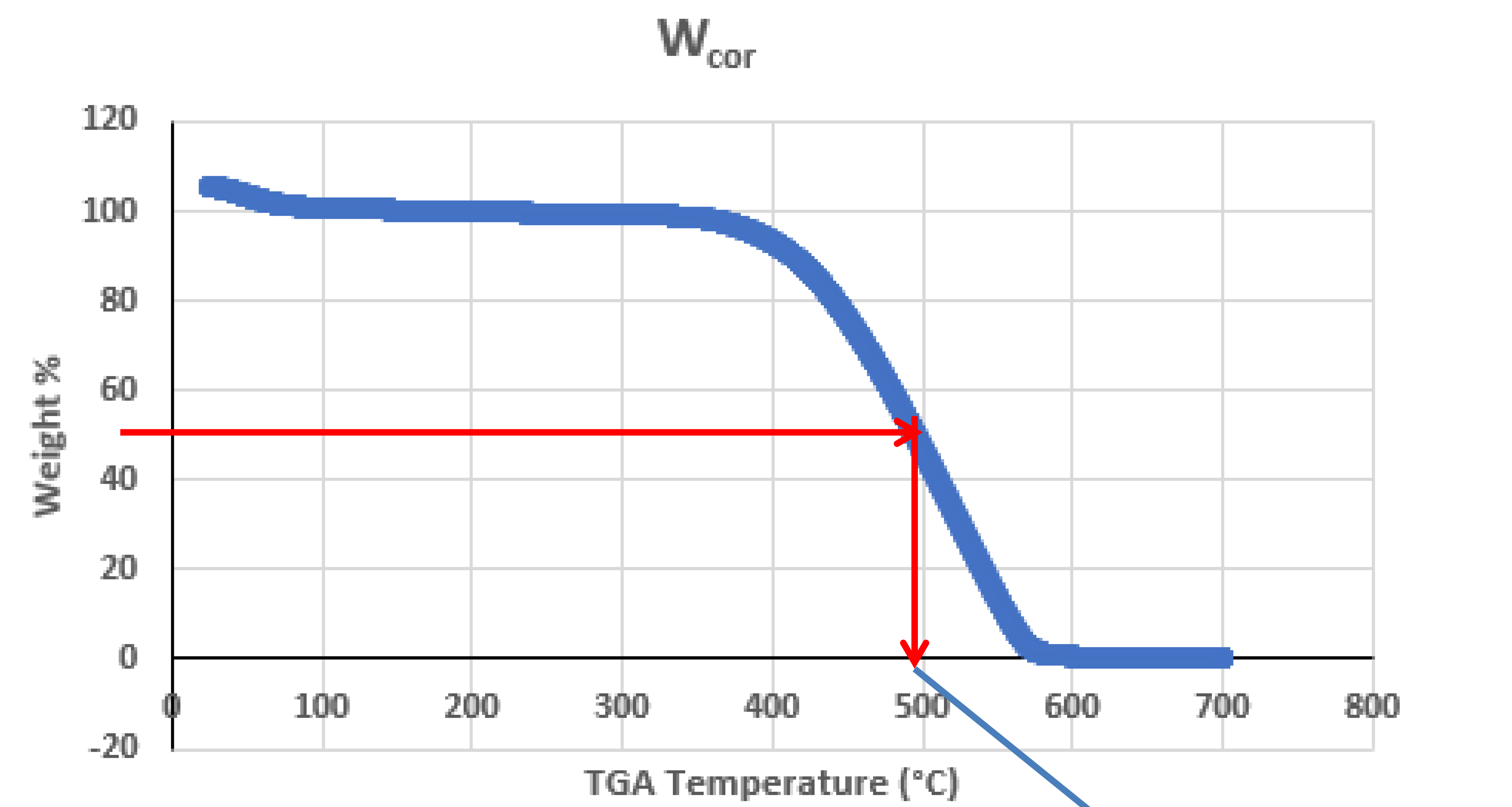


Discovery Series TGA

Research made possible in part by funding from the Canada First Research Excellence Fund

Data processing for oxidative recalcitrance





$$W_{cor} = 100 + (100 * \frac{W_T - W_{200}}{W_{200} - W_{fi}})$$

- W_{cor} = Moisture and ash content-corrected weight %
- W_T = Uncorrected weight %
- W_{200} = Weight % at 200 °C
- W_{fi} = Final weight %

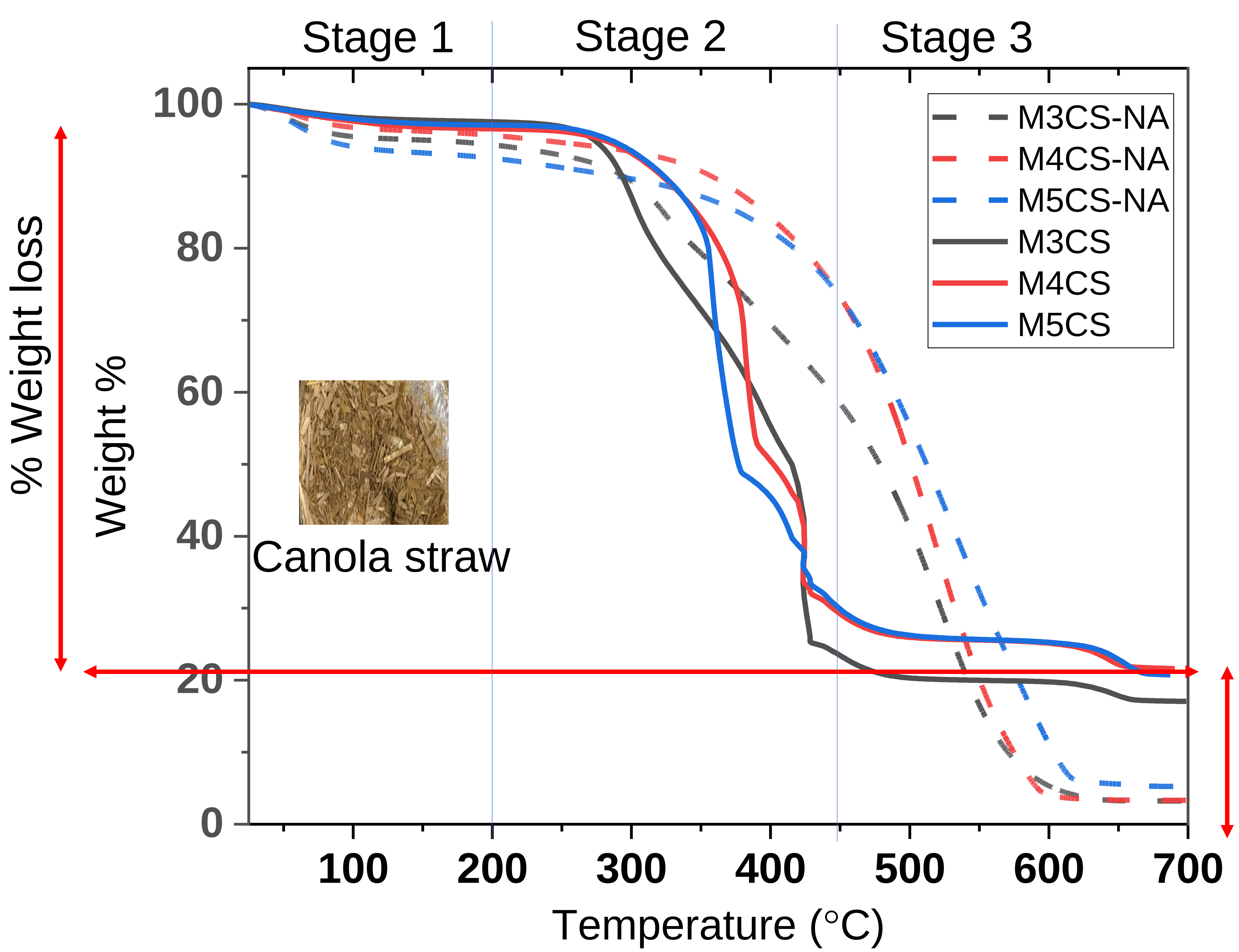
$$Oxidative\ recalcitrance, R_{50} = \frac{T_{50,biochar}}{T_{50,graphite}}$$

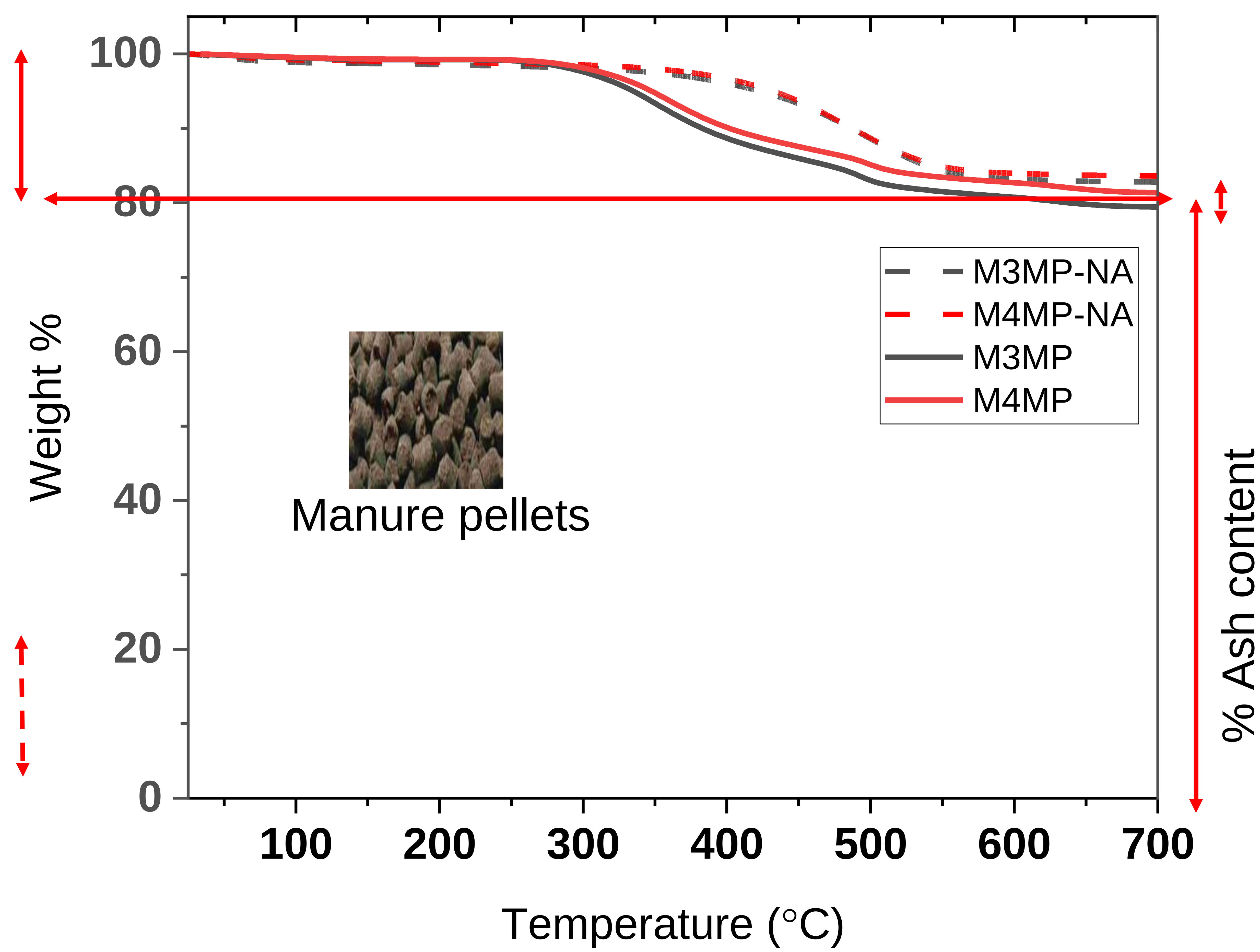
- $T_{50,\ biochar}$ = Temperature at which 50% of weight loss occurred for biochar
- Obtained from moisture and ash content-corrected thermograms
- $T_{50,\ graphite}$ = Temperature at which 50% of weight loss occurred for graphite

[2] Nzediegwu et al. (2022), Bioresource Technology 344, 126316

Research made possible in part by funding from the Canada First Research Excellence Fund

Feedstock type, pyrolysis temperature and activation affect thermal stability, weight loss and ash content

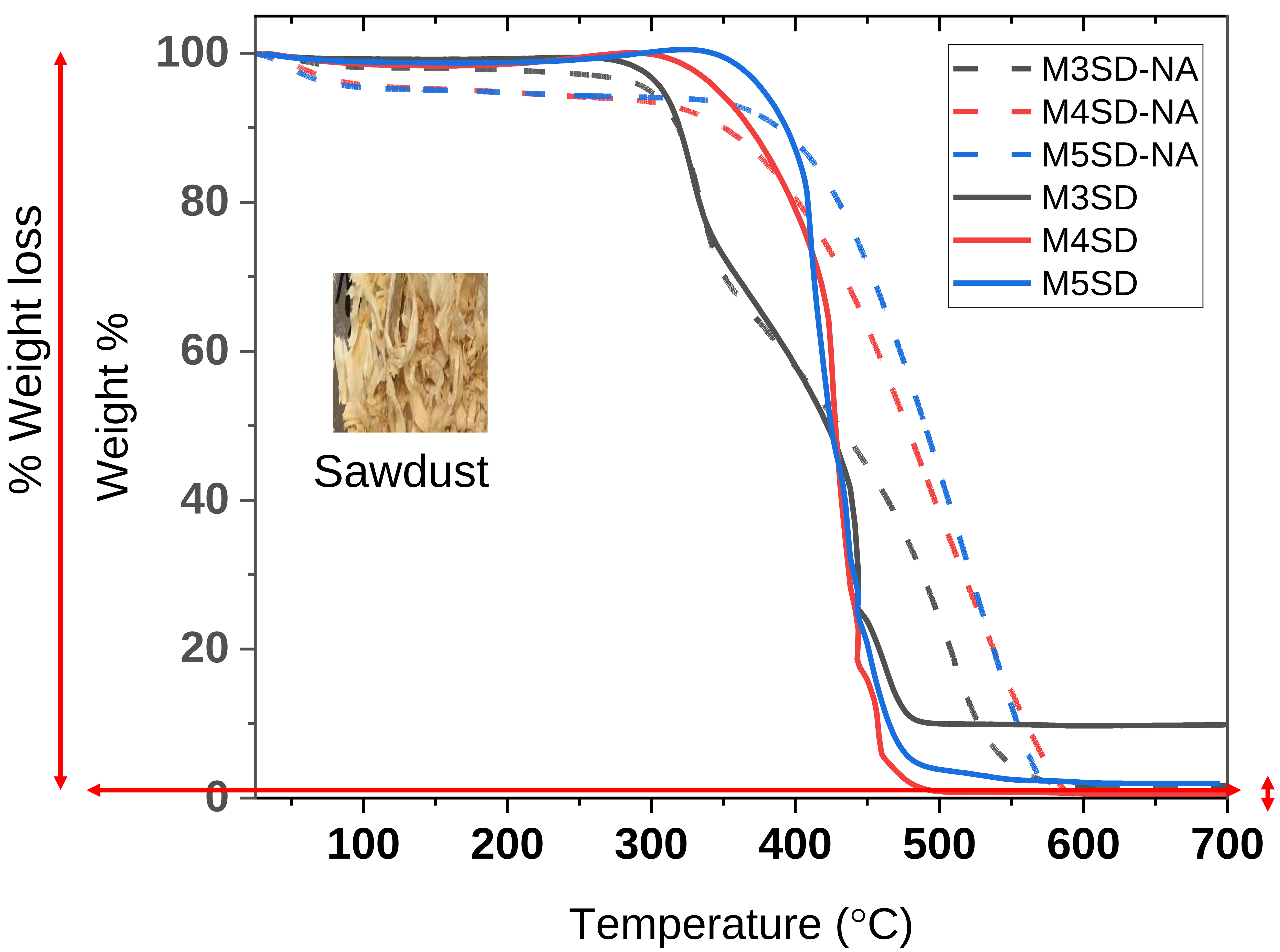


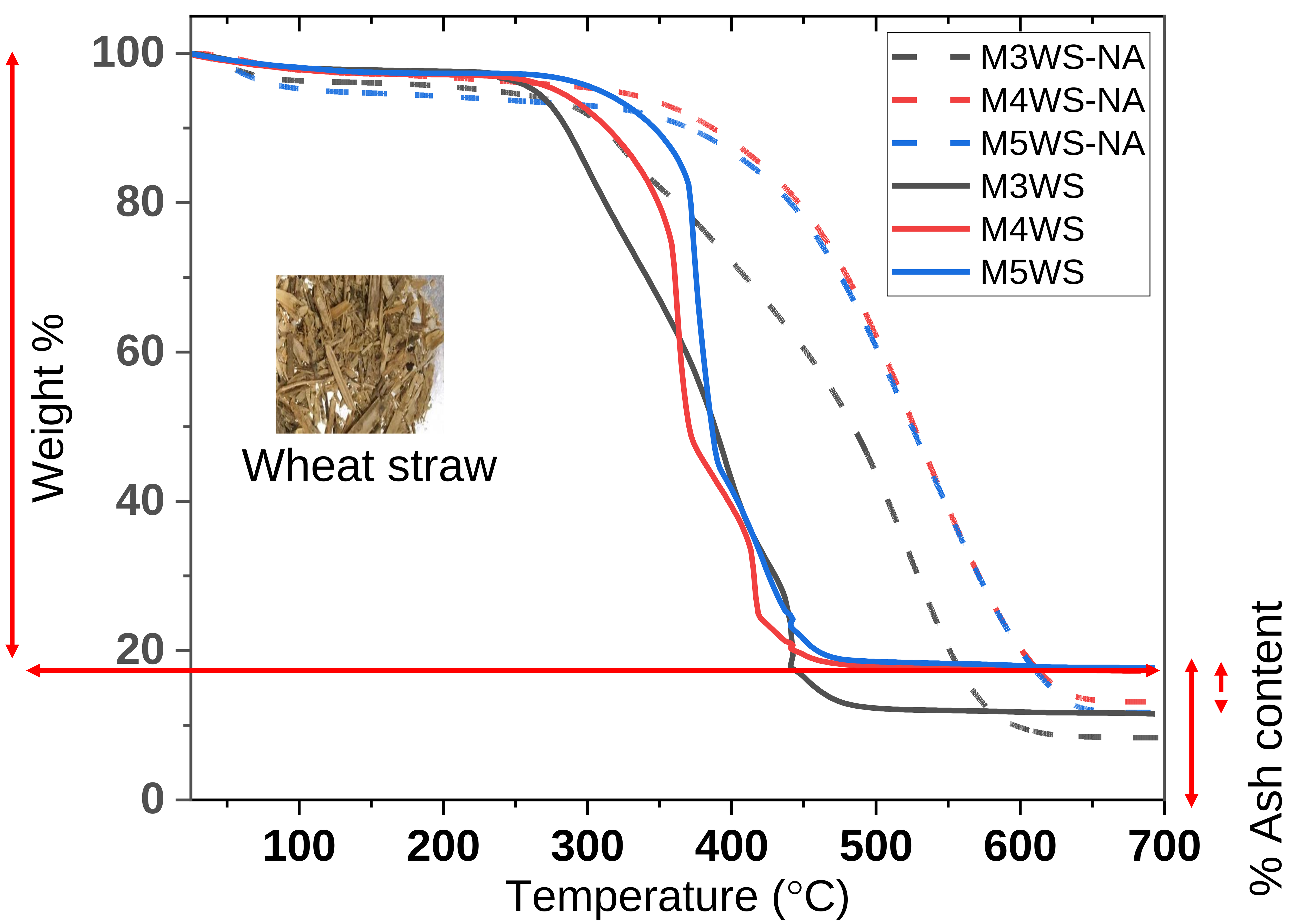


[2] Nzediegwu et al. (2022), Bioresource Technology 344, 126316

Research made possible in part by funding from the Canada First Research Excellence Fund

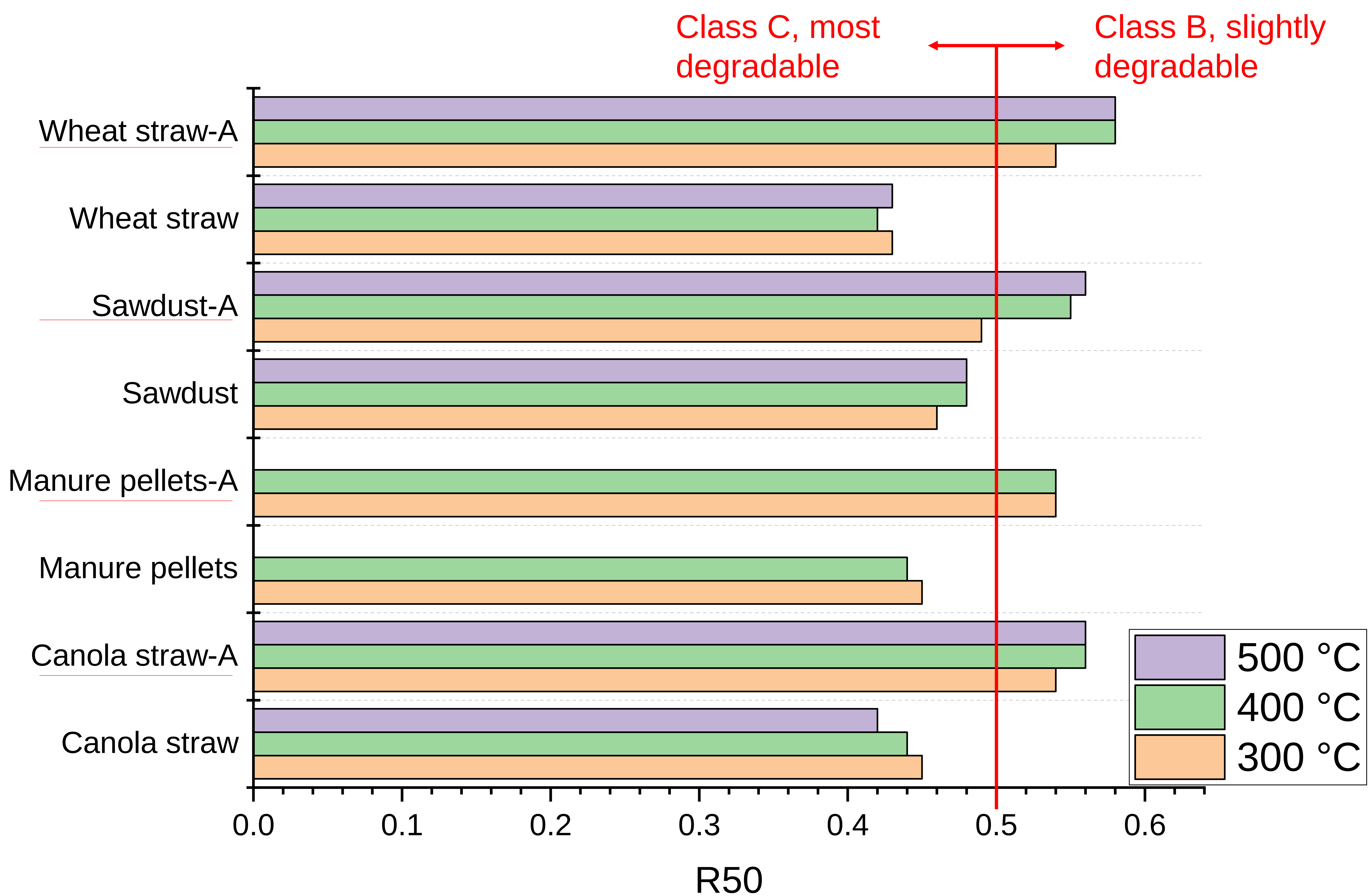
Feedstock type, pyrolysis temperature and activation affect thermal stability, weight loss and ash content





CANADA FIRST RESEARCH EXCELLENCE FUND
Research made possible in part by funding from the Canada First Research Excellence Fund

Feedstock type and activation affect oxidative recalcitrance more than pyrolysis temperature



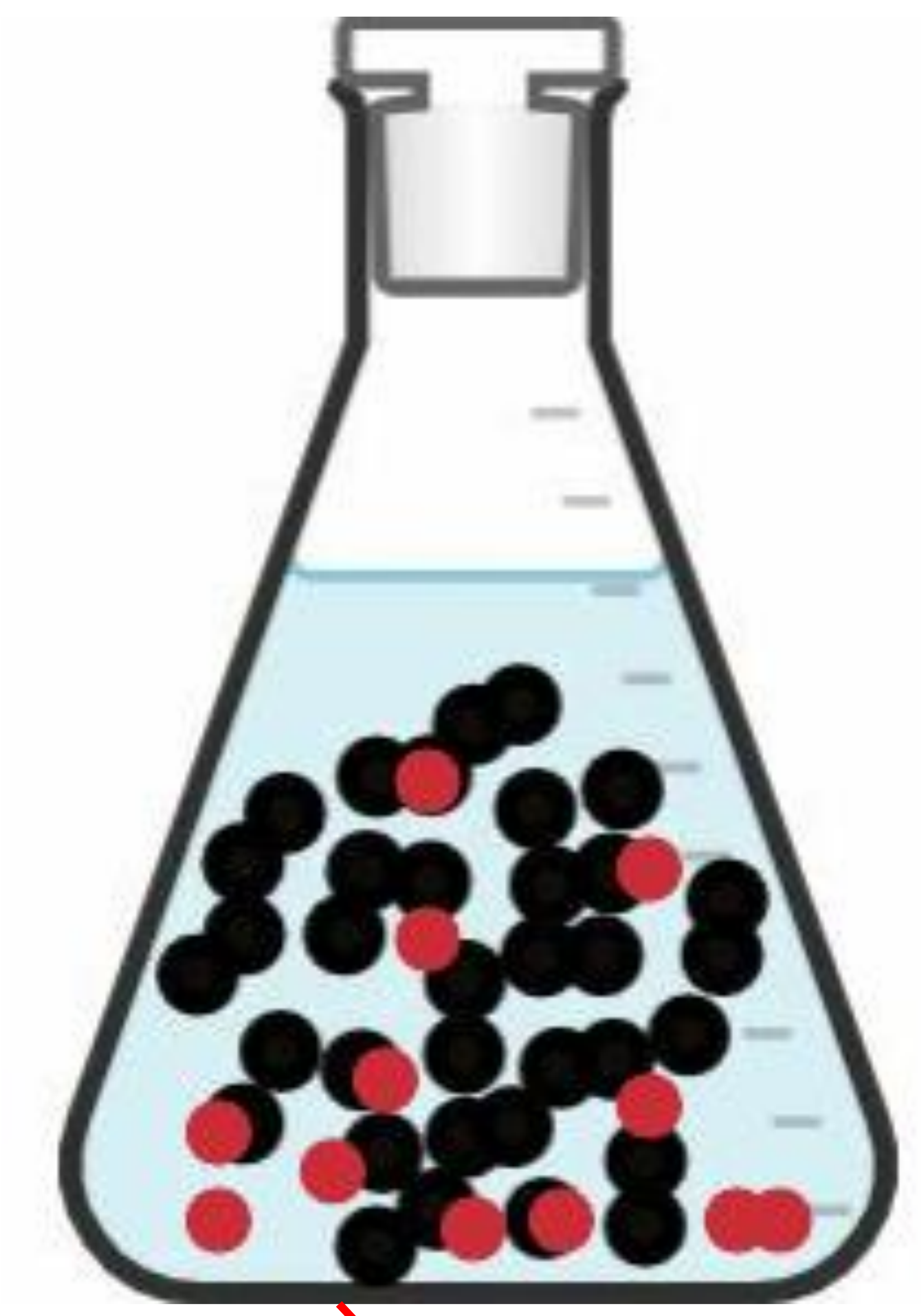
[2] Nzediegwu et al. (2022), Bioresource Technology 344, 126316

Research made possible in part by funding from the Canada First Research Excellence Fund

Objectives 1.2

To evaluate biochar element leaching by nitric acid and study the effect of feedstock type and pyrolysis temperature

Activation

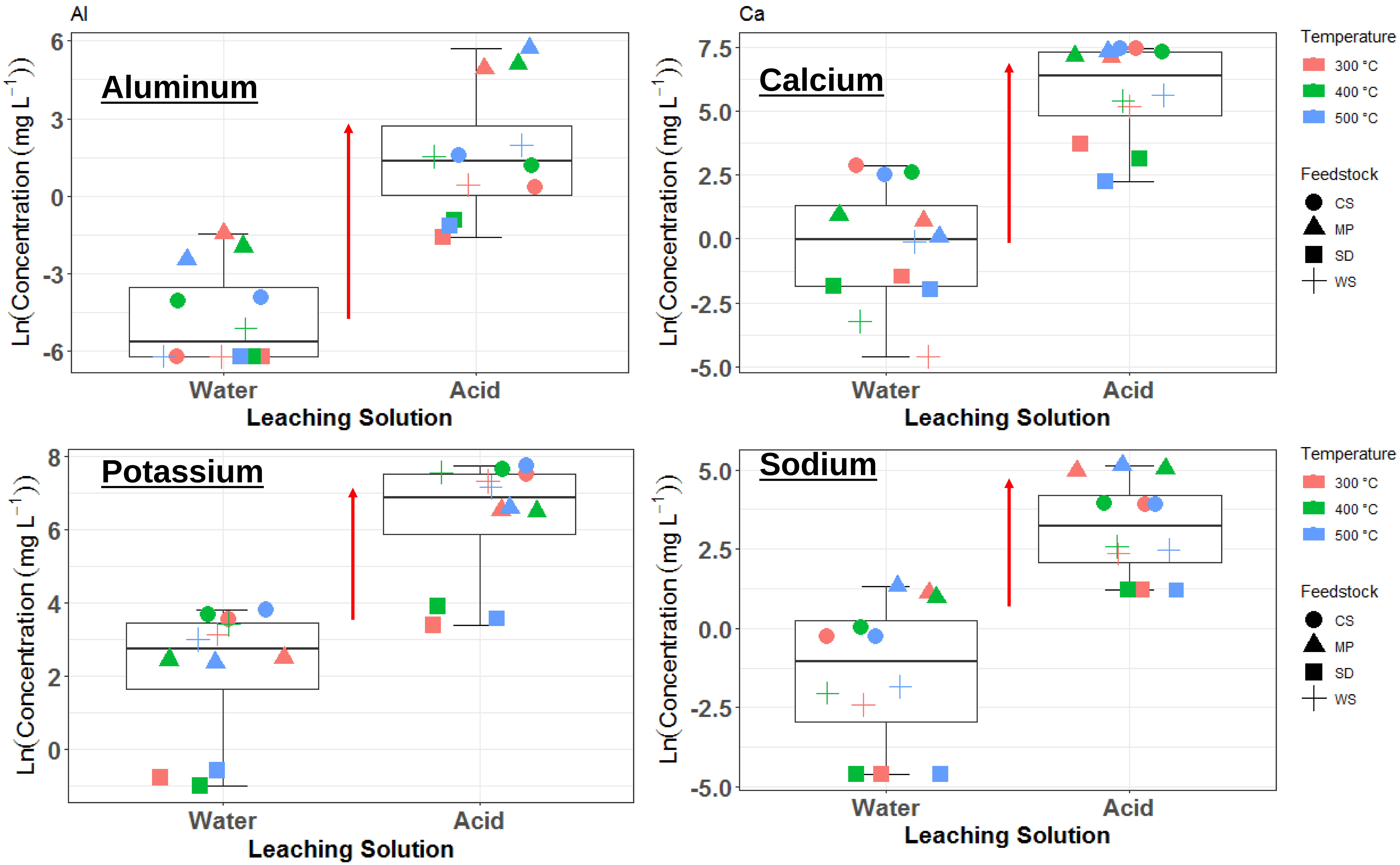


- **Nitric acid, 3.5% (deionized water as a control)**
- **Ambient temperature (~25 °C)**
- **1:20 (w/w) solid:liquid ratio, soaked overnight**
- **Filtered (0.45 μm)**
- **Elements in filtrate were analyzed using ICP-OES**

ICAP 6300 ICP-OES
Elemental analyses

CANADA FIRST RESEARCH EXCELLENCE FUND
Research made possible in part by funding from the Canada First Research Excellence Fund

Nitric acid significantly leached elements from biochars



2 - 5 order increase

[2] Nzediegwu et al. (2022), Bioresource Technology 344, 126316

CANADA FIRST RESEARCH EXCELLENCE FUND
Research made possible in part by funding from the Canada First Research Excellence Fund

Conclusions

- Nitric acid-activated biochars are more stable than their pristine counterparts
- Feedstock type, pyrolysis temperature and activation affect thermal stability, weight loss and ash content
- Feedstock type and activation affect oxidative recalcitrance more than pyrolysis temperature
- Nitric acid significantly leached elements from biochars depending mainly on feedstock type

Acknowledgements

Thank you for listening

Forest Soils
Lab Members

Christopher Nzediegwu, PhD (McGill)

Expertise

- Soil and water remediation
- Sustainable waste management
- Clean energy generation
- Data analysis

Phone: 438-827-7030
Email: nzediegw@ualberta.ca
Twitter: @nzediegwu23