INL/CON-22-70080-Revision-0

Improving bamboos fuel and storage properties with a net energy export through torrefaction paired with catalytic oxidation

November 2022

Changing the World's Energy Future

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Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

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Nepu Saha[1], Eric Fillerup[1], Brad Thomas[1], Corey Pilgrim[1], Thomas Causer[2], Dan Herren[2], and Jordan Klinger[1]

[1]Idaho National Laboratory
[2]Advanced Torrefaction Systems

Improving bamboo's fuel and storage properties with a net energy export through torrefaction paired with catalytic oxidation

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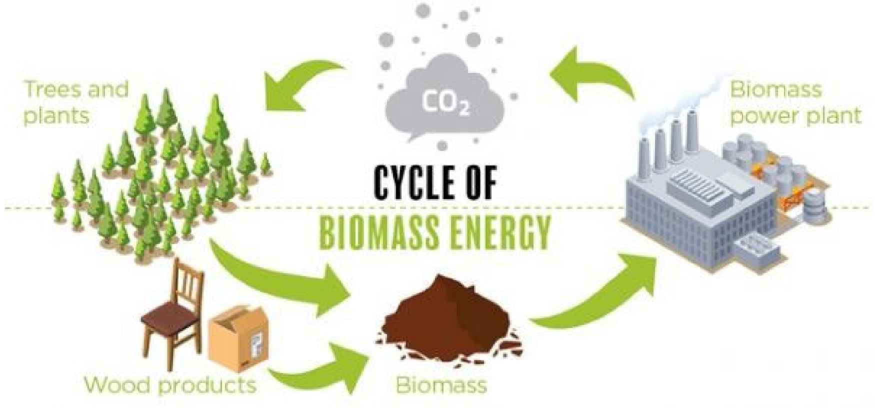
Outline

- Background
- Objectives
- Material and Methods
- Results and Discussion
- Conclusions
- Future Works
- Acknowledgements

Background

- Due to wide availability and the potential to achieve greenhouse gas neutrality, biomass has become a potential candidate for replacing fossil fuels.
- According to the U.S. Energy Information Administration (EIA), biomass provided 39% of the total renewable energy consumed in the U.S. in the year 2020.
- In recent times, bamboo, a grassy lignocellulosic biomass, which is widely distributed in many countries across the world, has gotten the attention in the energy field.



https://sites.psu.edu/crp5406civicissues/2018/03/23/biomass-energy/

https://www.ecoandbeyond.co/articles/is-bamboo-sustainable/

Background

- Torrefaction is a mild thermochemical process that offers the ability to improve the energy density, durability, and hydrophobicity of biomass feedstocks.
- The main product of this treatment is a solid (50–80 wt%), commonly known as torrefied char or biocoal. Meanwhile, this process creates a large amount of various gases (*e.g.*, CO, CO_2, HC).

How torrefaction improves the processing efficiency?

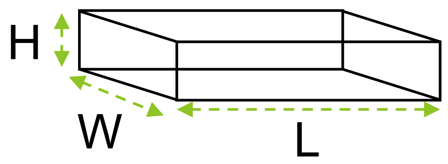
What are the benefits we can get if we utilize the torrefied gas?

Objectives

- To investigate the physiochemical properties, such as mass and energy yields, calorific value, energy density, hydrophobicity, and grindability (in terms of energy required) of the torrefied bamboo char.
- To explore how the catalytic oxidation of torrefaction gas could improve the heat and mass balance of a commercial torrefaction plant.

Material

- Malaysian bamboo (*Gigantochloa Scortechinii*)
- Average dimension of the as received chips:
  L: 42.1 ± 2.3 mm
  W: 19.3 ± 2.4 mm
  H: 6.3 ± 0.6 mm
- The moisture content was 13-15 wt%



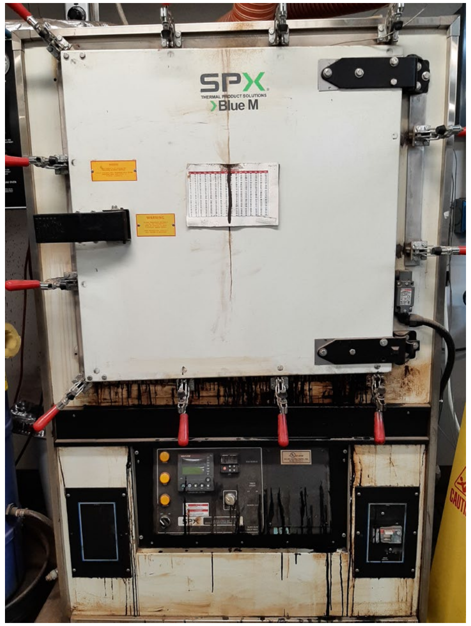
Torrefaction of Bamboo

- Experimental temperature: 210, 230, 250, 270, and 290 ºC
- Residence time: 1 h

Raw Bamboo

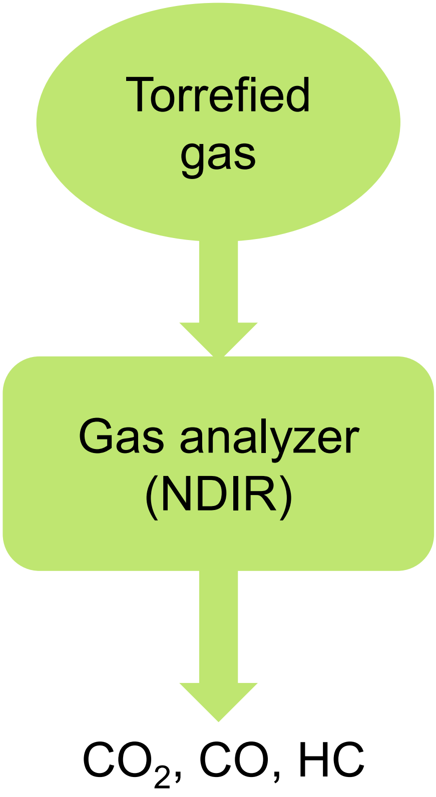
Torrefied Bamboo at 270 °C for 1 h

LECO Thermogravimetric Analyzer (TGA)



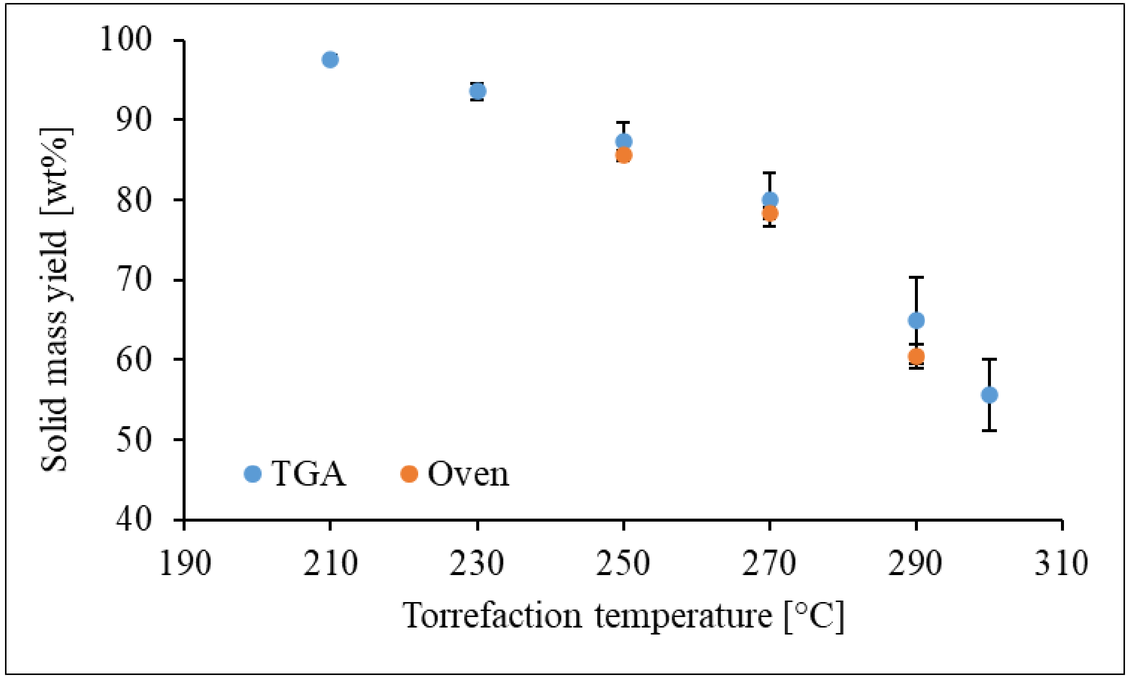
SPX Blue M batch oven

Characterization of Torrefied Char and Gas



Solid Mass Yield

- The mass yield decreases with the increase of torrefaction temperature.
- The yields suggest that the oven was operated at a higher temperature compared to the set value.
- The mass yield results showed <10 wt% mass loss which indicates a minimal degradation of bamboo occurred under those conditions (210 and 230 ºC).



$$MY(\%) = \frac{Mass\ of\ dried\ torrefied\ char}{Mass\ of\ dried\ feedstock} \times 100\%$$

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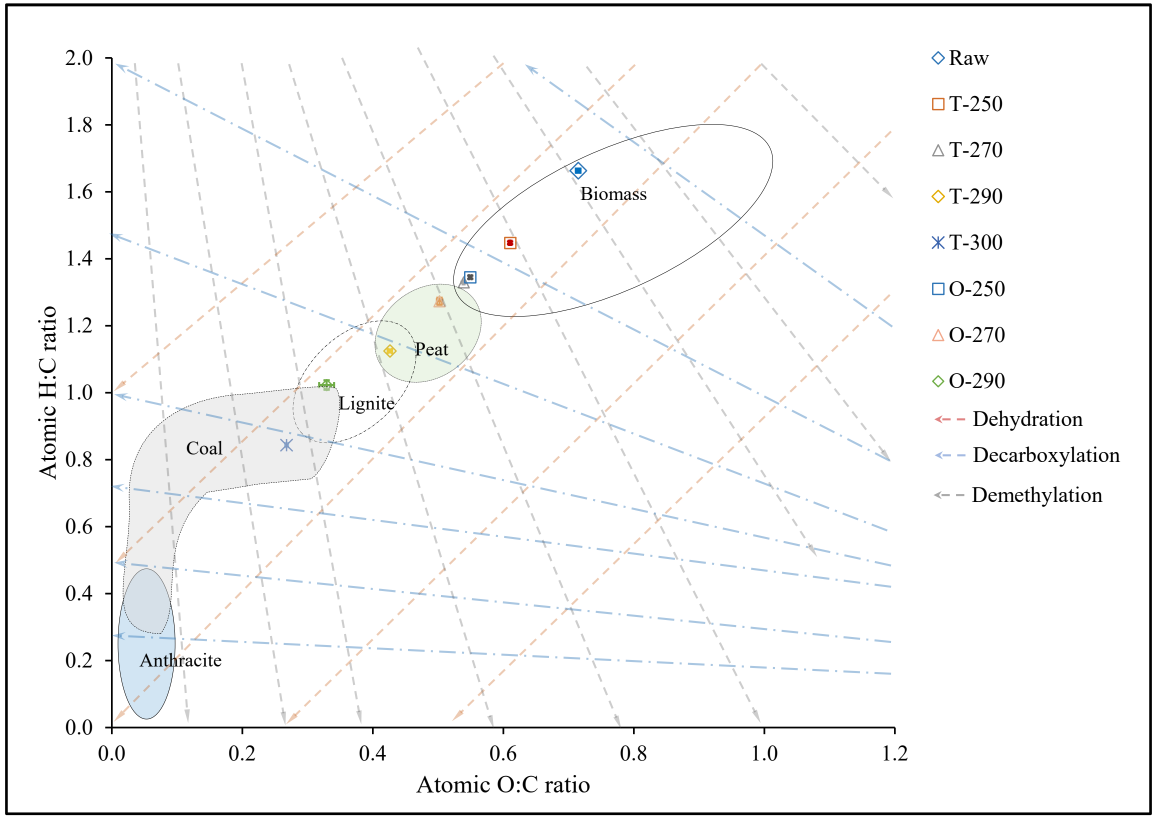
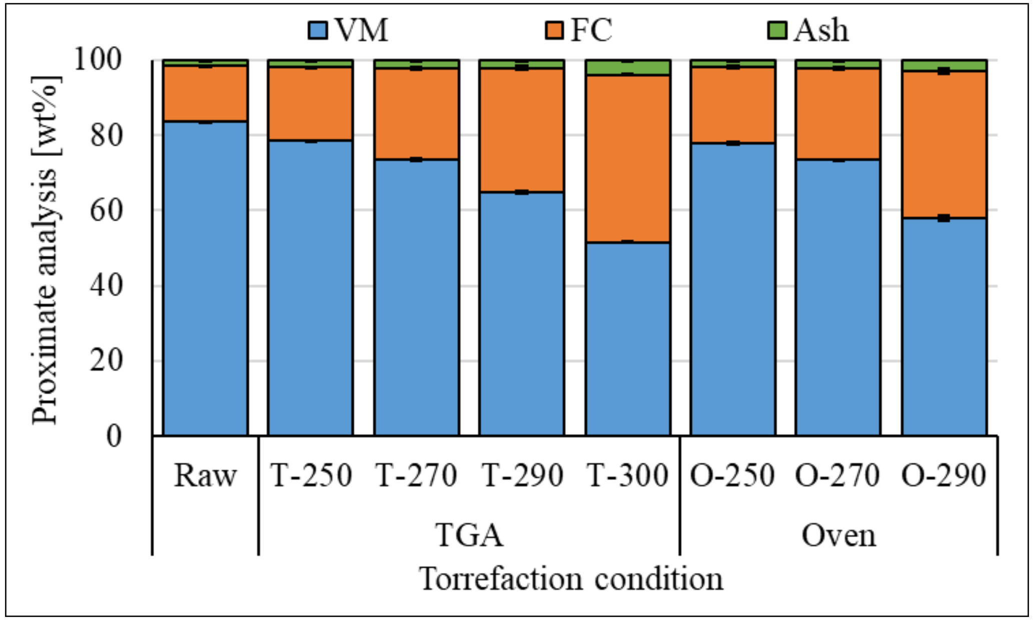
Ultimate Analysis



- The fuel properties enhanced with the increase of the torrefaction, and it moved from biomass to the lignite and coal regions.

Proximate Analysis



- The fixed carbon (FC) increased with the increase of temperature while volatile matter (VM) decreased.
- The ash content increased with the increase of torrefaction temperature.

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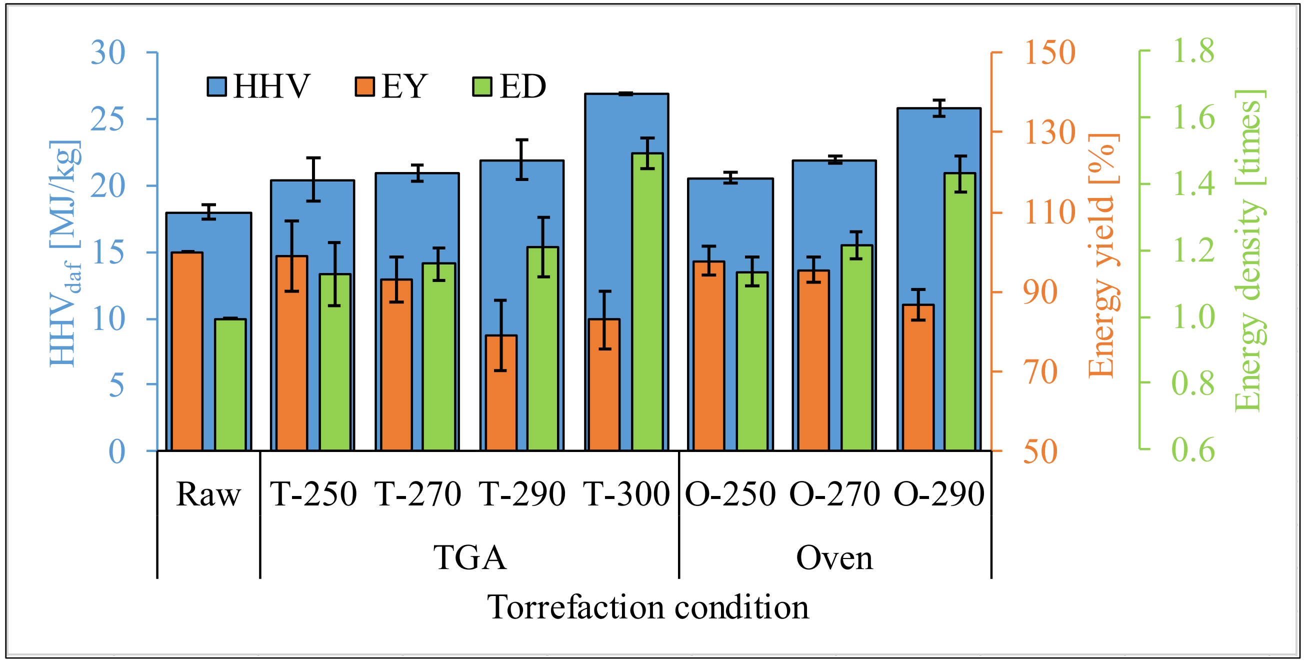
Energy Content and Density

- The calorific values of the torrefied chars increased with the torrefaction temperature and fall within the lignite and sub-bituminous coal.
- The higher HHV signifies the improvement of ED as well.

$$ED = \frac{HHV_{daf}\ of\ torrefied\ char}{HHV_{daf}\ of\ raw\ raw\ bamboo}$$

$$EY(\%) = MY(\%) \times \frac{HHV_{daf}\ of\ torrefied\ char}{HHV_{daf}\ of\ raw\ raw\ bamboo}$$



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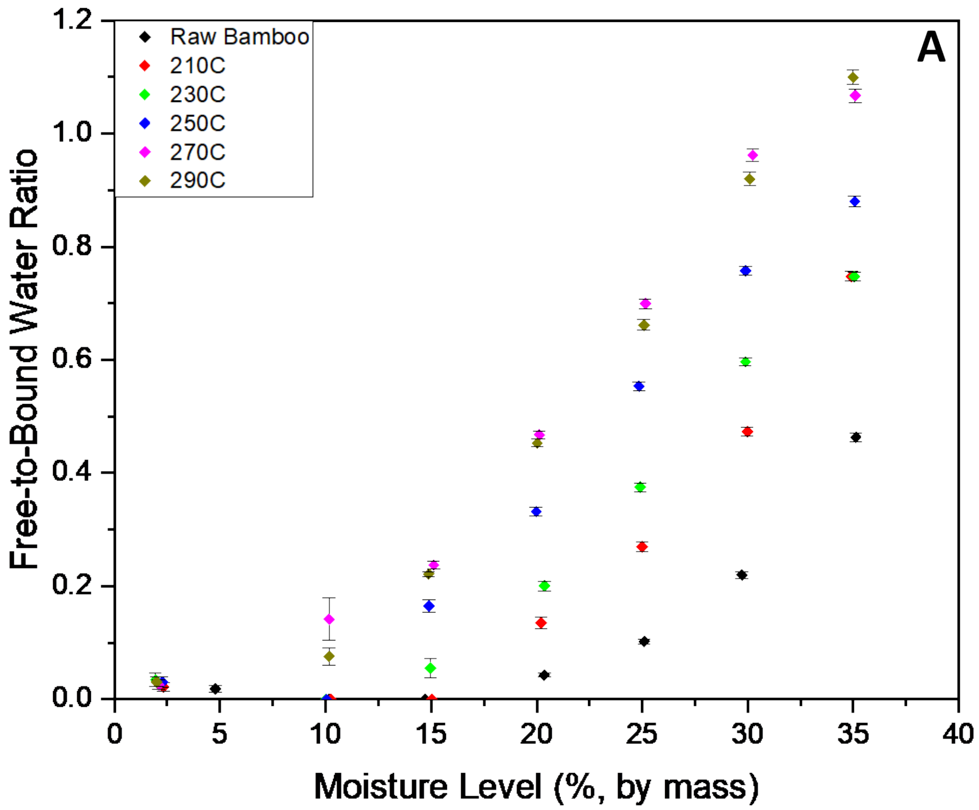
Hydrophobicity: Free-to-Bound Water Ratio

- Decrease of polarity index with the increase of torrefaction temperature.
- It reveals the reduction of polar groups (-OH and C-O) occurred with the increase of torrefaction temperature.
- The increase of torrefaction temperature drives off excess water and volatile organic compounds.

Sample	Polarity index (O/C)
Raw	0.71
O-250	0.55
O-270	0.50
O-290	0.33



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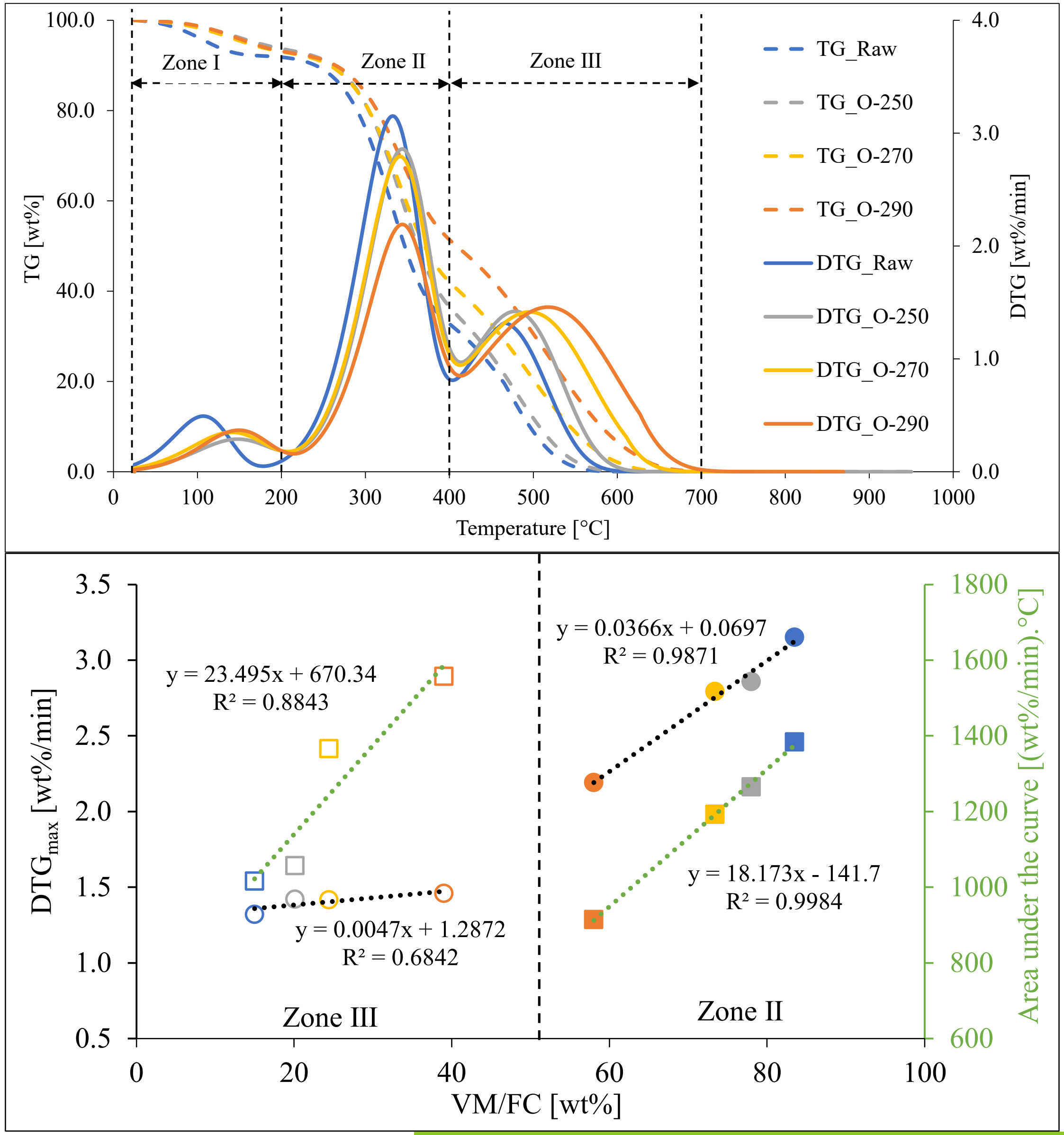
Combustion Characteristics

- The combustion behavior of all the studied samples showed three distinct combustion zones.
  - Zone I: 25–200 °C,
  - Zone II: 200–400 °C
  - Zone III: 400–700 °C
- The VM (Zone II) showed a linear relation with both DTG_{max} and area under the curve while FC (Zone III) was poorly related with them.



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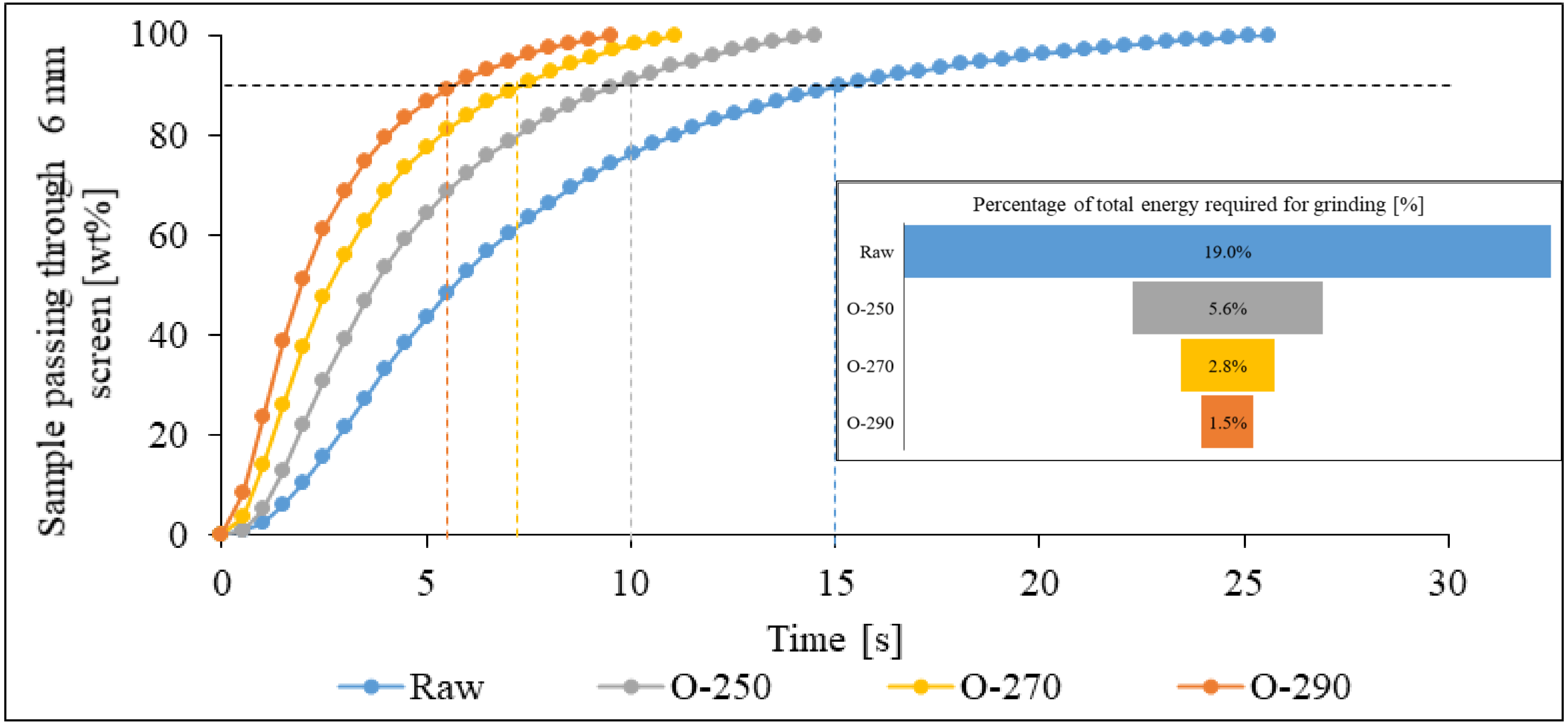
Grindability of Torrefied Bamboo



- The time required to mill the raw bamboo is about 2.7 times higher than the torrefied bamboo.
- Torrefied bamboo took upto 8.5 times less energy to grind through 6 mm screen.

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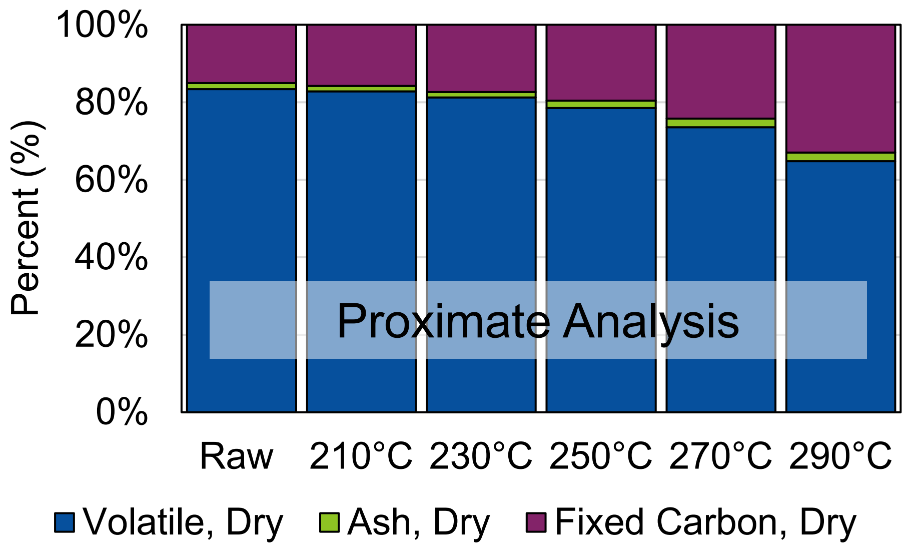
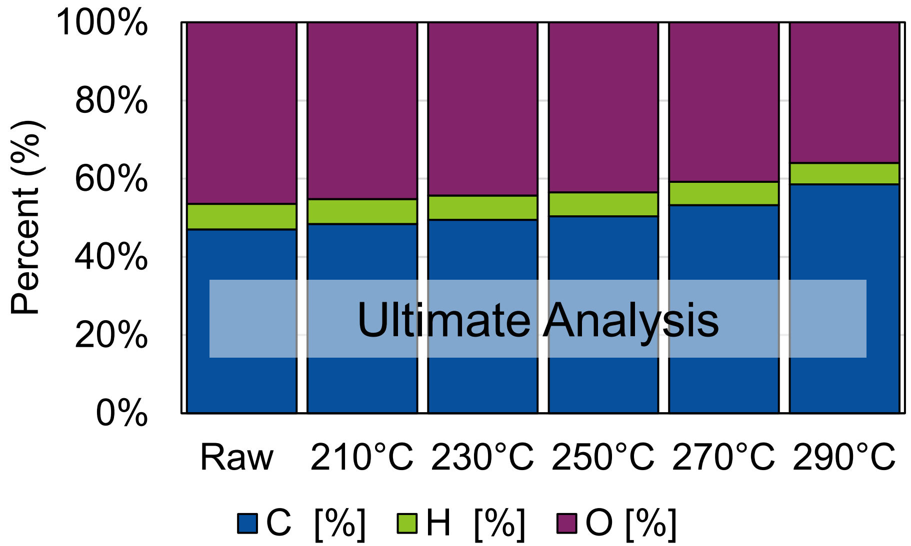
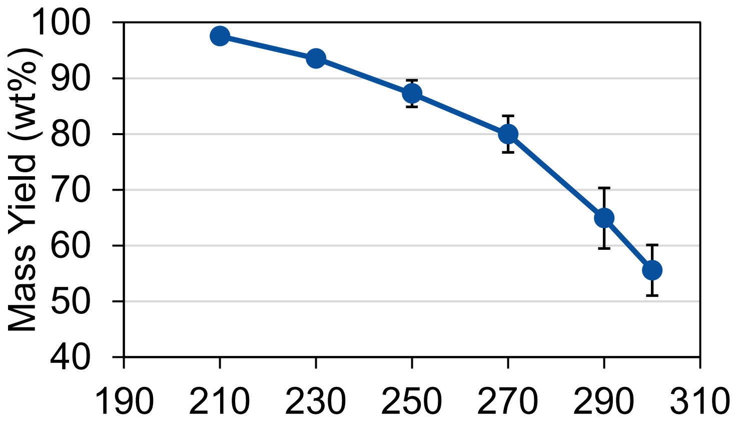
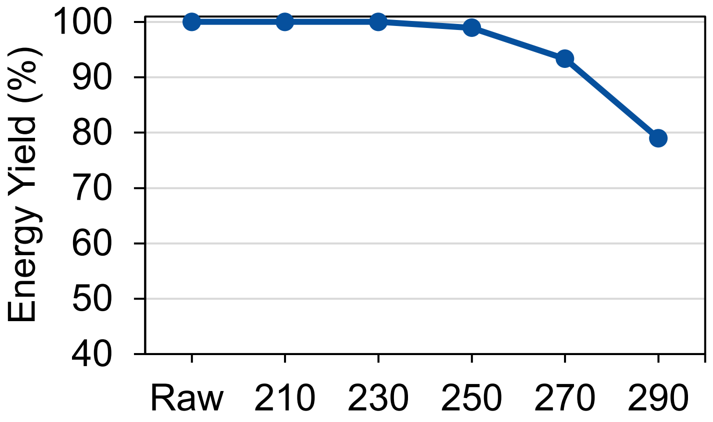
Grindability of Torrefied Bamboo

- As biomass is torrefied, the concentration of carbon increases and it becomes a more energy-dense solid fuel.
- Volatiles are removed from the material, leaving a more porous structure.
- Volatiles can be captured in heat. integration to maintain reactor temperatures, and running autothermally



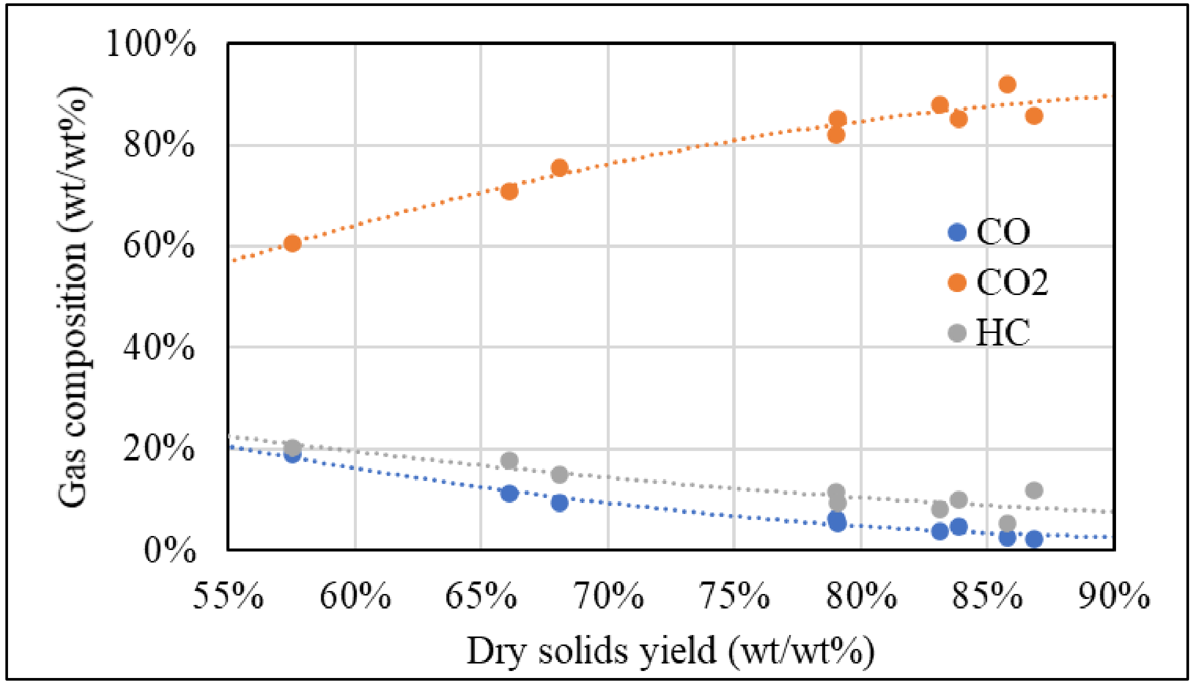






Torrefaction Off-gas

- Evolved gases are predominantly CO_2, paired with the dehydration reactions resulting in the formation of reaction water.
- As the treatment increases in severity, the composition shifts toward a lower proportion of CO_2 to higher concentrations of CO and HC.



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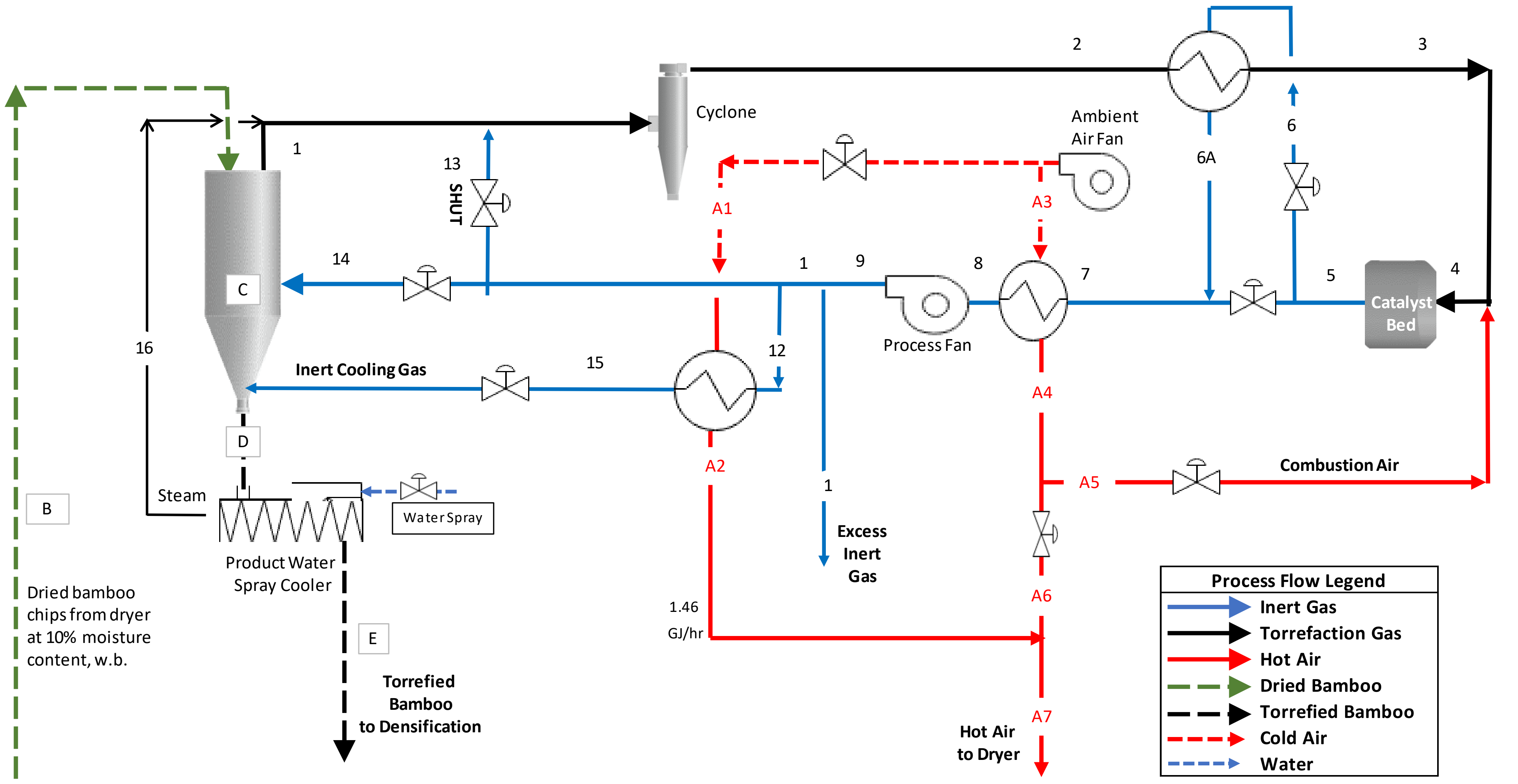
Torrefaction at Commercial Scale – An Example



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Torrefaction at Commercial Scale – An Example

- A 100,000 tonne/y torrefaction plant
- Operating condition: 270 °C for 1 h residence time

Sources of Energy	**GJ/h**	**Contribution (%)**
Thermal energy released from the catalytic oxidation of the torrefaction gases	22.18	85.2
Thermal energy recovered during the operation of the torrefaction system	3.87	14.8
Total energy available	26.05	100
Uses of Energy	**GJ/h**	**Contribution (%)**
Net Torrefaction Reactor energy demand	9.69	37.2
Thermal energy exported as excess inert gas	4.41	16.9
Thermal energy exported as hot air to the drying function	11.18	42.9
Misc. energy losses	0.77	3.0
Total uses	26.05	100

The excess beyond what the process needs: 15.59 GJ/h (1.25 GJ/tonne product)

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Conclusions

- Torrefaction at higher temperatures positively enhances higher heating value.
- Grinding energy reduced 8.5 times with the increase of torrefaction temperature.
- Catalytic oxidation converts chemical energy in the volatiles into thermal energy.
- 1.25 GJ/tonne excess energy can be generated from torrefaction gas.

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[a] Idaho National Laboratory, 1955 N. Fremont Avenue, Idaho Falls, ID 83415, USA
[b] Advanced Torrefaction Systems, 439 South Kirkwood Road, Suite 204, Kirkwood, MO 63122, USA

Future Works

- This is a framework where bamboo was used as a feedstock, however, a similar outcome could be expected from other biomasses. However, a comprehensive investigation various biomasses quantitatively track with these properties can draw more wider conclusions.

https://nextchem.it/what-we-do/technologies/2-g-ethanol

Acknowledgements

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