Presentation for Aviation biofuels workshop, 25 May, Trondheim

Impact of Torrefaction on Fuel Properties of Woody Biomass

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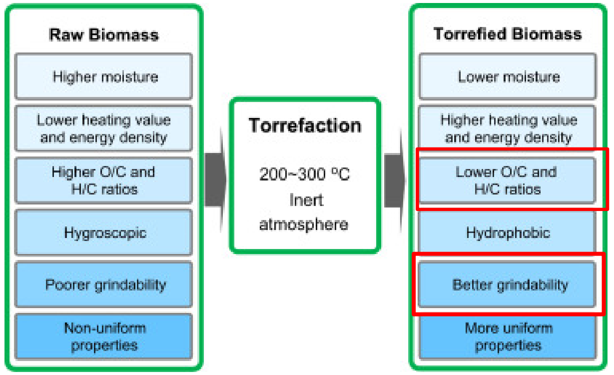
Presentation overview

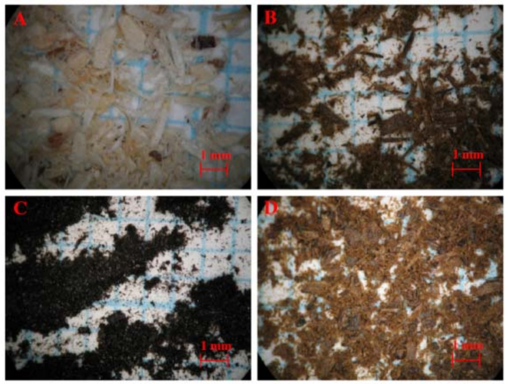
- Background
- Experiment and method
- Result and discussion
- Conclusion

Background

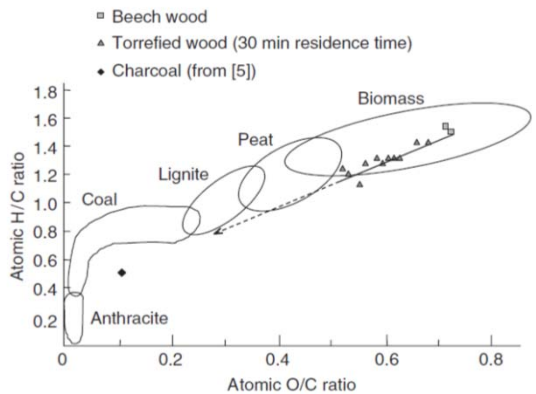
- Biomass and torrefaction
  - ✓ Torrefaction process
  - ✓ Upgrading biomass materials to high quality commodity solid fuels
  - ✓ Improving biomass thermal conversion efficiency



Tumuluru J.S. et al. 2011



Weiland F. et al. 2014

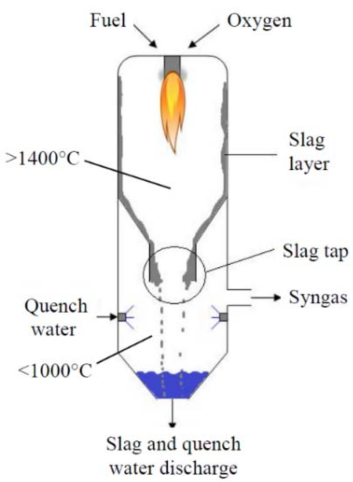


Prins MJ. et al. 2006

Background

- Woody biomass for gasification purpose
  - ✓ The most abundant biomass source in Nordic countries
  - ✓ Further exploiting the low grade woody biomass from forest
  - ✓ Fuel mixing for smooth and efficient entrained flow gasification process
- Torrefaction to improve woody biomass properties for more efficient gasification process

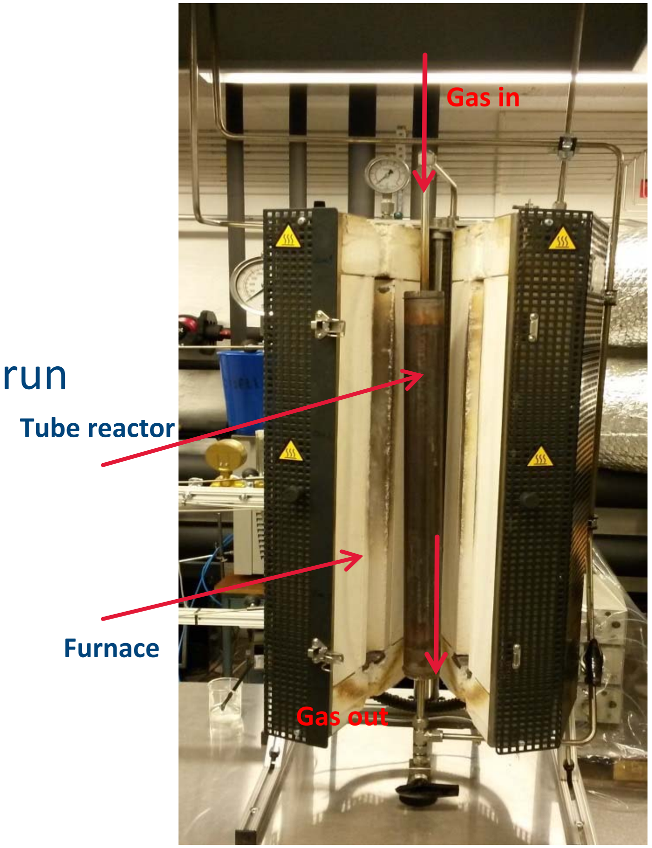
Norway spruce (Picea abies)



Fuel	Spruce stem wood	Spruce bark
Ash content (wt% d.b.)	0.30	2.53
Ca mg/kg (d.b.)	1030	7803
K mg/kg (d.b.)	272	2011
P mg/kg (d.b.)	13	407
Si mg/kg (d.b.)	82	3602
Na mg/kg (d.b.)	22	47
Al mg/kg (d.b.)	16	67
Mg mg/kg (d.b.)	117	807

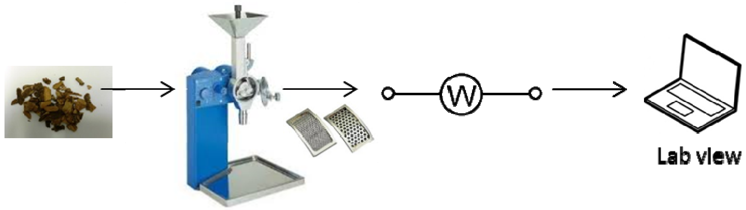
Experiment and method

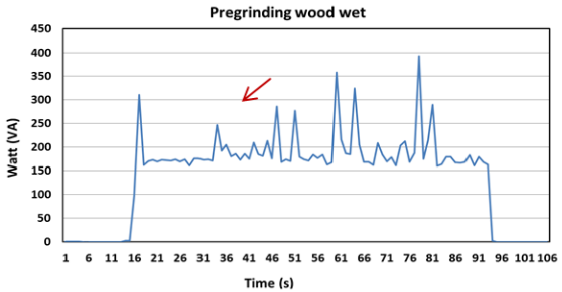
- Feedstock
  - ✓ Stem wood (debarked): 1 x 1 cm cubes
  - ✓ Bark: chipped into pieces (~5-7 cm)
  - ✓ Stump: shredded into pieces (~3-5 cm)
- Torrefaction experiment
  - ✓ Batch reactor with around 80 grams sample for each run
  - ✓ Torrefaction temperature: 225 °C, 275 °C and 300 °C
  - ✓ Residence time: 30 and 60 min
  - ✓ Heating rate 10 °C/min
  - ✓ Continuous nitrogen purge

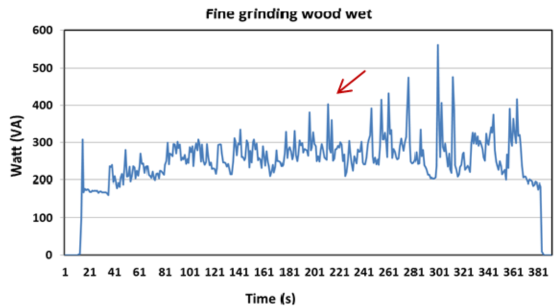


Experiment and method

- Measuring of mass yield
- Assessment of physical properties of raw and torrefied residues
  - ✓ Energy consumption for grinding (IKA MF 10 mill) + energy consumption logger
  - ✓ Particle size distribution of ground samples (FRITSCH vibration sieve shaker)
  - ✓ Morphology investigation of ground samples (Scanning electro microscopy)

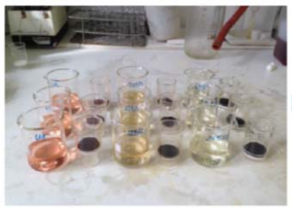






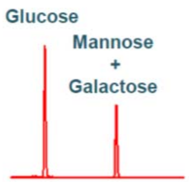
Experiment and method

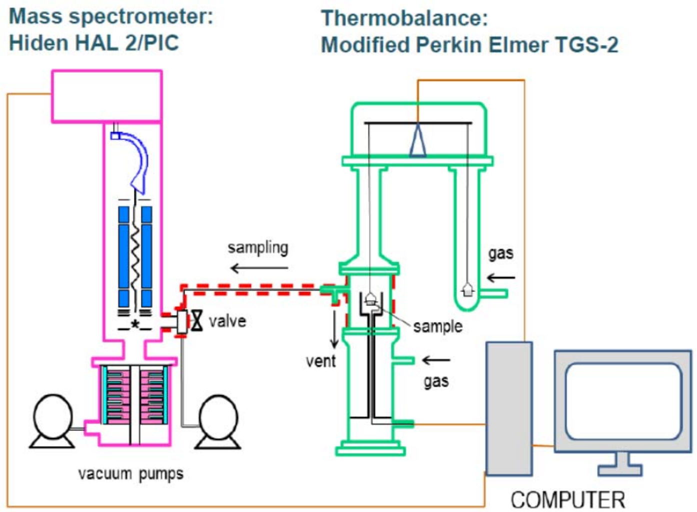
- Carbohydrate and Klason-lignin content
  - ✓ Two-step acidic hydrolysis
    - First step: 25°C, 120 min, 72 w/w% H_2SO_4
    - Second step: 121°C, 60 min, 2.5 w/w% H_2SO_4
  - ✓ Sugar concentrations of the supernatants were analyzed by High-performance liquid chromatography (HPLC)
  - ✓ Klason-lignin content = acid insoluble residue – acid insoluble ash
- Thermogravimetric analysis–mass spectrometry (TG–MS) analysis of raw and torrefied woody biomass
  - ✓ Atmosphere: Argon
  - ✓ Sample amount: ~ 4 mg
  - ✓ Heating rate: 20°C/min from 25°C to 900°C



Hydrolyzed samples

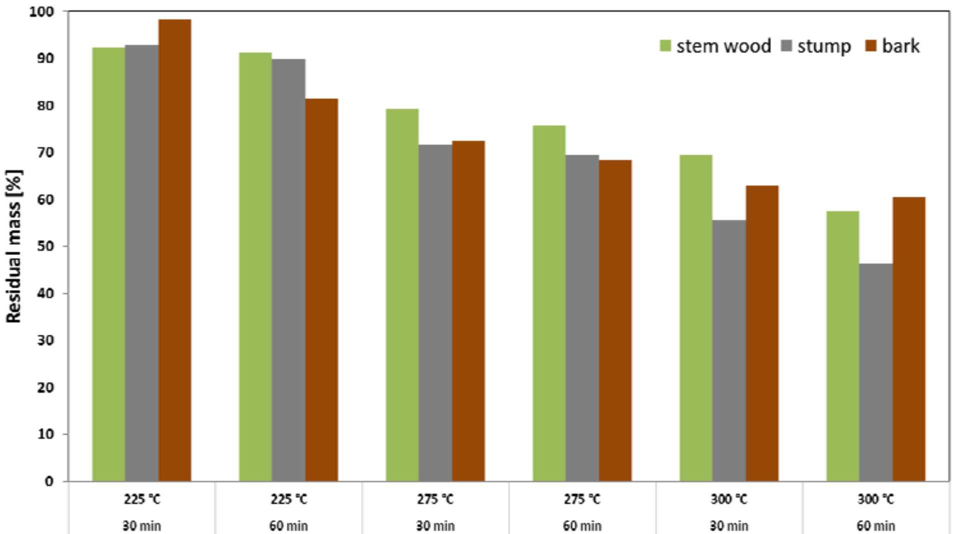
HPLC





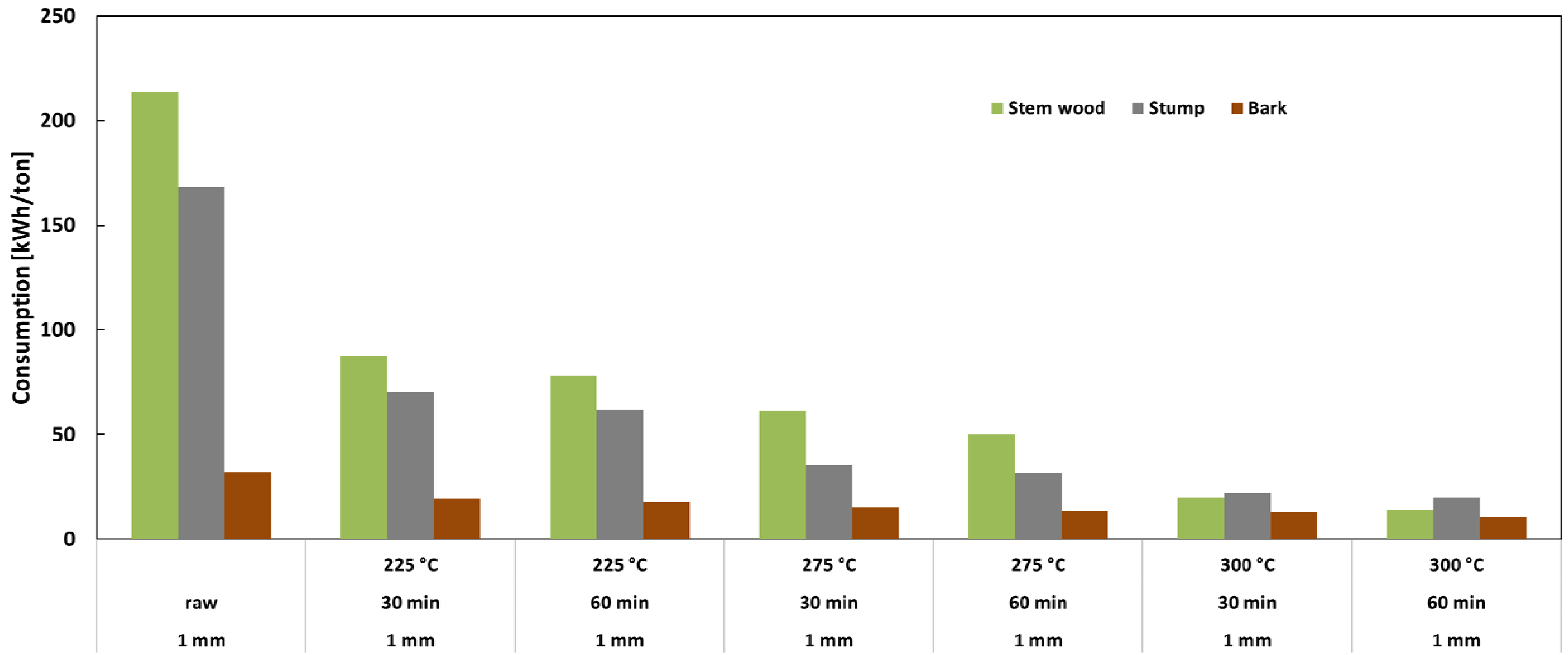
Results and discussion

- Torrefaction mass yield
  - ✓ Decrease of mass yield with increase of torrefaction time and residence time
  - ✓ Differences of mass yield of three woody biomasses
- Preliminary assessment of raw and torrefied woody biomasses



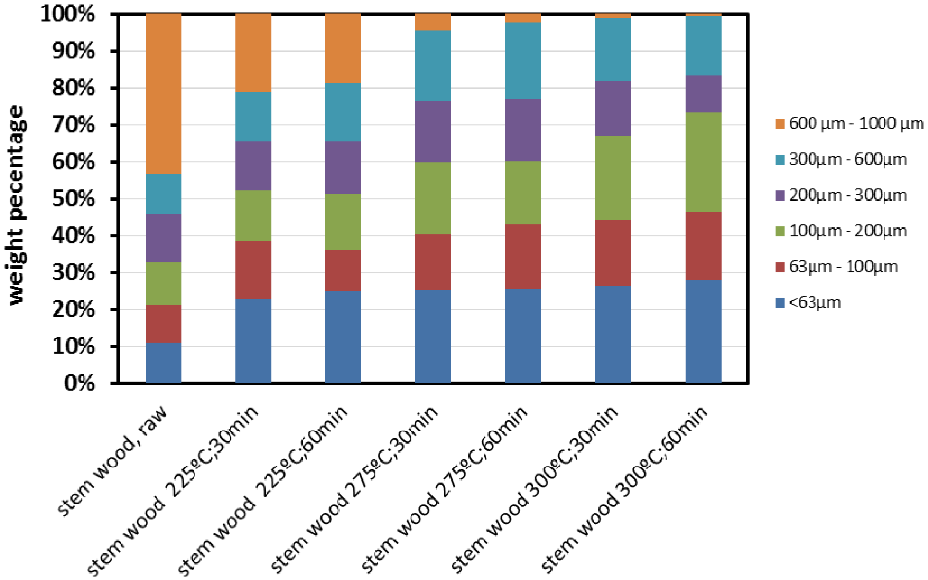
Results and discussion

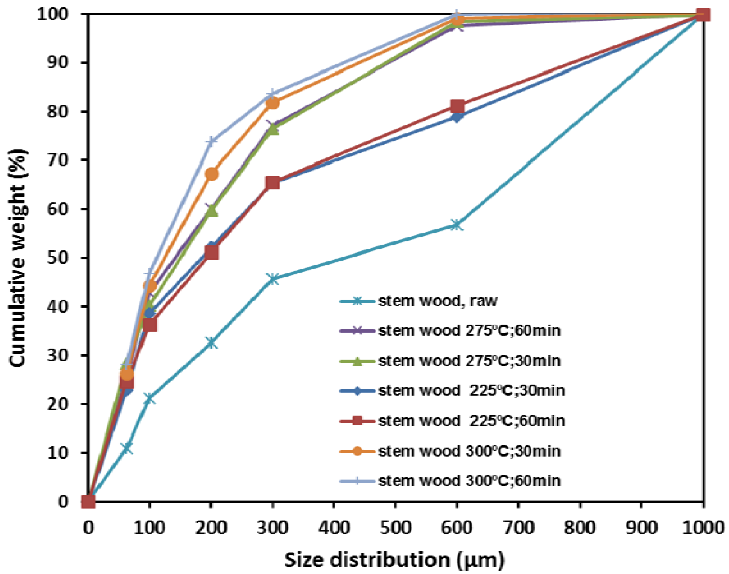
- Grindability of raw and torrefied woody biomasses
  - ✓ Significant reduction of energy consumption for grinding torrefied stem wood and stump
  - ✓ Minor effects of torrefaction treatment on energy consumption for grinding bark
  - ✓ Loss of tenacious nature of tested fuels after torrefaction



Results and discussion

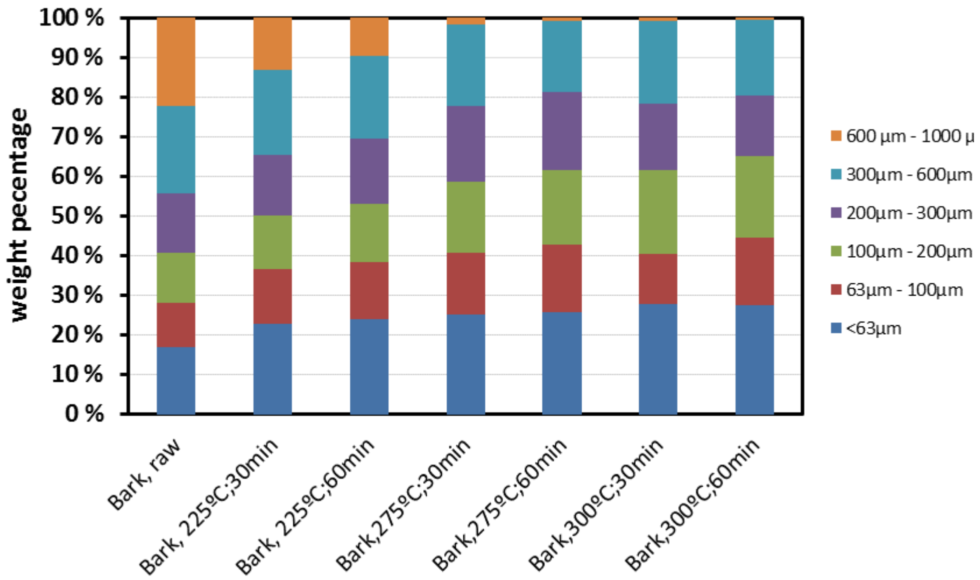
- Particle size distribution of ground raw and torrefied stem wood
  - ✓ Evident particle size reduction of the torrefied stem wood
  - ✓ More uniform and narrower particle sizes of ground stem wood torrefied at high 275 and 300 ◦C

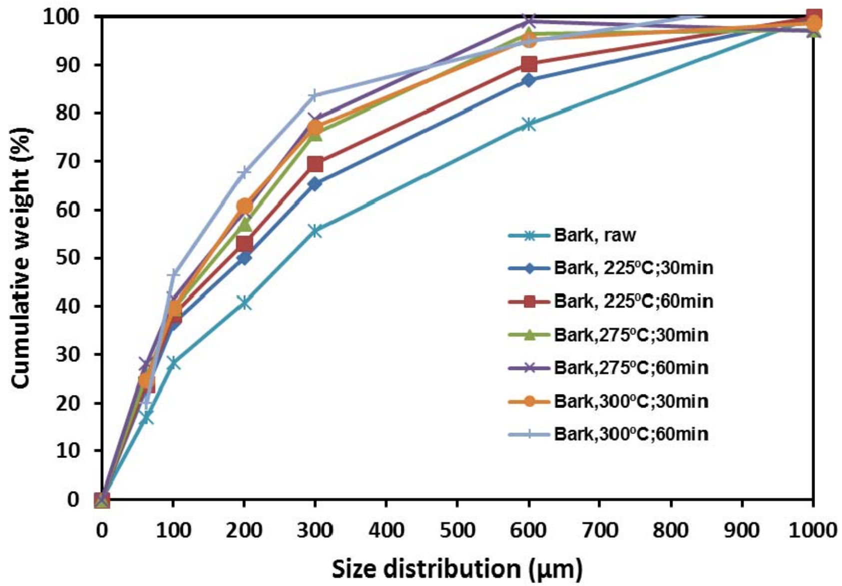




Results and discussion

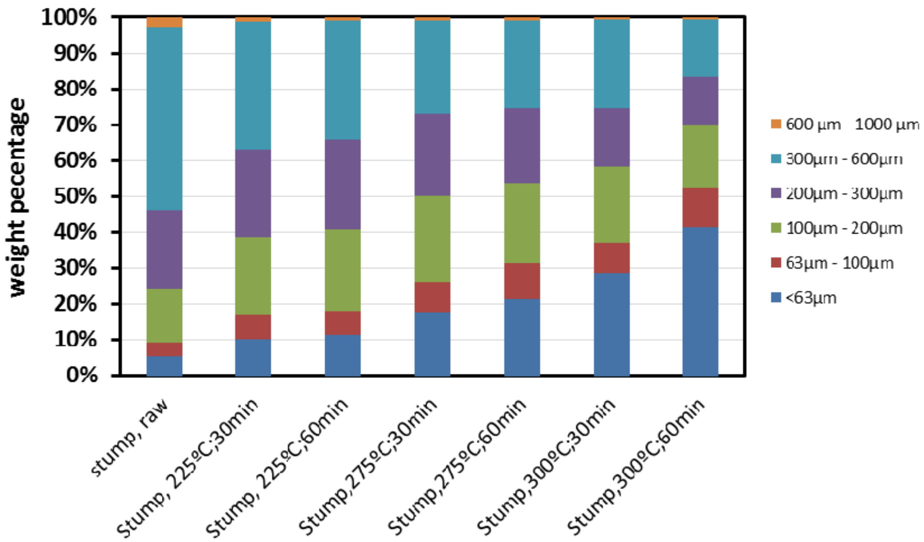
- Particle size distribution of ground raw and torrefied bark
  - ✓ Significant reduction of particles with size in the range of 600-1000 µm
  - ✓ Increase of fraction of particles smaller than 63 µm
  - ✓ Small effect of torrefaction on ground bark size distribution as torrefaction temperature higher than 275 ◦C

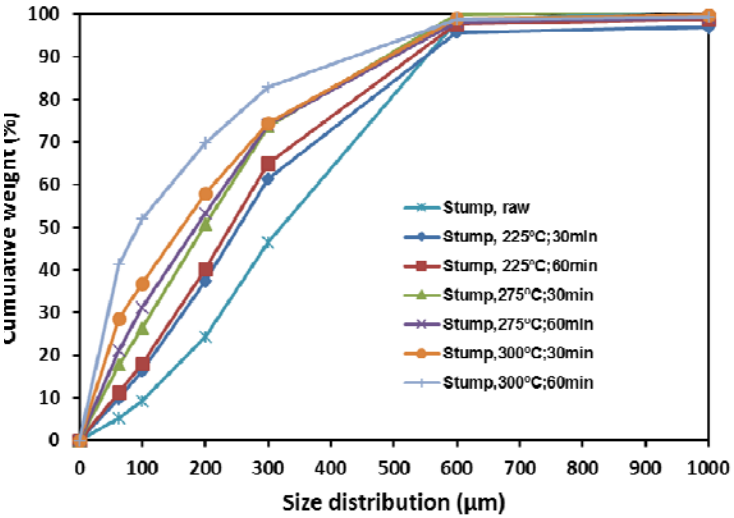




Results and discussion

- Particle size distribution of ground raw and torrefied stump
  - ✓ Better grindability compared to stem wood
  - ✓ Minor fraction of particles with size in range 600-1000 µm
  - ✓ Pronounced increase of particles with sizes smaller than 63 µm





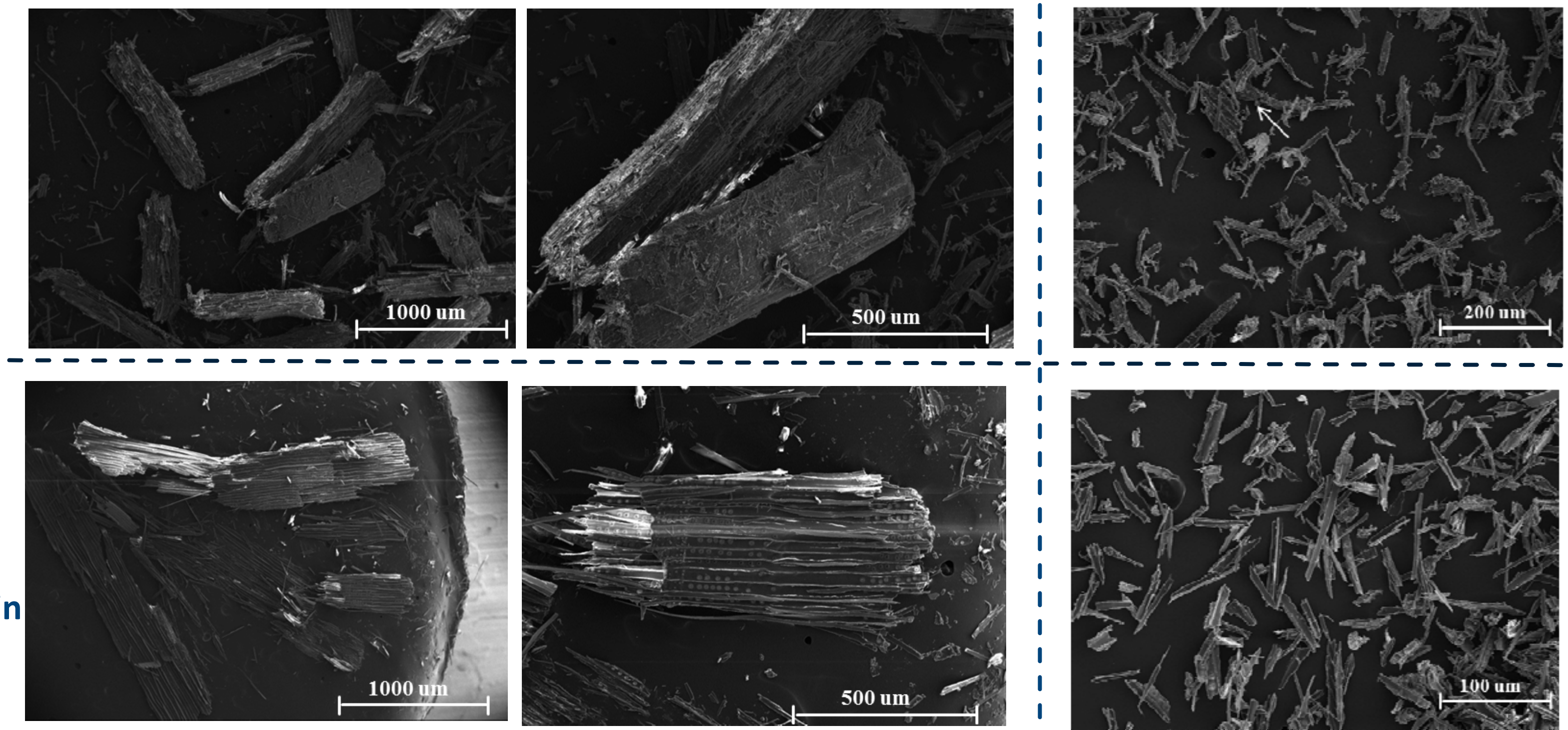
Results and discussion

- SEM images of raw and torrefied stem wood

	Large particle	Small particle
Raw stem wood	Dense structure	Long and fibrous structure
Stem wood 275◦C-60 min	Layer structure with more openings	Short and clean/smooth surface

Stem wood raw

Stem wood 275◦C-60 min



600 µm <d < 1000 µm

d < 63 µm

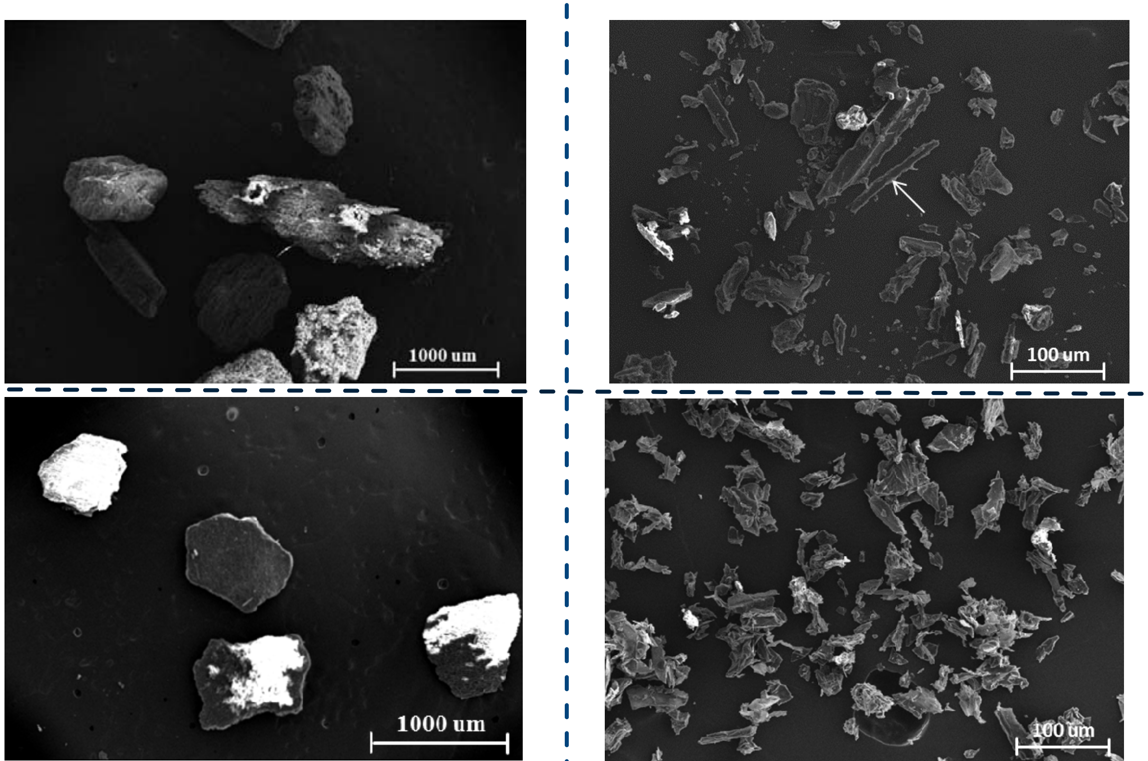
Results and discussion

- SEM images of raw and torrefied bark

	Large particle	**Small particle**
Raw bark	Porous fibrous structure	long stick particles with fibrous structure
Bark 275◦C-60 min	Dense flakelike structure	Short and clean/smooth surface

Bark raw

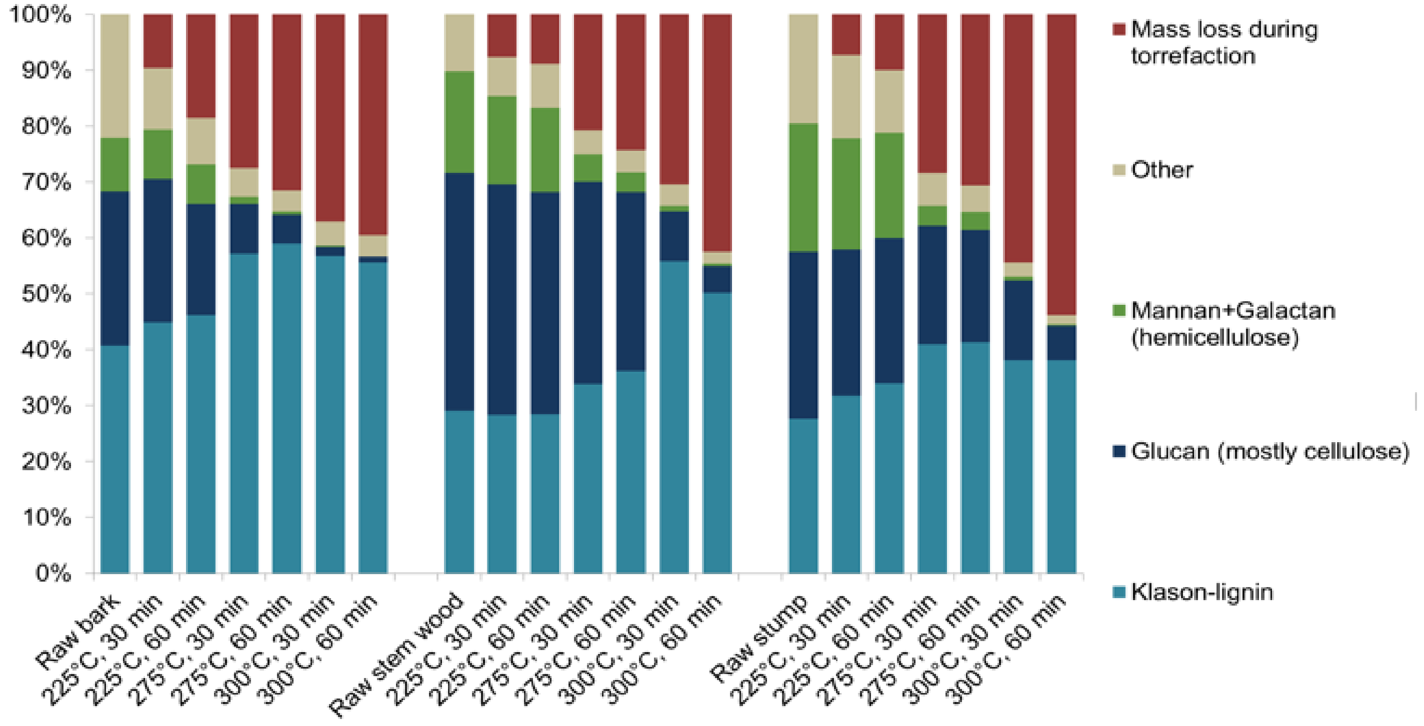
Bark 275◦C-60 min



600 µm <d < 1000 µm **d < 63 µm**

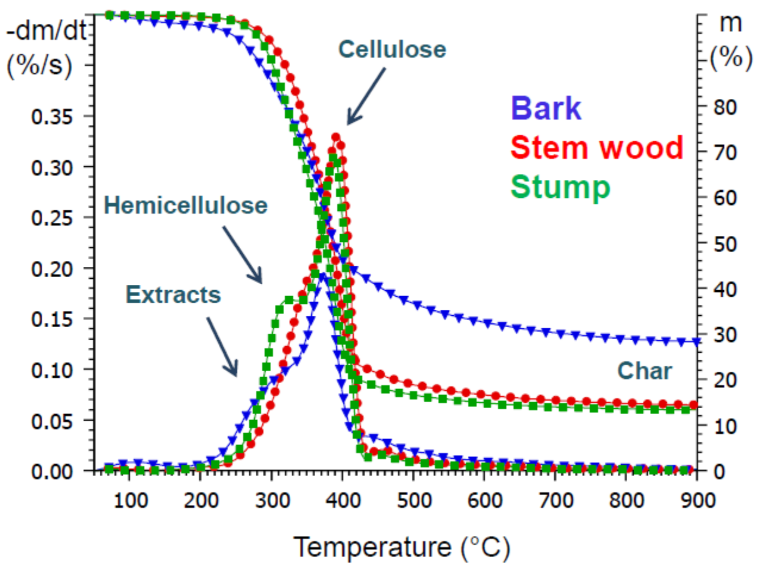
Results and discussion

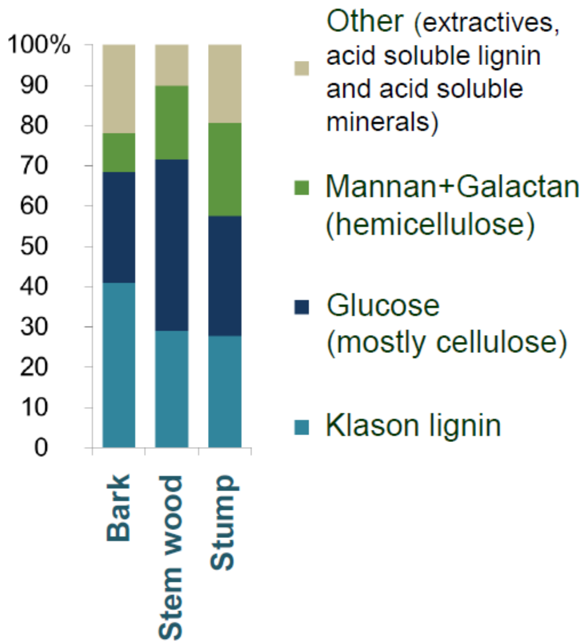
- Compositional analysis of raw and torrefied woody biomass
  - ✓ Different compositions of raw stem wood, bark and stump
  - ✓ Decrease of hemicellulose along increase of torrefaction temperature
  - ✓ Substantial decomposition of cellulose for bark sample at 275 ◦C
  - ✓ Significant decrease of hemicellulose and cellulose content at 300 ◦C



Results and discussion

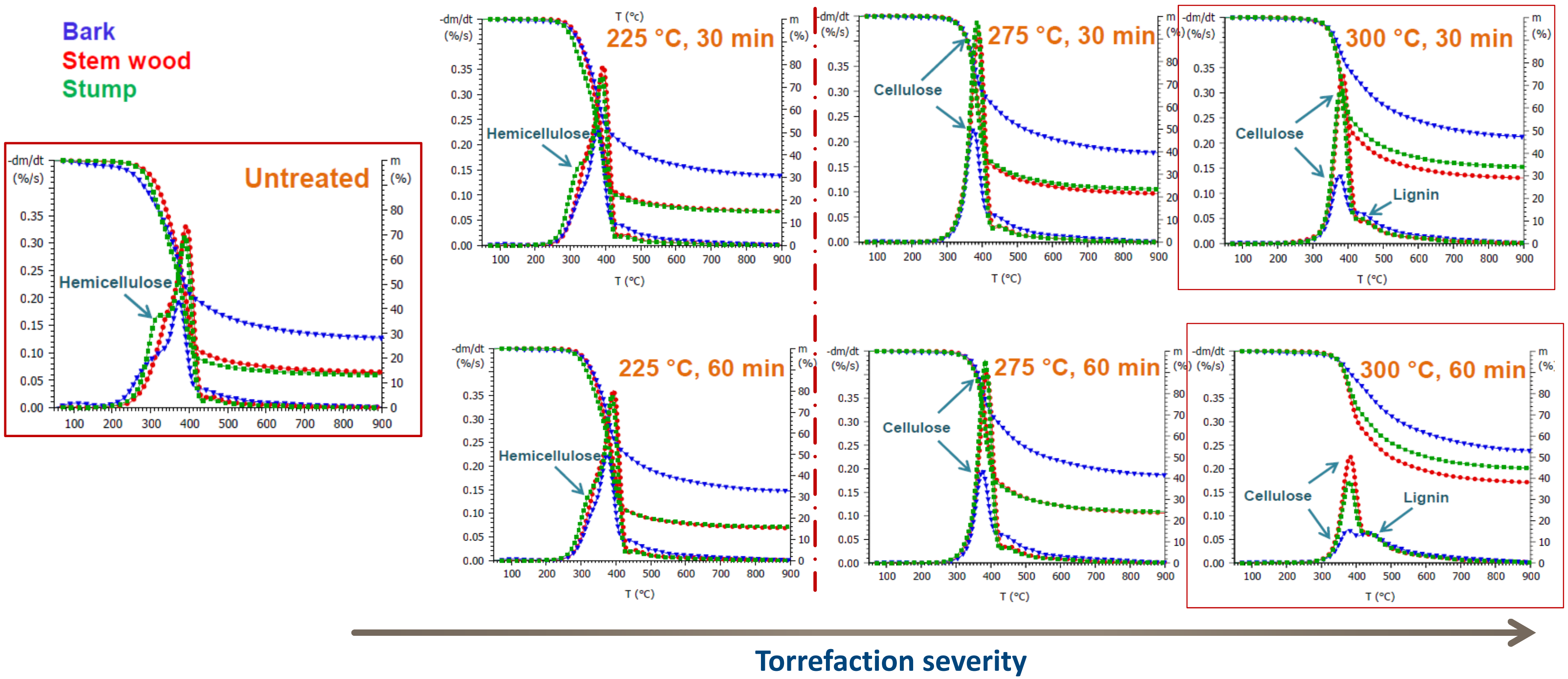
- Compositional and TG-MS analysis of raw and torrefied woody biomass
  - ✓ Correlating the chemical compositions with decomposition behaviours
  - ✓ Decomposition of hemicellulose at around 300 ◦C - the shoulder showing in DTG curve
  - ✓ Decomposition of cellulose around 350 ◦C – the main peak in DTG curve





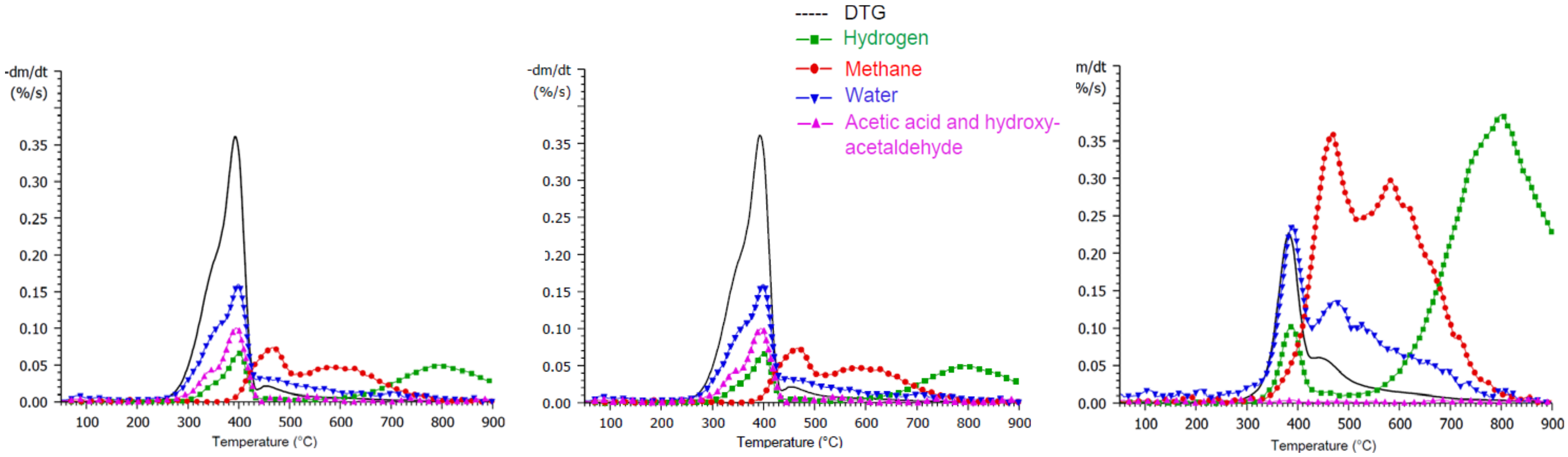
Results and discussion

- Compositional and TG-MS analysis of raw and torrefied woody biomass
  - ✓ Disappearing of characteristic shoulder – indication of decomposition of hemicellulose
  - ✓ Decrease of thermal decomposition for torrefied woody biomasses
  - ✓ Indication higher degradation degree of cellulose during torrefaction



Results and discussion

- TG-MS analysis of raw and torrefied stem wood
  - ✓ Release of gases and water during thermal decomposition
  - ✓ Evolution of acetic acid in the temperature range of 280-360 ◦C indicating scission of the acid groups from hemicellulose
  - ✓ Acetic acid and hydroxyl-acetaldehyde-product from decomposition of cellulose
  - ✓ Formation of hydrogen and methane due to charring of lignin



Raw stem wood

225 °C-60 min

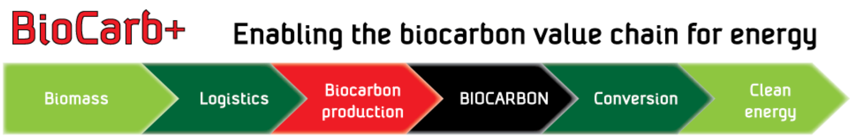
300 °C- 60 min

Conclusion

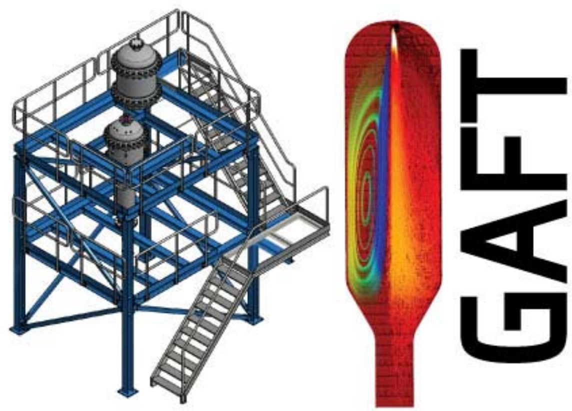
- Torrefaction operation conditions and biomass properties have significant effects on amounts of remaining solid residues (mass yield)
- Grindability of stem wood and stump can be significant improved via torrefaction treatment
- The energy consumption for grinding torrefied stem wood and stump are dramatically reduced
- Torrefaction significantly influence particles size distribution of ground stem wood and stump
- Energy used for grinding samples and sizes of ground samples can be further decreased with high temperature torrefaction process or/and longer torrefaction time
- Torrefaction causes considerably reduction of hemicellulose content and partially decomposition of cellulose
- At high conversion temperature, torrefied feedstocks have evidently different conversion behaviors, due to change of chemical compositions of the stem wood, bark and stump during torrefaction process

Acknowledgment

Financial support by the Research Council of Norway and a number of industrial partners through the project GAFT ("Gasification and FT-Synthesis of Lignocellulosic Feedstocks") and BioCarb+ ("Enabling the biocarbon value chain for energy").



https://www.sintef.no/projectweb/biocarb/



https://www.sintef.no/en/projects/gaft-gasification-and-ft-synthesis-of-lignocellulo/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