Torrefaction to improve biomass logistics (and end-use)

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Your energy. Our passion.

Torrefaction to improve biomass logistics (and end-use)

Mini symposium Biomass developments in ports

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Biomass – a difficult energy source

- In view of:
  - Logistics (handling, transport and feeding)
  - End-use (combustion, gasification, chemical processing)

- Difficult properties are:
  - Low energy density (LHV_{ar} = 10-17 MJ/kg)
  - Hydrophilic
  - Vulnerable to biodegradation
  - Tenacious and fibrous (grinding difficult)
  - Poor "flowability"
  - Heterogeneous

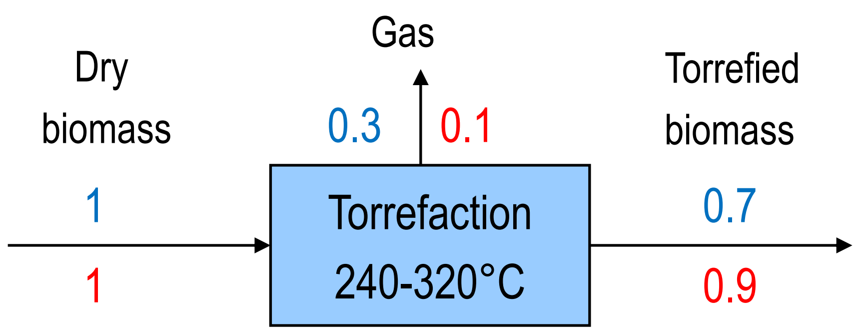
Bioenergy – major challenge

- Enable decoupling of biomass production and use
  - Place
  - Time
  - Scale

- By converting biomass in high-quality bioenergy carriers (solid, liquid or gas), that:
  - Better fit in (existing) logistic infrastructures
  - Allow efficient, reliable and cost effective conversion into electricity and heat, transport fuels and chemicals

Solve biomass related problems at the source

Torrefaction for upgrading biomass



Energy densification (MJ/kg) $1 \frac{0.9}{0.7} = 1.3$

mass **energy**

Process parameters

– Temperature: 240-320°C

– Absence of oxygen

Torrefaction for upgrading biomass

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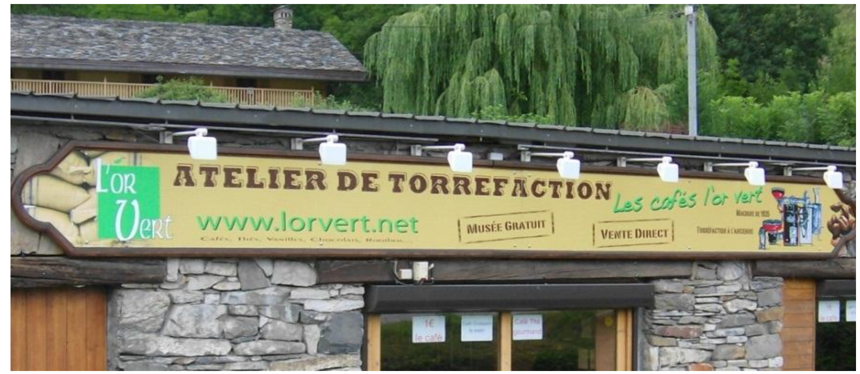


Tenacious and fibrous
LHV = 9 - 12 MJ/kg
Hydrophilic
Biodegradable
Heterogeneous

Torrefaction

Friable and less fibrous
LHV = 18 - 24 MJ/kg
Hydrophobic
Preserved
Homogeneous

Pelletisation

Bulk density = 650-800 kg/m^3
Bulk energy density = 12 - 19 GJ/m^3

Torrefied biomass properties in perspective

	Wood chips	Wood pellets	Torrefied wood pellets	Charcoal	Coal
Moisture content (wt%)	30 – 55	7 – 10	1 – 5	1 – 5	10 – 15
Calorific value (LHV, MJ/kg)	7 – 12	15 – 17	18 – 24	30 – 32	23 – 28
Volatile matter (wt% db)	75 – 84	75 – 84	55 – 65	10 – 12	15 – 30
Fixed carbon (wt% db)	16 – 25	16 – 25	22 – 35	85 – 87	50 – 55
Bulk density (kg/l)	0.20 – 0.30	0.55 – 0.65	0.65 – 0.80	0.18 – 0.24	0.80 – 0.85
Vol. energy density (GJ/m³)	1.4 – 3.6	8 – 11	12 – 19	5.4 – 7.7	18 – 24
Hygroscopic properties	Hydrophilic	Hydrophilic	(Moderately) Hydrophobic	Hydrophobic	Hydrophobic
Biological degradation	Fast	Moderate	Slow	None	None
Milling requirements	Special	Special	Standard	Standard	Standard
Product consistency	Limited	High	High	High	High
Transport cost	High	Medium	Low	Medium	Low

<u>Abbreviations:</u>
db = dry basis
LVH =Lower Heating Value

sources: ECN (table, fig.1, 3), Pixelio (fig. 2, 5), ofi (fig. 4)





Markets

- Feedstock
  - Woody biomass (residues): torrefaction pellets expected to “largely” replace conventional wood pellets, especially for large-scale applications (Poyry-study forecasts 46 Mtonne/a global pellets production in 2020) + disclosure of additional forestry residues
  - Agricultural residues (e.g., straw, bagasse, palm oil residues)
  - Paper-plastic fractions and other “wastes”

- End-use applications
  - Co-firing in pulverised-coal boilers
  - (Co-)gasification in entrained-flow gasifiers (biofuels production, IGCC)
  - Small-scale pellet boilers and stoves

The added value of torrefaction

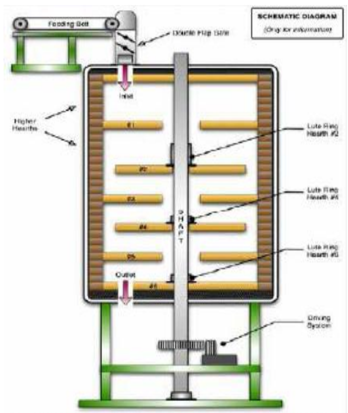
- Torrefaction (+ densification) enables energy-efficient (>90%) upgrading of biomass into *commodity solid biofuels* with favourable properties in view of logistics and end-use
- Favourable properties include high energy density, better water resistance, slower biodegradation, good grindability, good “flowability”, homogenised material properties
- Therefore, cost savings in handling and transport, advanced trading schemes (futures) possible, capex savings at end-user (e.g. outside storage, direct co-milling and co-feeding), higher co-firing percentages and enabling technology for gasification-based biofuels and biochemicals production
- Applicable to a wide range of lignocellulosic biomass feedstock, even mixed waste streams



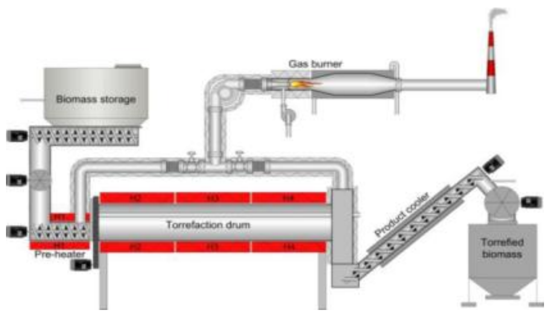

Torrefaction technology

- Many technology developers (>50) due to strong market pull
- Often application of reactor technology proven for other applications (drying, pyrolysis, combustion)
- Good process control is essential for good performance and product quality control (temperature, residence time, mixing, condensables in torrefaction gas)
- High energy efficiency is crucial in view of overall cost and sustainability; overall energy efficiency is strongly dependent on heat integration design
- In general: torrefaction technology in demonstration phase with >10 demo-units and first commercial units in operation and under construction

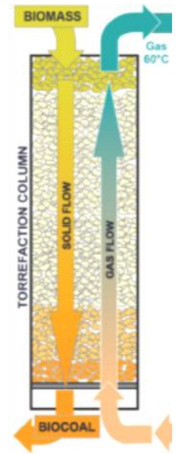
Torrefaction technology – many reactor concepts considered



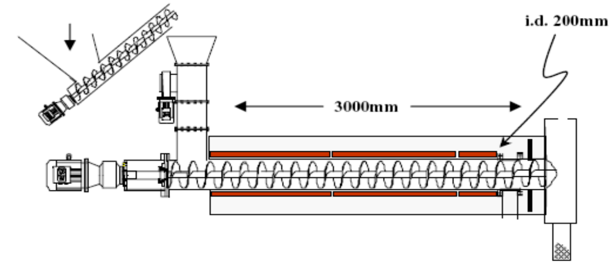
Multiple hearth furnace



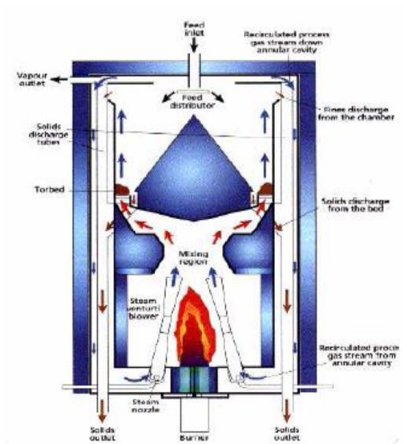
Rotary drum reactor



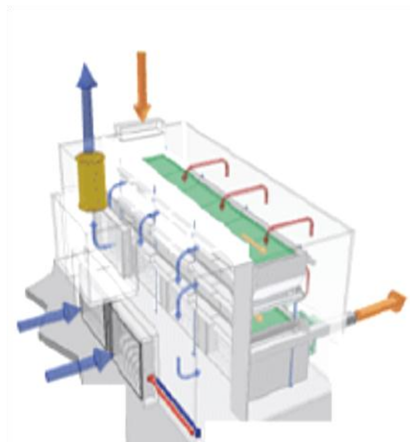
Moving bed reactor



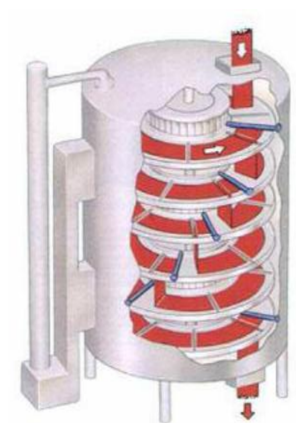
Screw conveyor reactor



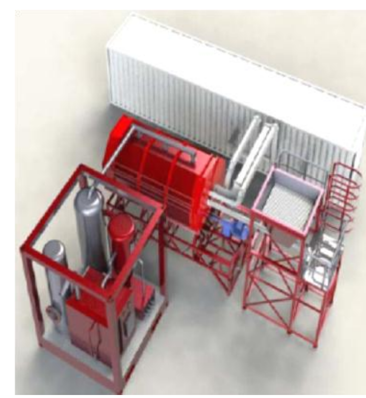
Torbed reactor



Oscillating belt reactor

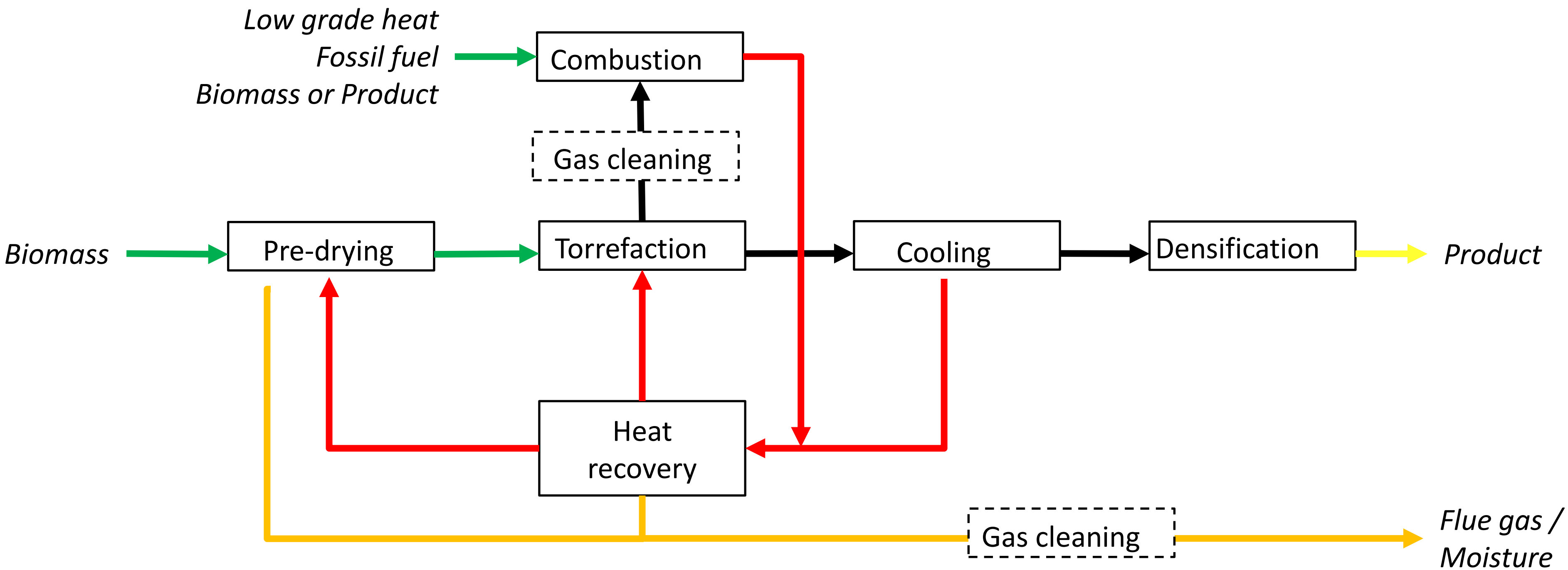


TurboDryer



Microwave reactor

Torrefaction technology – process design



- Heat integration:
  - Pre-drying, torrefaction and cooling
  - Use of low-grade heat from other industrial processes
  - Torrefaction: indirect heating or direct heating by recycling flue gas or torrefaction gas

Densification

- Focus on pelletisation, but briquetting considered as well
- Good quality pellets can be produced without additional binder
- But:
  - Pelletisation performance strongly dependent on biomass feedstock
  - Case-by-case tuning of the pelletisation conditions (e.g., die type) required
  - Good control of torrefaction conditions is essential
  - Without binder, window for tuning product quality to logistics and end-use requirements may be small
  - Special attention to safety issues (e.g., self heating, dust explosions)

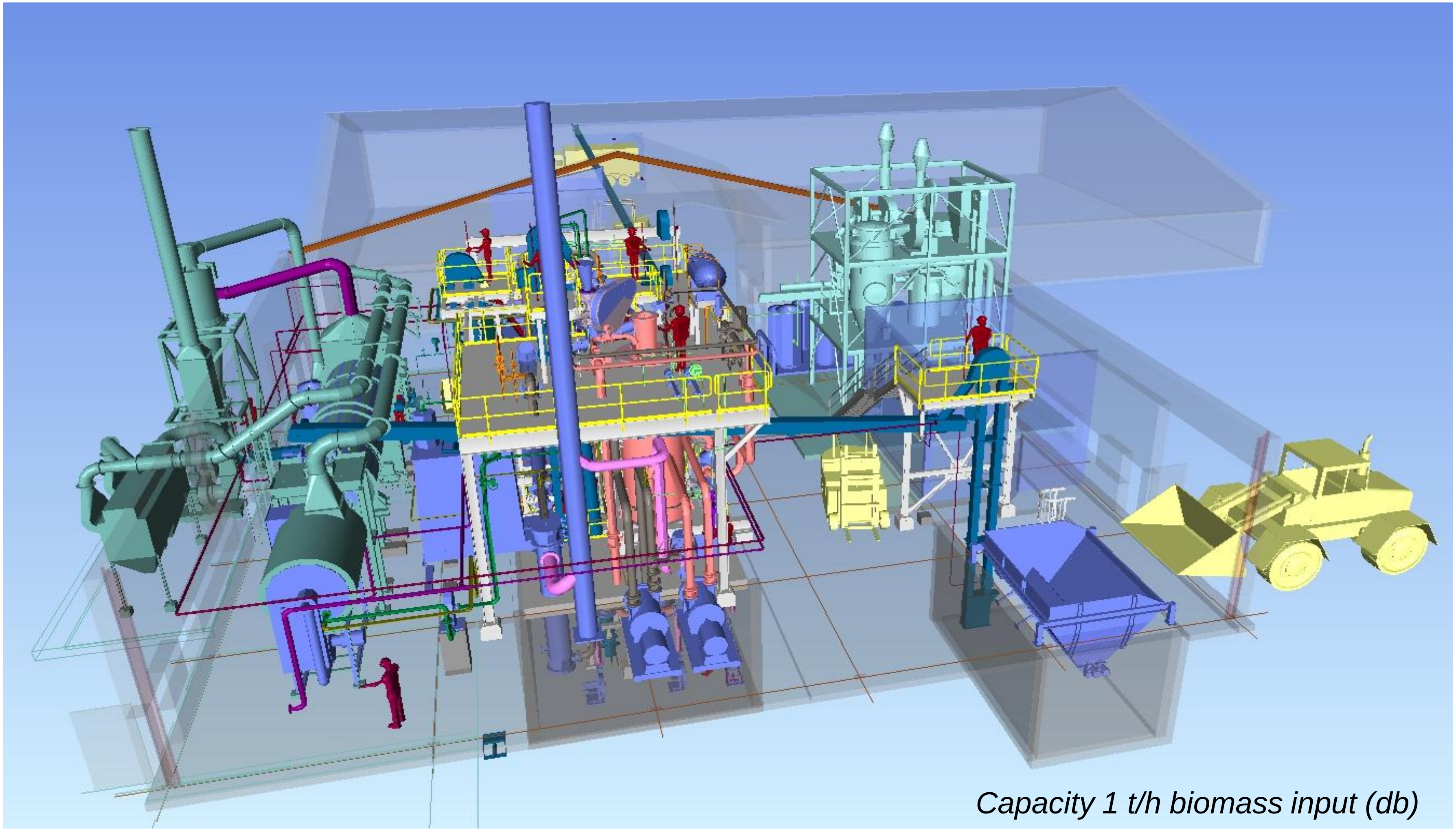
ECN and torrefaction

- 20 years experience in biomass co-firing R&D, identified the potential of torrefaction and played a pioneering role in adapting torrefaction to bioenergy applications since 2002
- ECN's torrefaction technology proven on pilot-scale and together with industrial partners now taken to demonstration and commercial market introduction
- Contract R&D for industry to assess the torrefaction potential of specific feedstocks, produce test batches and optimise product quality

ECN 50 kg/h torrefaction pilot-plant

Torrefaction demo plant

Overall view



Capacity 1 t/h biomass input (db)

Torrefaction demo plant

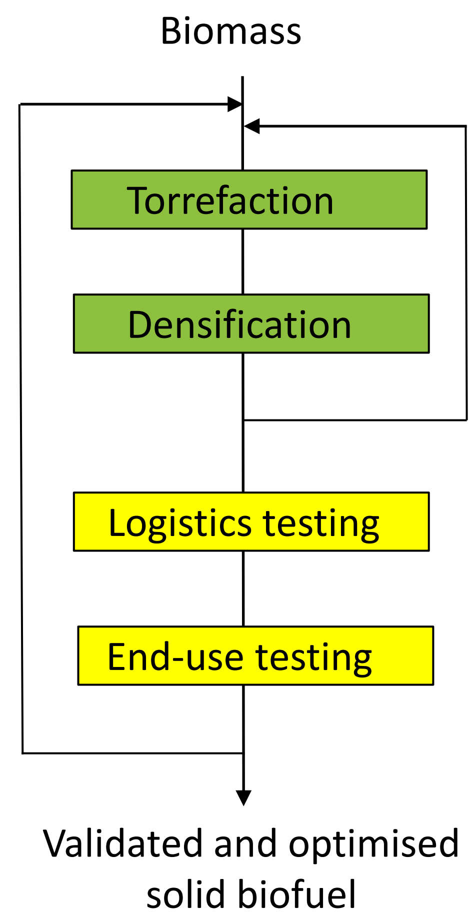
Key features and status

- Demo plant comprises pre-drying, torrefaction and pelletisation
- Blends ECN and Andritz technologies
- Torrefaction pressurized for more effective heat transfer
- Torrefaction reactor contains separate zones for final drying and torrefaction
- Torrefaction reactor design lends itself to scale up to large single unit capacities
- Status: successful production of first test batches (> 100 ton torrefied pellets)

Torrefaction reactor process area

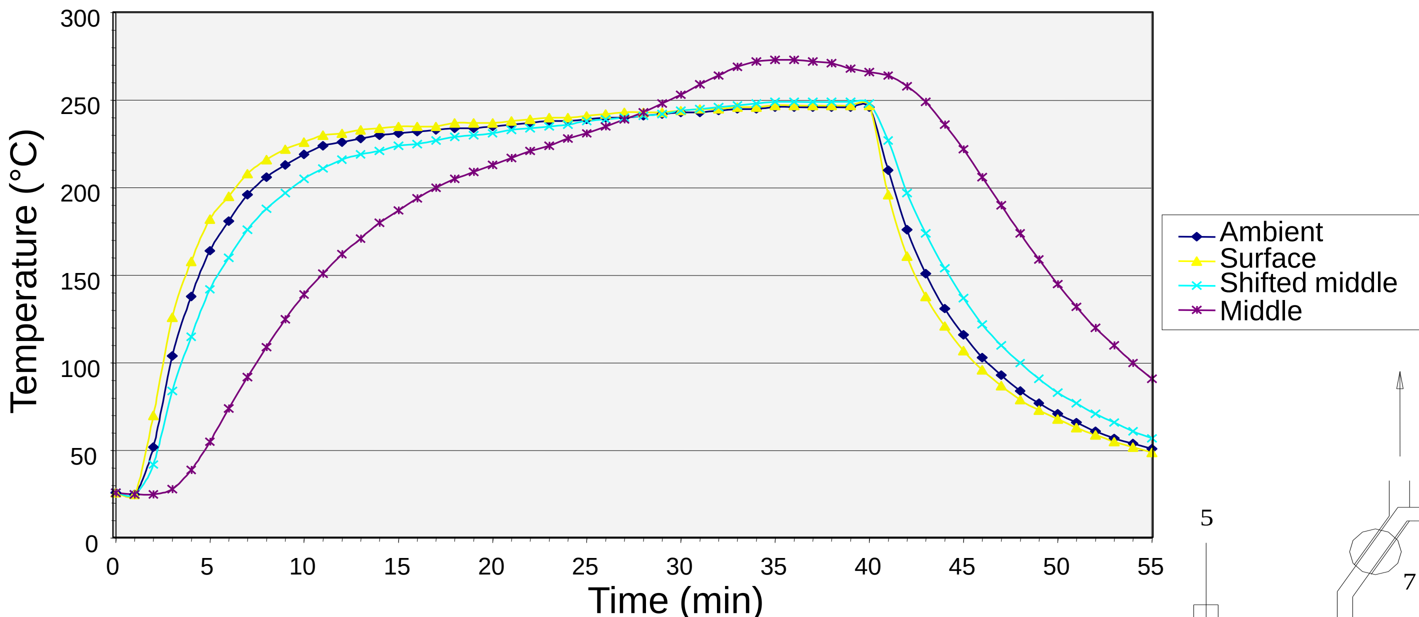
Product quality optimisation

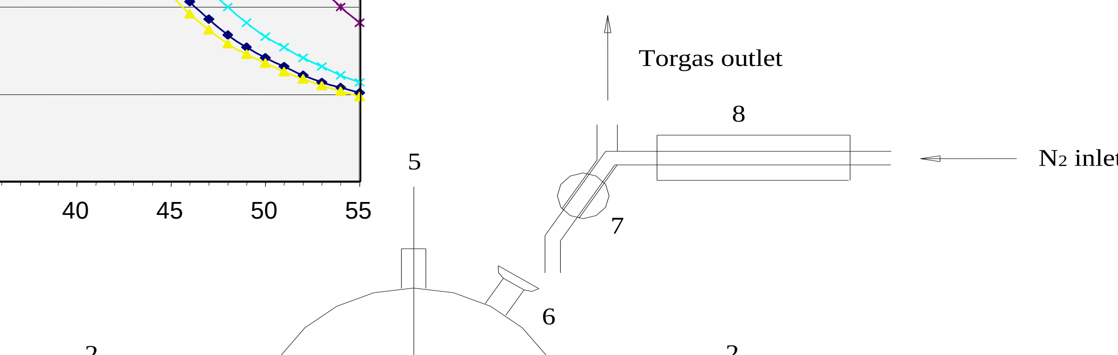
- Pilot, demo and first commercial plants produce kg-tonne scale batches allowing representative logistics and end-use performance testing by industry
- Many coal-fired power plants want to be early adaptors and show interest in conducting co-firing trials (e.g., RWE, Vattenfall, CEATI consortium)
- Product quality optimisation requires a systematic iterative approach (2 iterative loops)
- For this purpose, European torrefaction developers, combustion and gasification technology providers and end-users have joined forces in the EU-FP7 project proposal SECTOR



Exothermicity

Single particle tests





1. Thermal ceramic bricks
2. Screws
3. Glass sphere cut by the middle
4. Woody ball
5. Themocouples and their inlet
6. Gas inlet-outlet
7. Steel ball with double tube to act as inlet and outlet
8. Gas heater

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Self-heating

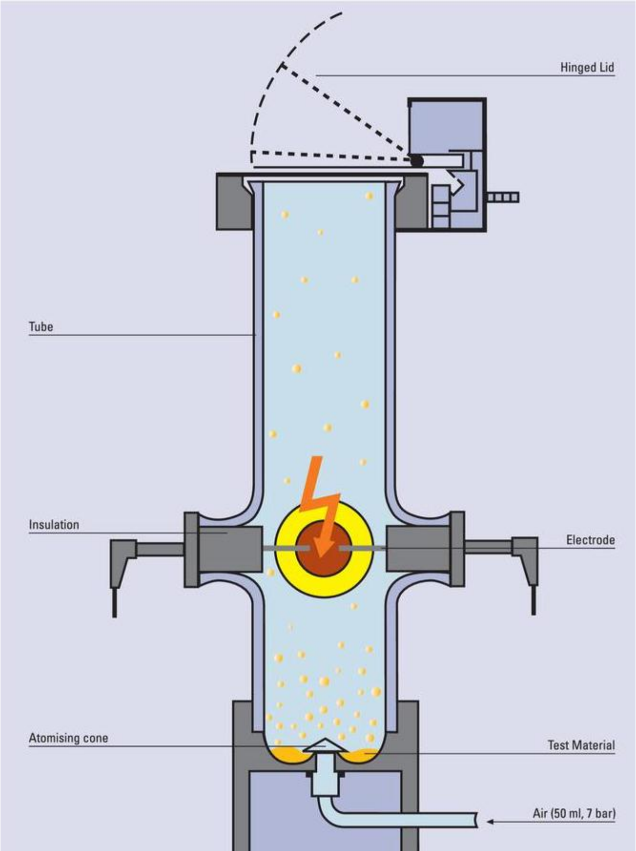
Chemical oxidation of torrefied material

- Accidents detrimental to the entire torrefaction industry
- ECN conducted extensive bench-scale testing to better understand and quantify self-heating propensity
- Self-heating propensity dependent on type of biomass, torrefaction degree and type of product (e.g., torrefied chips or pellets)

End of production run on Wednesday → **Fire on Saturday**

Dust explosion
How to test

- Approach: open Hartmann tube
  - Simple, effective, world wide recognised equipment
  - Readily available from several vendors
  - Suitable for small batches (thus relatively safe)
  - Allowing for the determination of crucial parameters:
    - minimum ignition energy
    - concentration explosion limits
    - in the function of T, $[O_2]$,$[H_2O]$



Source: STAHL explosion protection

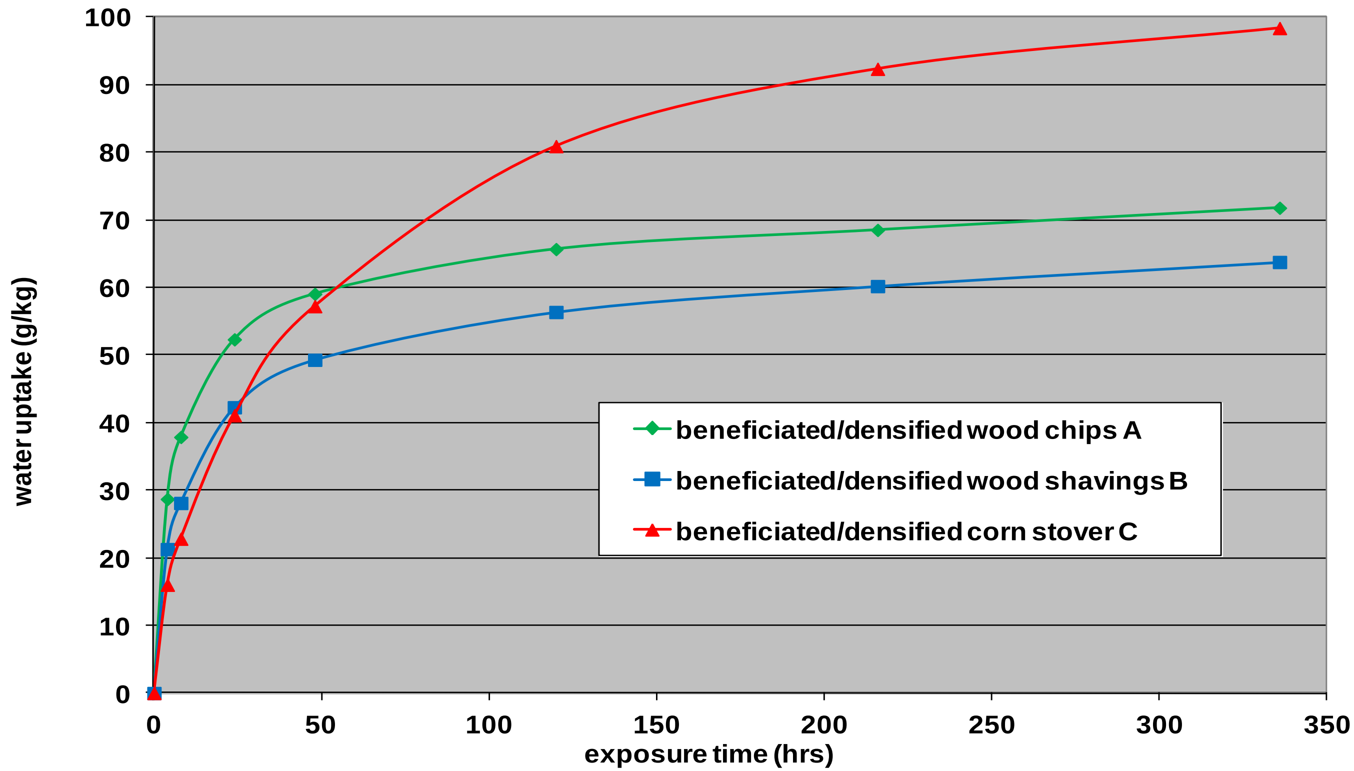
Storage

Water uptake

- Climate chamber (ESPEC ESL2-CA)
  - Typical test duration 2 weeks (336 hrs)
  - Standard exposure conditions 27 °C and 90 % Relative Humidity
  - test materials pre-dried at 30 °C in a ventilated drying stove
  - residual moisture levels determined by drying at 105 °C
  - water uptake measured by directly weighing the (wire-mesh) containers during the test
- Optional
  - rain event simulation
  - microbiologic analyses

Storage

Water uptake

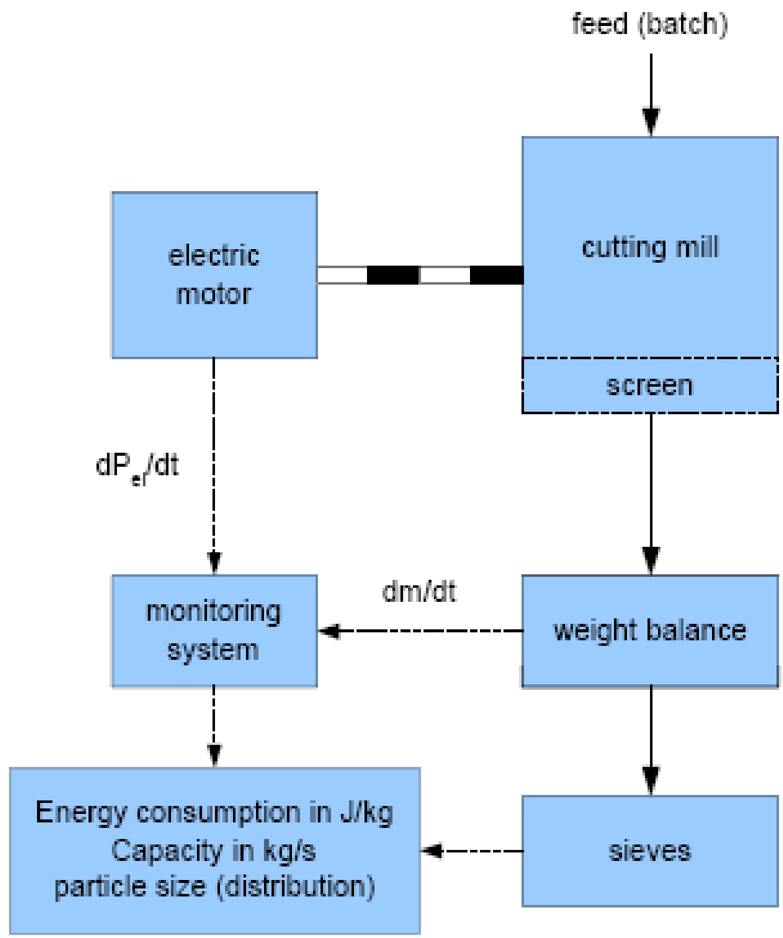


- Good performance beneficiated/torrefied materials, uptake ~10% w/w
- Pelletized materials (A/B) < uptake than non-densified chips (not shown)
- Bulky briquettes (C) slower uptake but more in total
- No biological (mold)/mechanical (swell, cracking) degradation

Source: CEATI SOIG 0530 B/C project

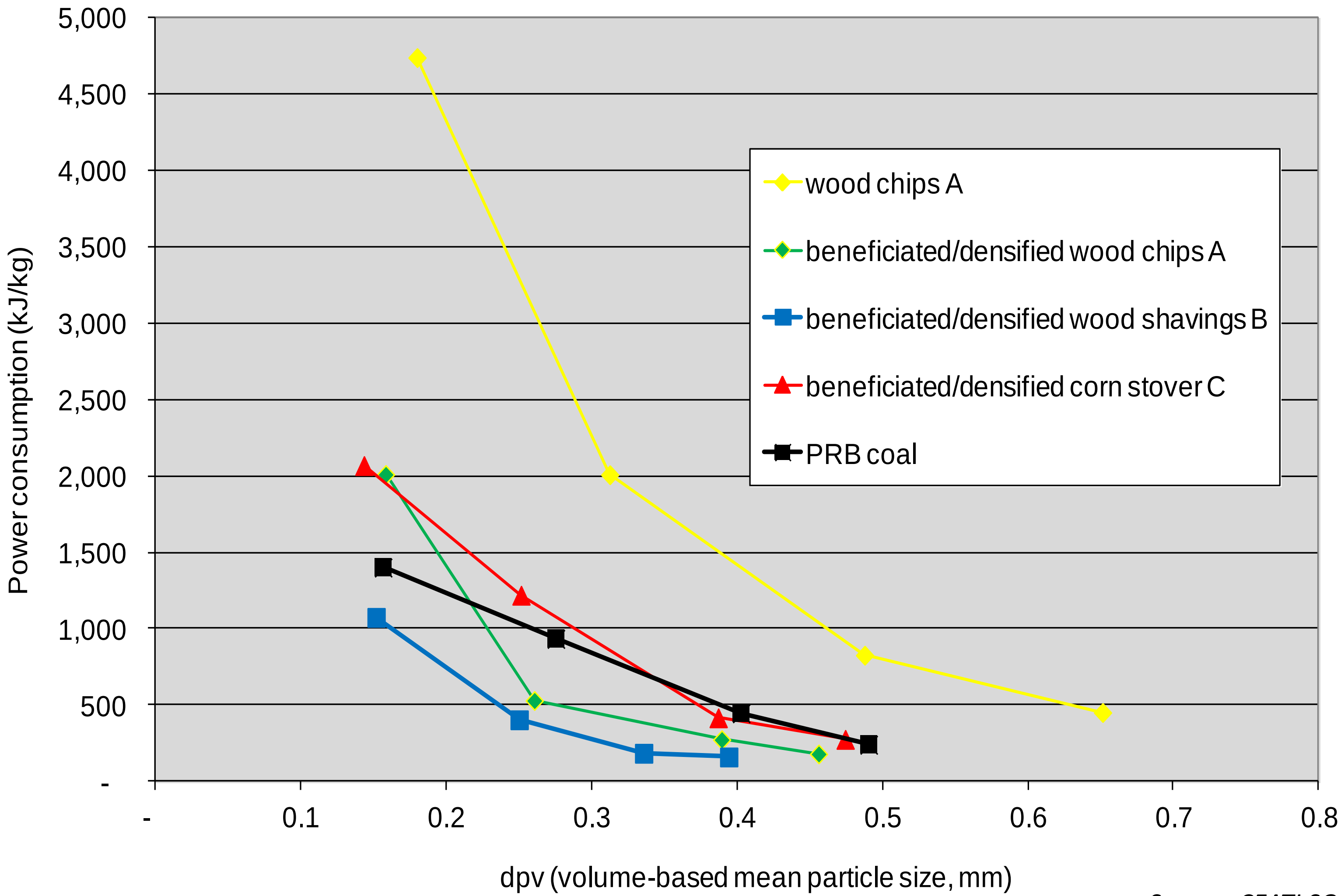
Grindability
Equipment and method

- ECN method
  - Based on a cutting mill (RETSCH SM 2000, 1 kg batch) or hammer mill (Condux, 5-50 kg/h, continuous)
  - Motor rpm kept constant and power consumption registered
  - Milled product is then dry sieved
  - Result: curves relating power consumption to particle size distribution
  - Integral particle size distribution verified by Malvern Mastersizer laser light scatter analyses



Grindability

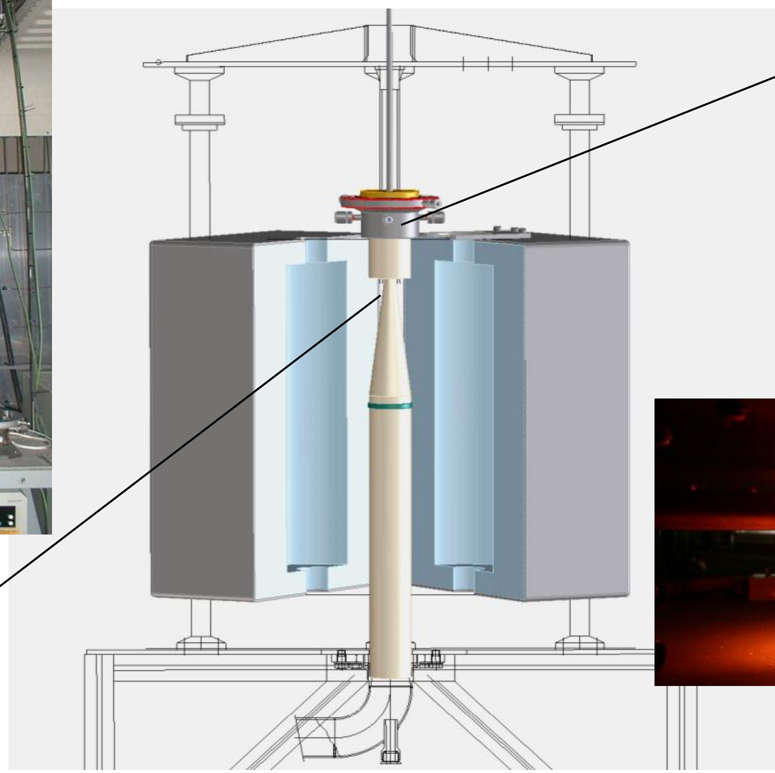
Results, power requirement



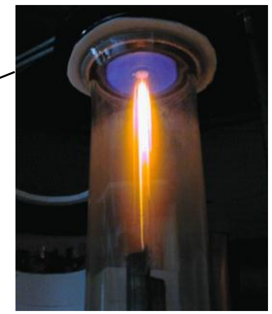
Source: CEATI SOIG 0530 B/C project

Lab-scale Combustion Simulator (LCS)

Mimic pulverised-fuel combustion <u>and</u> high-temperature gasification conditions



Special reactor design: 1-2s residence times with only limited total reactor length



Staged gas burner: high heating rate + proper gas atmosphere

Fouling probe

Particle sampling probe

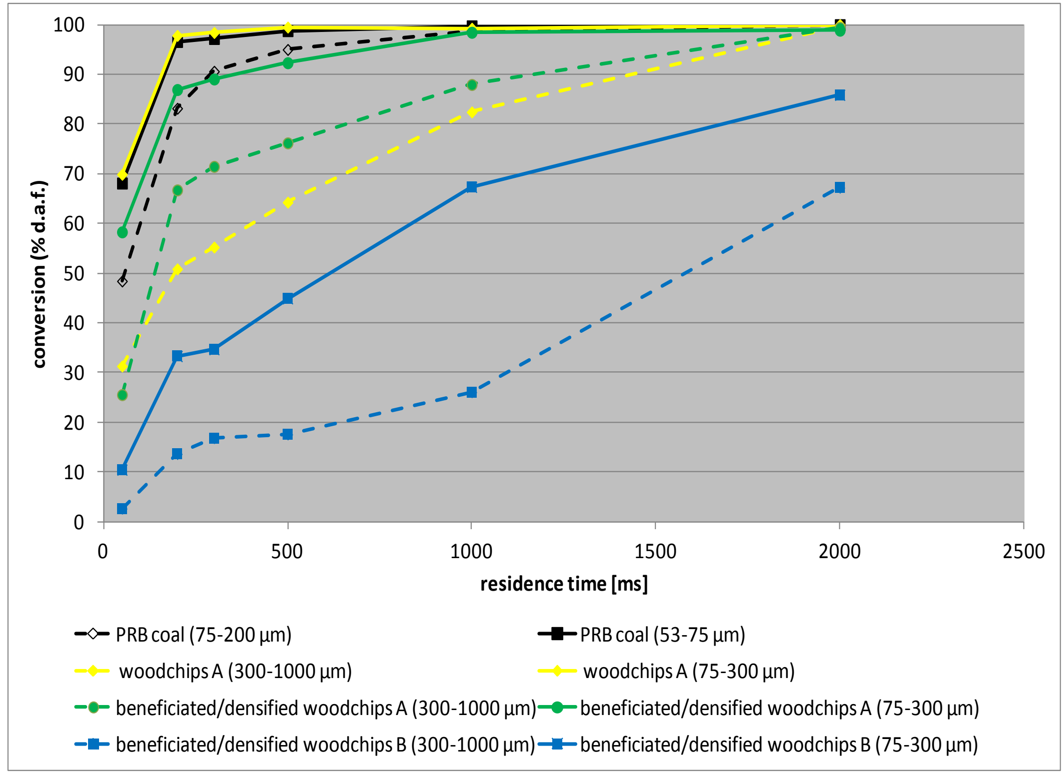
Fuel reactivity

Results, fresh/beneficiated fuels kinetics

$T_{flame/furnace}$ = 1450/1300 °C

$[O_2]_{final}$= 3.8 % vol dry

(shallow) burner staging (~200 ms)

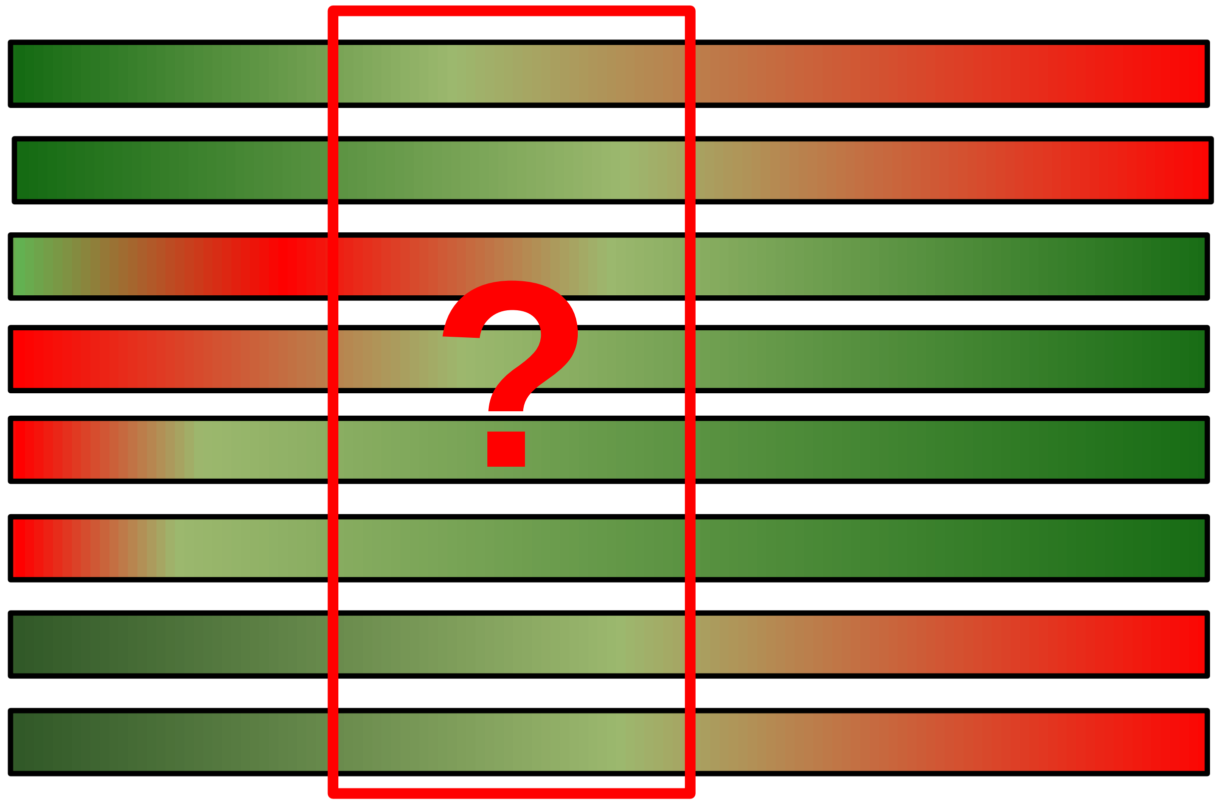


- Reactivity:
  - High impact of milling
  - (300-75 µm) fresh wood > PRB coal (53-75 µm)
  - (300-75 µm) beneficiated wood ~ PRB coal (75-200 µm)
  - (300-1000 µm) biomass significantly slower (fresh and upgraded)
  - Very low for deeply-torrefied B material

Source: CEATI SOIG 0530 B/C project

Impact of torrefaction degree

- Densification
- Self-heating
- Dust explosion
- Water uptake / leachability
- Grindability
- Heating value
- Reactivity
- Cost / Sustainability
- …….



Indicative trends

Summary

- Torrefaction potentially allows cost-effective production of *commodity solid biofuels* from a wide range of biomass/waste feedstock with a high energy efficiency (>90%) allowing a decoupling of biomass production and use
- Torrefaction should be considered as a separate thermal regime and requires dedicated reactor/process design
- Torrefaction development is in the pilot/demo-phase, with >10 demo initiatives underway in Europe; strong market pull for torrefaction plants and torrefaction pellets
- Main characteristics of torrefaction are known, but performance testing still is in an early phase, which holds even more for iterative optimisation of production recipes for torrefied biomass pellets (www.sector-project.eu)

Thank you for your attention!

For more information, please contact:

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