Energy research Centre of the Netherlands

Torrefaction in the supply chain

Technology overview and development status

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ECN

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ECN

Energy research Centre of the Netherlands

- Dedicated to Sustainable Energy Innovation

  ECN develops and brings to market high-level knowledge and technology for a sustainable energy society

- Core activities
  - Sustainable energy technology development
  - R&D services to industry
  - Feasibility studies, system and technology assessments

ECN

- Largest Dutch energy R&D institute
- Independent
- 570 employees
- R&D units:
  - *Biomass*
  - *Solar energy*
  - *Wind energy*
  - *Efficiency & Infrastructure*
  - *Policy studies*

ECN and Torrefaction

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

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

Torrefaction for upgrading biomass

- Process parameters
  - Temperature: 200-300°C
  - Absence of oxygen

Torrefaction

Pelletisation

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

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

Bulk density = 650-800 kg/m^3
Bulk energy density = 15 - 19 GJ/m^3

ECN

Bench-scale testing – batch test example

Gas phase composition	
CO	0.1 %
CO_2	3.3 %
H_2O	89.3 %
acetic acid	4.8 %
furfural	0.2 %
methanol	1.2 %
formic acid	0.1 %
remainder	1.0 %
Tad = 1045 °C	

Feed: Willow
Size: 10 - 30 mm
LHV: 14.8 MJ/kg
Moisture: 14.4%
Fixed carbon: 16.8 %

Torrefaction
32 min, 260 °C

Mass yield: 75.3%
Energy yield: 94.3%

Torrefied Willow
Size: 10 - 30 mm
LHV: 18.5 MJ/kg
Moisture: 1.9%
Fixed carbon: 22.1%

20 l batch reactor

Torrefied biomass pellets in perspective

	Wood chips	Wood pellets	Torrefied wood pellets	Charcoal	Coal
Moisture content (wt%)	30 – 45	7 – 10	1 – 5	1 – 5	10 – 15
Calorific value (LHV, MJ/kg)	9 – 12	15 – 17	18 – 24	30 – 32	23 – 28
Volatile matter (wt% db)	70 – 75	70 – 75	55 – 65	10 – 12	15 – 30
Fixed carbon (wt% db)	20 – 25	20 – 25	22 – 35	85 – 87	50 – 55
Bulk density (kg/l)	0.20 – 0.25	0.55 – 0.65	0.65 – 0.80	0.18 – 0.24	0.80 – 0.85
Vol. energy density (GJ/m^3)	4.5 – 6.0	8 – 11	15 – 19	6.0 – 6.4	18 – 24
Hygroscopic properties	Hydrophilic	Hydrophilic	Moderately Hydrophobic	Hydrophobic	Hydrophobic
Biological degradation	Fast	Fast	Slow	None	None
Milling requirements	Special	Special	Standard	Standard	Standard
Product consistency	Limited	High	High	High	High
Transport cost	High	Medium	Low	Medium	Low

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 ….. how difficult can it be?

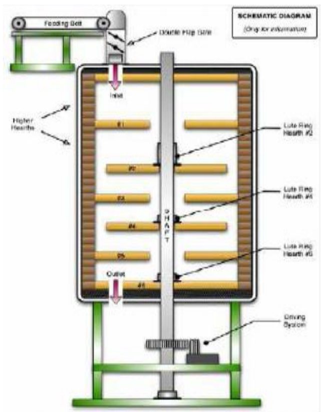
- Coffee roasting is practiced since the late 13th century
- Isn't torrefaction just high-temperature drying or low-temperature pyrolysis?

Old coffee roasting machine
Bourg St. Maurice, France

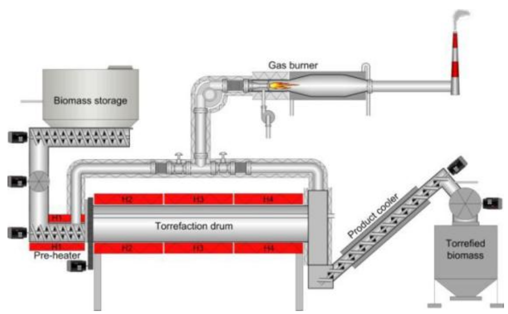
Biomass torrefaction for energy applications

- Not straightforward !
- Absence of oxygen requires air-tight system
- Torrefaction should be considered as a separate thermal regime, distinctly different from drying, slow pyrolysis or charcoal production
- Characteristic features:
  - Overall exothermal reaction (due to secondary cracking reactions)
  - Condensables composition and behaviour
  - Nature and behaviour of the solid product
- Optimum energy efficiency is crucial in view of overall cost and sustainability
- Reactor and process should allow large-scale production with minimal environmental impact

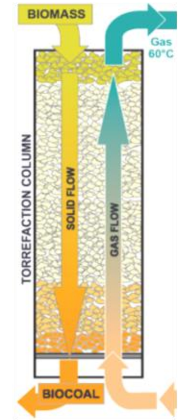
Torrefaction technology – reactor concepts



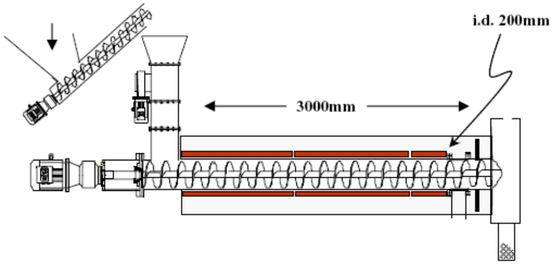
Multiple hearth furnace



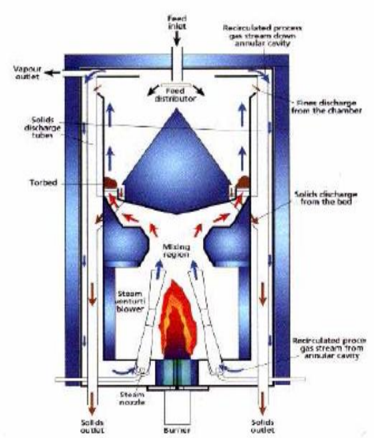
Rotary drum reactor



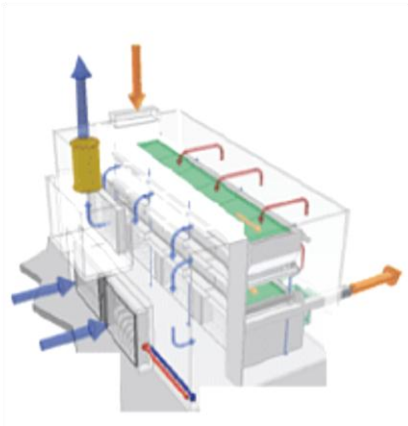
Moving bed reactor



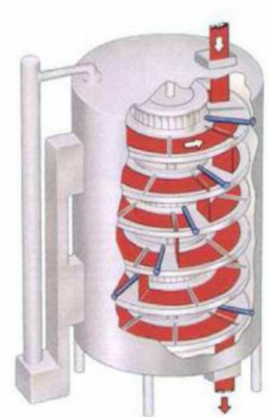
Screw conveyor reactor



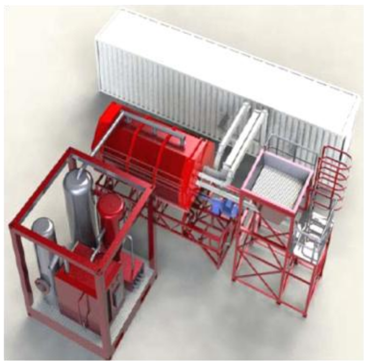
Torbed reactor



Oscillating belt reactor

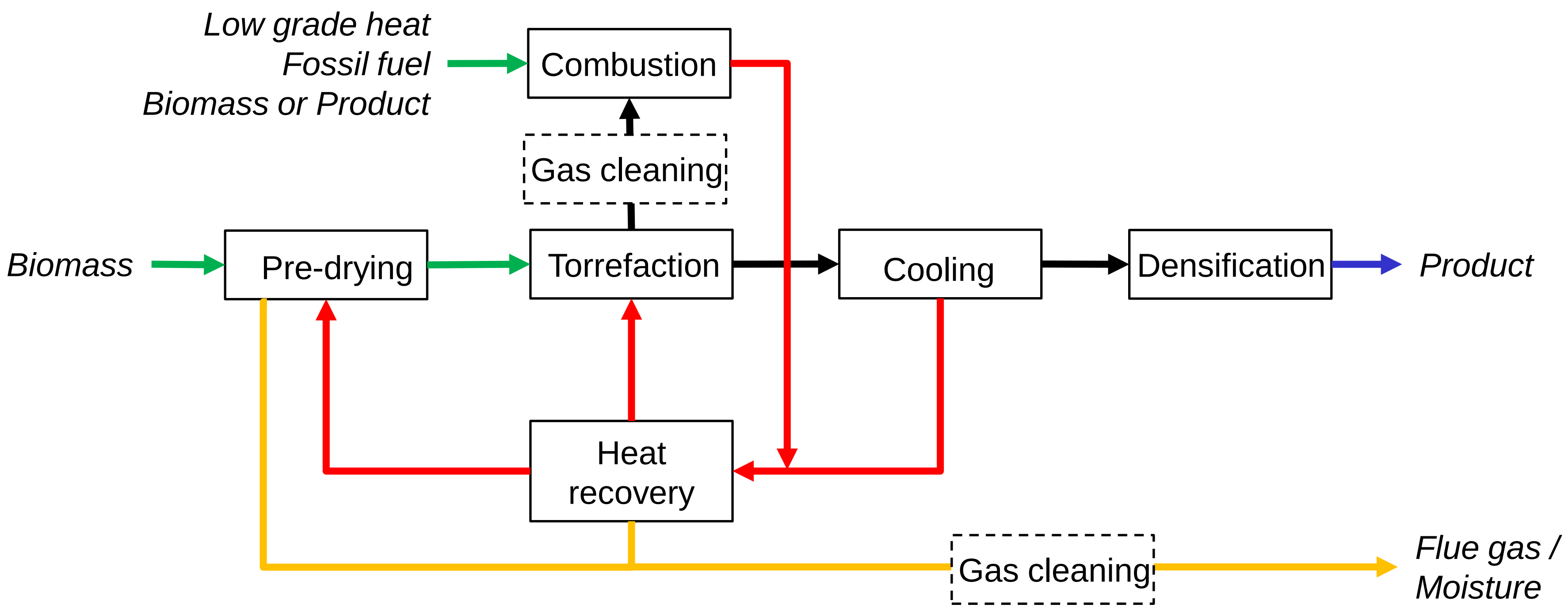


TurboDryer



Microwave reactor

Torrefaction technology – process design

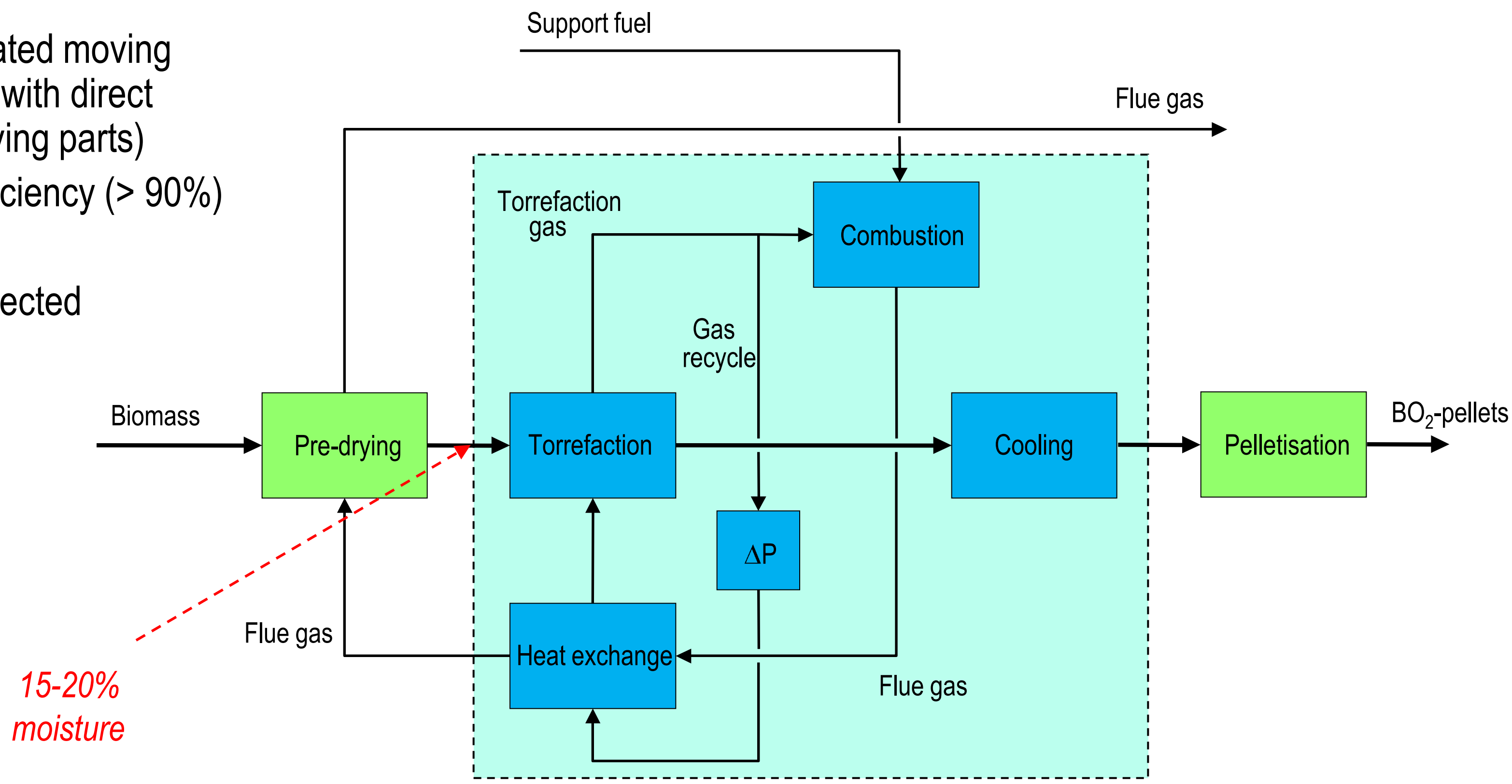


- Many heat integration options:
  - Torrefaction and pre-drying
  - Use of low-grade heat from other industrial processes
  - Torrefaction: indirect heating or direct heating by recycling flue gas or torrefaction gas

Example – ECN's torrefaction-based BO_2-technology

Features:

- Conventional drying and pelletisation
- Compact dedicated moving bed technology with direct heating (no moving parts)
- High energy efficiency (> 90%)
- Cost effective
- IP is patent protected



Torrefaction technology

- Many technology developers (>50) due to strong market pull
- Often application of reactor technology proven for other applications (drying, pyrolysis, combustion)
- Often limited bench-/pilot-scale testing (directly to demo), limited attention to energy efficiency and impact of exothermicity underestimated
- Good process control is essential for good performance and product quality control (temperature, residence time, mixing, condensables in torrefaction gas)
- 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 – a Dutch technology? No, but ....

- Pioneering role ECN (building on earlier French experience)
- Several Dutch technology developers, several demo-plants under construction / starting up (Stramproy Green, Torrcoal, Topell, ECN, Foxcoal)
- Dutch Torrefaction Association established (www.dutchtorrefactionassociation.eu)

DTA
Dutch Torrefaction Association

STRAMPROY GROUP
TORR COAL
TOPELL
ECN
4energyinvest
Foxcoal

Torrefaction technology developers

Reactor technology	Technology developers
Rotary drum	CDS (UK), Torrcoal (NL), BioEndev (SE), ACB (AU), BIO3D (FR), CENER/List (ES)
Vertical mechanical transport (Multiple hearth furnace)	CMI-NESA (BE), Wyssmont (USA), Integro (USA)
Screw reactor	Biolake (NL), FoxCoal (NL), BTG (NL), Agri-Tech (USA), RTF (USA)
Torbed reactor	Topell (NL)
Moving bed reactor	ECN (NL), Thermya (FR), Bühler (CH)
Belt reactor	Stramproy Group (NL), New Earth Eco Technology (USA)
Microwave reactor	Rotawave (UK)

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 (self ignition, spontaneous combustion, dust explosions)

Economics

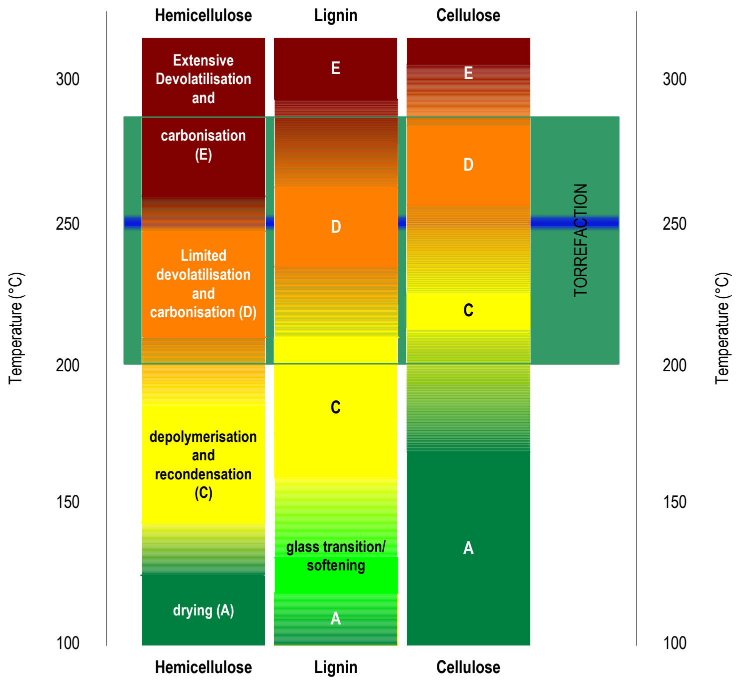
- Torrefaction plant: compared to conventional wood pellets plant, slightly more feedstock per GJ required (typically 2-5%), higher CAPEX (typically 25-30%), partly compensated by lower OPEX (overall production cost 5-10% higher)
- CAPEX and overall energy efficiency are major cost factors
- Supply chain studies indicate: torrefied pellets can be delivered at the gate of a power plant at similar or lower cost per GJ than conventional wood pellets
- Economic benefits at the power plant can be substantial, e.g., no need for dedicated storage and separate milling and feeding lines

Markets

- Feedstock
  - Woody biomass (residues): torrefaction pellets expected to largely replace conventional wood pellets (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): In EU-15, 43 Mtonne/a dry biomass (agro-residues) available for energy purposes
  - Paper-plastic fractions and other “wastes”
- End-use applications
  - Co-firing in pulverised-coal boilers: 10% co-firing in all EU-27 coal-fired plants requires approx. 70 Mtonne/a dry biomass ≅ 700 torrefaction plants with plant-size 100 ktonne/a input
  - (Co-)gasification in entrained-flow gasifiers (biofuels production, IGCC): 10% biofuels in EU-27, ≅ 1300 PJ/a, corresponding to approx. 110 Mtonne/a dry biomass (@ 60% conversion efficiency)
  - Small-scale pellet boilers and stoves

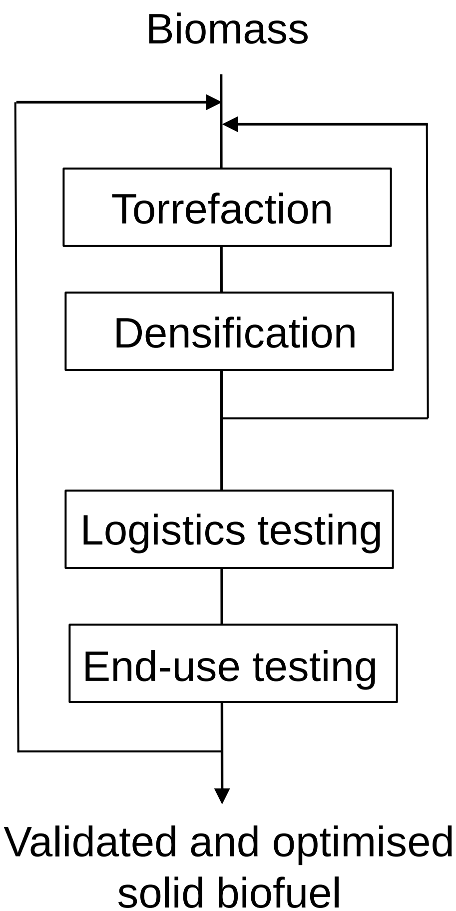
Product quality

- Initial small-scale research by ECN since 2002 and later by many others revealed:
  - Quantitative relations between torrefaction conditions (residence time, temperature) and product properties (solid + gas) for a broad range of biomass feedstocks
  - Underlying mechanisms (structural changes in the biomass)
  - Pelletisation behaviour of torrefied biomass
  - First insights in logistics and end-use performance
- But .... performance testing still is in an early phase, which holds even more for optimisation of production recipes for torrefied biomass pellets



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



SECTOR

In conclusion

- Torrefaction potentially allows cost-effective production of 2nd generation biomass pellets from a wide range of biomass/waste feedstock with a high energy efficiency (>90%)
- 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
- Compared to conventional wood pellets, higher production costs to be compensated by cost benefits in logistics and end-use

- Main characteristics of torrefaction are known and some quantitative relations have been determined between torrefaction conditions and product properties, but ....
- Performance testing still is in an early phase, which holds even more for iterative optimisation of production recipes for torrefied biomass pellets

Thank you for your attention!

For more information,
please contact:

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Production of tonne-scale test batches at ECN for industrial trials