Torrefaction for upgrading biomass into commodity fuel

Status and ECN technology development

Jaap Kiel

Presented at EUBIONET III Workshop Bioenergy and Forest Industry,
Espoo Finland, 15 April 2011

ECN-M--11-047 APRIL 2011

ECN

Energy research Centre of the Netherlands

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Presentation overview

- Torrefaction principles, characteristics and design challenges
- Development status
- Economics
- ECN's torrefaction-based BO_2-technology
- Conclusions

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

Gas

0.3 | 0.1

Dry biomass → **Torrefaction 200-300°C** → Torrefied biomass

1 / 1 → 0.7 / 0.9

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

mass energy

Process parameters

- Temperature: 200-300°C
- Residence time: 10-30 minutes
- Particle size: < 4 cm
- Absence of oxygen
- Pressure: near atmospheric

Why torrefaction: from biomass/waste to commodity fuel

Woody biomass

Agricultural residues

Mixed waste

Tenacious and fibrous
10 - 17 MJ/kg (LHV, ar)
Hydrophilic
Vulnerable to biodegradation
Heterogeneous

Torrefaction and pulverisation

Friable and less fibrous
19 - 22 MJ/kg (LHV, ar)
Hydrophobic
Preserved
Homogeneous

Fuel powder

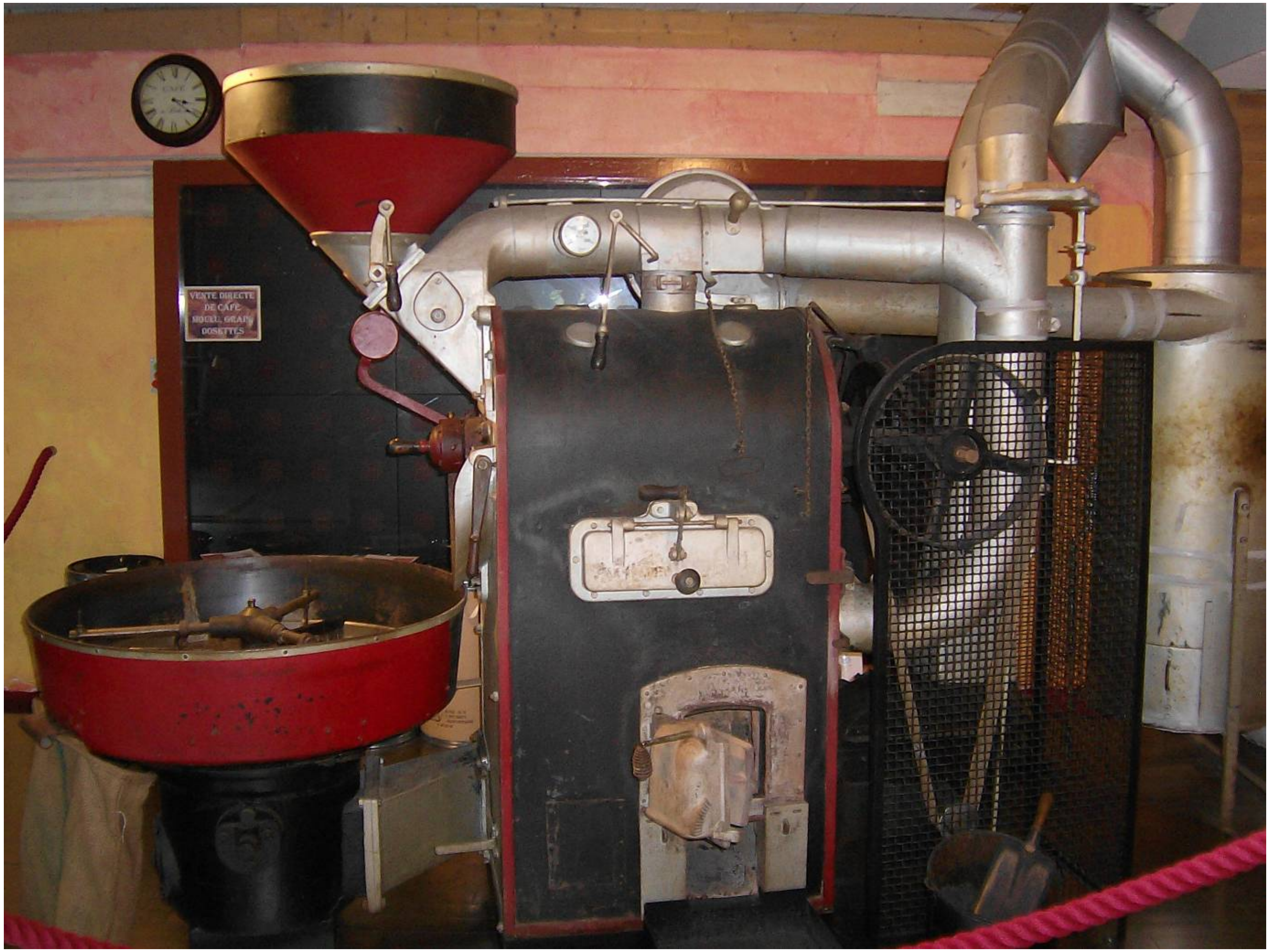
Pelletisation

Fuel pellets

Bulk density 650-750 kg/m^3
Bulk energy density 13-17 GJ/m^3

Superior fuel properties:
- Transport, handling, storage
- Milling, feeding
- Gasification, combustion
- Broad feedstock range
- Commodity fuel

Torrefaction ….. how difficult can it be?

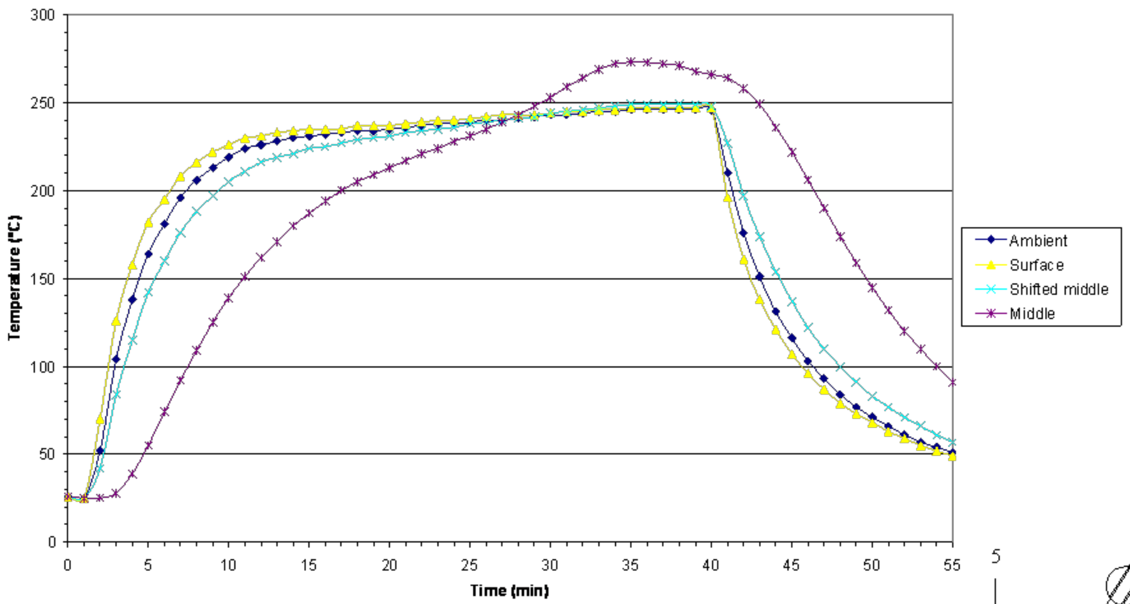


Small-scale coffee roasting machine in Bourg St. Maurice, France

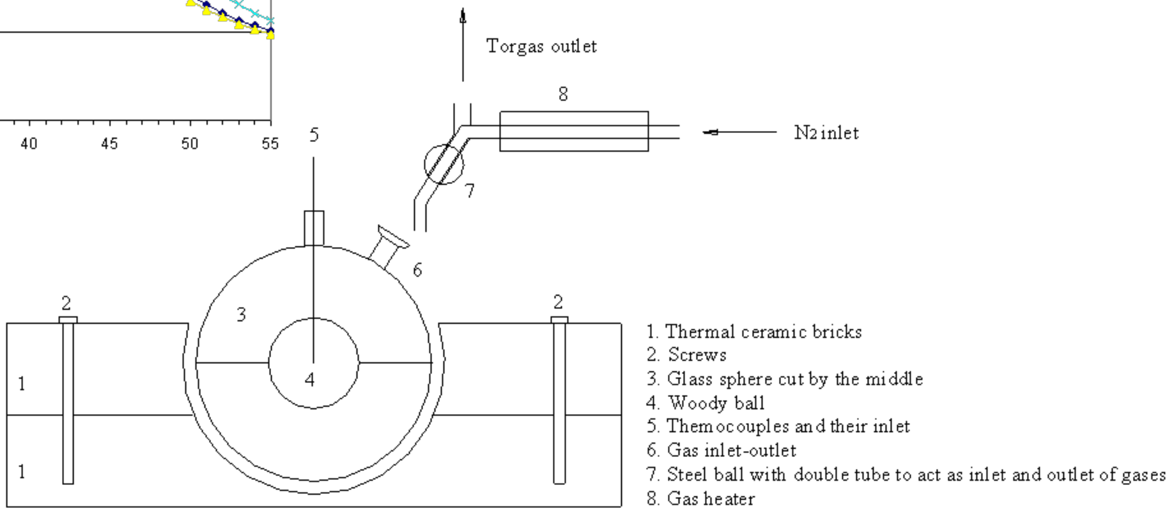
Biomass torrefaction for energy applications

- 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 reactions overall exothermal



Results from single-particle testing

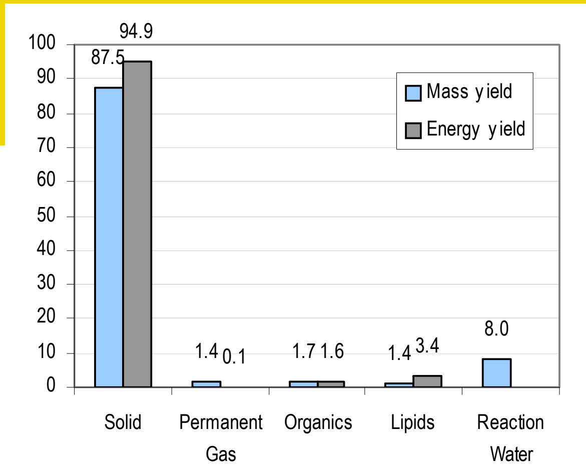


Bench-scale testing

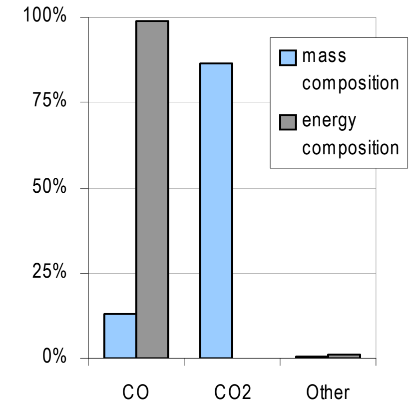
20 l batch reactor

5 kg/h Auger reactor (screw reactor)

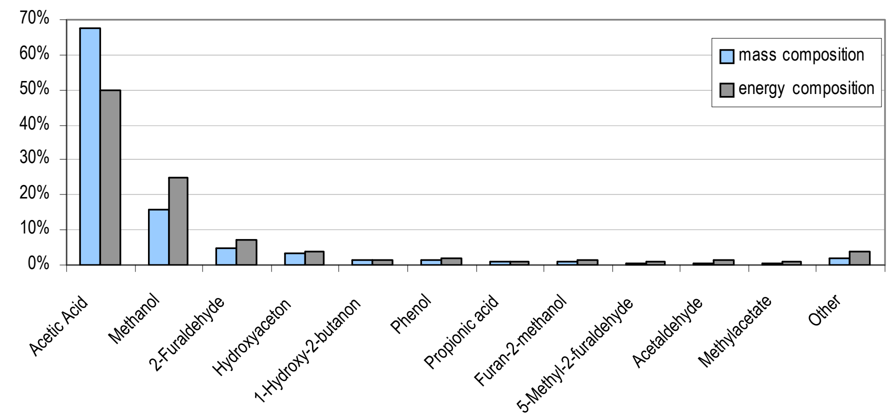
Main product groups (dry basis)



Permanent gases

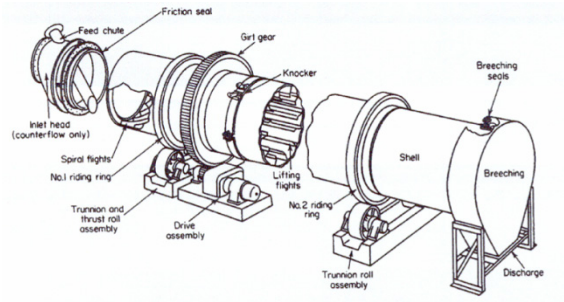


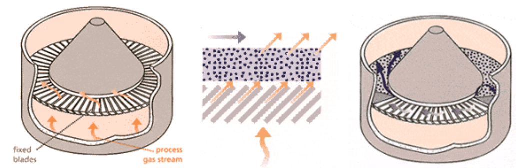
Organics

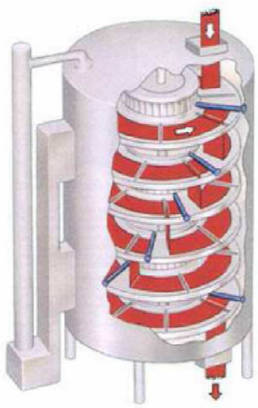


Development status

- In general: torrefaction technology in demonstration phase with first demo-units starting up
- Many technology developers due to strong market pull
- Often application of pre-existing reactor concepts, e.g., derived from drying or pyrolysis technology:
  - limitations: process control, efficiency, feedstock flexibility, scale-up
- Other observations:
  - Often limited bench-/pilot-scale testing; directly to demo
  - Often limited attention to energy efficiency
  - Impact of exothermicity often underestimated







Torrefaction technology developers

In Europe

Reactor technology	Technology developers
Rotary drum	CDS (UK), Torrcoal (NL), BioEndev (SE), ACB (AU), BIO3D (FR), CENER/List (ES)
Multiple hearth furnace	CMI-NESA (BE)
Screw reactor	BTG (NL), Biolake (NL), FoxCoal (NL)
Torbed reactor	Topell (NL)
Moving bed reactor	ECN (NL), Thermya (FR), Bühler (CH)
Belt reactor	Stramproy (NL)

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

DTA
Dutch Torrefaction Association

STRAMPROY GROUP
TORR COAL
TOPELL
ECN
4energyinvest
Foxcoal

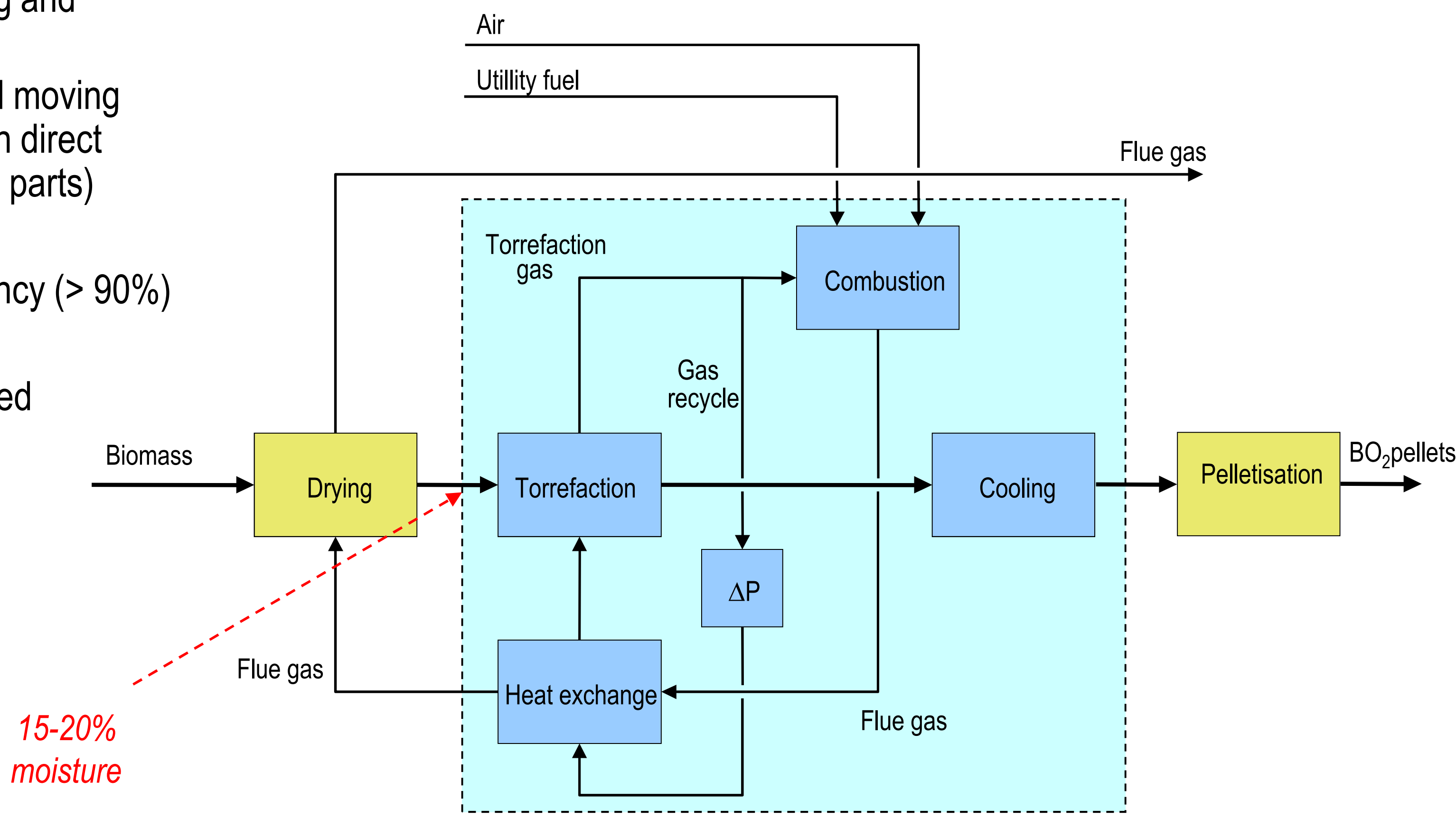
ECN torrefaction technology R&D

- ECN was one of the first to recognise the potential of torrefaction for biomass-to-energy purposes
- Initial small-scale research started in 2002-2003, revealing:
  - Quantitative relation 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
- Based on the small-scale research, dedicated reactor and process concepts were developed, aiming at: good process control, low investment cost, high capacity, high feedstock flexibility, high energy efficiency and minimum environmental impact
- To achieve high energy efficiency, heat integration using the energy content of the torrefaction gas is crucial

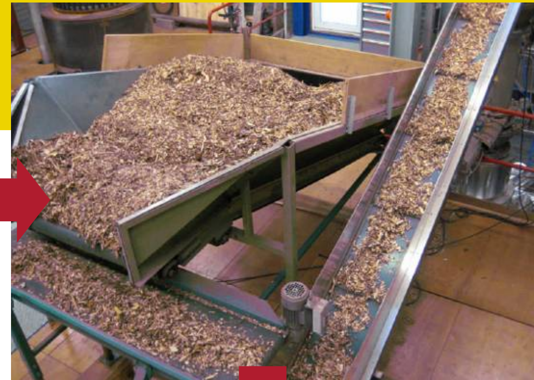
BO_2-technology

Features:

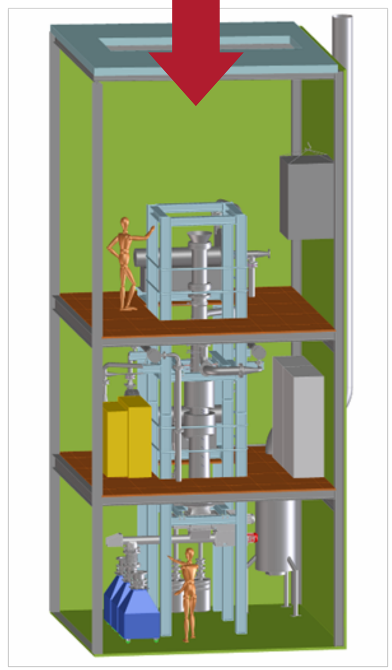
- Conventional drying and pelletisation
- Compact dedicated moving bed technology with direct heating (no moving parts)
- Heat integration
- High energy efficiency (> 90%)
- Cost effective
- IP is patent protected



Pre-drying



Feeding

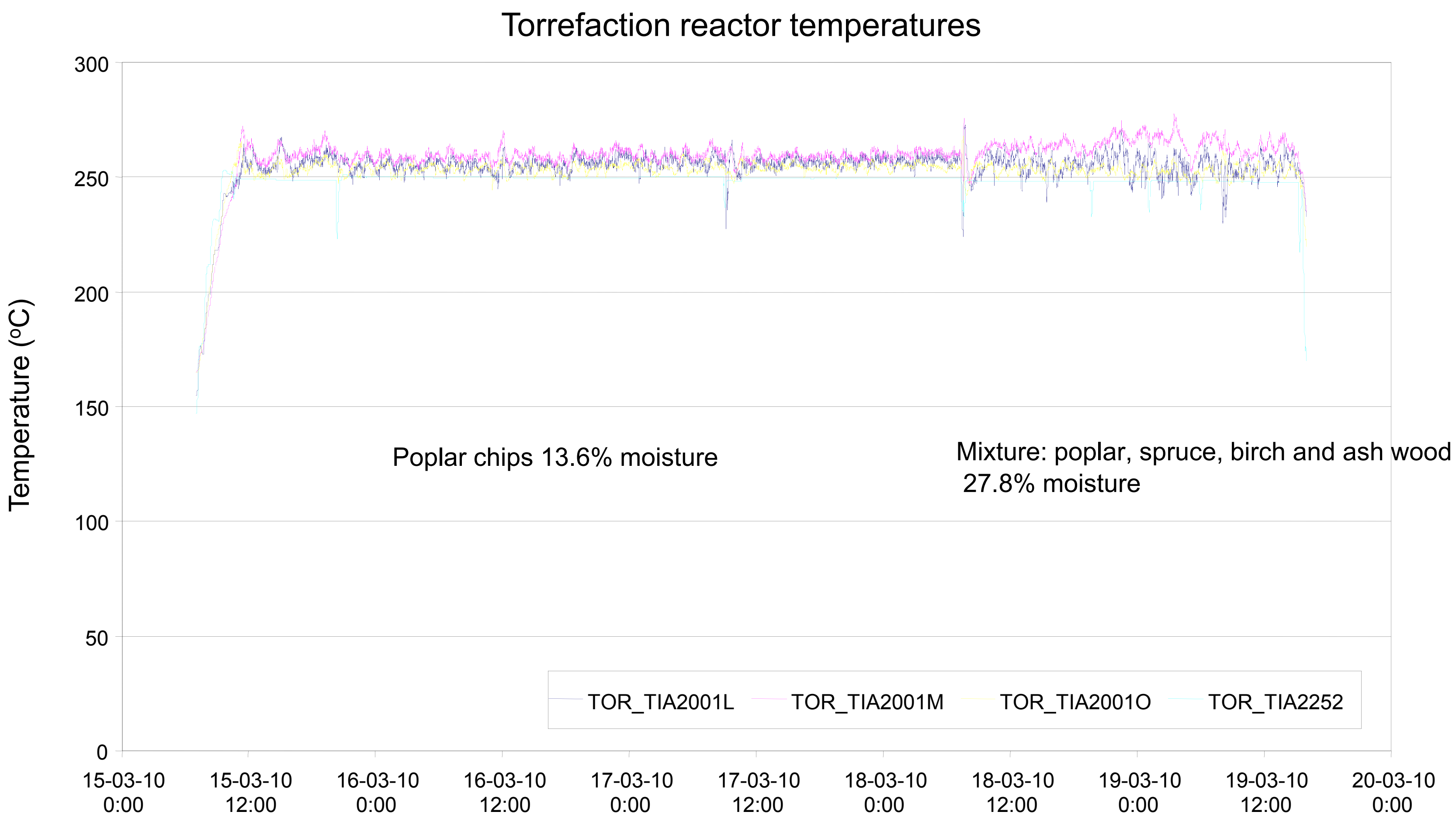


Torrefaction pilot-plant (50-100 kg/h)

Pilot-scale torrefaction

- Testing history:
  - Start-up 2008
  - Over 1000 hours of operation (day runs + 50-100 hour runs); >30 tonnes of torrefied material produced
  - Currently regular 50-100 hour runs
  - Biomass feedstock: poplar, pine, wood mixtures, forestry residues, agricultural residues (POR)
  - Conditions: 220-280 °C torgas inlet temp., throughput approx. 60 kg/h (input basis)
- Modifications after initial tests:
  - New continuous discharge system
  - Modifications to reactor design (better scale-up)
  - Modifications to the gas loop (long-duration operation)

Pilot-scale torrefaction – results of typical run



Pilot-scale pelletisation

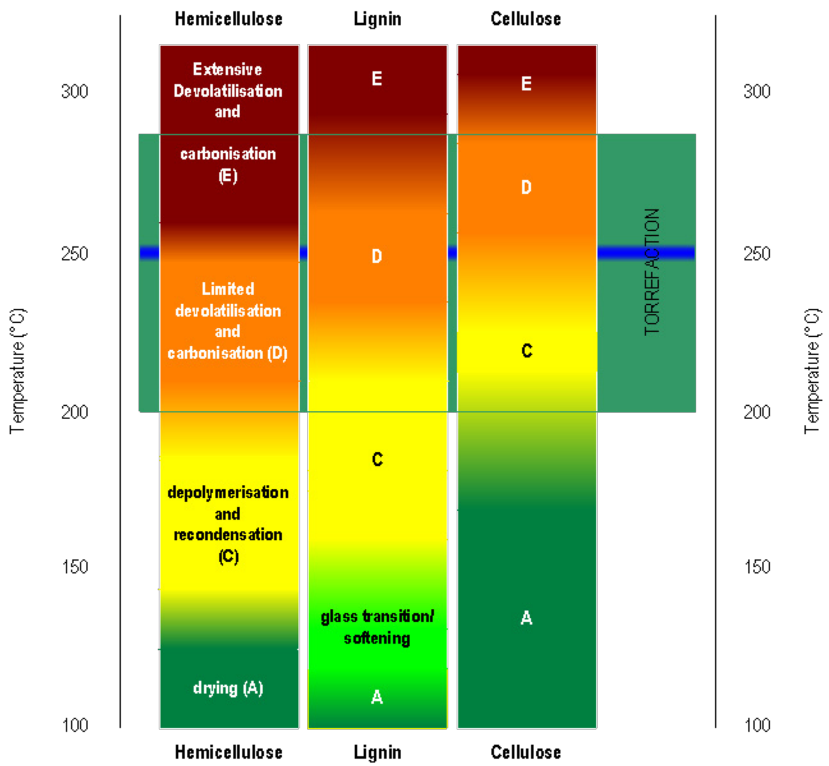
- Torrefied material from pilot-plant subjected to semi-industrial-scale pelletisation tests at CPM:
  - Good quality pellets can be produced *without additional binder*
  - But case-by-case tuning of the pelletisation conditions (e.g. die type) required
  - Good control of torrefaction conditions essential for proper pelletisation performance

BO_2-technology – demonstration and market introduction

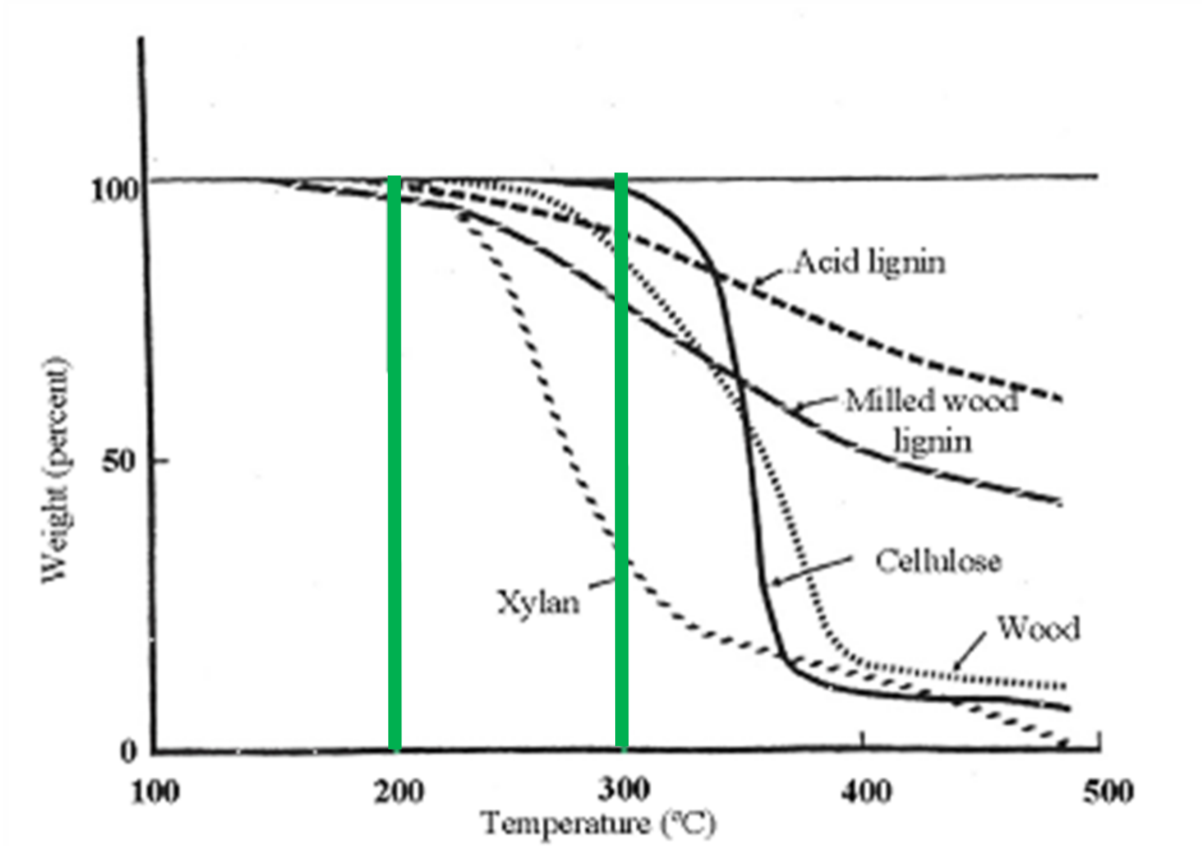
- ECN teamed up with Vattenfall to prepare for demonstrating the technology, including site selection and basic engineering
- Contract negotiations with technology supplier with world-wide presence for scale-up and commercial market introduction in final stage
- Demonstration unit scheduled for start-up by end 2011
- Supporting R&D aimed at:
  - Further process improvement and simplification
  - Broadening of the feedstock range
  - Further optimisation of torrefaction + densification
  - Product quality optimisation based on extensive logistics and end-use performance testing with test batches produced at pilot/demo scale:
    - Co-firing in pf boilers
    - (Co-)gasification in entrained-flow gasifiers (IGCC or biofuels production)
    - (Combustion in pellet boilers)

Torrefaction – challenges

- Torrefaction: destruction of hemicellulose, depolymerisation of cellulose, and lignin should keep its binding capacity (for pelletisation) ....
- ..... but is there an operating window where this can be accomplished simultaneously?
- ..... and where we can obtain all desired favourable properties (incl. easy pelletisation)?
- ..... and what is the impact of biomass type (with different quantities and composition of lignocellulose fractions)?



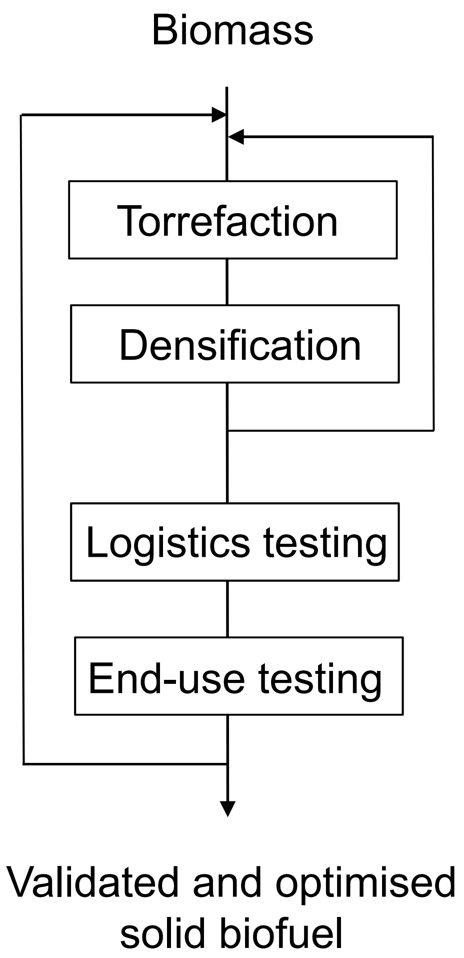
Thermogravimetry of (cotton) wood and its constituents



Source: Shafizadeh, F. and McGinnis, G.D., "Chemical composition and thermal analysis of cottonwood, Carbohydrate Research, 258, 1971

Iterative optimisation of production recipes

- Systematic work on both loops has started
- Iterations from small via pilot to full scale
- ECN is well equipped to conduct small/pilot-scale iterations and to support large-scale validation and optimisation (both loops)
- ECN currently conducts a large small-scale logistics and end-use performance testing programme for a range of torrefied biomass pellets from different producers for a North-American consortium of 6 power utilities (CEATI)



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
- For ECN's BO_2-technology, demo-plant in preparation and industrial partnership for world-wide market introduction nearly established

- 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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