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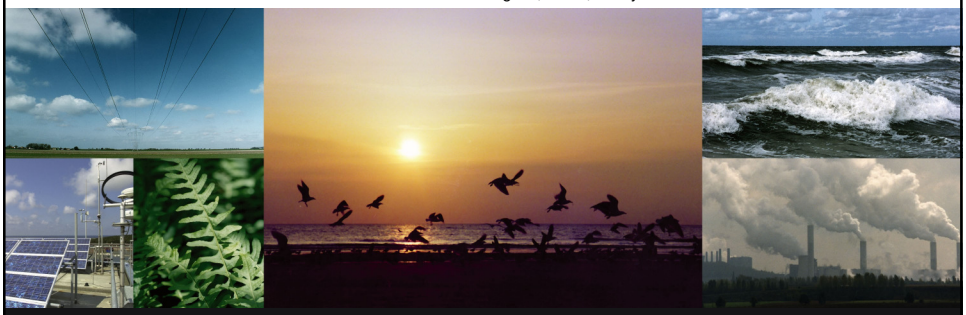
Energy research Centre of the Netherlands

Torrefaction for biomass upgrading into commodity fuels

Jaap Kiel

IEA Bioenergy Task 32 workshop "Fuel storage, handling and preparation and system analysis for biomass combustion technologies", Berlin, 7 May 2007



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Presentation overview

- ECN
- Torrefaction principles
- ECN TOP technology
- Economics
- Development status and market implementation

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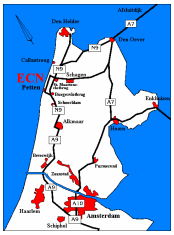
in the dunes of North Holland



ECN develops high-quality knowledge and technology for the transition to a sustainable energy supply and brings it to the market

- Independent energy research institute
- 650 staff
- Annual turnover: 80 million EURO
- Activities:
  - Biomass, Solar, Wind
  - Fuel Cell Technology
  - Clean Fossil Fuels
  - Energy Efficiency
  - Policy Studies

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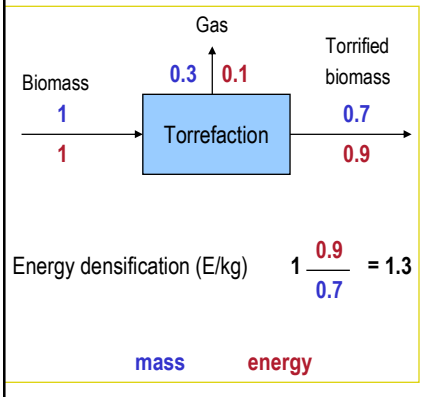
Torrefaction for biomass upgrading

general process description



Temperature: 200-300 °C
Pressure: near atmospheric
Absence of oxygen
Product: solid fuel
Particle size < 4 cm thickness
Residence time 10-30 min
Heating rate: <50 °C/min

From biomass/waste to commodity fuels

Woody biomass **Agricultural residues**

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

Superior fuel properties:

- Transport, handling, feeding
- Milling
- Combustion/gasification
- Feedstock bandwith
- Standardisation

Mixed waste

Torrefaction and pulverisation

Fuel powder

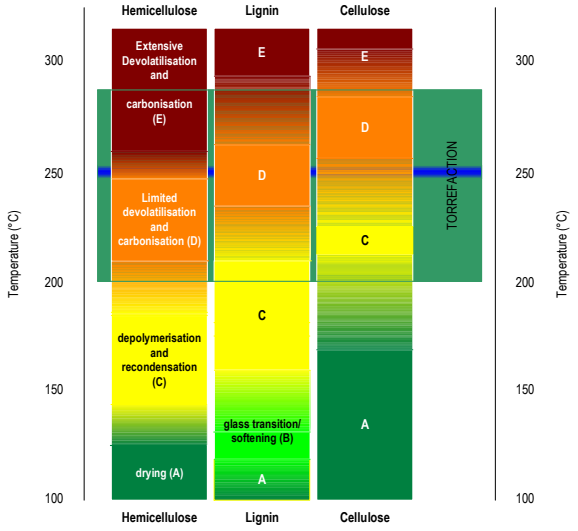
Pelletisation

Fuel pellets

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

Bulk density 750-850 kg/m^3
Bulk energy density 15-20 GJ/m^3

Decomposition regimes



Starting points ECN TOP technology development (1)

- Torrefaction (combined with pelletisation) has the potential of becoming a *key unit operation* in biomass upgrading schemes for a wide range of applications, including:
  - Biomass storage and (long-distance) transport – biomass import
  - Co-firing in pf boilers
  - (Co-)firing in entrained-flow gasifiers for producing power (IGCC) or transportation fuels (e.g., Fischer-Tropsch diesel)
  - Small-scale pellet boilers and stoves

⇒ Torrefied biomass pellets may become a biomass commodity fuel

Starting points ECN TOP technology development (2)

- Torrefaction principle not new, but many aspects relevant to application for upgrading biomass into biomass fuel for thermal conversion processes were not addressed, including:
  - Scale of operation in relation to reactor technology and process layout
  - Characterisation and quantification of product quality and how this relates to process conditions
  - Nature and quantity of emissions
  - Prospects of heat integration including utilisation of the energy containing torrefaction gases
  - The economic viability of torrefaction as a biomass upgrading technique for bulk applications

⇒ 2002 start ECN TOP technology development

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Proof-of-concept approach

5 kg/h screw reactor

20 l batch reactor

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Torrefaction
Typical experimental results

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

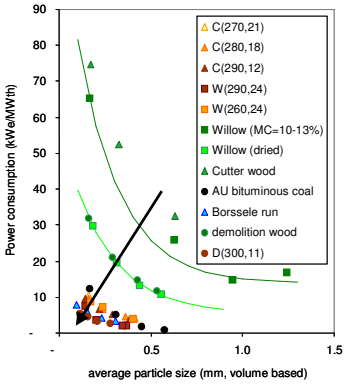
Feed: Willow
Size: 10 - 30 mm
LHV = 14.8 MJ/kg (ar)
MC = 14.4%
Fixed carbon: 16.8 %

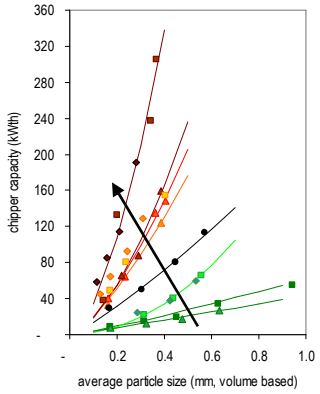
Torrefaction
32 min, 260 °C

Mass yield: 75.3% (ar)
Energy yield: 94.3% (ar)

Torrefied Willow
Size: 10 - 30 mm
LHV = 18.5 MJ/kg (ar)
MC = 1.9%
Fixed carbon: 22.1%

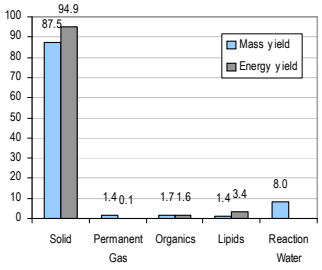
Grindability of (torrefied) biomass





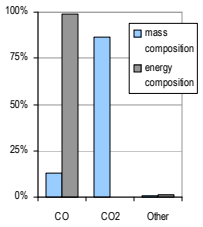
Torrefaction leads to a dramatic decrease in required milling power and increase in milling capacity

Torrefaction of willow (280 °C, 17.5 min)
Product distribution

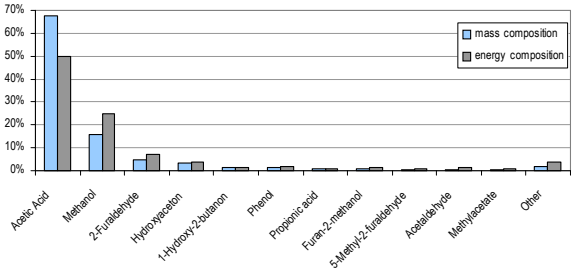


Main product groups (dry basis)

Permanent gases



Organics



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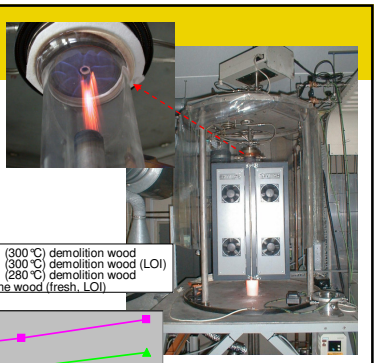
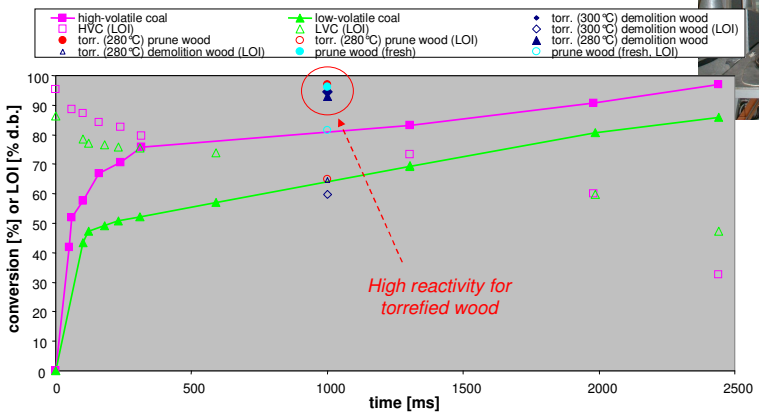
Combustion reactivity of torrefied wood
Lab-scale Combustion Simulator experiments





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Semi-industrial pelletisation tests

Features:
- 10 kg/h
- No automatic moisture supply

- Preliminary findings:
  - Easy pelletisation
  - Low energy input required
  - Pellet quality strongly dependent on pelletisation conditions

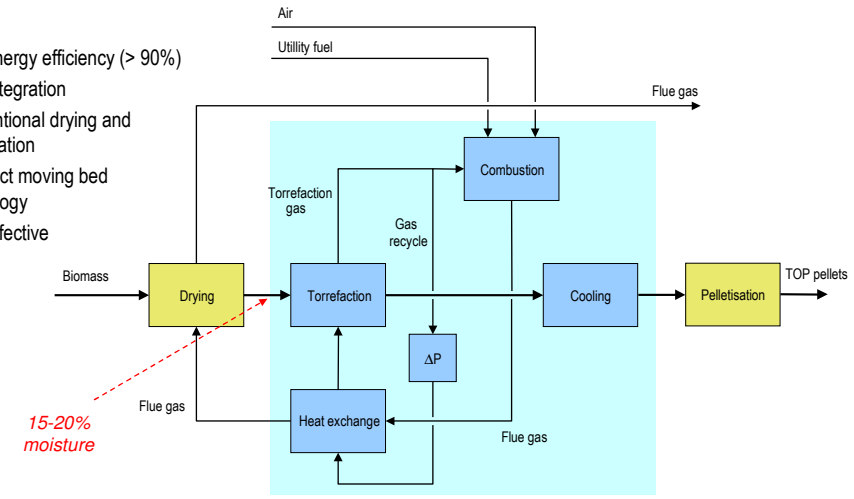
TOP pellets vs. wood pellets

Properties	unit	Wood	Torrefied biomass	Wood pellets		TOP pellets	
				low	high	low	high
Moisture content	% wt.	35	3	7	10	1	5
Calorific value (LHV)							
dry	MJ/kg	17.7	20.4	17.7	17.7	20.4	22.7
as received	MJ/kg	10.5	19.9	15.6	16.2	19.9	21.6
Mass density (bulk)	kg/m3	550	230	500	650	750	850
Energy density (bulk)	GJ/m3	5.8	4.6	7.8	10.5	14.9	18.4
Pellet strength		-	-	Good		Very good	
Dust formation		Moderate	High		Limited		Limited
Hygroscopic nature		Water uptake	Hydrophobic	Swelling / Water uptake		Limited swelling / Hydrophobic	
Biological degradation		Possible	Impossible	Possible		Impossible	
Seasonal influences (noticable for end-user)		High	Poor	Moderate		Poor	
Handling properties		Normal	Normal	Good		Good	

ECN directly heated torrefaction technology

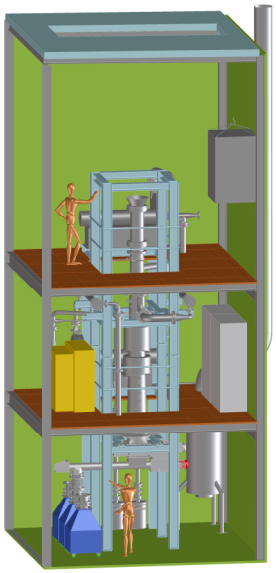
Features:

- High energy efficiency (> 90%)
- Heat integration
- Conventional drying and pelletisation
- Compact moving bed technology
- Cost effective



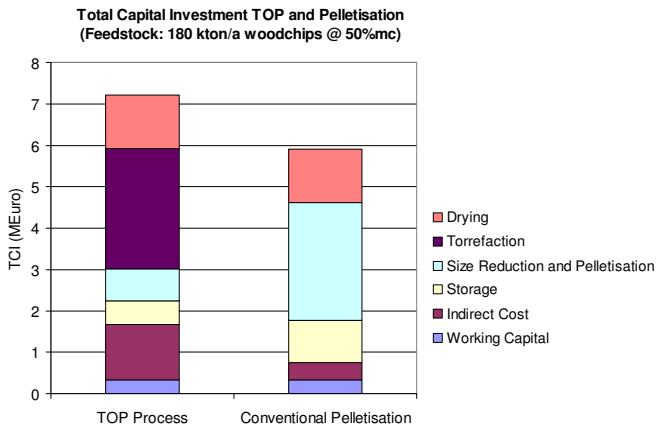
ECN torrefaction technology
Innovative moving bed reactor

- Compact reactor
- Small footprint
- High heat transfer rates
- Accurate T-control
- Uniform product quality
- Feedstock flexibility
- Low capital investment



Pilot-scale torrefaction reactor at ECN

Total capital investment – study estimate (TOP pellets vs. wood pellets)



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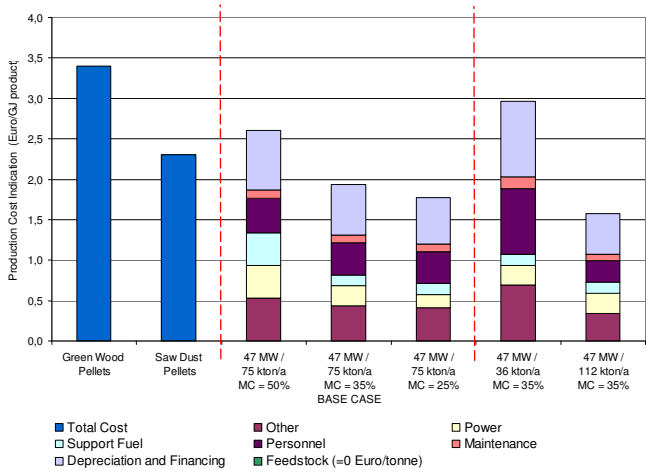
Total production cost (TOP pellets vs. wood pellets)



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Chain study (TOP pellets vs. wood pellets)

Sawdust
0.7 EUR/GJ
TOP process (South Africa)
2.0 EUR/GJ
Logistics
<2.0 EUR/GJ
<4.7 EUR/GJ
(Co-)firing coal-fired power stations or entrained-flow gasifiers North-West Europe
Higher co-firing capacity
Lower capital investment
Higher co-firing flexibility and availability
5.9 EUR/GJ
Favourable economics!
0.7 EUR/GJ
Sawdust
2.3 EUR/GJ
Conventional Pelletisation (South Africa)
2.9 EUR/GJ
Logistics

Road map ECN TOP technology development

capacity			5-10 kg/h		100 kg/h	20 kton/a	60-100 kton/a	
Green biomass	Proof-of-principle		Proof-of-concept		Prototype (pilot-scale)	Technical demonstration	Commercial demonstration	
Time	2002	2003	2004	2005	2006	2007	2008	2009	2010
Waste	Proof-of-principle		Proof-of-concept				Prototype (pilot-scale)	Technical demonstration	

Proof-of-concept
- Experimentally based process design
- Technology identification
- Knowledge base torrefaction
- Experimental infrastructure torrefaction
- Economic evaluation full-scale (study estimate 30%)
- Set-up pilot phase of development

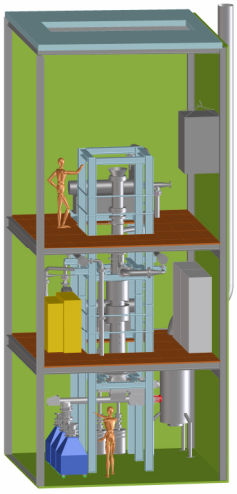
Prototype (pilot-scale evaluation)
- Pilot plant / prototype technology
- Demonstration technical feasibility
- Process and product characterisation (design data)
- Economic evaluation full-scale (preliminary estimate 20%)
- Business plan(s) (technical demo, semi-commercial)

Technical demonstration
- Demonstration plant (semi-commercial)
- Technical feasibility (refined design)
- Product applications (large scale)
- Economic evaluation full-scale (definite estimate <10%)
- Business plan(s) (commercial operation)

ECN TOP technology development – 2007 activities

- Pilot-scale testing
  - Validation of reactor and process concept
  - Optimisation of process conditions for a broad feedstock range
  - Industrial pelletisation tests
  - Extensive quality evaluation TOP pellets
    (e.g., hygroscopic nature, biodegradation, strength, milling characteristics, combustion/gasification reactivity)
- Demonstration plant basic design
- Business plan for technical demonstration(s) through BO2 Energy Concepts
- Continued basic R&D (co-operation with TU Eindhoven)
  - Contaminated biomass (residues) and waste

BO2 | energy concepts



40-100 kg/h torrefaction pilot-plant at ECN

In conclusion

- ECN TOP technology allows cost effective production of commodity fuels from a wide range of biomass/waste feedstocks with a high energy efficiency (>90%)
- ECN TOP fuels show:
  - High energy density
  - High water resistance
  - No/Limited biological degradation
  - Excellent grindability
  - Good combustion properties
- Fields of application:
  - Long distance biomass transport
  - Co-firing in pf boilers
  - (Co-)firing in entrained-flow gasifiers
  - Small-scale pellet boilers/stoves
- In 2007 pilot-plant testing and initiation of demo-projects

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