SECTOR

GA no 282826

Production of Solid Sustainable Energy Carriers from Biomass by Means of Torrefaction

Deliverable No. D10.3

Proceedings of the Workshops

Annex 1

Torrefaction by ECN

SECTOR/IEA Bioenergy Torrefaction Workshop
20th European Biomass Conference and Exhibition

Jaap Kiel, Robin Zwart and Fred Verhoeff

Milan, Italy
June 21st, 2012

www.ecn.nl

Presentation overview

- Introduction to ECN
  - Mission
  - Core activities in biomass
- ECN and torrefaction
  - Small-scale research
  - ECN's torrefaction technology
  - Pilot-scale testing
  - Logistics and end-use testing of torrefied material
- Torrefaction technology demonstration and commercialisation
  - Co-operation between ECN and Andritz
  - Demo plant features
  - Status

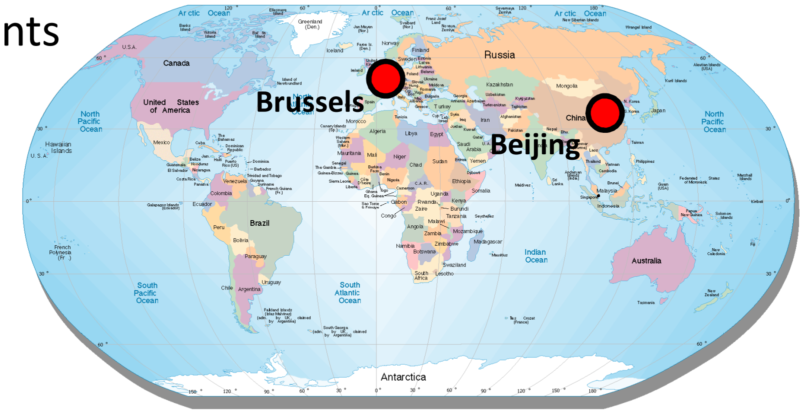
Energy research Centre of the Netherlands (ECN)

- Dedicated to Sustainable Energy Innovation

  With and for the market, ECN develops knowledge and technology that enable a transition to a sustainable energy system

- Core activities in biomass

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



Biomass

Solar

Wind

Energy efficiency

Policy studies

ECN and torrefaction

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

Initial torrefaction R&D at ECN

- 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
- Heat integration, using the energy content of the torrefaction gas, is crucial to achieve high energy efficiency (minimize cost and GHG footprint)

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 ºC	

Torrefaction
32 min, 260 ºC

20 l batch reactor

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

Mass yield: 75.3%
Energy yield: 94.3%

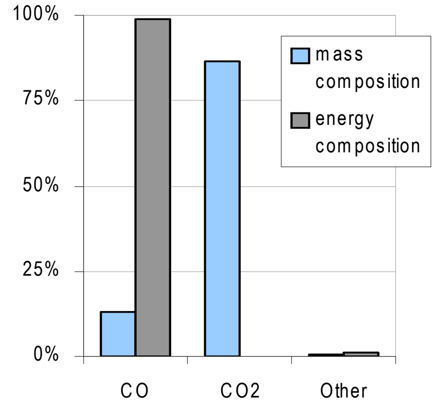
Torrefied Willow
Size: 10 - 30 mm
LHV: 18.5 MJ/kg
Moisture: 1.9%
Fixed carbon: 22.1%

Bench-scale testing

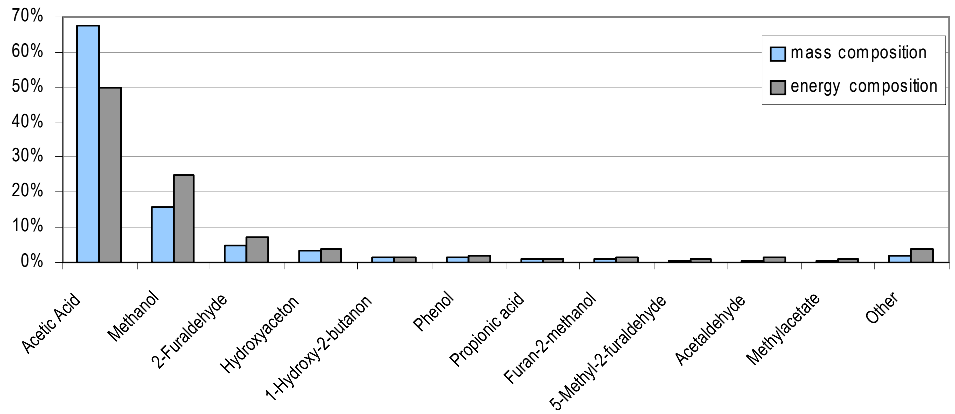
Continuous test – Torrefaction of willow (280 °C, 17.5 min)

5 kg/h Auger reactor
(screw reactor)

Permanent gases

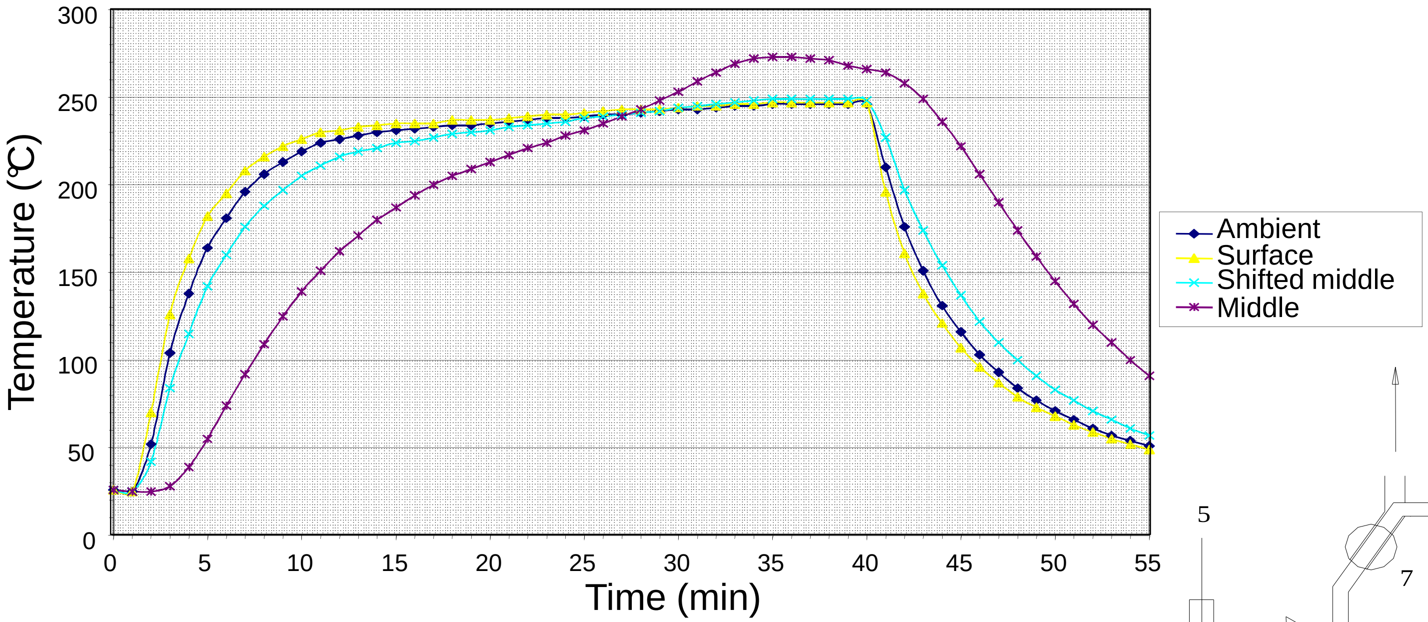


Organics

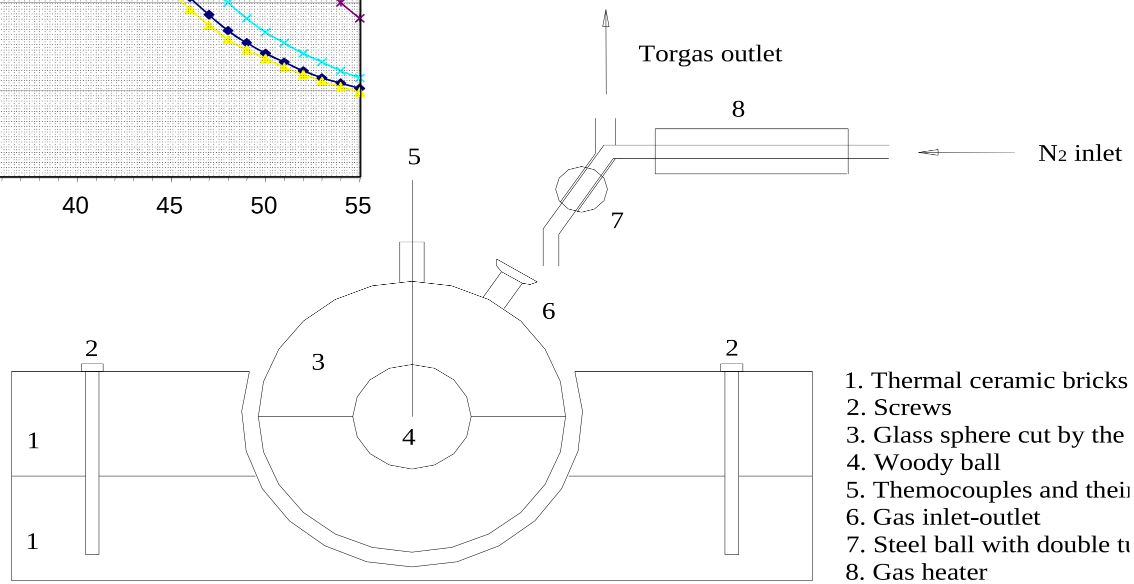


Exothermicity

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



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**

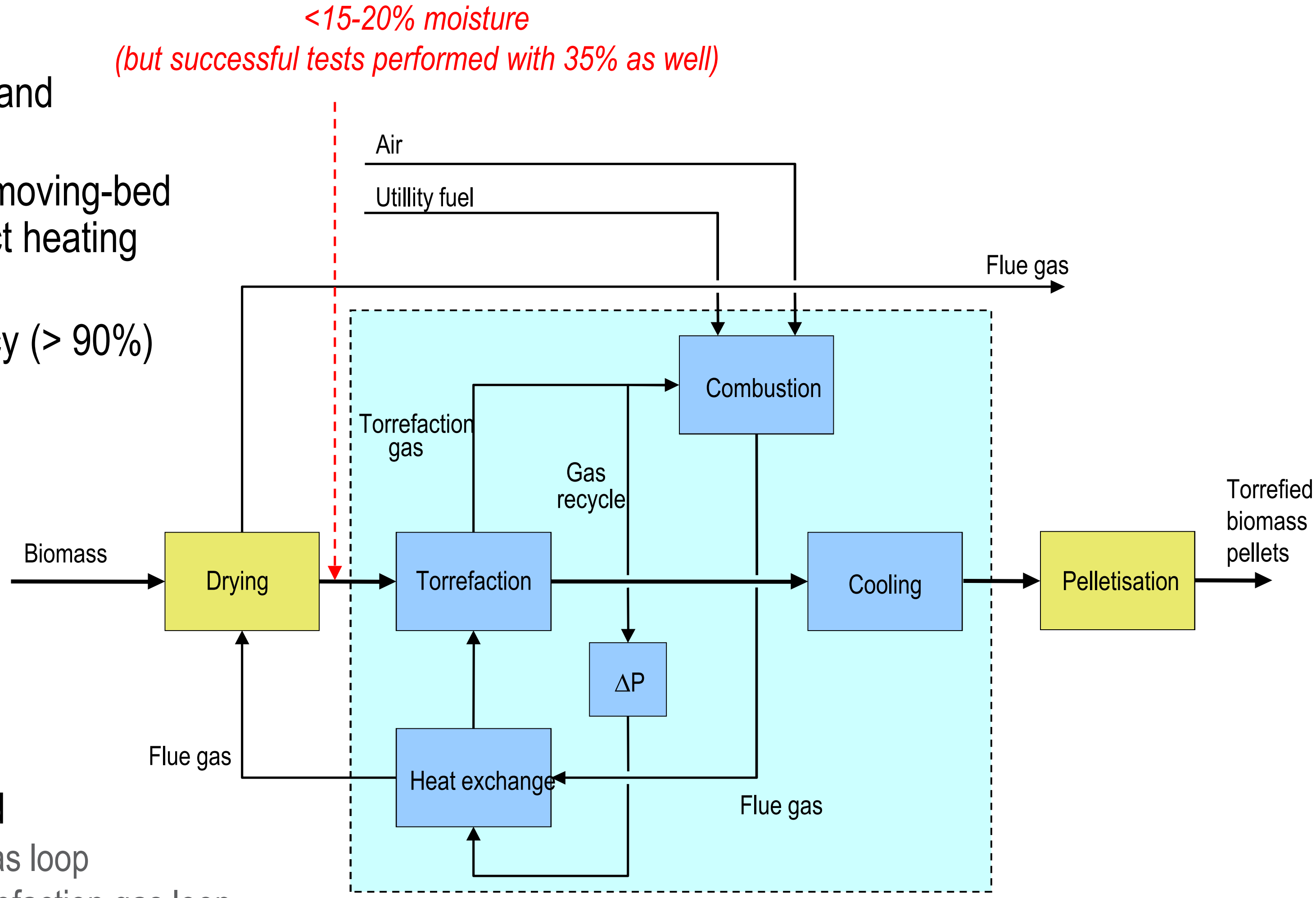
Densification

- 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 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's torrefaction technology

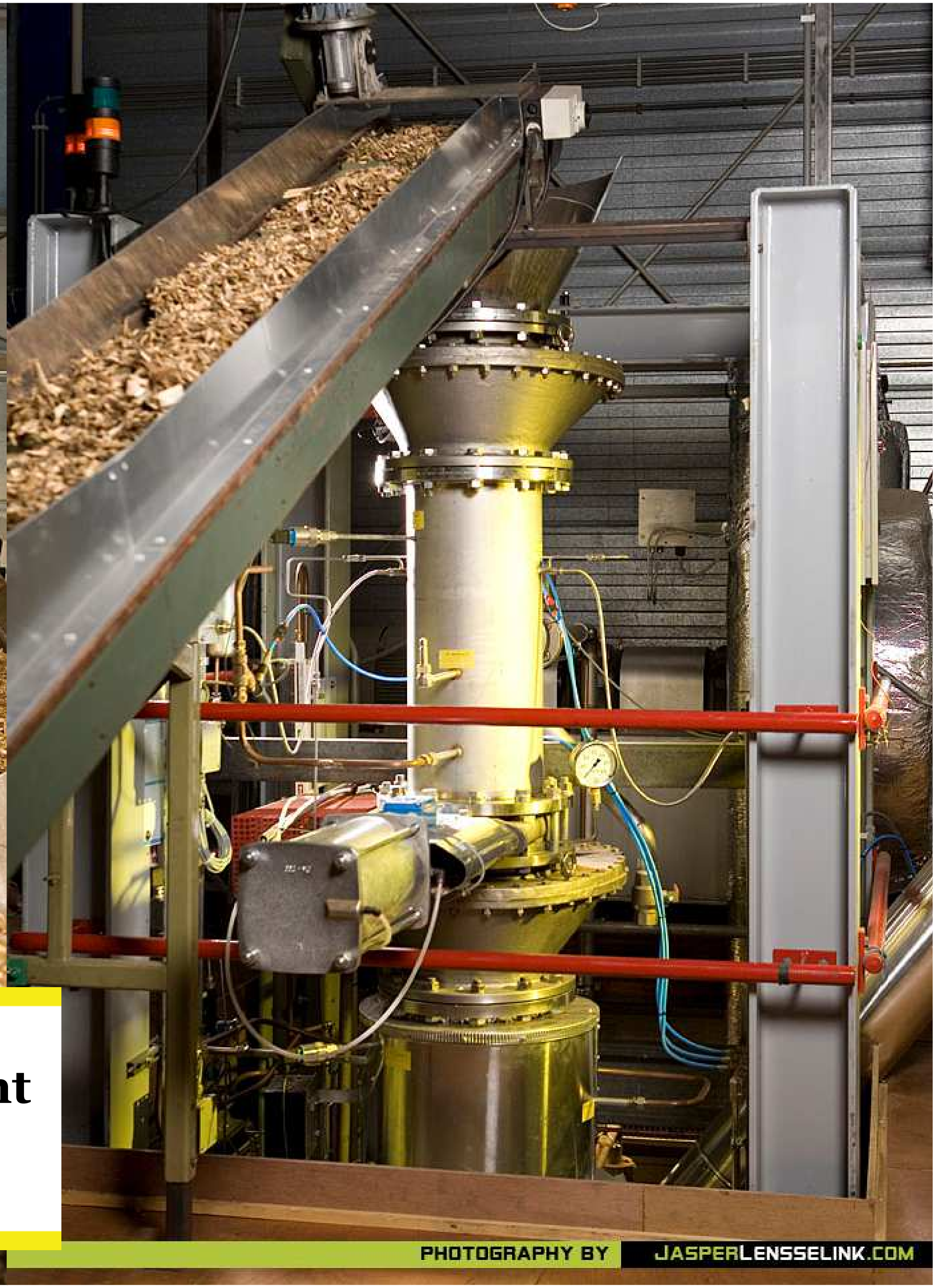
Features:

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



Intellectual Property:

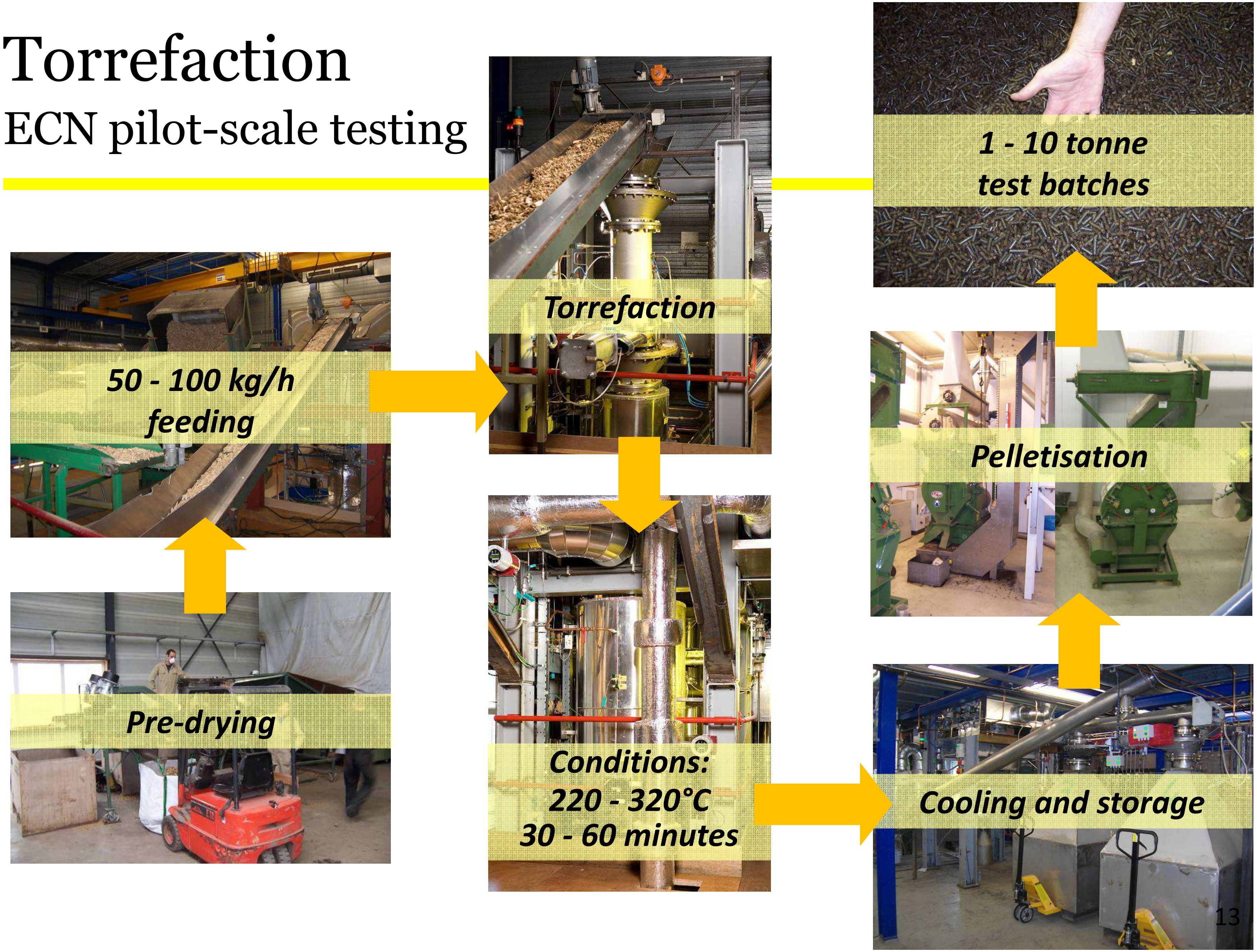
- IP is patent protected
  - Co-current drying gas loop
  - Counter-current torrefaction gas loop



ECN 50 kg/h torrefaction pilot plant
(Since February 2008)

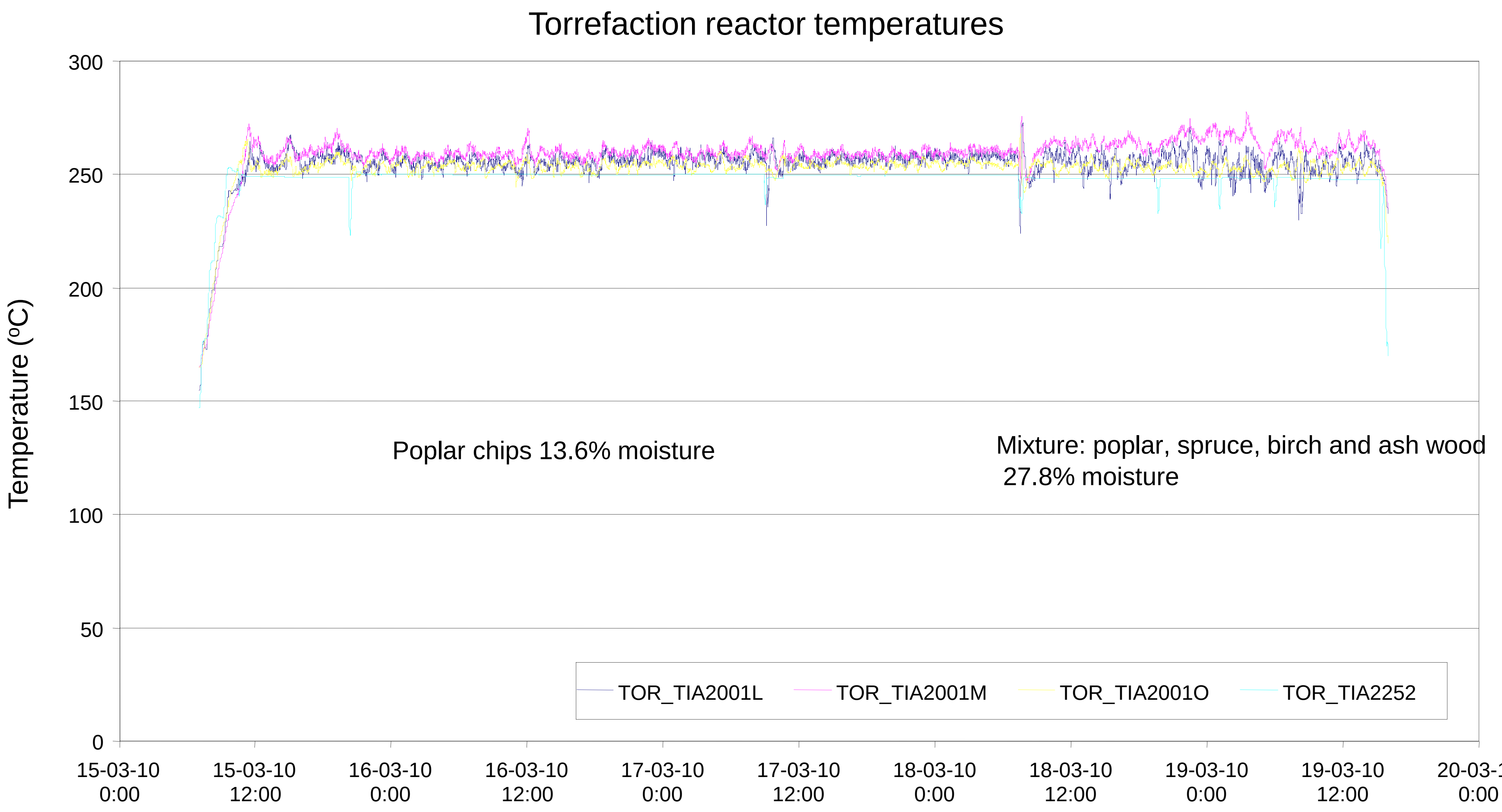
Torrefaction

ECN pilot-scale testing



ECN pilot-scale torrefaction

Results of typical 100 hour test run



ECN pilot-scale torrefaction

Biomass feedstock and test conditions

- Biomass feedstock
  - Aspen
  - Bamboo
  - Birch
  - Empty Fruit Bunches (EFB)
  - Forest residues
  - Oil Palm Fronds (OPF)
  - Pine
  - Poplar
  - Whole tree chips
- Temperatures & residence times
  - 220°C – 320°C
  - 30 – 60 min

ECN pilot-scale torrefaction

Recent test run – bamboo

ECN biomass (co-)firing R&D

Focal points and methodology

Focal points
- Grindability
- Pneumatic feeding
- Conversion kinetics
- Slagging / Fouling / Corrosion
- SCR catalyst performance
- Ash quality
- Emissions

Full-scale diagnostics
- PM / Gas emissions
- Slagging / Fouling / Corrosion

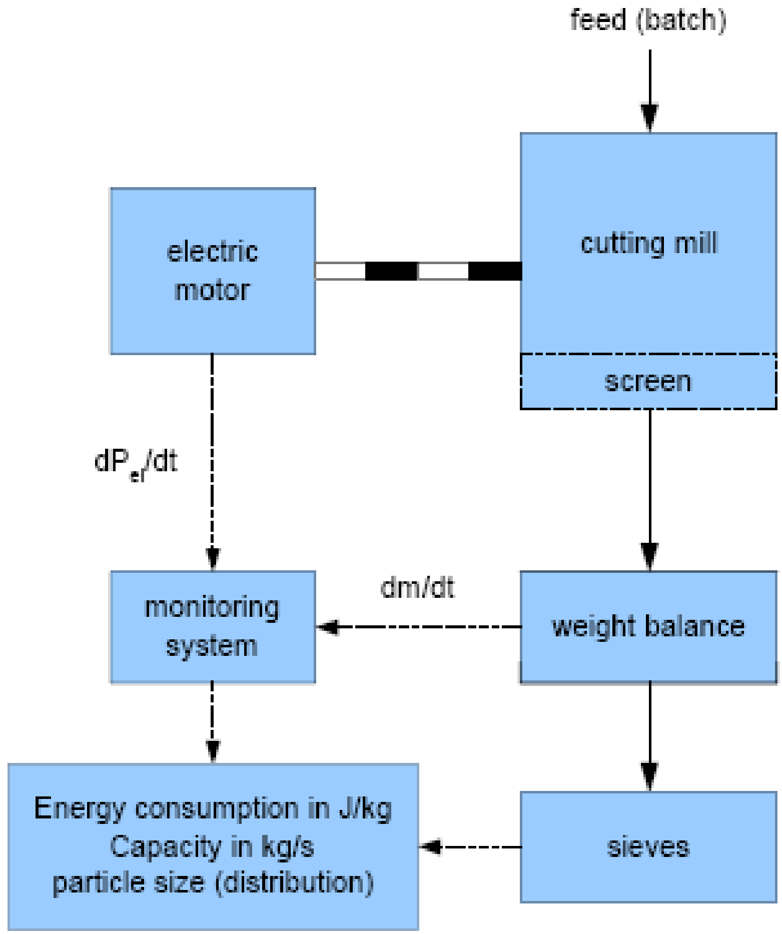
Advanced analytical tools
- Wet chemical
- (CC)SEM/EDX
- TGA/DSC, GC/LC/MS

Experimental tools
- Grinding test
- Fluidisation and bridging tests
- Lab-scale Combustion Simulator (LCS)
- Fluidised-bed combustion test rigs
- Deposition probes + cascade impactor
- SCR catalyst test facility
- pH-static extraction

Numerical tools and databases
- BIOMax ash model
- ORCHESTRA / LeachXS
- Co-firing Advisory Tool
- CFD
- Thermodynamics
- Phyllis/BIODAT biomass property database

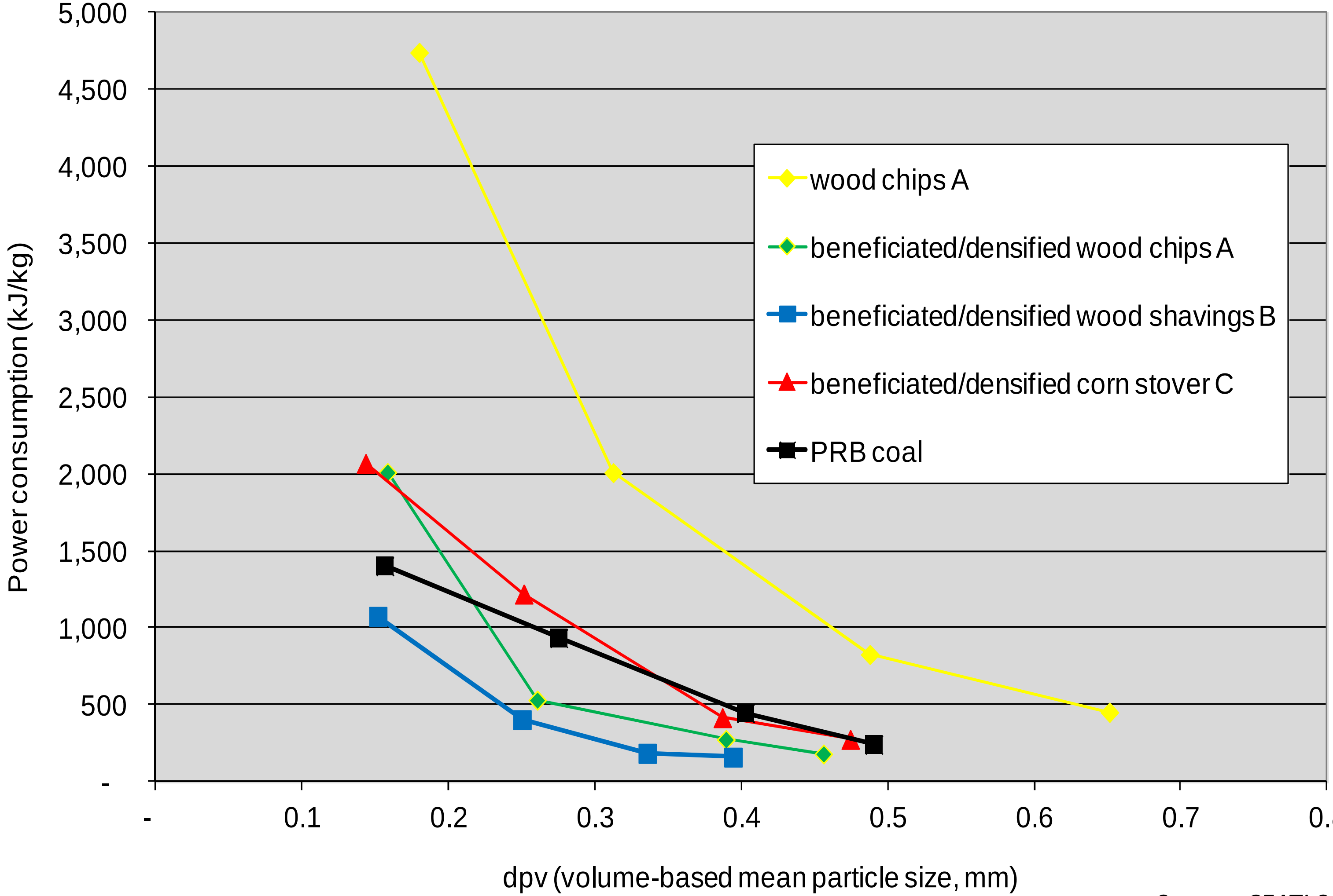
Grindability
Equipment and method

- ECN method
  - based on a cutting mill (RETSCH SM 2000)
  - 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

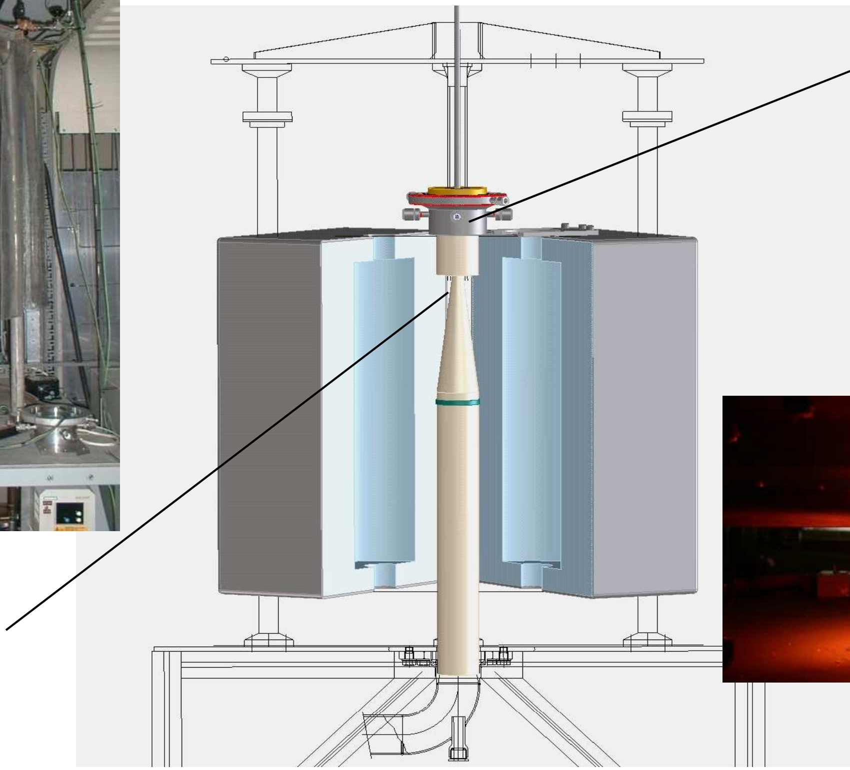
Results, power requirement



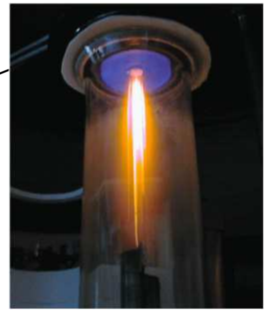
Source: CEATI SOIG 0530 B/C project

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

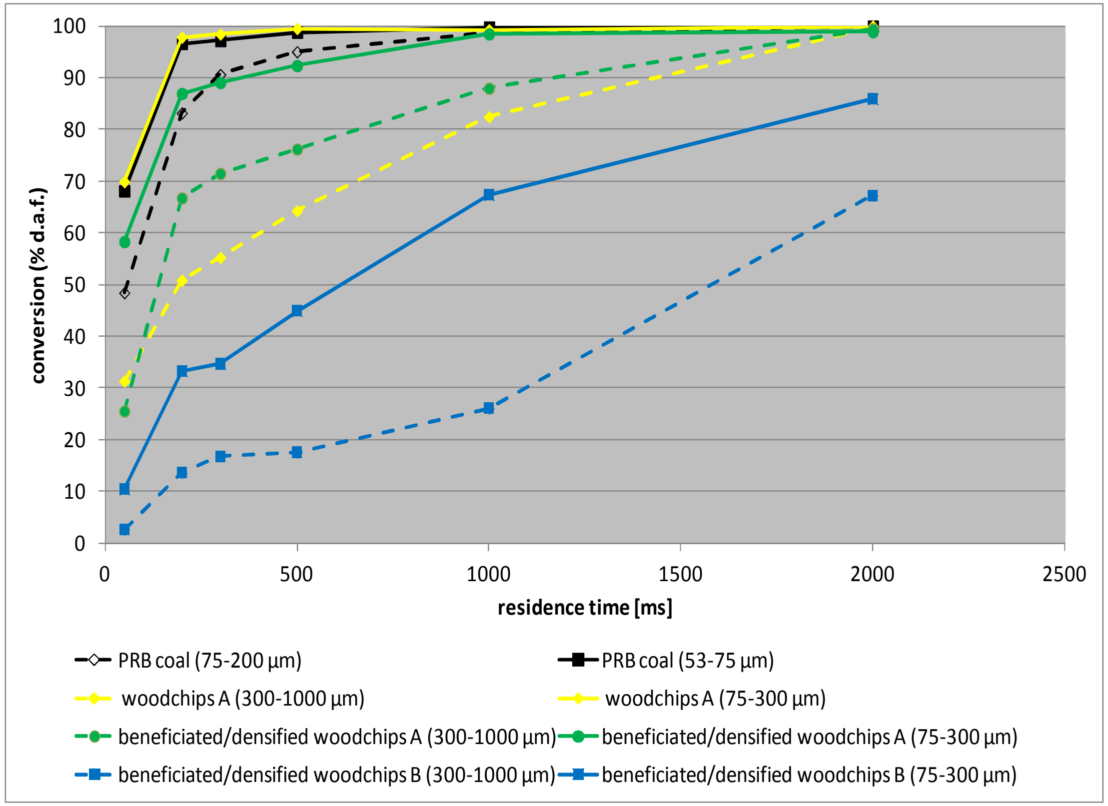
Fuel reactivity

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)

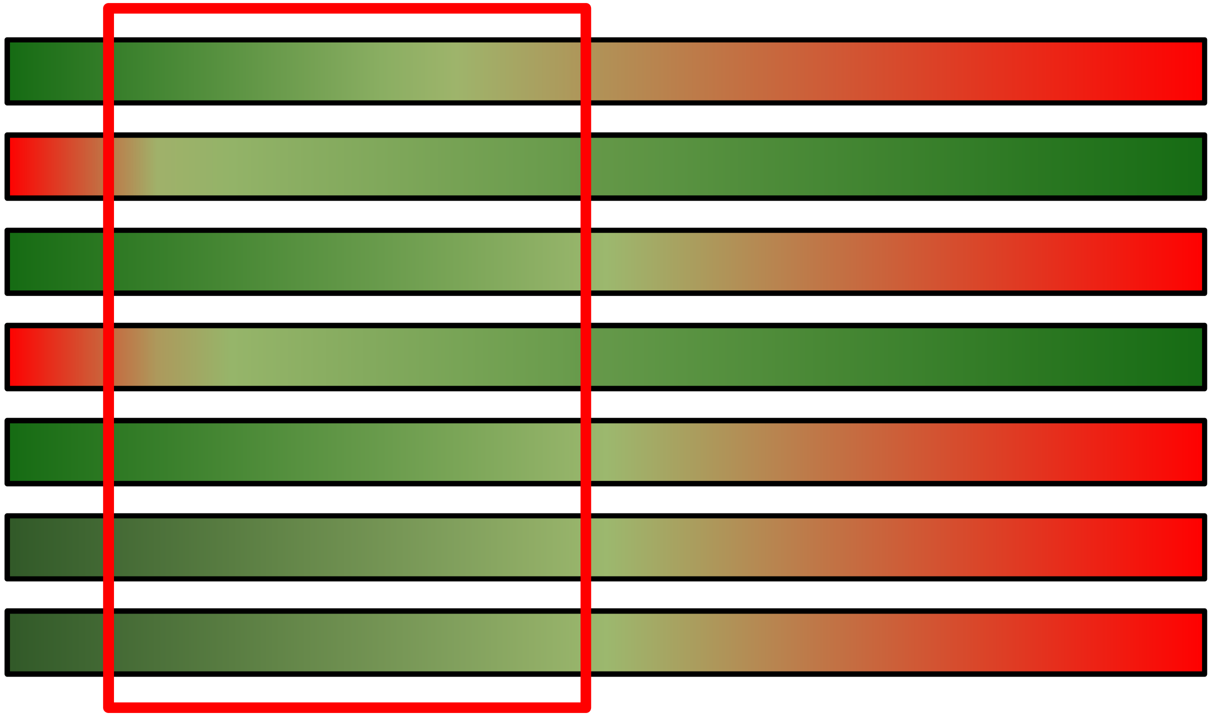
- (300-1000 µm) biomass significantly slower (fresh and upgraded)

- Very low for deeply-torrefied B material

Source: CEATI SOIG 0530 B/C project

Impact of torrefaction degree

- Densification
- Grindability
- Self-heating
- Heating value
- Reactivity
- Cost
- Sustainability
- .....



Mild torrefaction preferable
for most applications

Andritz-ECN Demo Plant
(March 2012)

ECN and Andritz

- ECN and Andritz signed a cooperation agreement on the development of torrefaction technology in mid-2011
- Andritz has licensed key technology from ECN
- ECN is providing technical and research services to Andritz
- The combination of ECN and Andritz technology is being tested in a Demo Plant in Denmark

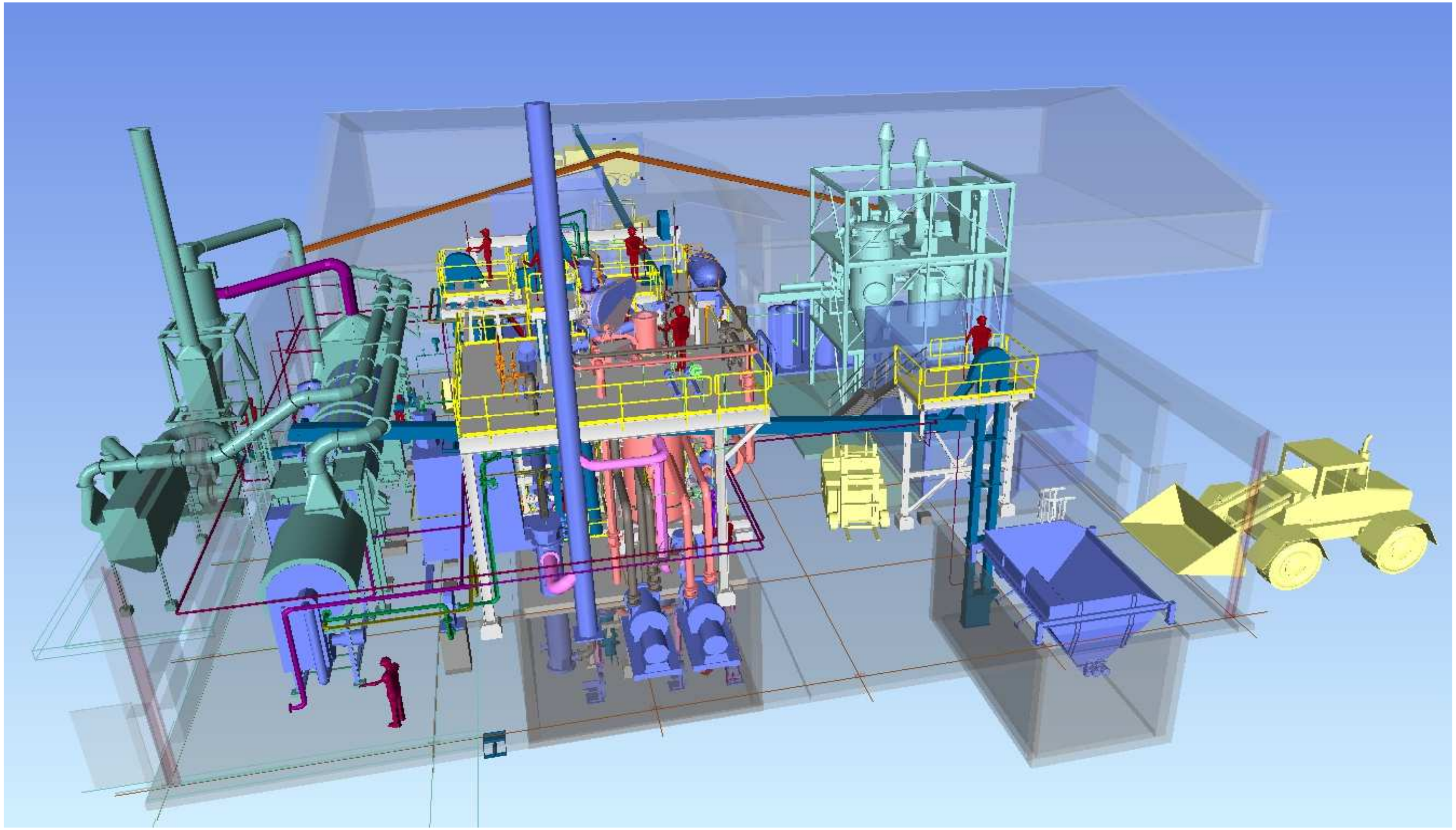
Torrefaction demo plant

Key features torrefaction reactor

- Blends ECN and Andritz technologies
- Pressurized for more effective heat transfer
- Provides a separation between the final drying zone and the beginning of torrefaction
- Includes a co-current torrefaction zone followed by a counter-current torrefaction zone
- Lends itself to scale up to large single unit capacities

Torrefaction demo plant

Overall view



Torrefaction demo plant

Status

- The demo plant is in the final stages of construction
- Commissioning is underway
- Initial operation on biomass will commence following commissioning

Pictures: March 2012

Thank you for your attention!

This presentation was prepared in close co-operation with:

ANDRITZ
Pulp & Paper

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

TOPELL ON TORREFACTION

LEADERS IN TORREFACTION TECHNOLOGY

TOPELL ENERGY HISTORY

GLOBAL TOP 3 UTILITY AS INVESTOR, WORLD'S LARGEST PLANT, VARIOUS REWARDS

2005
3.5 MW biomass gasifyer on waste wood

2006
Start of torrefaction R&D

2007
Proof of 100 seconds torrefaction pilot

2008
RWE Innogy takes 25% share in Topell

2008
Pilot plant in operation

2009
RWE Innogy and Topell close B-round

2010
65 % senior project debt ($15 million) financing by RABObank

2010
300.000 mt sales contract with Essent(5 yrs)

New Energy Pioneer 2010 – Bloomberg New Energy Finance Summit – WINNER

2010
Start construction Duiven Plant

2010
Construction finished 6 months after start

World Economic Forum – Technology Pioneer 2011

2011
Proof of 8 mt/hr+ production

WNF Clean Tech Star '11

2012
Start of construction of 80.000 mt systems

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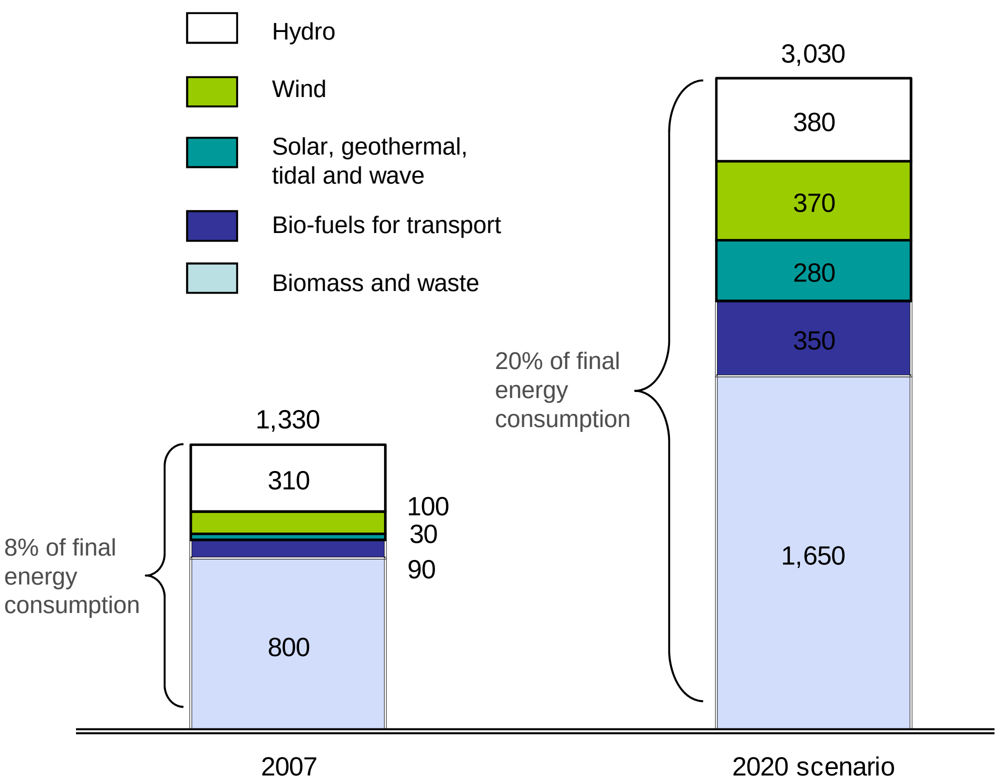
BIOMASS IS A KEY RENEWABLE FUEL NOW AND IN THE FUTURE, AS CONFIRMED BY UTILITY SECTOR EXECUTIVES

EU-27 mandated final renewable energy consumption
(TWh)



"Torrefied biomass provides a great opportunity not only for RWE but also for the Netherlands as a whole."
Leonhard Birnbaum, COO RWE

"Electricity generation from biomass has the potential to grow significantly and make a vital contribution to meeting the UK's challenging renewables and climate change targets at least cost to UK consumers."
Dorothy Thompson, Chief Executive of Drax

"The entire Vattenfall Group is fully engaged in changing our power plants and production methods such that we can meet the expectations that world has on us to provide clean, environmentally friendly energy,"
Hans von Uthmann, VP Vattenfall

Source: 'Biomass for heat and power: opportunity and economics'. Report by Vattenfall, SÖDRA, SVEASKOG, and the European Climate Foundation, with the assistance of McKinsey. Published June 10th 2010

TORREFACTION PRODUCES COAL-LIKE PRODUCT

INVOLVES THERMO-CHEMICAL TREATMENT OF BIOMASS

	Biomass (pellet, chip)	Torrefied biomass	Coal
Tough	Yes	No	No
Fibrous	Yes	No	No
Hydrophilic	Yes	No	No
Biodegradable	Yes	No	No
Heterogeneous	Yes	No	No
Poor energy density	Yes	No	No
Sustainable fuel	Yes	Yes	No

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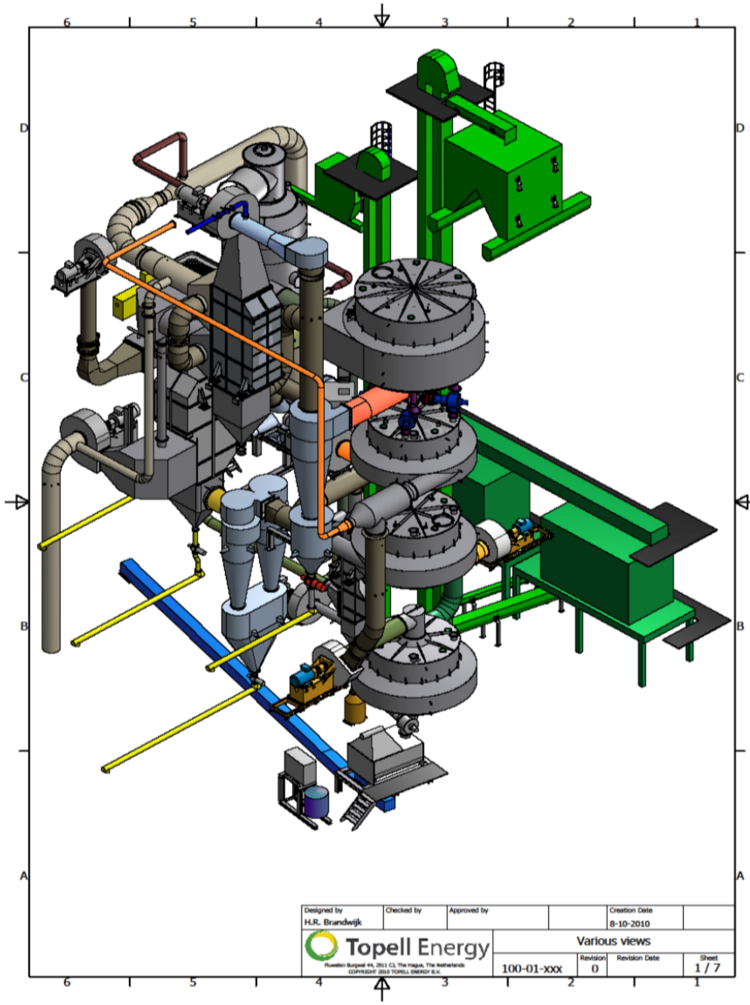
TOPELL TECHNOLOGY CHARACTERISTICS

IT TAKES 100 MILLION YEARS TO MAKE COAL NOW TAKES 100 SECONDS



- **Process time of 100 seconds.**
- **No moving parts(low maintenance)**
- **Proven reactor technology**
- **Heat transfer 40++ times faster than plug flow reactors**
- **Ability to precisely control product specifications**
- **Low energy consumption**
- **Scalable to 25 mt/hr+**

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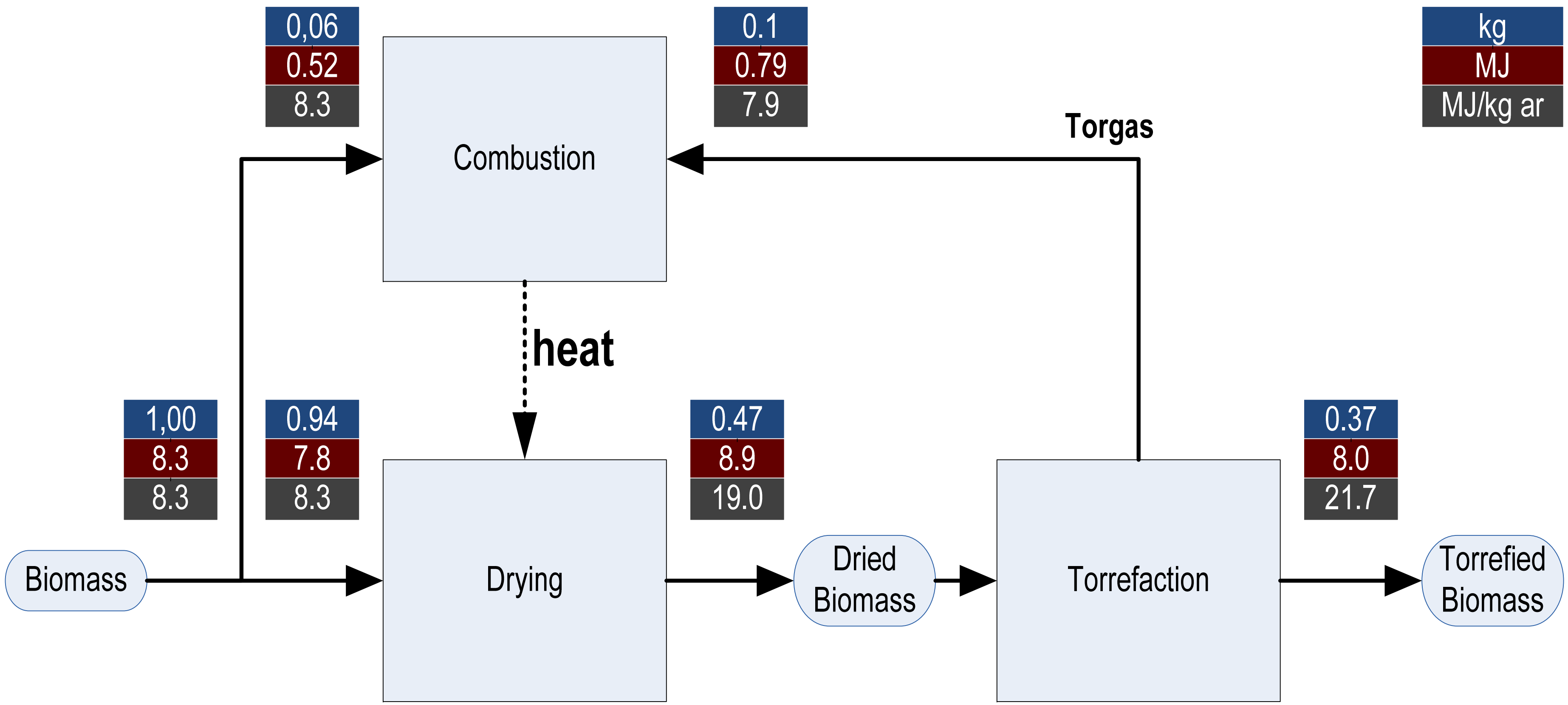
THERMAL EFFICIENCY TOPELL PROCESS IS 95%+

UTILIZATION OF COMBUSTION OF TORREFACTION GASES DRIVES HIGH EFFICIENCY



1. Feed is 50% moisture biomass.
2. Biomass co-combustion is zero at 35% or less moisture(autothermal point of operation)
3. Over 100% thermal effieciency possible due to exponential increase in LHV when reducing moisture from 50% to 0%

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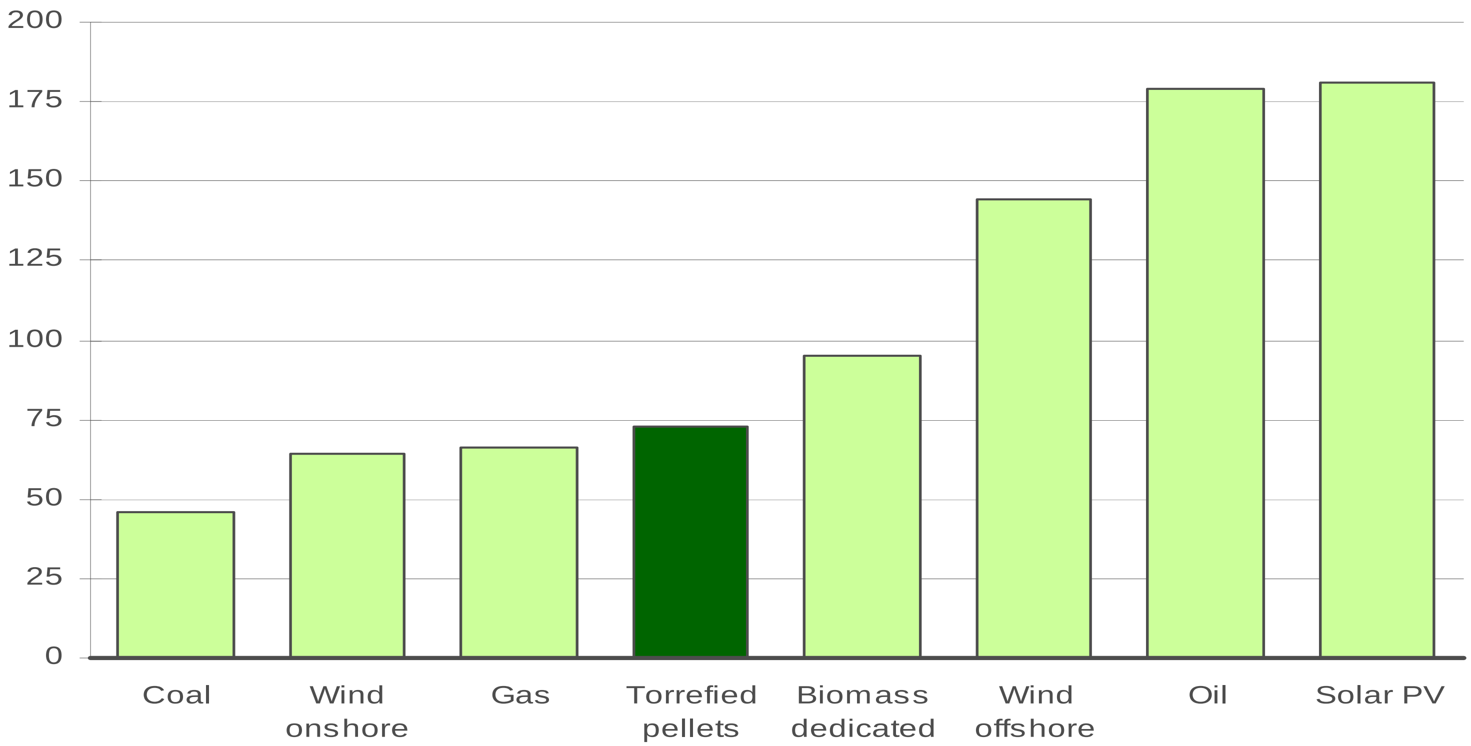
BIOMASS, AND MORE SPECIFICALLY TORREFIED BIOMASS, IS A COST COMPETITIVE RENEWABLE ENERGY FUEL

ENERGY PRODUCTION COSTS ANNO 2010 (€/MWH)



1. Torrefied biomass: base load + renewable
2. Wind & solar: renewable
3. Gas, oil, coal: base load

Source: Roadmap2050.eu

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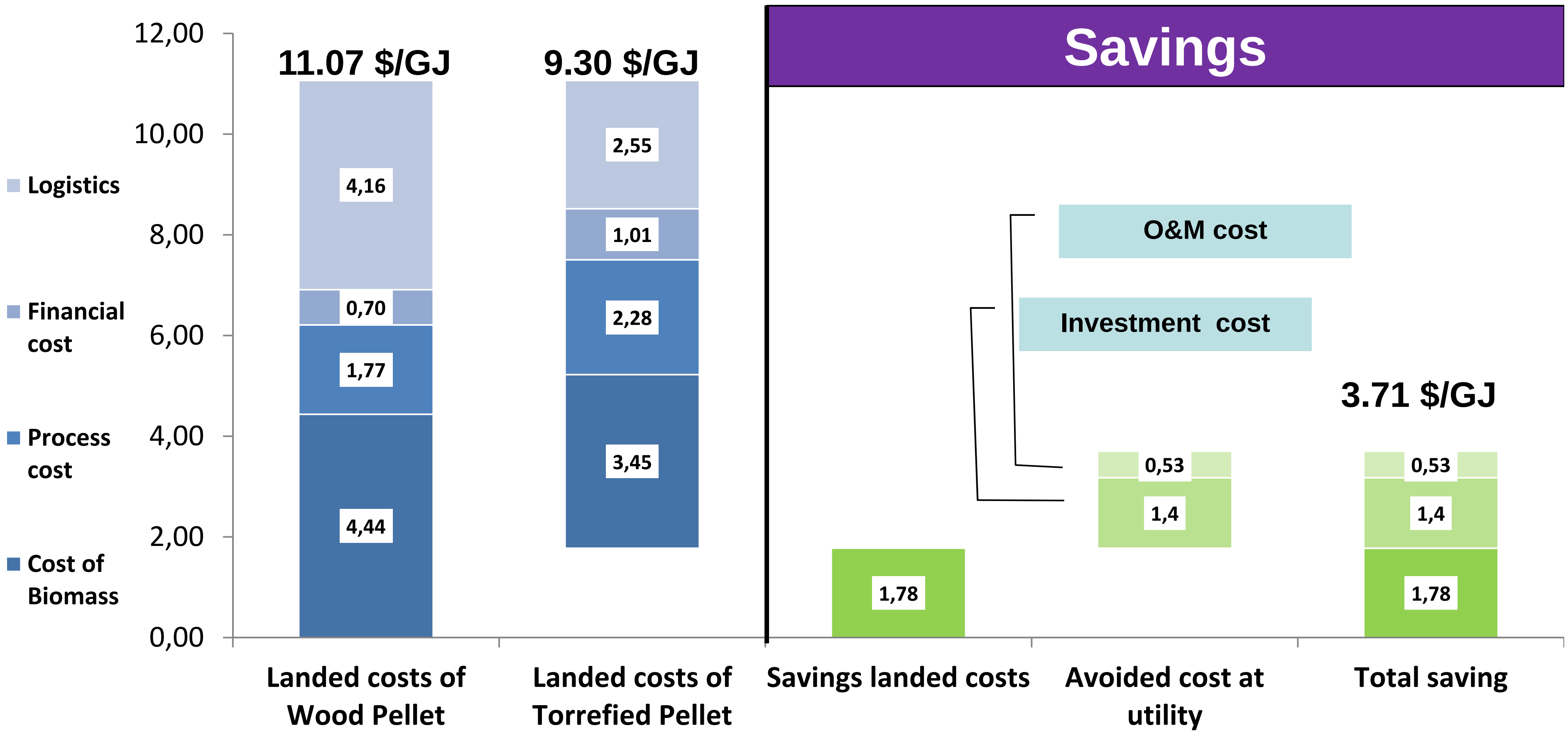
TORREFACTION RESULTS IN SIGNIFICANTLY LOWER COSTS IN THE ENTIRE VALUE CHAIN

COST COMPARISON BASED ON THE SAME PHYSICAL VALUE CHAIN USD/GJ



*Feedstock cost includes: delivered chipped cost of whole logs for wood pellet; whole logs and logging residues for torrefied pellet assuming 50% moisture content

**Process cost includes: electricity, labour, SG&A, binding agent, royalty and other operating costs

***Financial cost includes: depreciation, interest on debt

****Logistics includes: the cost of transportation and handling from plant to power plant

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TORREFACTION BASED ON TOPELL TECHNOLOGY PROVIDES A SOLID VALUE PRPOSITION TO ITS CUSTOMERS

POSSIBILITY OF LONGTERM TAKE-OFF AGREEMENTS SECURE STABLE CASH FLOWS

Torrefaction plants' IRRs depends on 2 main cost drivers

Biomass (40% moisture, chipped)
($/ton)

Deapsea freight costs *($/ton)*	16	22	28	34	40	45
28	40%	36%	32%	27%	24%	21%
36	38%	34%	29%	24%	21%	18%
44	36%	32%	27%	21%	18%	14%
51	34%	29%	24%	18%	14%	9%
58	32%	27%	21%	14%	9%	2%

likely

either unlikely or not viable

Assumptions

- A greenfield project costs $28 mln for 100,000 ton plant
- 40% equity financed, 60% is bank debt financed
- Sales prices $11.50/GJ CIF Rotterdam.
- Staff 25
- All costs included
- Average local corporate taxation: 25%

IRR for the plant owner > 20-25%, which is a relevant return for large number of customers

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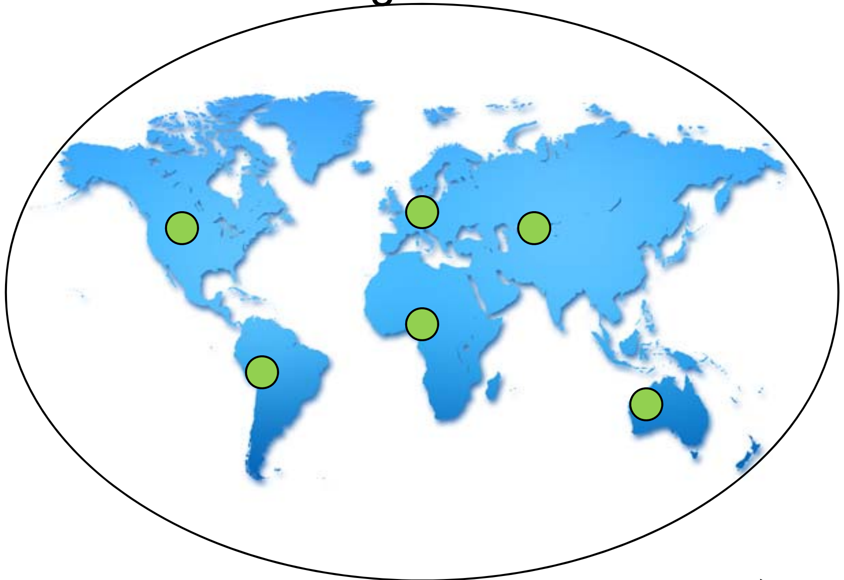
TOPELL ENERGY HISTORY

FROM A PLAN TO REALITY TAKES 6-8 YEARS AND SIGNIFICANT CAPITAL

Stage I.	Stage II.	Stage III.	Stage IV.
			
€0.5-1M*	**€2-3 M***	**€20-25M***	**€35-50M***
Idea	Pilot Plant	Commercial Plant	International Roll Out
- Concept-business plan - Planning - License	- Organization - Engineering commercial plant -IP portfolio -R&D	- Bank financing - Commissioning - Sales contract - Process know how	-Organization -R&D -Engineering -Process know how

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* Cummulative capital expenditure

TOPELL TORREFACTION PLANT

PELLETS PRODUCED AND PRODUCTION BOOSTED

Densification concepts for torrefied biomass

Torrefaction workshop

European Biomass Conference, Milano 2012

Wolfgang Stelte*, Jonas Dahl, Niels Peter K. Nielsen, Hans Ove Hansen

Danish Technological Institute

Presentation overview

- Danish Technological Institute and its role in SECTOR
- Advantages to combine torrefaction and densification
- Difficulties and challenges
- Possible Solutions
- Conclusions

Danish Technological Institute (DTI)

DANISH
TECHNOLOGICAL
INSTITUTE

STATUS

An independent, non-profit institution

Approved as a technological service institute by the Danish Ministry of Science, Technology and Innovation.

OBJECTIVE

Address the needs of the industrial sector and society as a whole through the development and dissemination of technological innovation.

Danish Technological Institute (DTI)

DANISH TECHNOLOGICAL INSTITUTE

LOCATIONS

Role of DTI in SECTOR project

DANISH TECHNOLOGICAL INSTITUTE

- Several years of experience with torrefaction and pelletization processes
- Heavily involved in national and international R&D projects
- Wide network with industry and academia
- Torrefaction and pelletization from laboratory to production scale

→ **Major activities within SECTOR project will be in WP4**

Densification of torrefied biomass

Why combining torrefaction and densification ?

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INSTITUTE

- **Torrefied biomass is difficult to handle**

  - Porous and brittle structure
  - Low density
  - Dust and dirt formation (health & explosion risk)

  → **Poor handling properties**

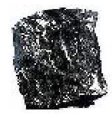
- **Densification**
  - Pelletizing & briquetting
  - Increase density
  - Homogeneous shape and size (automatization, standardization)
  - Less dust and fine formation

Densification of torrefied biomass

- **Benchmark**







	Wood Chips	Wood Pellets	Torrefied Pellets	Charcoal	Coal
Moisture (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/m^3)	200-300	550-650	**650-800**	180-240	800-850
Vol. Energy density (GJ/m^3)	1.4 – 3.6	8-11	**12-19**	5.4-7.7	18-24
Hygroscopic properties	Hydrophilic	Hydrophilic	**(Hydrophobic)**	Hydrophobic	Hydrophobic
Biological degradation	Fast	Moderate	**None**	None	None
Milling requirements	Special	Special	**Standard**	Standard	Standard
Transport cost	High	Medium	**Low**	Medium	Low

Data from ECN

Densification of torrefied biomass

DANISH TECHNOLOGICAL INSTITUTE

- Pelletization and Briquetting
- Both established processes for many decades
- Torrefied biomass: Focus is set on pelletization, but briquetting is considered as well
- Experience with many different raw materials (wood, agro, waste)

→ So how difficult can it be to pelletize torrefied biomass?

→ Unfortunately its not as straight forward

Challenges when pelletizing torrefied biomass

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- High friction in press channel
  - High energy uptake of pellet mill 150 kWh/t (50-60 kWh/t for wood)
  - Heat generation in pellet mill (risk of fire / dust explosion)
  - Lower capacity
  - More wear on the pellet mill parts
- Pellet quality
  - Durability
  - Density
  - Hydrophobicity
  - Storage of torrefied pellets

Issues are closely linked to

- Biomass feedstock
- Torrefaction parameters
- Pelletization parameters
- Can be different case by case

Requires knowledge and further studies

Challenges when pelletizing torrefied biomass

DANISH TECHNOLOGICAL INSTITUTE

- Process development is time consuming and expensive
  - Lack of knowledge
  - Process development via pilot trials
  - "trial and error" & experience → learning by doing

→ **Aim of the SECTOR project is to provide solutions**

- Method development for fast and simple testing of pelletizing properties
- Create knowledge about combinig torrefaction & pelletiziation
- Improve process and product
- Cost competetitive solutions

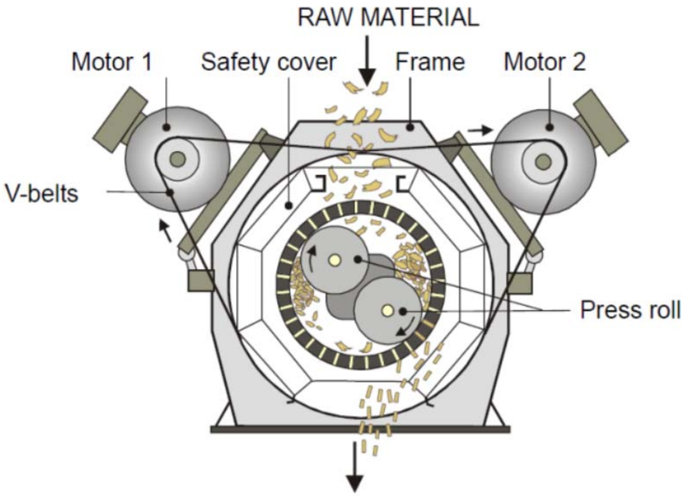
Challenges to pelletize torrefied biomass

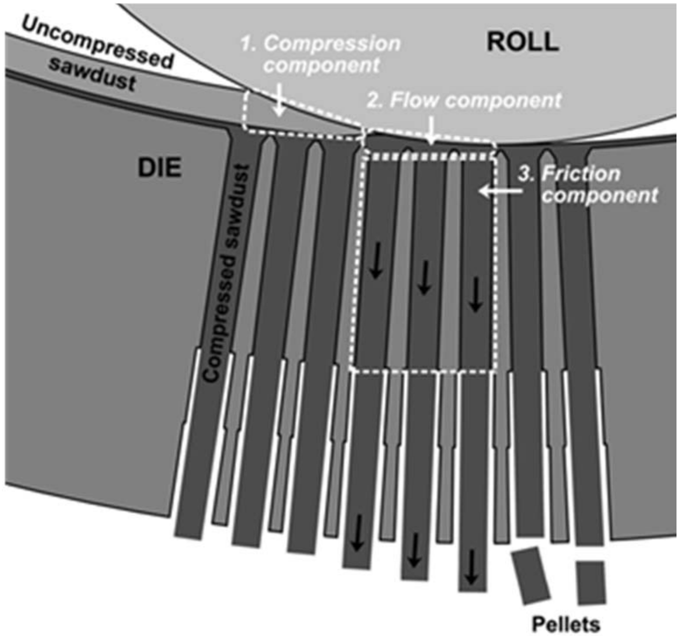
DANISH TECHNOLOGICAL INSTITUTE

- We have a laboratory method to screen the pelletizing properties of (torrefied) biomass
  - Fast and simple
  - Just a few grams are needed
  - Adjustment of different pelletizing parameters
- Pelletizing tests and optimization on laboratory scale
- Results give indication what equipment and parameters should be used for pelletization
- Correlation between lab trials and production size pellet mill has been shown

Pelletizing process

- Pelletizing process

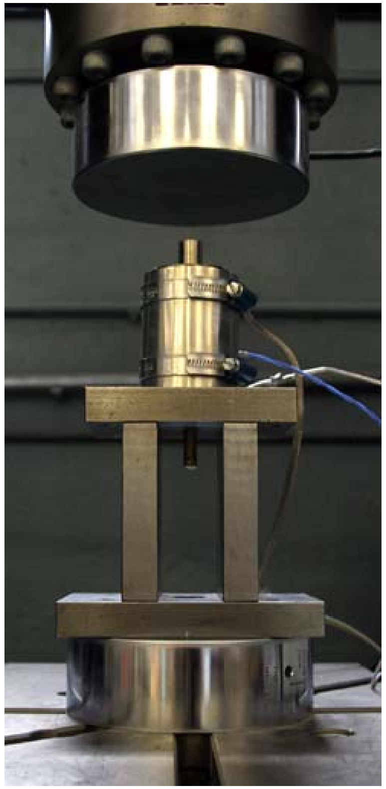


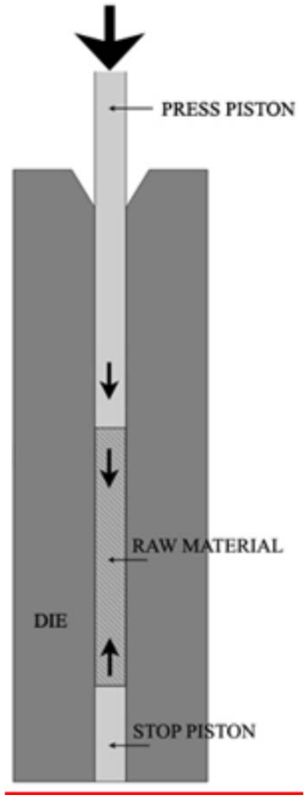


Pelletizing process can be separated into different stages

The energy required for the process is a sum of these parts

Single pellet press method





For every biomass type we test 4 parameters

1. Compression of biomass

2. Static & dynamic friction

After pelletization…

3. Pellet compression strength

4. Pellet density

Single pellet press method

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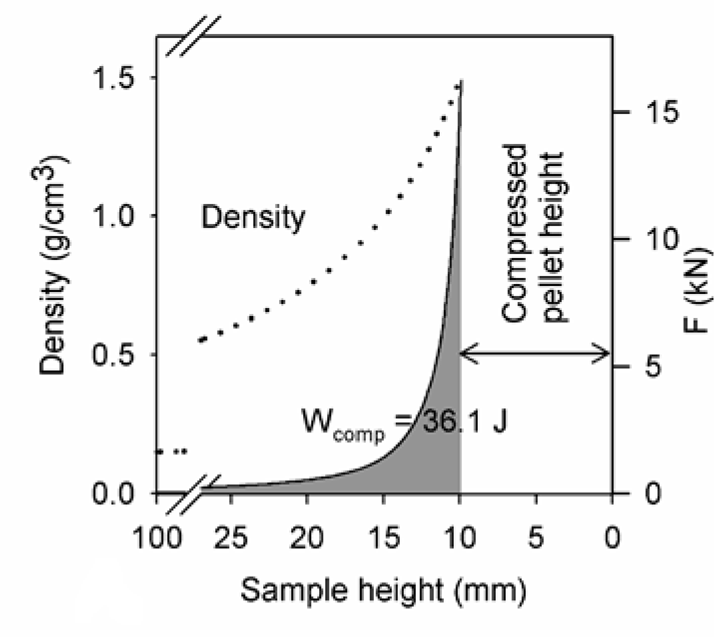
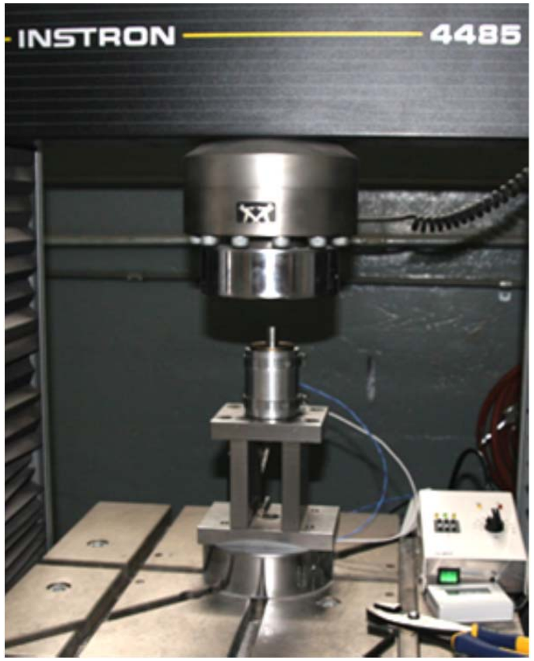
1. Compression





8 mm diameter

Temp. up to 200 °C

Instron Material test system

Force distance curves

750 mg of biomass

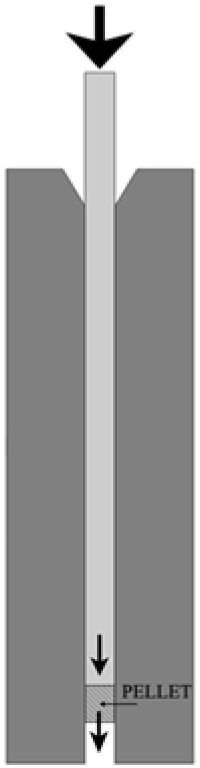
300 MPa pressure

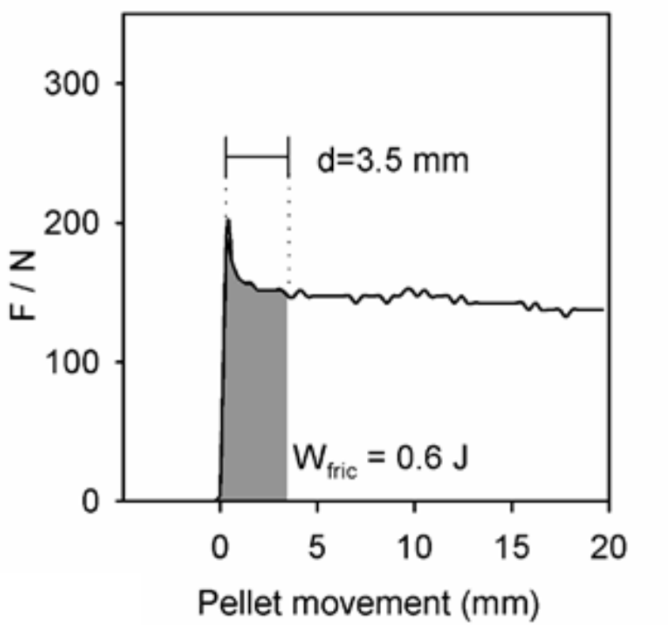
Detection of force, integration over distance → W_{comp}

Single pellet press method

DANISH TECHNOLOGICAL INSTITUTE

2. Static and dynamic friction





Static friction: Force to make the pellet move

Dynamic friction: Force to keep it going

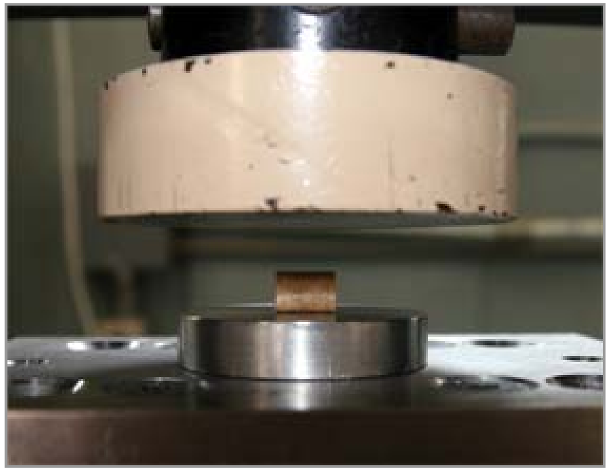
Pellet is moved over a defined distance (here 3.5 mm)

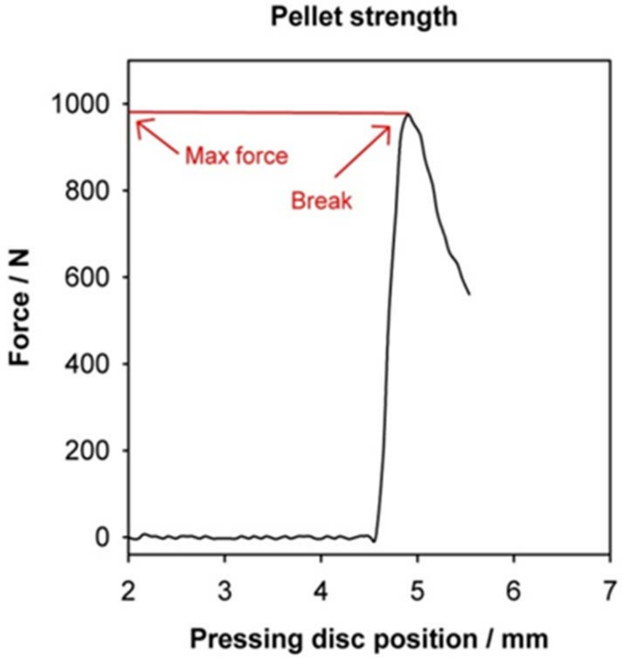
Calculation of W_{Fric}

Single pellet press method

DANISH TECHNOLOGICAL INSTITUTE

3. Pellet compression strength
4. Density





The pellet quality is determined by compression testing

The pellet is placed perpendicular to its axis and crushed → force-distance curve

Pellet density is determined by length and weight measurement of pellets

Selected results

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- How to lower the friction when pelletizing torrefied biomass

Selected results

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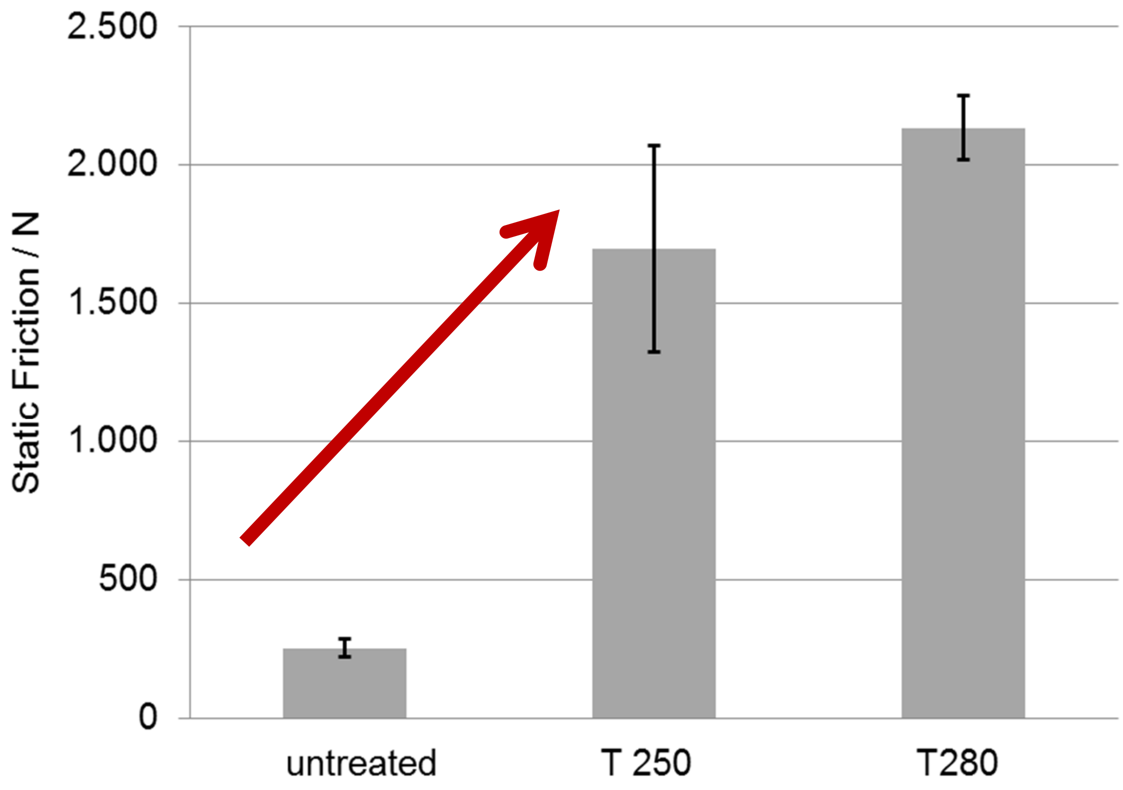
- Friction increase when pelletizing torrefied pine tree



Strong increase of friction for torrefied biomass

Pellet mill:

Energy requirements increase

Capacity gets lower

More heat development in press

Torrefied pine tree / 0.5 % MC / 125 °C die temperature

Selected test results

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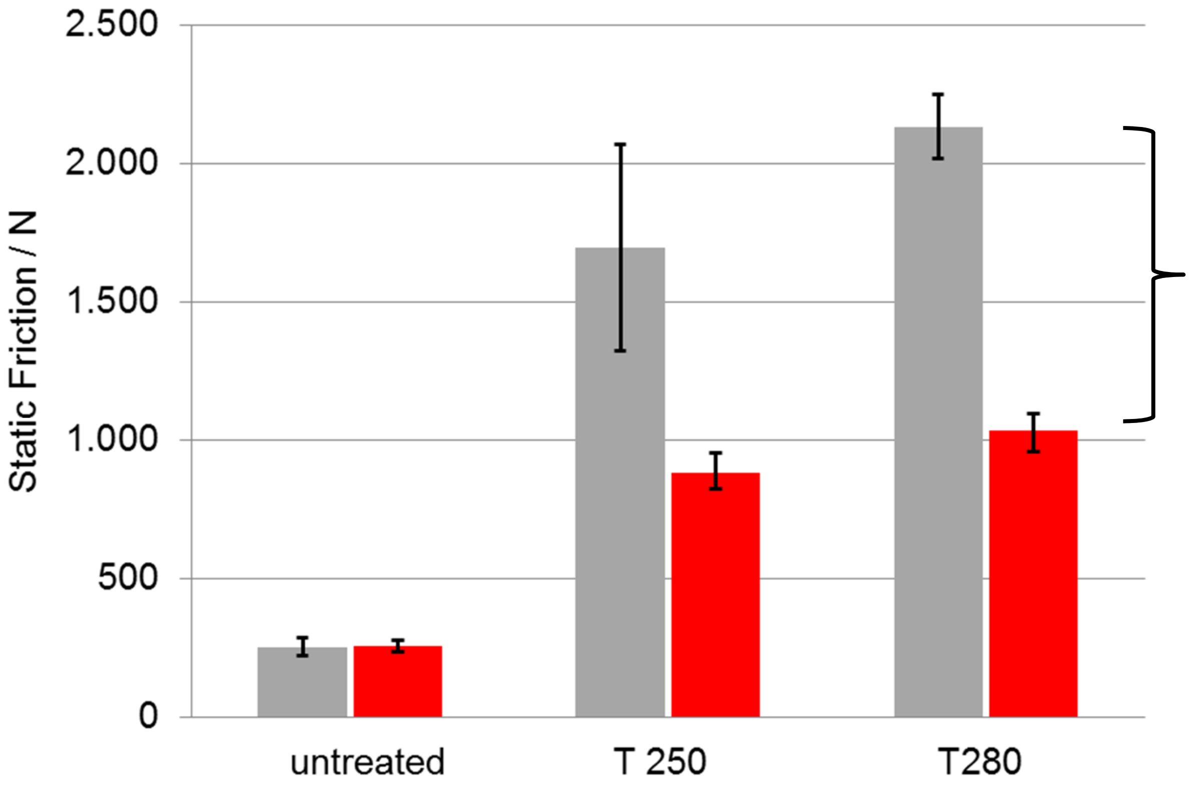
- What can we do to improve the pelletizing properties?
  - Increase moisture content
  - Increase die temperature
  - Add a lubricant to reduce friction
  - Additives
  - Change press channel dimensions
  - Torrefaction parameters
    - Temperature
    - Reaction time
  - …

We have looked on a few of them
Some examples

Selected results

- Increase of die temperature 125 → 190 °C

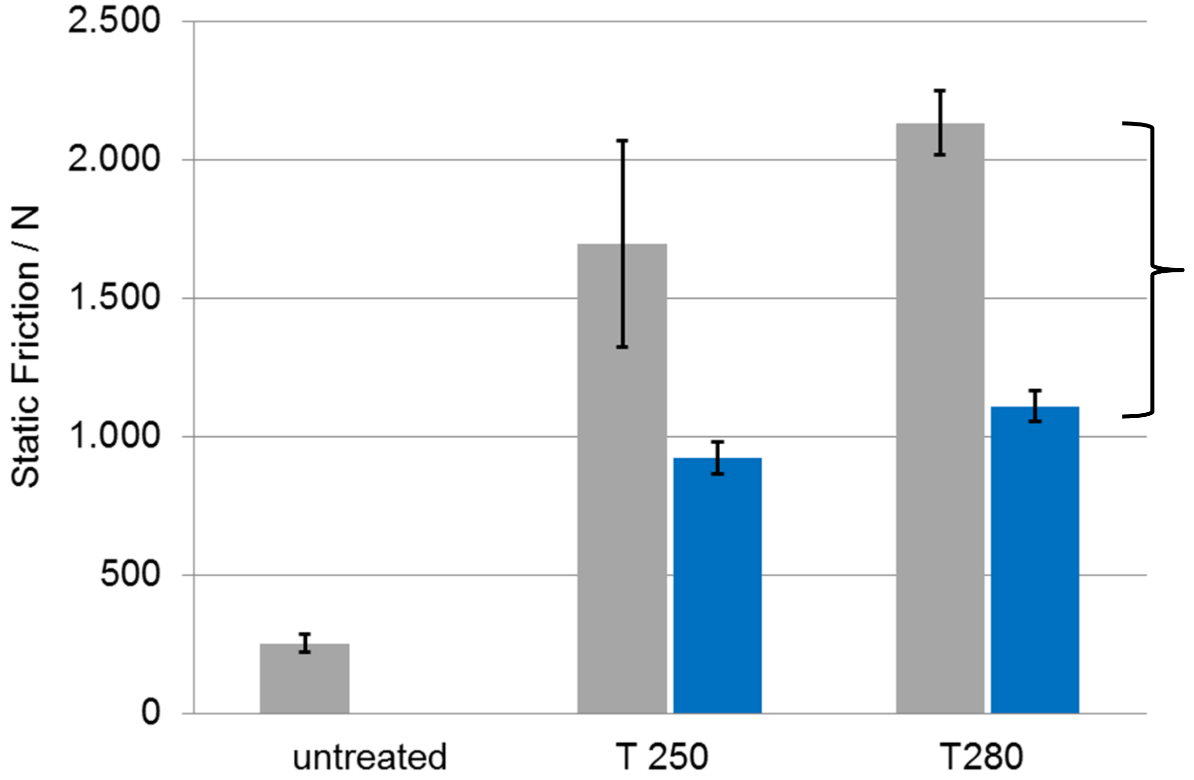


Friction is reduced by 50%

No effect on the untreated pine tree

Selected results

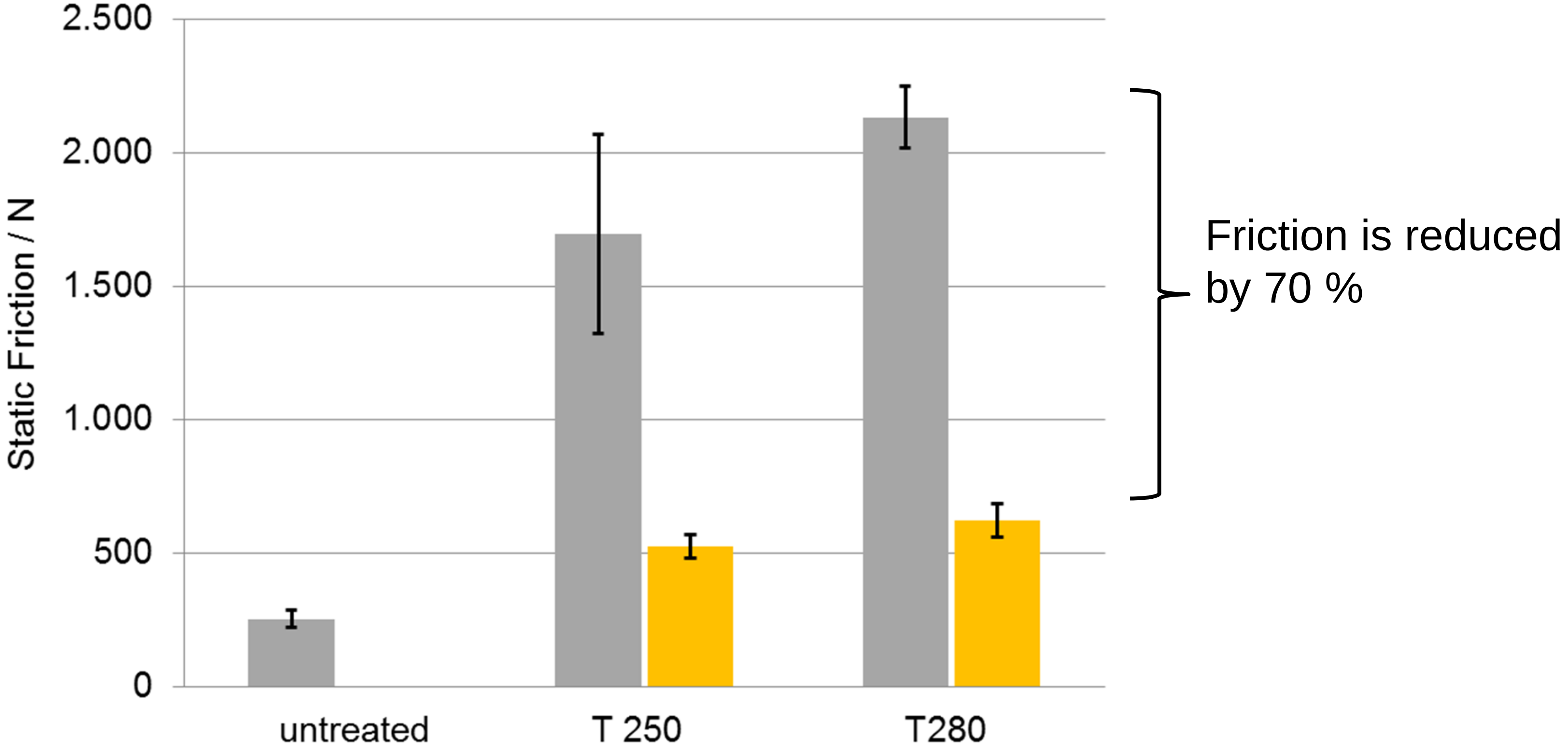
- Increase moisture content from 0.5 to 5% (wb)



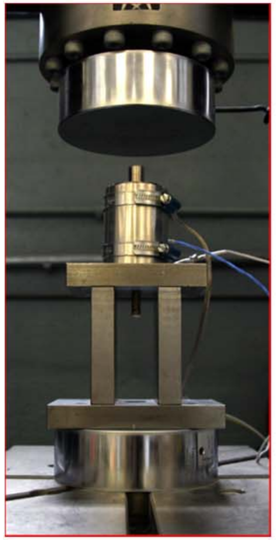
Friction is reduced by 50%

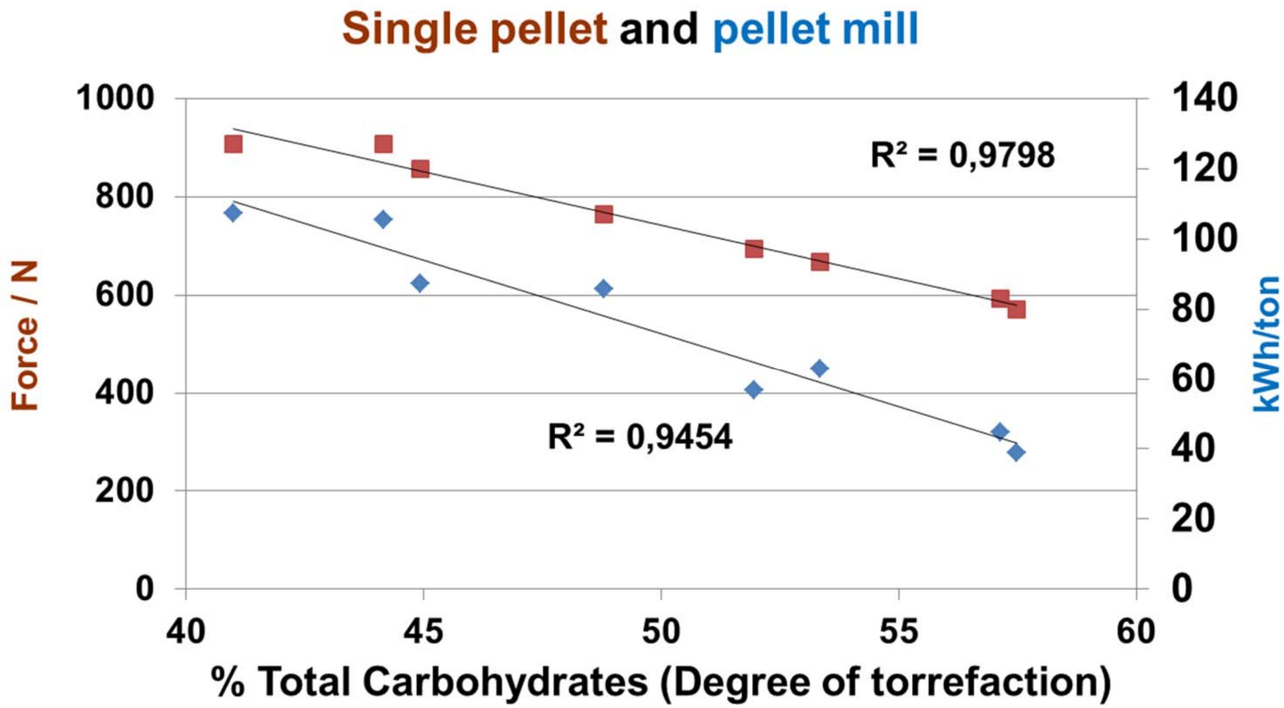
Selected results

- Add a lubricant (2% oil)



Single pellet press vs. pellet mill





Good correlation between single pellet press and production size pellet mill data

Static friction from single pellet press (N)

Energy consumption of press (kWh/t)

Selected results

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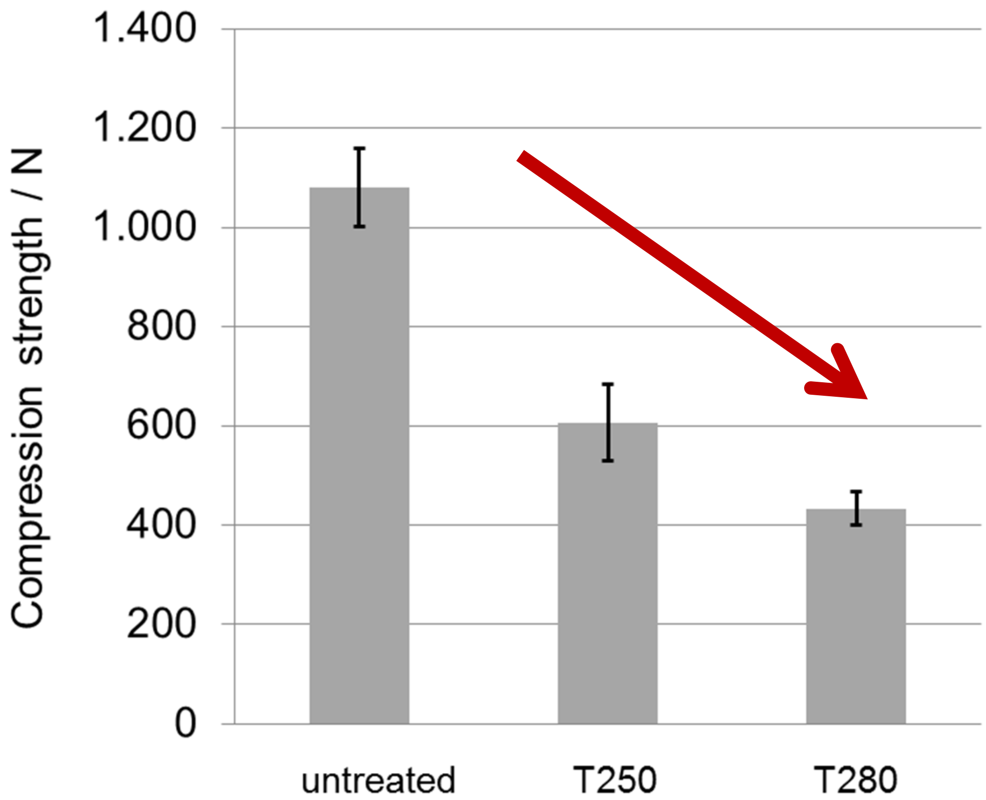
- How to improve the quality of torrefied pellets

Selected results

- Effect of torrefaction on pellet strength



Decrease of pellet strength with torrefaction temperature

Positive/Negative effects

Better grinding properties
Coal mills can be used to crush torrefied pellets

Dust and fines formation under transportation

Selected results

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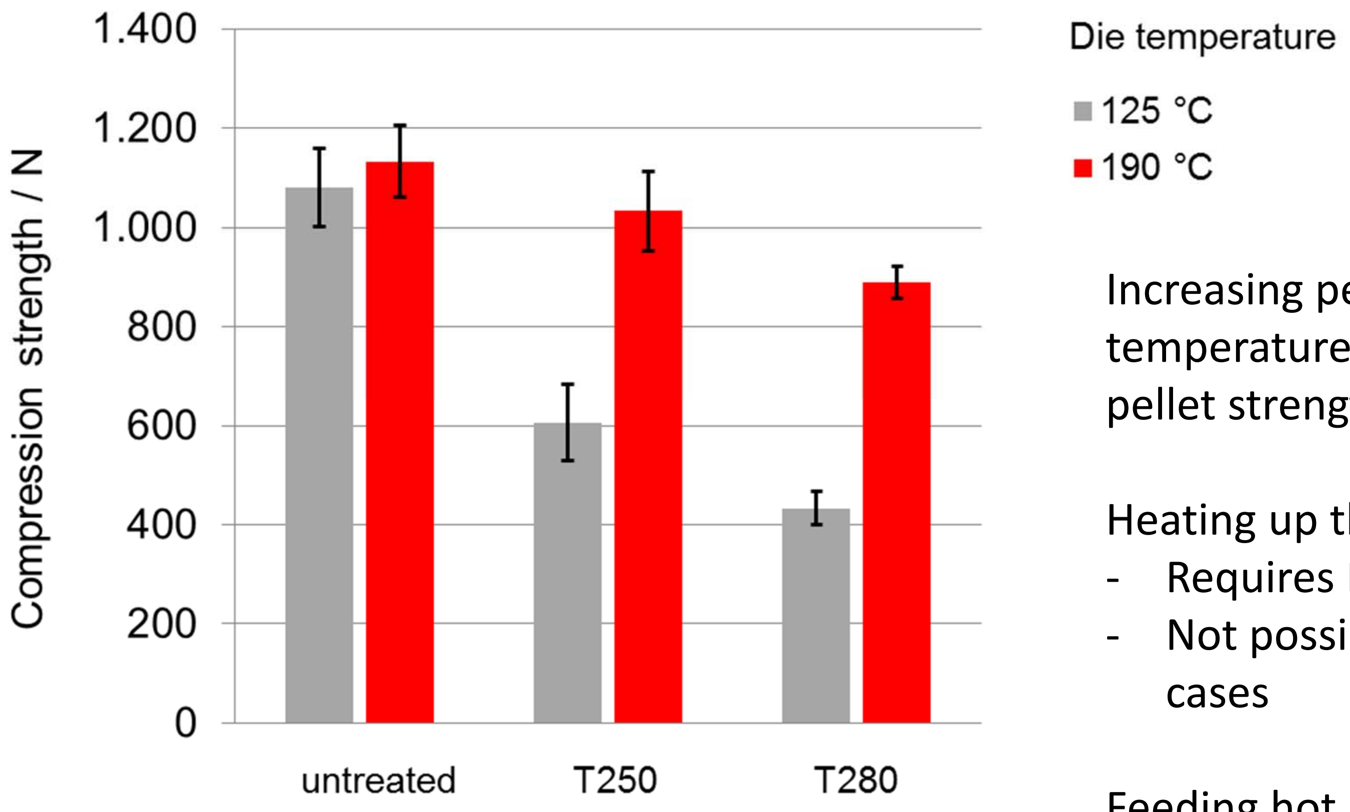
- Increase of die temperature to increase pellet quality



Increasing pelletizing temperature improves the pellet strength

Heating up the die
- Requires Energy
- Not possible in most cases

Feeding hot biomass directly after torrefaction?

Selected results

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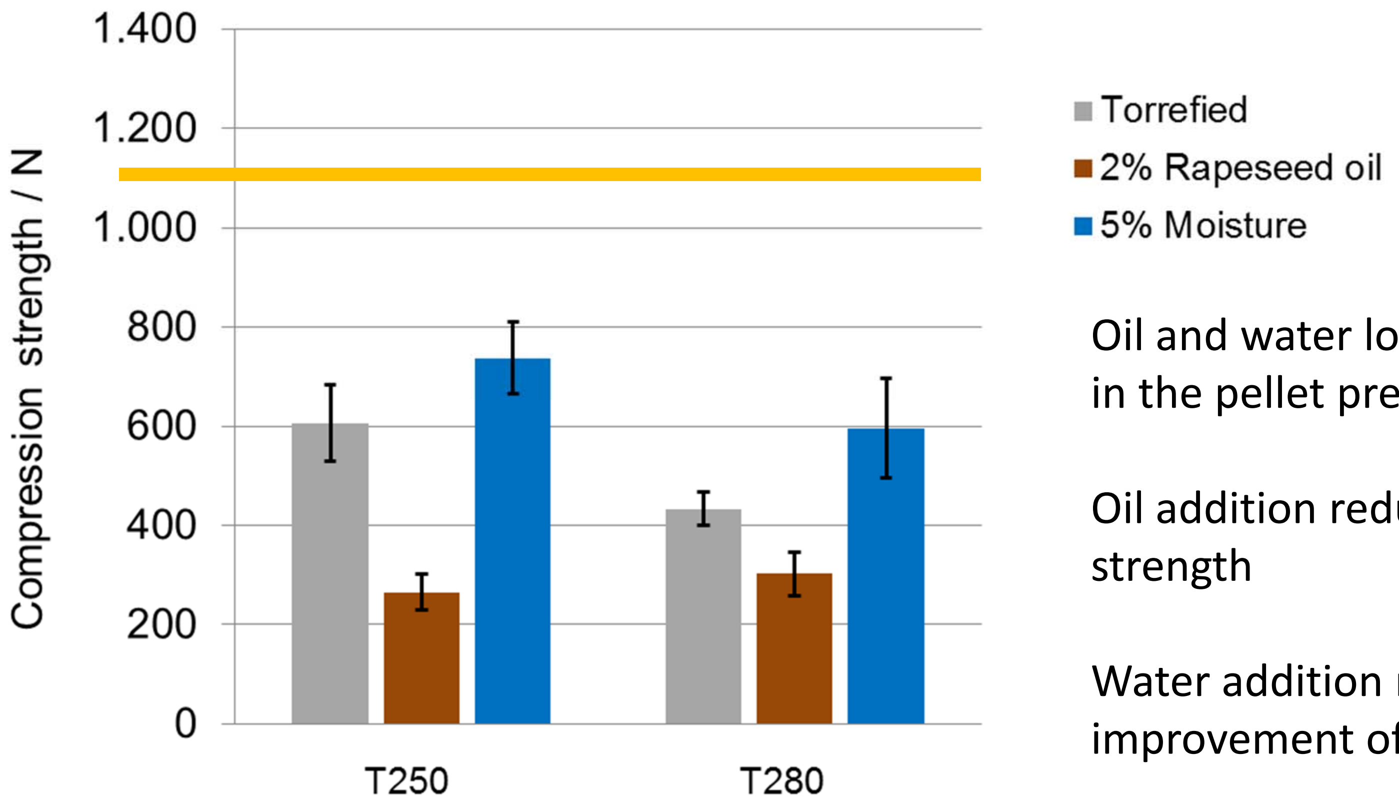
- Effect of oil and water addition



Oil and water lower the friction in the pellet press

Oil addition reduces pellet strength

Water addition results in an improvement of pellet strength

Quality is acceptable > 500 N

What can be learnt from these trials

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- Pelletization of torrefied biomass without additives is possible
- Process is not straight forward
- Issues when pelletizing torrefied biomass
  - Increase of energy uptake
  - Decrease of pellet strength
- → Many parameters influence the pelletizing process and pellet quality
- Pelletizing can be improved by heating the die or the addition of moisture and/or lubricants

Can briquetting be used as alternative?

- Briquetting of torrefied biomass is a possible alternative
- Similar results have been observed for briquetting trials
  - Some materials are easier to press into briquettes than others
  - Variation in density
  - Improvement when briquetting at higher temperatures (pre-heating of die)
  - Moisture addition eases briquetting process

C.F. Nielsen, Denmark

What can be learnt from these trials

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- Densification of torrefied biomass is not straight forward
- Many parameters influence densification processes and product quality
- Lacking knowledge and experience

→ **SECTOR project**

→ Process and product optimization

→ Economic and sustainable production of solid energy carriers by means of torrefaction

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- **Thank you for your attention!**

For more information please contact:

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www.dti.dk

ANDRITZ Separation

Torrefaction of biomass

ACB Technology and Overview of ANDRITZ Activities

Table of Contents

The ANDRITZ Group

Overview

Company
▪ ANDRITZ AG, Graz, Austria (Group Headquarters)
▪ More than 180 production and service sites worldwide
▪ Employees: approximately 17,000 worldwide (as of March 31, 2012)

Key figures 2011
▪ Order intake: 5,707 MEUR
▪ Sales: 4,596 MEUR
▪ Net income (including non-controlling interests): 232 MEUR
▪ Equity ratio (as of end of 2011): 21%

Products and services
Plants and services for hydropower stations, the pulp and paper industry, solid-liquid separation in the municipal and industrial sectors, the steel industry, and the production of animal feed and biomass pellets

ANDRITZ Group Company Profile

A world market leader in most business areas

HYDRO
40-45%*

Electromechanical equipment for hydropower plants (mainly turbines and generators); pumps; turbo generators

Torrefaction

PULP & PAPER
30-35%*

Systems for the production of all types of pulp and of certain paper grades (tissue, cartonboard); boilers

Torrefaction

SEPARATION
10%*

Equipment for the mechanical and thermal solid/ liquid separation for municipalities and various industries

METALS
10%*

Systems for the production and processing of stainless steel and carbon steel strips; industrial furnaces

Pelleting

FEED & BIOFUEL
5%*

Systems for the production of animal feed pellets (pet and fish food) and biomass pellets (wood, straw)

* Long-term average share of the ANDRITZ GROUP's total order intake

ANDRITZ Separation

Torrefaction of biomass

ANDRITZ approach towards torrefaction

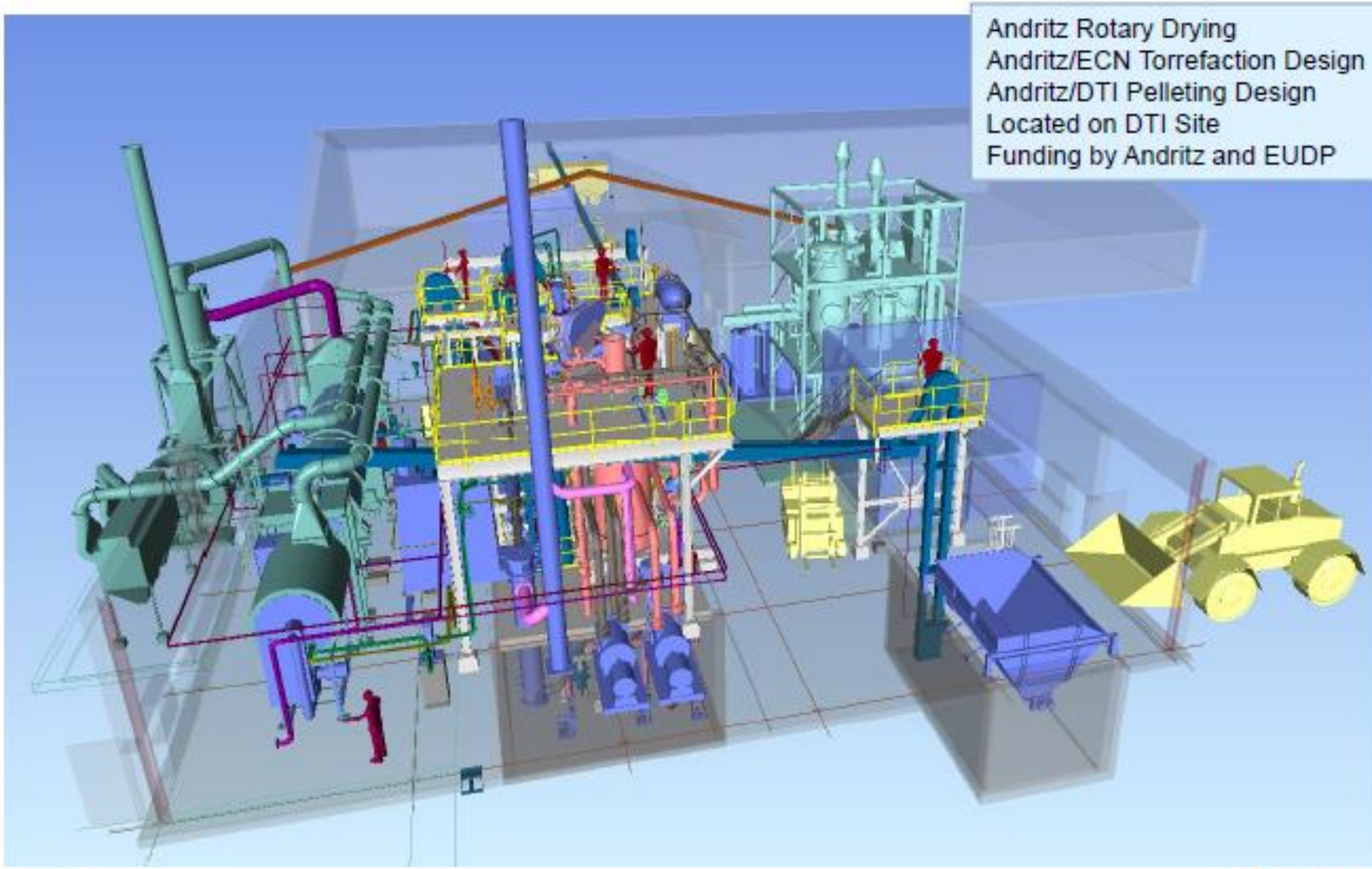
ANDRITZ is targetting to provide solid solutions for production of torrefied biomass-fuel

Large plants: > 250.000 t/a	Small / medium plants: 50-250.000 t/a
Andritz/ECN Torrefaction Design	**Andritz ACB® Torrefaction Design***
Industrial Demoplant (1t/h) in Denmark under comissioning	Industrial Demoplant (1t/h) in Austria in operation!
Pressurized, vertical reactor Andritz/DTI Pelleting plant	Rotating, indirectly heated drum reactor Briquetting plant
Key Features: Scale up to huge capacities possible (experience from pulp&paper division) Feedmaterial: chips	**Key Features:** Simple process concept specially developed for decentralized plants Flexibility in feedmaterial

*ACB Process is developed by the ABC Entwicklungs GmbH with support from the ACB consortium consisting of ANDRITZ POLYTECHNIK W&P
Scientific support by: ofi

Torrefaction of biomass

Andritz Biofuels Test Center, Sdr. Stenderup, DK; Start-up: Summer 2012



Andritz Rotary Drying
Andritz/ECN Torrefaction Design
Andritz/DTI Pelleting Design
Located on DTI Site
Funding by Andritz and EUDP

Torrefaction of biomass

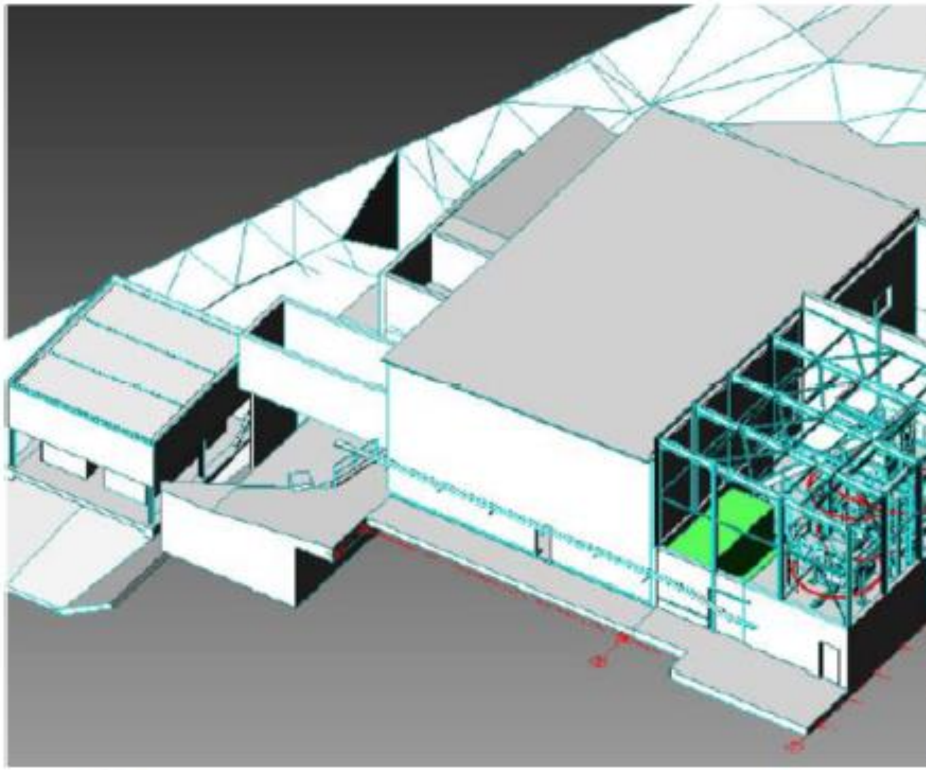
Demoplant: Andritz ACB Process, Austria

Demonstration plant in Frohnleiten, Austria for production of 1 ton/hr of torrefied material;
Phase I (drying, torrefaction, energy supply) successfully in operation

Torrefaction of biomass

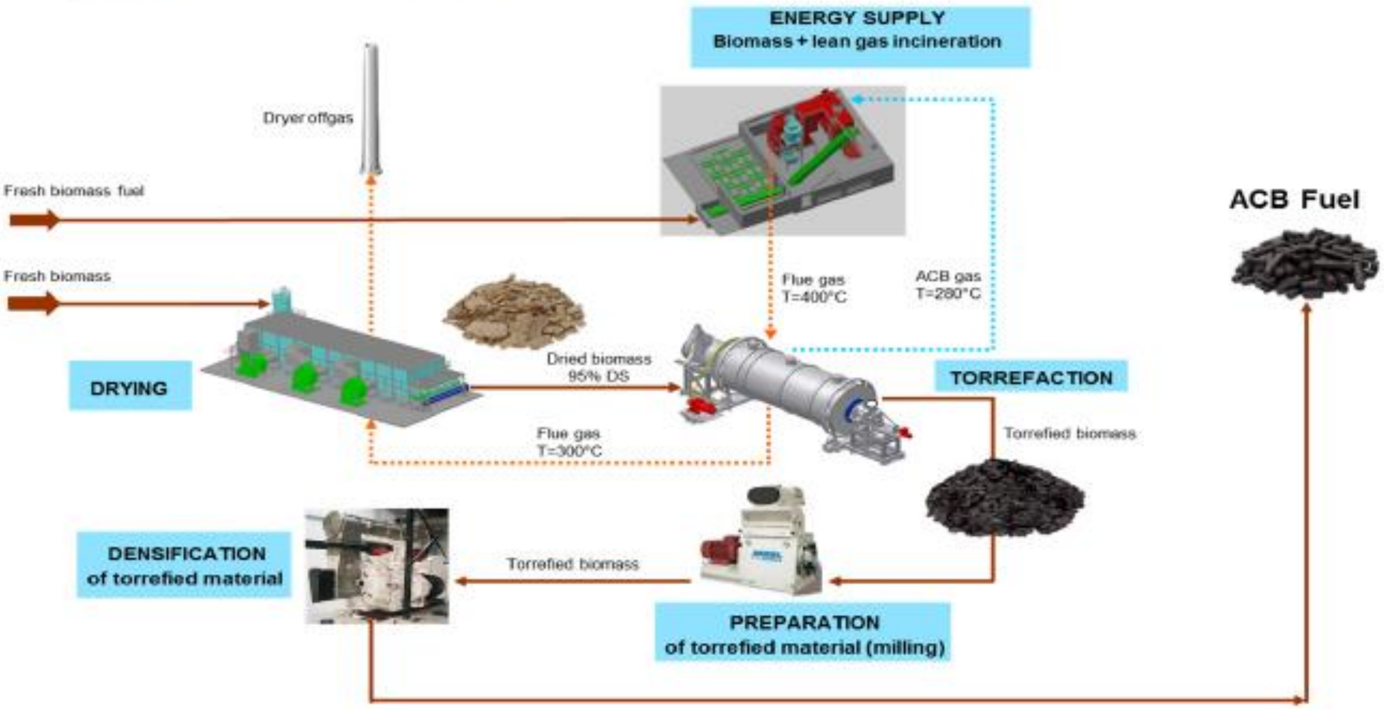
Demoplant: Andritz ACB Process, Austria

Demonstration plant in Frohnleiten, Austria for production of 1 ton/hr of torrefied material;
Phase II (briquetting): comissioning July 2012



Torrefaction of biomass

ACB process: Overview



Process Features:

- simple and robust design based on proven or modified equipment
- flexibility in feedstock (moisture, particle size, species,..)
- small to medium throughput range (50 -250 kt/a of product)

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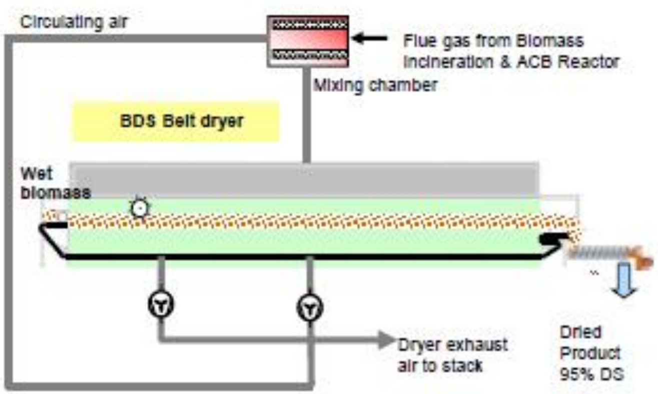
Torrefaction of Biomass

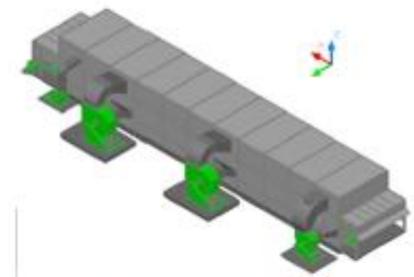
ACB Process: Drying

Pre-drying of biomass for torrefaction, up to 95% DS

BDS RD (closed air loop dryer)

- Directly heated by flue gas from biomass combustion
- Utilization of waste heat from drum reactor
- worldwide 28 references for biomass and sludge drying since 2003





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Torrefaction of Biomass

ACB Process: Torrefaction

Torrefaction of biomass at 250-300°C under inert conditions

ACB-Reactor

- Rotating, indirectly heated drum
- Prevention of condensation problems due to special flow pattern
- High flexibility in terms of allowable particle size
- No clogging, channeling or increase in pressure drop
- Avoidance of oxygen presence by ANDRITZ sealing technology
- Construction based on ANDRITZ Drum Drying System (more than 110 dryer lines installed worldwide)

klima+ energie fonds

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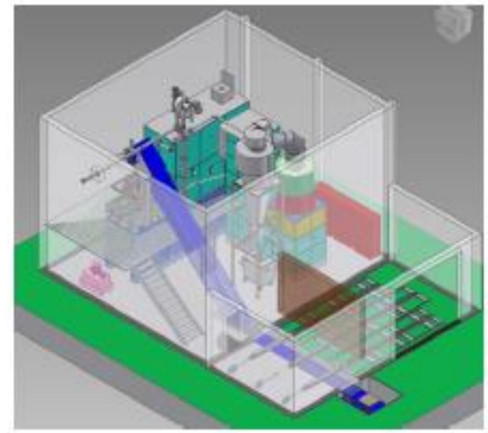
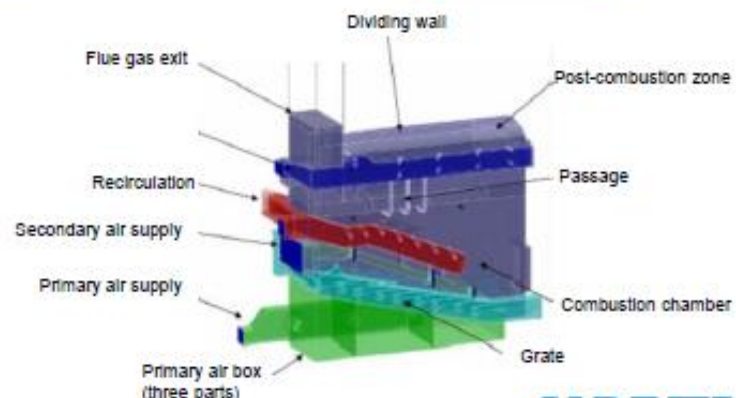
Torrefaction of Biomass

ACB Process: Energy Supply (Lean Gas Combustion)

Provision of the energy supply by Biomass Grate firing system by *POLYTECHNIK*

- Hydraulic reciprocating grate firing
- Special burner for hot lean gas (280 °C)
- Maximum heat recovery from lean gas
- Additional fuel: wood chips with 20 – 55% water content
- Long residence time for low emissions
- Mixing chamber for hot gas generation (400 °C)





ANDRITZ Separation

Torrefaction of Biomass

ACB Pilotplant: Results

Accomplished test runs: Spruce: chips P30, mini chips;

Pine: chips P30

Saw mill residues (mixed softwood)

Example:

Raw material: mini chips from local production (spruce)

Torrefied product
approx. 280°C, 35 min
TG*= approx. 11%

6 mm Pellets (w/o binder)

Briquettes (w/o milling, w/o binder)

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Torrefaction of Biomass

Densification: Briquetting

Tests made with ram extrusion press (same type of press as now installed at pilot plant)

Test: saw mill residues;

→ ~500 kg briquettes produced, smooth operation

Development project with TU Freiberg, Germany

Content:

- Analysis of sample material
- Assessement of size reduction properties; selection of preferred technology
- Evaluation of briquetting characteristic curves
- Test briquetting using technical scale ram extrusion press

Test briquetts from ACB material
source: TU-Freiberg

Torrefaction of Biomass

Densification: Pelleting

„Economically feasible pelleting of torrefied material is not straight forward"

Andritz Feed&Biofuel /DTI* research and test-programm to develop optimized pelleting process:

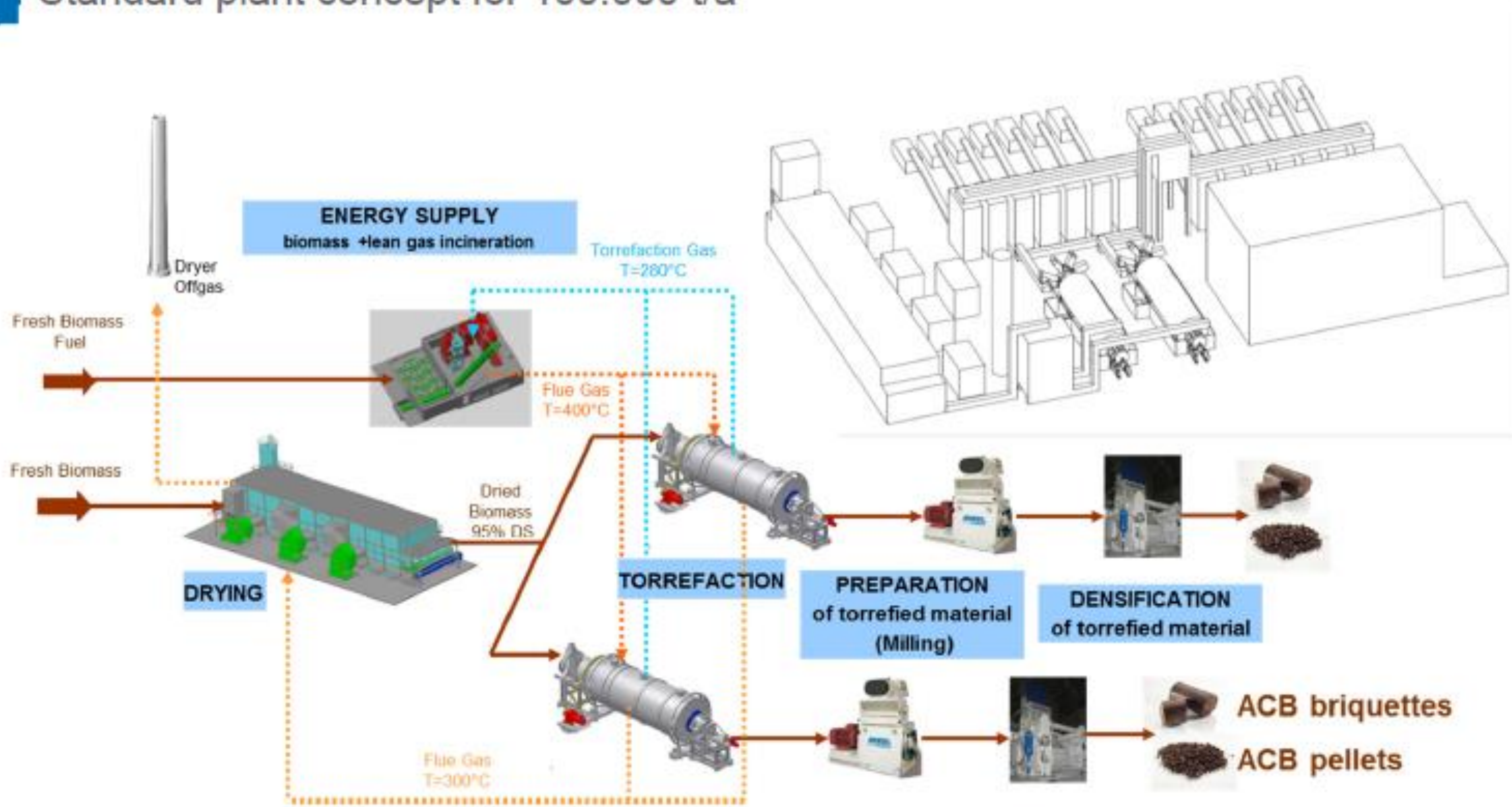
- Single pellet tests (unique facility developed at DTI to examine pelleting properties)
- Test runs with semi-industrial pellet press; using different torrefied samples
- Test runs with industrial press
- Optimization of: particle size, conditioning, die specification
- Evaluation of: energy consumption, durability, density
- Success Criteria: equal or better than „white pellets" and some degree of hydrofobicity

→ Encouraging results available so long but further work necessary!

DTI.. Danish technological institute, Sdr. Stenderup pilotplant project partner of Andritz FB

ACB Torrefaction – commercial plant concepts

Standard plant concept for 100.000 t/a



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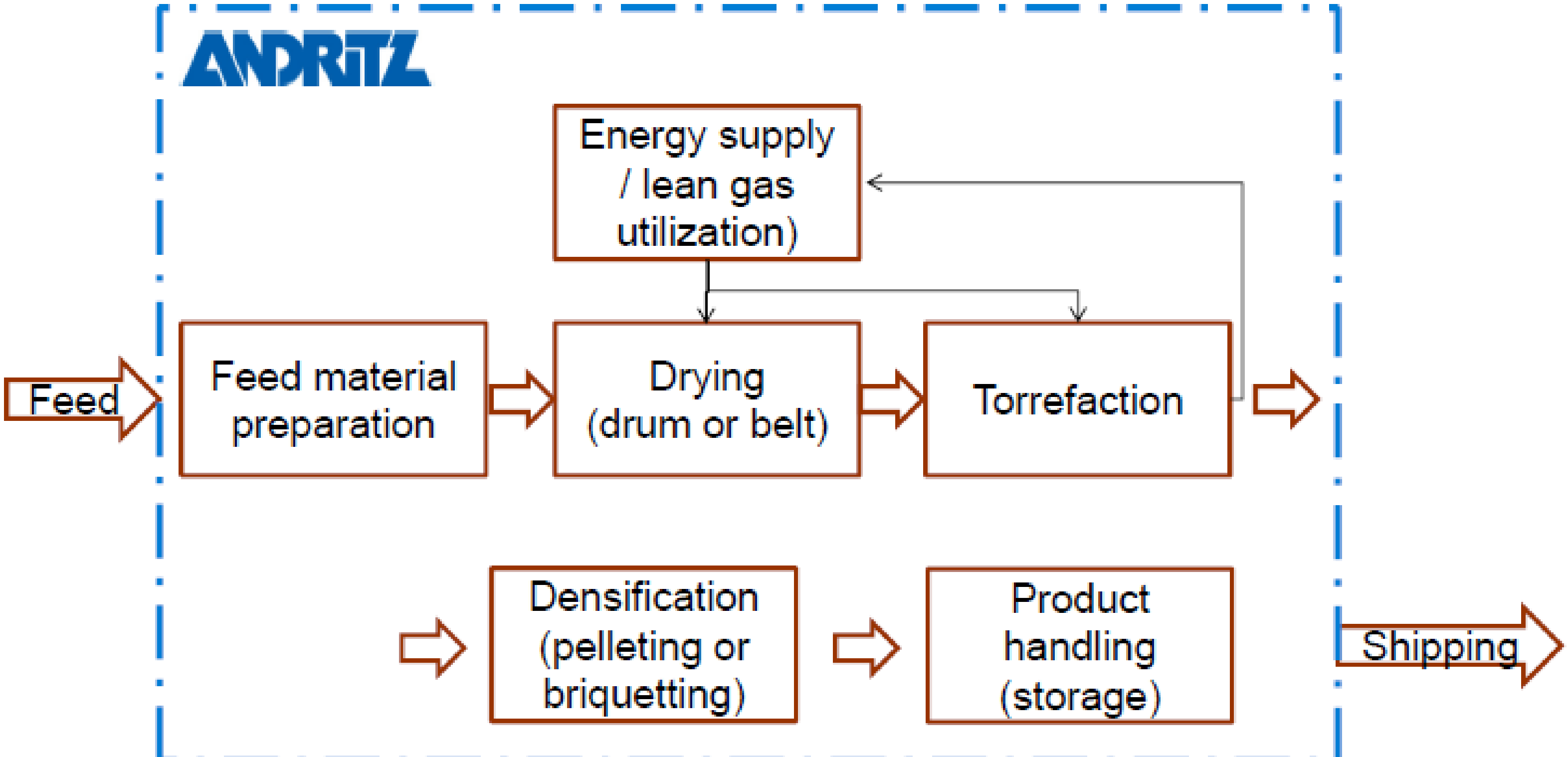
Torrefaction of biomass

Commercial plant concepts: ACB

Scope: Andritz can supply complete electro-mechanical installation including site services (erection, commissioning,..)



Torrefaction of biomass

At last…

3 things need to be controlled/assured to make a biomass project (black or white pellets) successful:

- Raw material supply
- Product take-off
- Process / Equipment

ANDRITZ helps you controlling the last one…

Thanks for your attention!

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klima+ energie fonds

ANDRITZ Separation

a place of mind
THE UNIVERSITY OF BRITISH COLUMBIA

TORREFACTION IN NORTH AMERICA

Shahab Sokhsansanj,
Oak Ridge National Laboratory
and
University of British Columbia

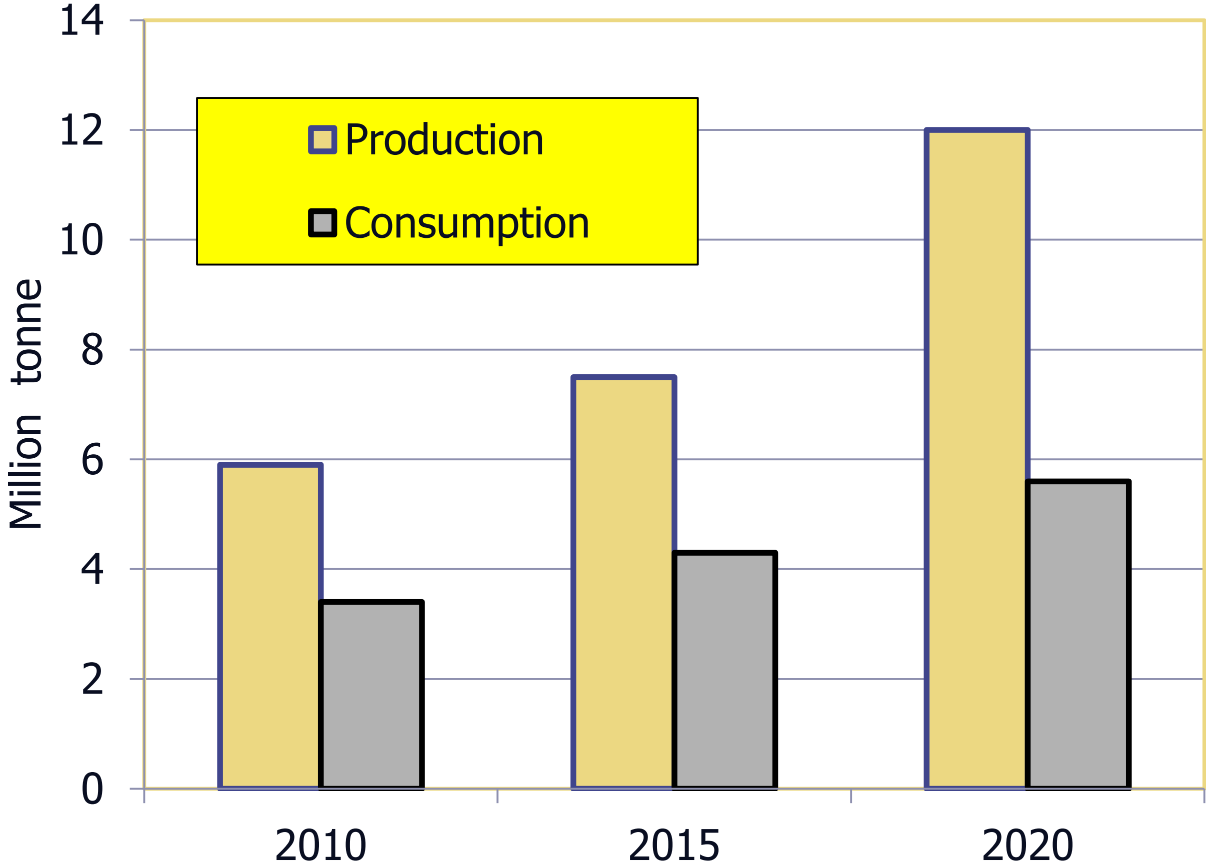
Presented at the SECTOR Workshop
Milan, Italy,
June 21, 2012

Outline

1. Introduction
2. Industry
3. Research
4. Summary
5. Acknowledgement

1. Introduction

Production and domestic consumption of wood pellets in North America.



Excess pellets are exported

Current size of wood pellet industry in the U.S. and Canada

- Wood pellet manufacturing and consumption began in the United States three decades ago.
- 147 pellet wood plants in the U.S., with a capacity of 3.5 million ton
  - Largest in the U.S. 750,000 ton
  - Raw material mostly logs from loblolly pine
- 37 plants in Canada with a capacity of more than 2.5 million ton
  - Largest 250,000 metric ton
  - Raw material mostly saw mill residue but recently logging residue and some limited beetle killed pine
- 20 enterprises are involved in torrefaction

  One known to me that is in its final phase of commercial testing of torrefied pellets

Challenges with regular pellets

- High cost ($/GJ) associated with long distance transportation of pellets to overseas markets in Europe and Asia
- Health and safety concerns over off-gas emissions, self-heating and spontaneous combustion associated with combustible gases and dust.
- Low heating value, flowability, and burn quality to be blended with coal for co-firing biomass with coal
- Increasing shortage of white wood saw dust is forcing pellet producers use logging residues and hog fuel as feedstock.
- Regular pellets degrade fast when exposed to weather elements

Torrefaction may alleviate some of the challenges

What is torrefaction?
Torrefaction is a mild pyrolysis of biomass

Possible pitfalls:

- Loss of value in mass loss
- Negative energetics – more energy input than output
- Poor environmental consequences
- Poor quality pellets

Like any other process, the idea is not to overdo it such that the economics of torrefied pellets become unattractive

2. Industry

List of torrefaction companies in North America

	Name	Torrefaction	Densification	Remarks
1	zilkha.com	Steam treatment	Yes	Plans for 275k in Selma, Alabama
2	wyssmont.com	Dryer application	No	Several companies
3	torrsys.com	Bepex Continuous	Integrated with torrefaction	10-30% co mingled with coal
4	torrproc.com	Not known	Grind & pellet	Mostly conventional equipment, binder
5	torrefuels.com	Rotary counterflow	No	150-400°C. CanMet is involved
6	threedimensionaltimberlands.com/	Fast pyrolysis batch – vacuum	No	Bio oil and bio char (1/3. 1/3)
7	terradyneenergy.com	Heat lock?	No	Little known – tested at University of New Brunswick
8	steeperenergy.com/hydrofaction	Supercritical pressure and catalyst	No	Low oxygen liquid fuel and char
9	riverbasinenergy.com/	Fluidized bed	Yes – no details	Coal upgrading Swiss company?
10	renewablefueltech.com/	indirectly heated, screw auger	No	California,
11	pcsbiofuels.com	Catalyst	No	Polymeric Carbon Solid or PCS Biofuels
12	nfibiorefinery.com/	NFI Hydro-Torrefied	Yes, outdoor storage is not recommended	Low ash, Low alkali salts, washing (?)
13	newearth1.net/about.html	ECO Pyro-Torrefaction (EPT).	Pelletized	Co product bio oil
14	hm3e.com/index.php	Torr B – not clear	Briquettes	Reduced drying cost
15	globalbiocoalenergy.ca	Wyssmont	Regular pellet to torrefied pellets	Initially on microwave
16	diacarbon.com/	Fast pyrolysis (400-900oC)	No	Co product bio oil
17	cnfbiofuel.com/index.html	Regular pellets torrefied	Regular pellets torrefied	Conduction heat in a liquid paraffin
18	bioenergyinc.ca/	Not known	Pelletization, briquetting	Mobile
19	agri-techproducers.com/	Screw indirect heat	No	Pilot scale
20	airex-energy.com/	Cyclonic fluidization	No	Pilot scale testing

3. Research

The system

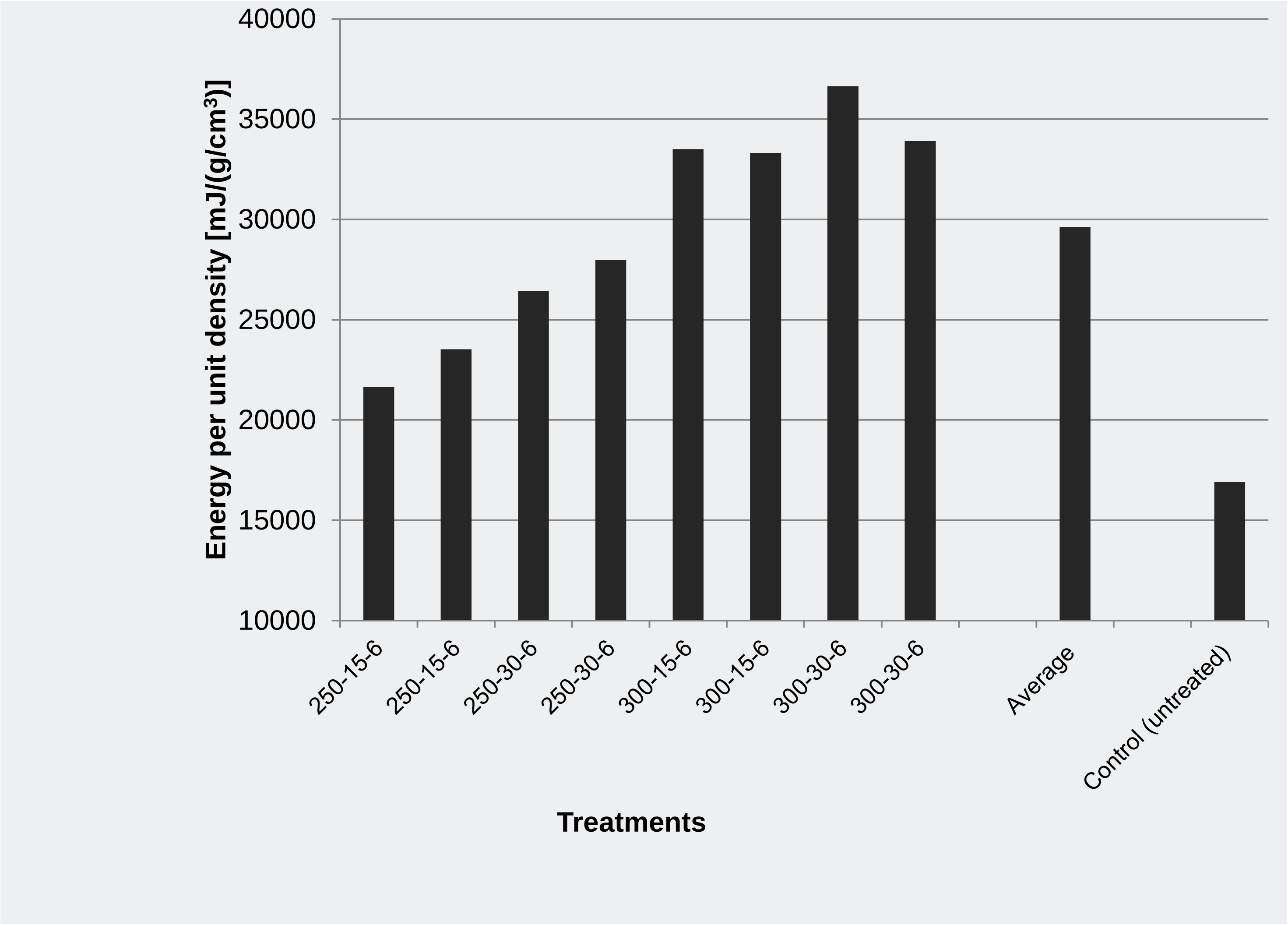
Torrefaction and densification are inter connected Two ways to make torrefied pellets

Wood chips

Dry → Grind → Torrefy → Pelletize → Re-Grind

Dry → Grind → Pelletize → Torrefy → Re-Grind

Specific energy required to form pellets



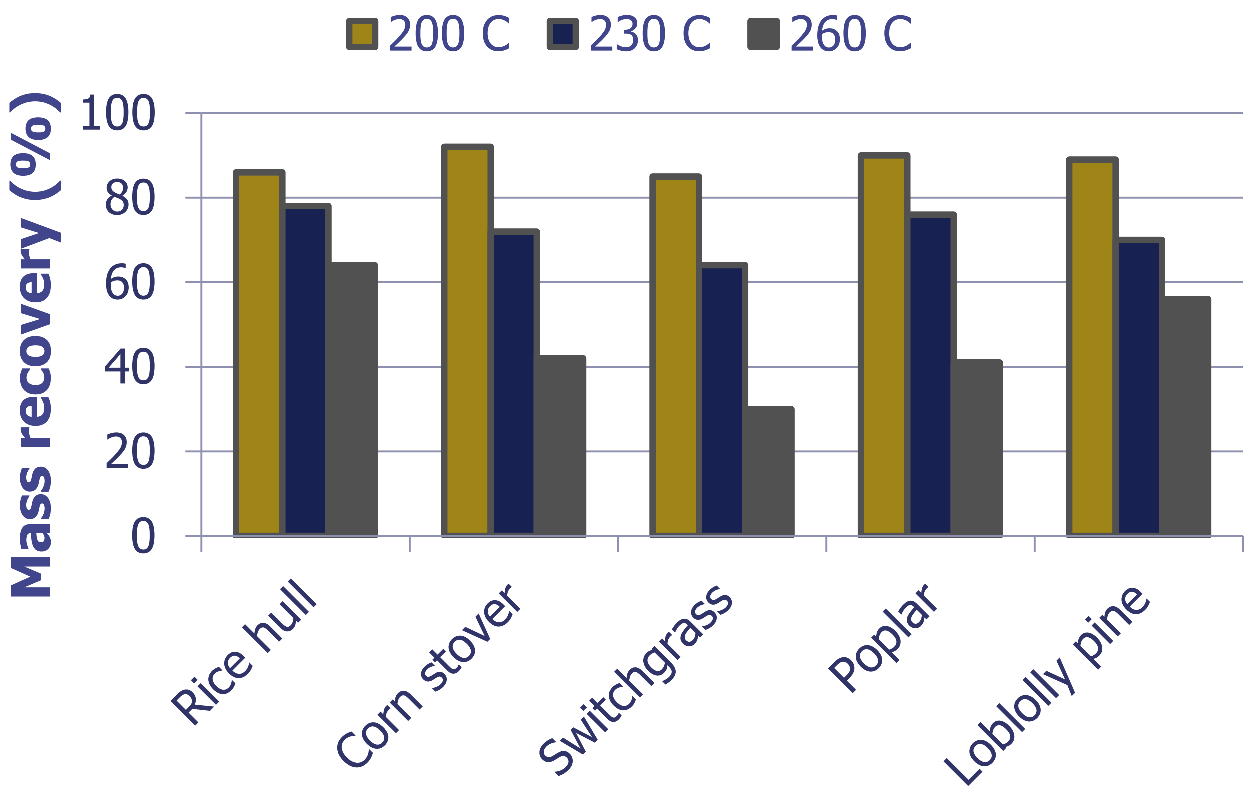
Wet torrefaction in hot water

Hot water 200-260°C,

Duration 5 min.

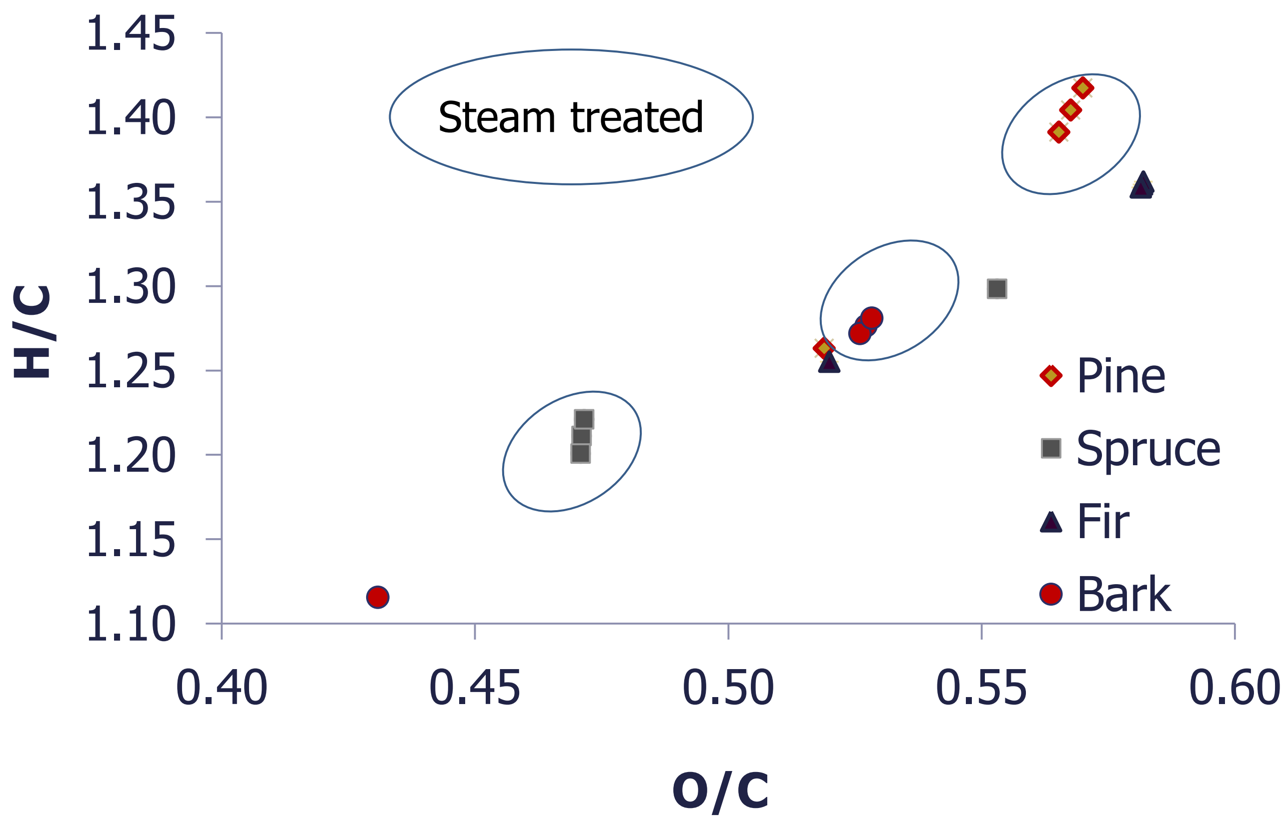
Water to biomass ratio 5:1,

Pressure 50 atm



Wei Yan, Tapas Acharjee, M. Toufiq Reza, Charles Coronella, Victor Vasquez. 2012. Wet Torrefaction of Lignocellulosic Biomass Chemical & Materials Engineering Dept. University of Nevada, Reno

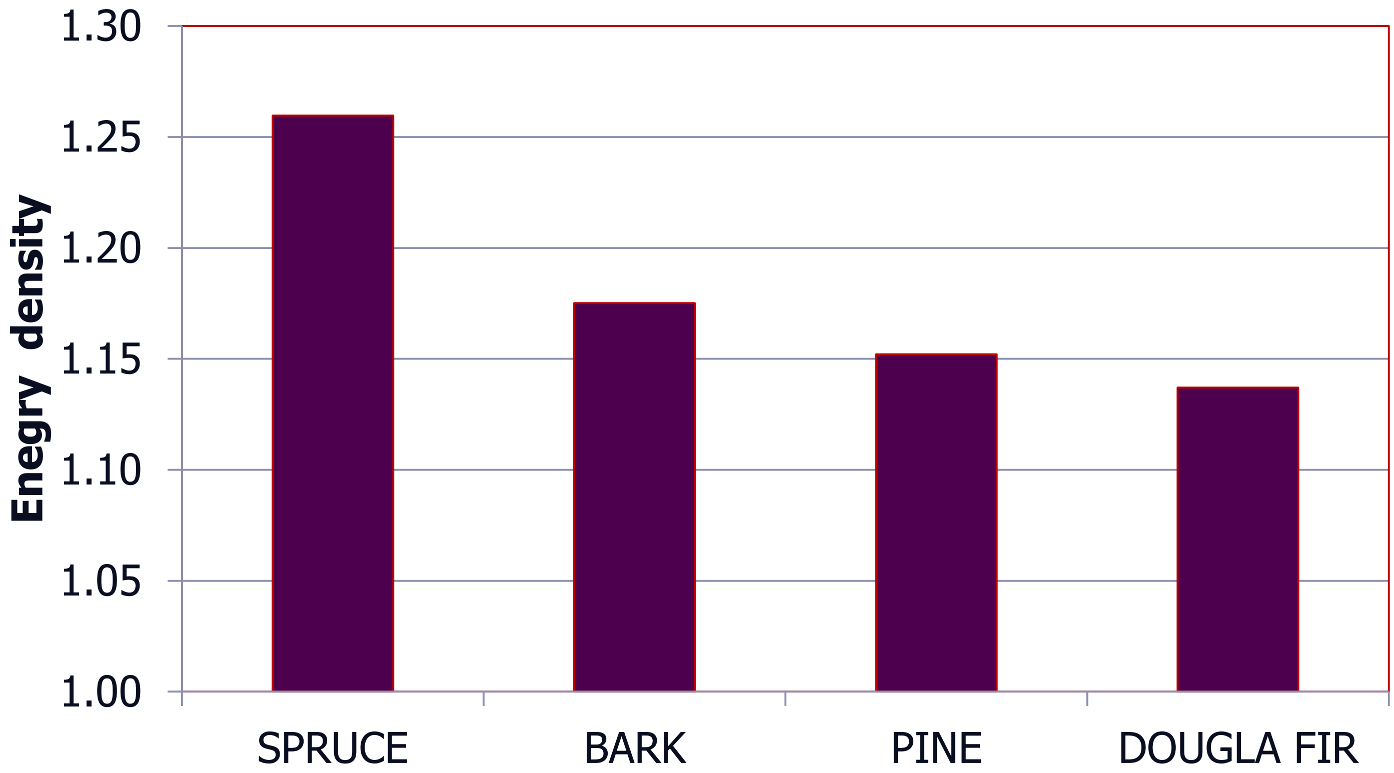
Steam treatment



Tooyserkani et al. 2012. Torrefaction and pelletization od steam treatment of soft wood species. Applied Energy (under review).

Steam treatment torrefaction

$$Energy\ density = \frac{Calorific\ value\ of\ treated\ biomass}{Calorific\ value\ of\ raw\ biomass}$$



Tooyserkani et al. 2012. Torrefaction and pelletization od steam treatment of soft wood species. Applied Energy (under review).

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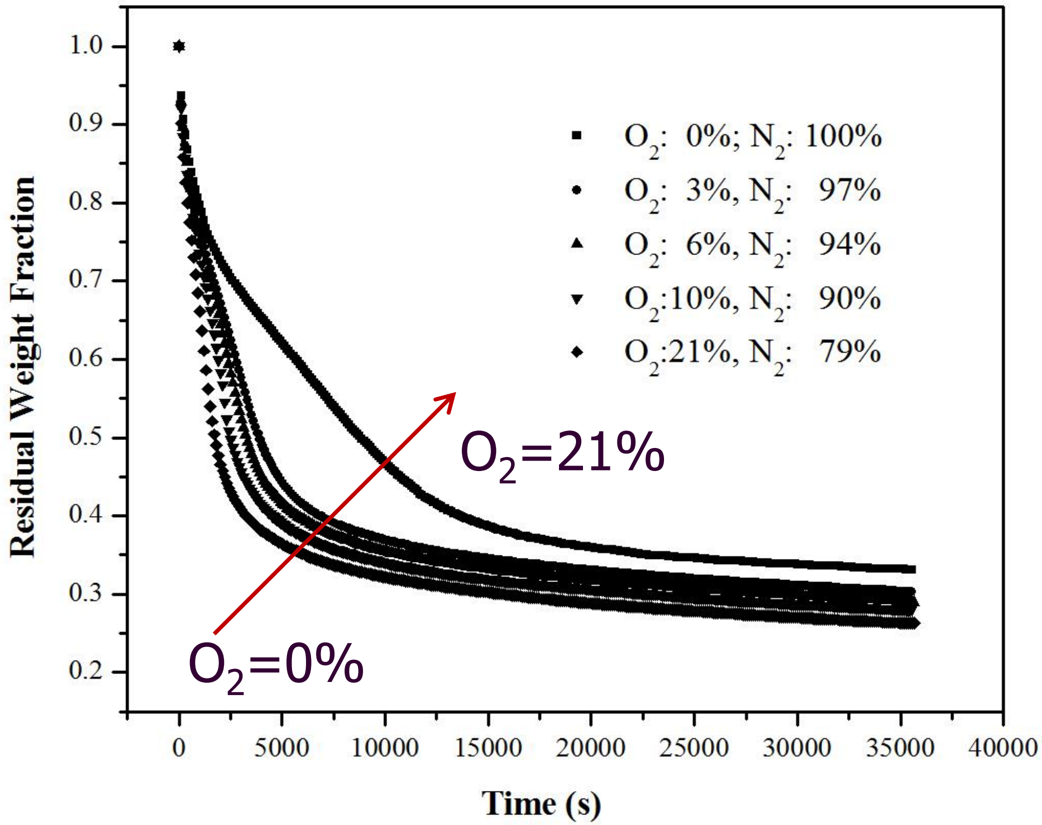
THE UNIVERSITY OF BRITISH COLUMBIA

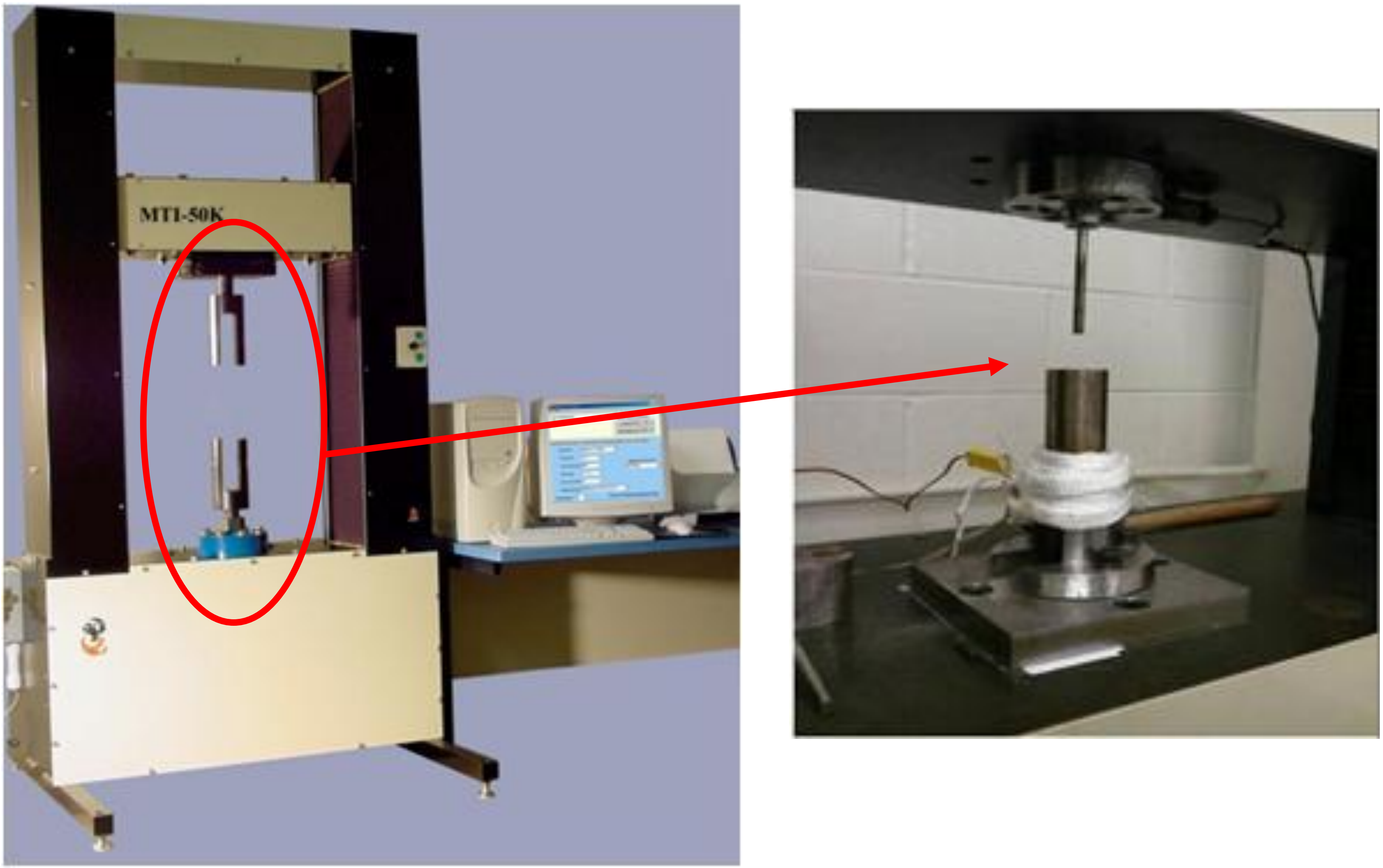
Torrefaction at different gas O_2 content



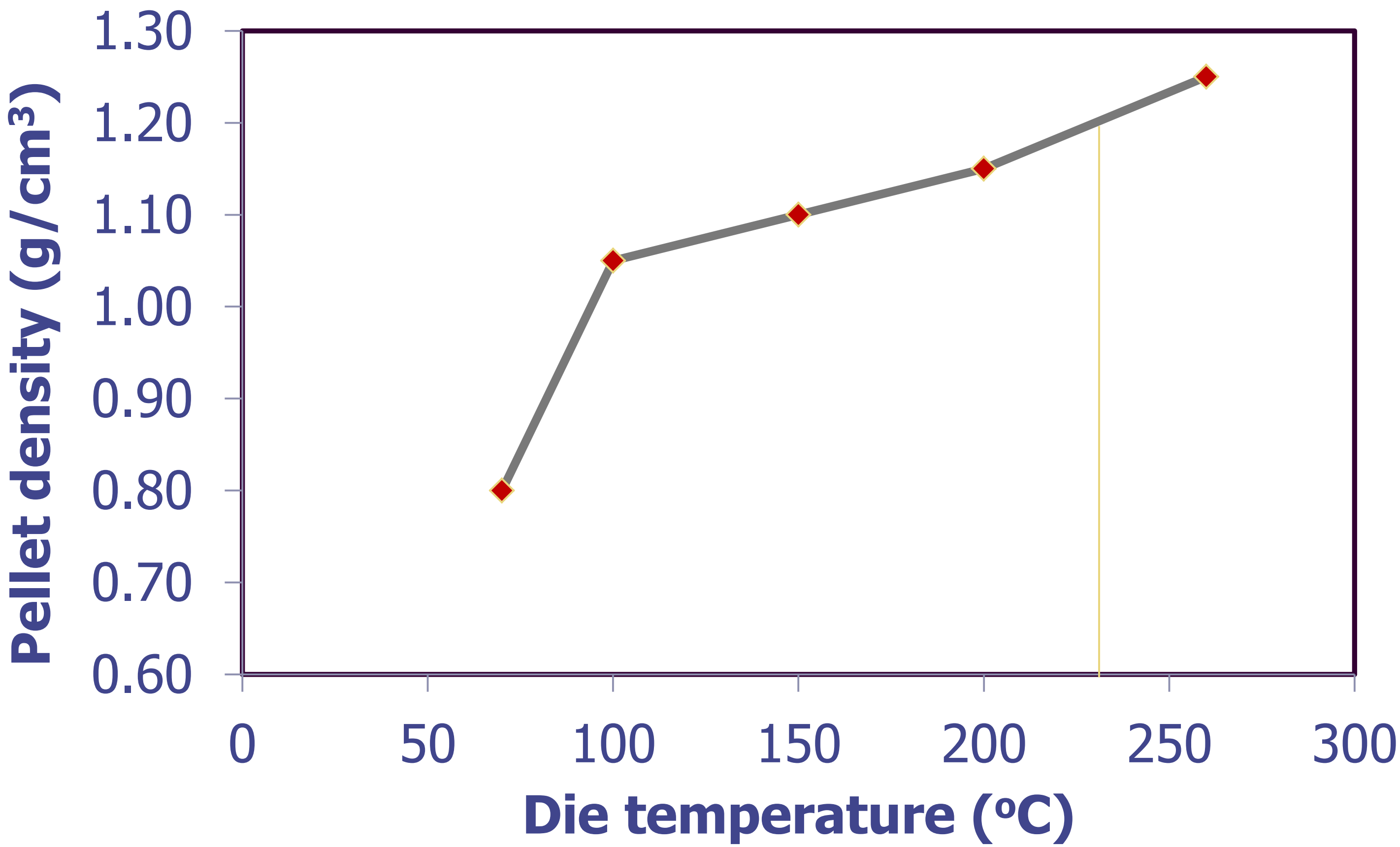
TGA

Peng, J. 2012. A study of softwood torrefaction and densification for the production of high density wood pellets. Ph.D. Thesis. University of British Columbia Canada.

Pelletization equipment



Density vs. compacting die temperature



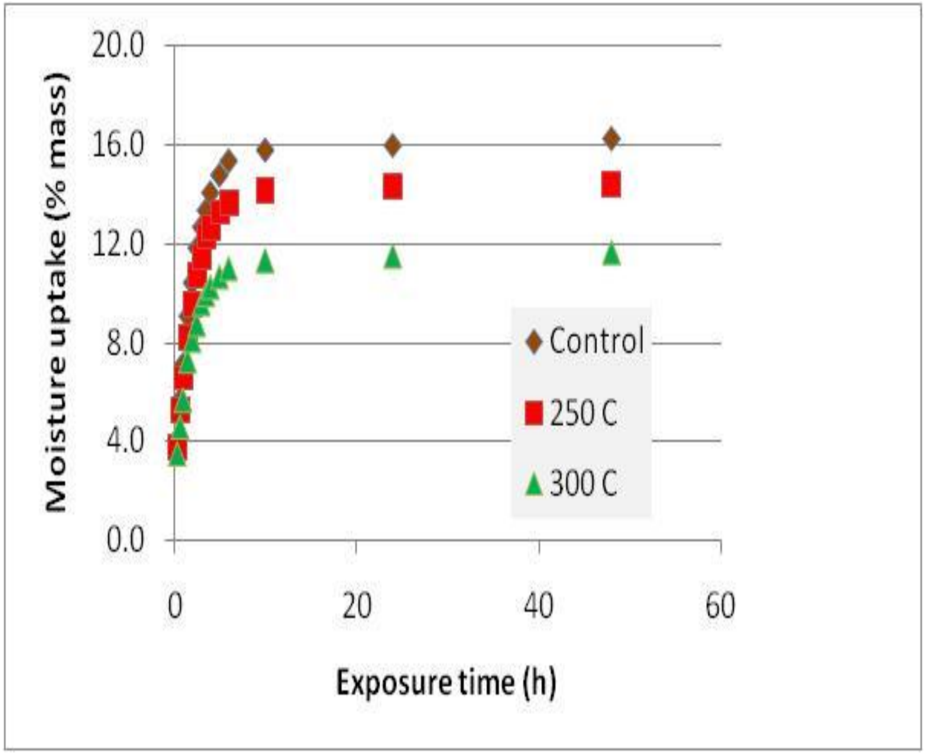
Tooyserkani et al. 2012. Torrefaction and pelletization od steam treatment of soft wood species. Applied Energy (under review).

Hydrophobicity equipment

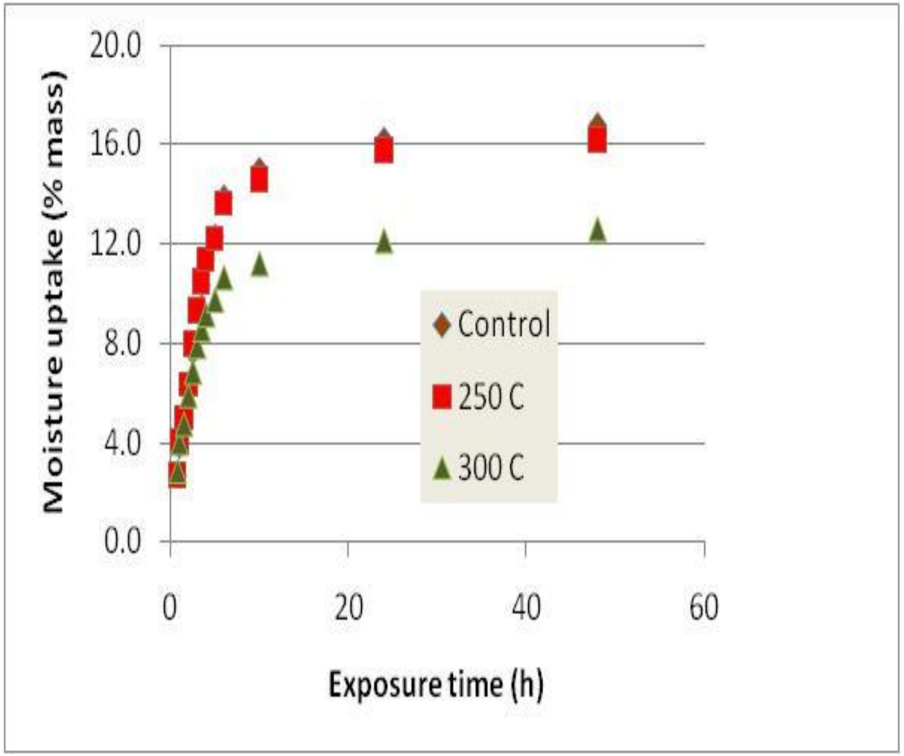
- Chamber to maintain constant temperature and humidity
- Temperature: 30ºC
- Humidity: 90%
- Duration: Variable
- 2 - 3 pellets in a petri dish
- Weigh at time intervals

Results on hydrophobicity

Pellets from small particles 0.8 mm



Pellets from large particles 6.2 mm



Humid chamber at 30ºC 90% RH

Summary

- Manufacturing and marketing wood pellets in Canada and the U.S. is well underway, albeit with emerging technical challenges.
- Technical challenges are associated with variability in feedstock and safe handlings.
- Commercial production of torrefied pellets is where every body else is at, going through growing pains.
- Research and developments in torrefaction and pelletization is at its infancy in the U.S. and Canada.

Research institutions / universties working on torrefaction pelletization

University of Minnesota	Dr. Vance Morey	U.S.
University of Georgia	Dr. Sudhagar Mani	U.S.
Auburn University	Dr. Oladiran Fasina	U.S.
University of Reno	Dr. Charles Coronella	U.S.
University California, Davis	Dr. Bryan Jenkins	U.S.
Idaho National Laboratory, DOE	Dr. Boardman	U.S.
Gas technology Institute	Dr. Larry Felix	U.S.
University of Saskatchewan	Dr. Lope Tabil	Canada
NRCan - CanMet	Dr. Fernando Preto	Canada
University of British Columbia	Dr. Shahab Sokhansanj	Canada

Biomass & Bioenergy Research Group current research

- Safe handling and storage of wood pellets
  - Off-gassing
  - Self heating
- Development of new pellets:
  - Steam treatment and explosion
  - Torrefaction (enhancing carbon conte
- Integration with biomass utilization
  - Gasification
  - Pyrolysis oil
  - Ethanol production
- Modeling
  - Logistics
  - Life Cycle Analysis

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  - NSERC
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  - US Department of Energy
  - BC Ministry of Forest
  - BC Bioenergy Network