ECN
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Black Pellets: Status Update

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Energy research Centre of the Netherlands (ECN): *62 years of dynamic development*

~500 employees

~ 90 MEUR turnover

not-for-profit organisation

~500 reports (2014)

~250 publications and conference papers (2014)

~5 technology licences per year

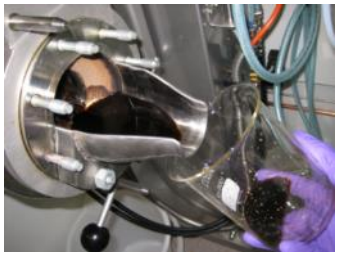
~20 patents per year

Main biomass R&D areas

- Upgrading: Biomass to commodity fuel
  - Torrefaction: ECN technology commercially available
  - New technology for torrefaction of wet biomass: TORWASH

- Combustion: Biomass boilers and co-firing
  - Fuel behavior during combustion & gasification
  - Ashes, slags, agglomeration behavior

- Gasification: Production of power or fuels
  - Gasification technology: MILENA
  - Tar removal and product synthesis
  - Test equipment and expertise to provide services
- Biorefinery: Technology for a biobased economy
  - Organosolv fractionation into cellulose, hemicellulose, and lignin
  - Conversion of fractions into marketable products



Examples in biomass torrefaction, combustion and co-firing services

ECN

1. **Feedstock** → find optimum technology/clients
2. **Feedstock for proprietary energy generation** → Combine optimum technology with energy use
3. **New feedstock for existing installation** → identify problems, come up with solutions
4. **Problem in current operation** (corrosion/slagging/etc) → obtain samples & in-depth analysis -> hands-on solutions

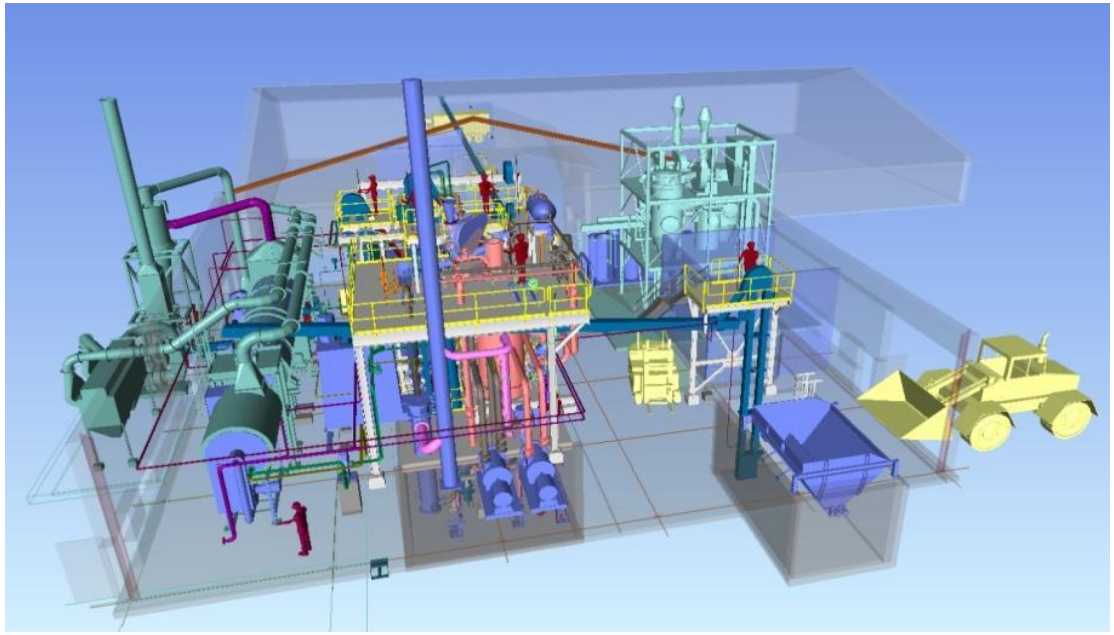
ECN and Torrefaction

- 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 demonstration scale; Andritz ready for market introduction
- Contract R&D for industry to assess the torrefaction potential of specific feedstocks, produce test batches and independently assess product quality

ECN 50 kg/h torrefaction pilot-plant

Technology licensed to Andritz

- Industrial demo plant in Sønder Stenderup, Denmark
  - Operational since 2012
  - Capacity 1 ton/hour torrefied pellets
- ECN involved in commissioning, start-up and operation



Torrefaction demo plant

Black Pellets Introduction

The added value of black pellets

- Torrefaction or steam explosion (combined with densification) enables energy-efficient 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

Torrefaction

- Pre-drying to moisture content typically below 15%
- Thermal treatment decomposes hemi-cellulose content (250-320 °C)
- Either in absence of oxygen or at limited concentrations
- Volatile components are partially driven off and can be combusted (for pre-drying and further heating)
- Mild torrefaction temperatures do not affect lignin which can be used as a binder during pelleting

- First used around 1000 A.D. to treat coffee beans, nuts, etc. in Africa
- Treatment of wood for construction in the 1980's in Nordic countries
- First plant in France in the late 1980's
- Potential as bioenergy carrier identified early 2000's

Steam explosion

- (Pre-dried) biomass is impregnated with steam (10-35 bar, 180-240 °C)
- Followed by explosive decompression to atmospheric pressure
- Fibres are ruptured to pulp
- Lignin is softened and distributed across pulp surface
- Eases densification (after post-drying)
- Typical higher mass yields than torrefaction, but also more oxygen

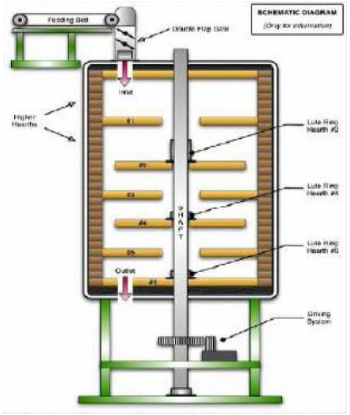
- First developments aimed at pulp production in the 1920's
- Later on recognised as pre-treatment/fractionation step in e.g. 2nd generation bioethanol production
- Potential as bioenergy carrier identified early 2000's

Black Pellet Technology Overview

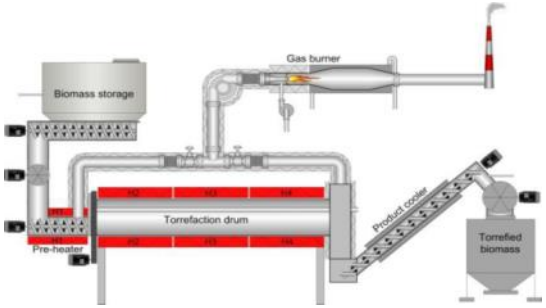
Torrefaction technology

- 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: over 10 demonstration plants and first commercial plants in operation/under construction

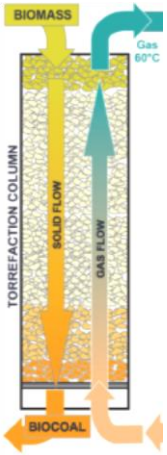
Torrefaction technology – many reactor concepts considered



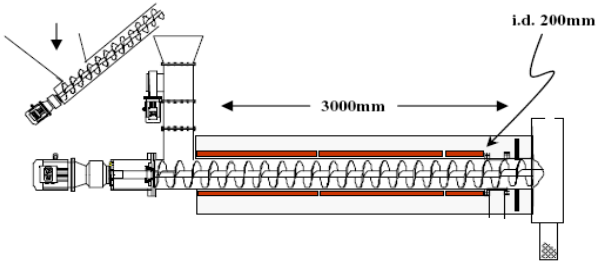
Multiple hearth furnace



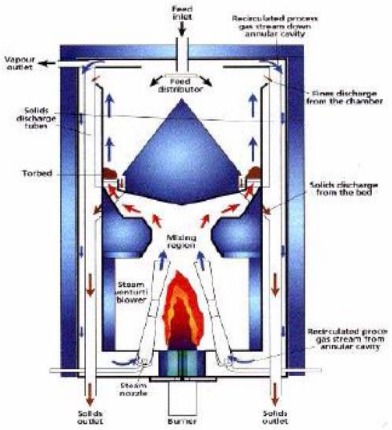
Rotary drum reactor



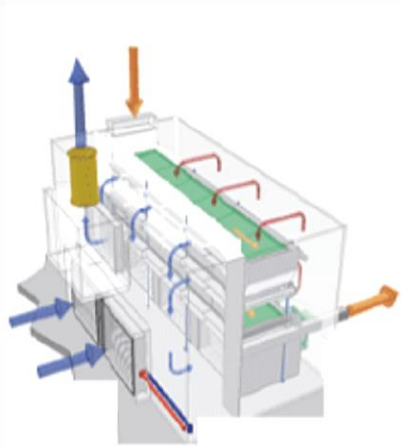
Moving bed reactor



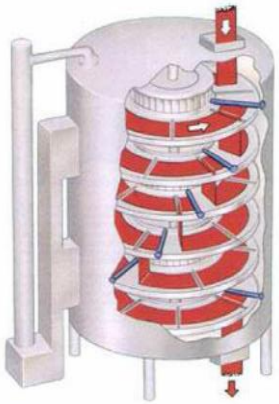
Screw conveyor reactor



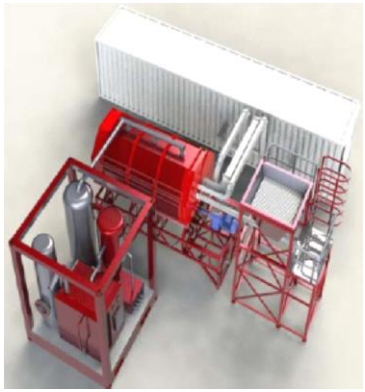
Torbed reactor



Oscillating belt reactor



TurboDryer



Microwave reactor

Torrefaction initiatives (1)

Developer	Technology	Location	Production capacity (ton/a)	Scale	Full Integration	Status
American Biocarbon	Unknown	White Castle LA (USA)	200,000	Commercial	Unknown	Under constr.
Clean Electricity Generation (UK)	Oscillating belt	Derby (UK)	30,000	Commercial	Yes	Available
Hip Lik Green Energy Ltd.	Unknown	Malaysia	100,000	Commercial	Yes	Available
New Biomass Energy (USA)	Screw reactor	Quitman MS (USA)	80,000	Commercial	Yes	Available
Black wood/ Topell (NL)	Multistage fluidized bed	Duiven (NL)	60,000	Commercial	Yes	Idle
Arigna Fuels (IR)	Screw conveyor	Roscommon (IR)	20,000	Commercial	Yes	Available
Torr-Coal (NL)	Rotary drum	Dilsen-Stokkem (BE)	30,000	Commercial	Yes	Available

Sources: Wild et al. 2016, IEA Bioenergy Task 40, April 2016 and ECN information

Torrefaction initiatives (2)

Developer	Technology	Location	Production capacity (ton/a)	Scale	Full Integration	Status
Airex (CA)	Cyclonic bed	Bécancour QC (CA)	16,000	Demonstration		Available
Andritz (AT)	Rotary drum	Frohnleiten (AT)	8,000	Demonstration	Yes	New ownership
Andritz (DK)/ECN (NL)	Multiple hearth	Stenderup (DK)	10,000	Demonstration	Yes	Stand by
BioEndev (SE)	Screw reactor	Holmsund (SE)	16,000	Demonstration	Yes	Available
CMI NESA (BE)	Multiple hearth	Seraing (BE)	Undefined	Demonstration		Unknown
Earth Care Products (USA)	Rotary drum	Independence KS (USA)	20,000	Demonstration		Available

Sources: Wild et al. 2016, IEA Bioenergy Task 40, April 2016 and ECN information

Torrefaction initiatives (3)

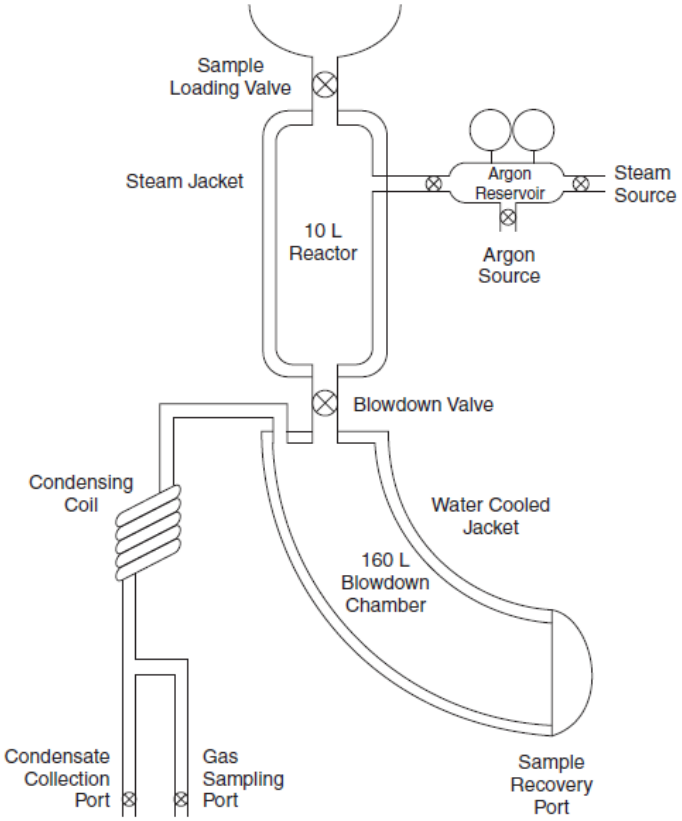
Developer	Technology	Location	Production capacity (ton/a)	Scale	Full Integration	Status
Grupo Lantec (ES)	Moving bed	Urnieta (ES)	16,000	Demonstration		Unknown
Integro Earth Fuels, LLC (US)	Multiple hearth	Greenville SC (USA)	11,000	Demonstration		Unknown
LMK Energy (FR)	Moving bed	Mazingarbe (FR)	20,000	Demonstration		Unknown
Konza Renewable Fuels (USA)	Rotary drum	Heally KS (USA)	5,000	Demonstration		Unknown
River Basin Energy (USA)	Fluidized bed (aerobic)	Rotterdam (NL)	7,000	Demonstration		In commissioning
TSI (USA)	Rotary drum	White Castle LA (USA)	15,000	Demonstration		Available

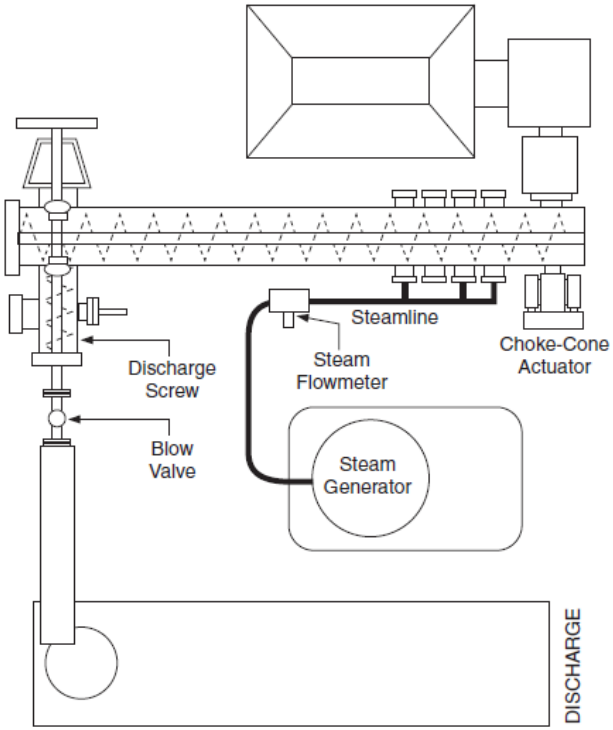
Sources: Wild et al. 2016, IEA Bioenergy Task 40, April 2016 and ECN information

Steam explosion

- Perhaps fewer steam explosion developers than for torrefaction
- But 5-10 years of experience at demonstration scale, as opposed to 5 years for torrefaction
- First large-scale commercial plants operational/under construction

Steam explosion





Batch process (Turn et al., 1998)

Continuous process (Heitz et al., 1990)

Both figures reproduced from (Melin, 2013)

Steam explosion initiatives

Developer	Technology	Location	Production capacity (ton/a)	Scale	Full Integration	Status
Zilkha (USA)	Batch	Selma AL (USA)	275,000	Commercial	Yes	Available
Arbaflame (NO)	Batch	Kongsvinger (NO)	40,000	Commercial	Yes	Available

Sources: Press releases Zilkha and Arbaflame

Mapping black pellets characteristics

Black pellet properties in perspective

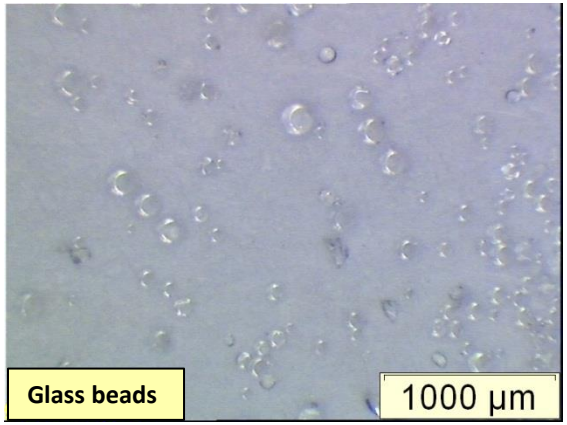
	Wood chips	Wood pellets	Torrefied wood pellets	Steam expl. pellets	Charcoal	Coal
Moisture content (wt%)	30 – 55	7 – 10	1 – 5	2 – 6	1 – 5	10 – 15
LHV (MJ/kg db)	7 – 12	15 – 17	18 – 24	18.5 – 20.5	30 – 32	23 – 28
Volatile matter (wt% db)	75 – 85	75 – 85	55 – 80	72	10 – 12	15 – 30
Fixed carbon (wt% db)	16 – 25	16 – 25	20 – 40	ND	85 – 87	50 – 55
Bulk density (kg/l)	0.20 – 0.30	0.55 – 0.65	0.65 – 0.75	0.73-0.75	0.18 – 0.24	0.80 – 0.85
Vol. energy dens. (GJ/m^3)	1.4 – 3.6	8 – 11	12 – 19	~15	5.4 – 7.7	18 – 24
Hygroscopic properties	Hydrophilic	Hydrophilic	(Moderately) Hydrophobic	Hydrophobic	Hydrophobic	Hydrophobic
Biological degradation	Fast	Moderate	Slow	Slow	None	None
Milling requirements	Special	Special	Standard	Standard	Standard	Standard
Product consistency	Limited	High	High	High	High	High
Transport cost	High	Medium	Low	Low	Medium	Low

Abbreviations:
db = dry basis
LHV =Lower Heating Value

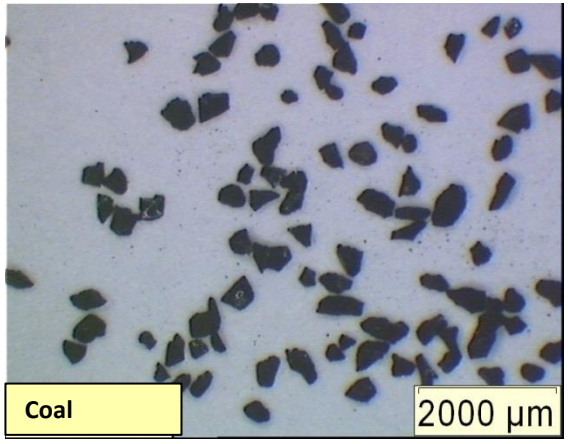
sources: ECN (table, fig.1, 3), Pixelio (fig. 2, 6), Valmet (fig. 4), OFI (fig. 5), ISO/TC 238 WG2 (table)

Fuel morphology after milling (1)

- Glass beads:

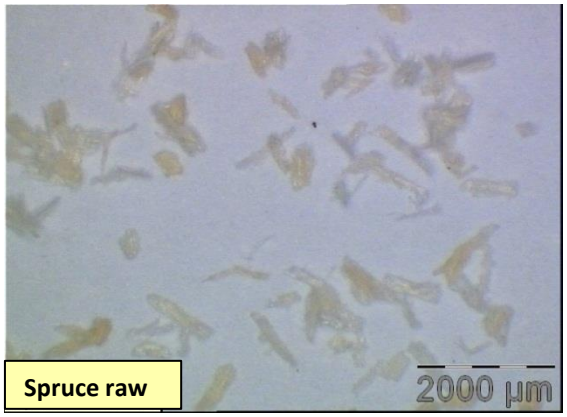


- Coal:

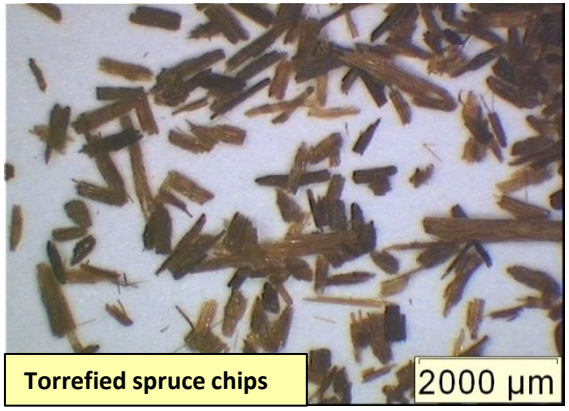


Fuel morphology after milling (2)

- Raw spruce:

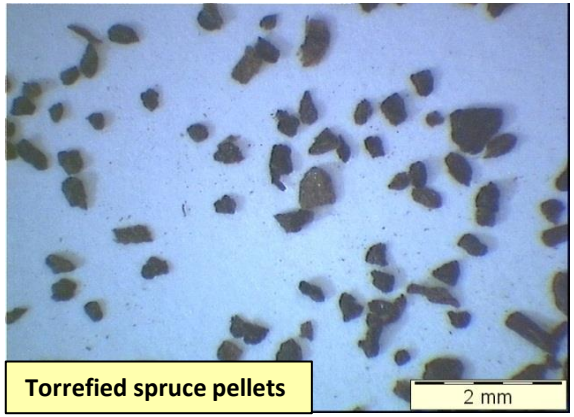


- Torrefied spruce chips:



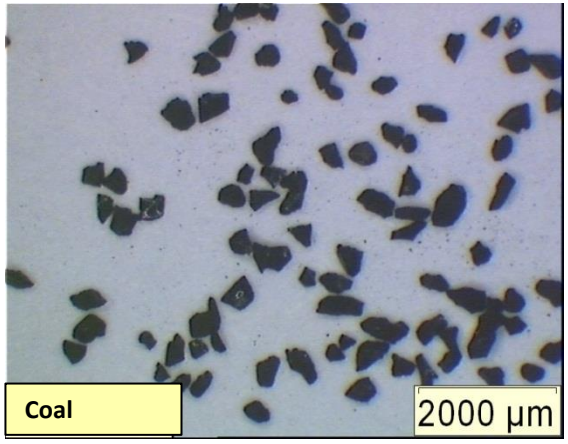
Fuel morphology after milling (3)

- Torrefied spruce pellets Andritz/ECN demo:



- Particle “sphericity” pulverised torrefied wood pellets comparable to pulverised coal

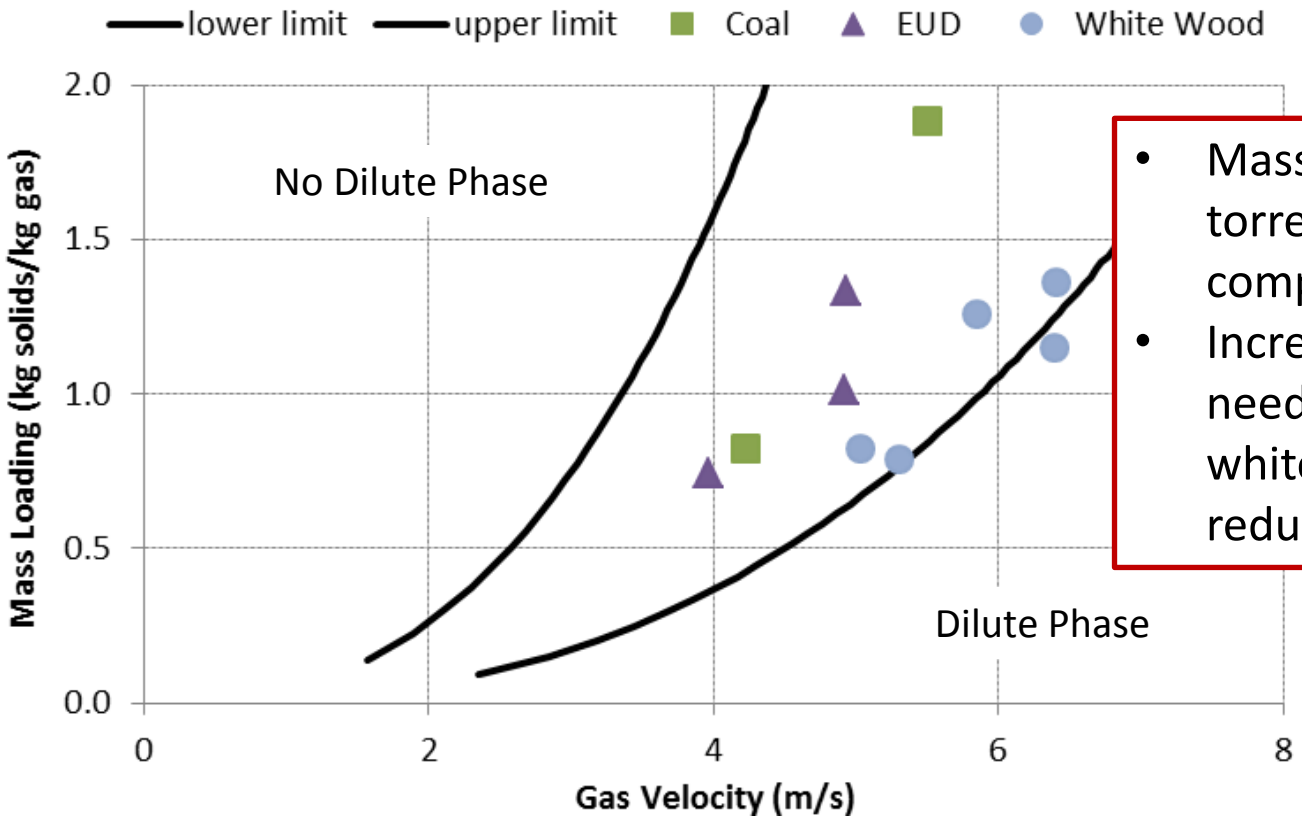
- Coal:



Pneumatic lean-phase transport (1)

- Fluidization tests to assess flowability
- Bulk densities pulverised torrefied pellets typically between 450-600 kg/m^3
- Bulk densities between 550-600 kg/m^3 display fluidization behavior similar to coal
- Limited de-rating for pulverised torrefied wood pellets compared to pulverised white wood pellets
- Setup used to determine solids loading/entrainment during dense/lean phase feeding

Pneumatic lean-phase transport (2)



- Mass loading of pulverised torrefied pellets comparable with coal
- Increased gas velocities needed for pulverised white wood pellets to reduce risk of saltation

Lower limit: saltation velocity coal; Upper limit: 1.6x saltation velocity coal
EUD: Torrefied eucalyptus pellets
Relatively low velocities in lab-scale setup result from tube diameter

Experience with torrefied biomass at industrial scale

NUON/Vattenfall Buggenum experience*

- Maximum 70% co-gasification on energy basis achieved at 90% nominal load without major modifications
- 1200 tons of torrefied pellets during 24 hours trial
- Observations:
  - Relatively low durability led to significant dust formation
  - Low durability disadvantageous during outdoor storage
  - Low Minimum Ignition Energy (MIE)

- Also 5000 tons of steam explosion pellets tested (at lower shares)
- ECN conducted lab-scale test programme to characterise pellets and provided consultancy to mitigate risks during commercial operation

* Source: N. Padban, Central European Biomass Conference, Jan ’14, Graz

RWE/Essent AMER-9 experience*

- Consortium of Topell, Essent, NUON, GdF Suez and ECN as part of Dutch TKI Pre-treatment Project
- Maximum 25 wt% co-milling on weight basis; 5 wt% co-firing
- 2300 tons of Blackwood Technology (Topell) torrefied pellets during November & December ‘13
- Observations:
  - No significant issues

- ECN conducted lab-scale characterisation of pellets and provided consultancy to mitigate risks during commercial operation

* Source: Press release Topell/Essent, Feb ‘14

RWE/Essent AMER-9 experience

DONG Studstrup-3 experience

- Two units with total capacity of 714 MW_e and 986 MW_{th}
- Dedicated milling on MPS roller mill adapted for either coal or white pellets
- 200 tons of Andritz/ECN torrefied spruce pellets during 8 hours trial
- Co-firing share: 33 wt%
- Observations:
  - No dust formation during unloading
  - Sufficiently high durability; no issues with dust formation in chain conveyors
  - Normal Minimum Ignition Energy (MIE)

- ECN conducted lab-scale characterisation of pellets

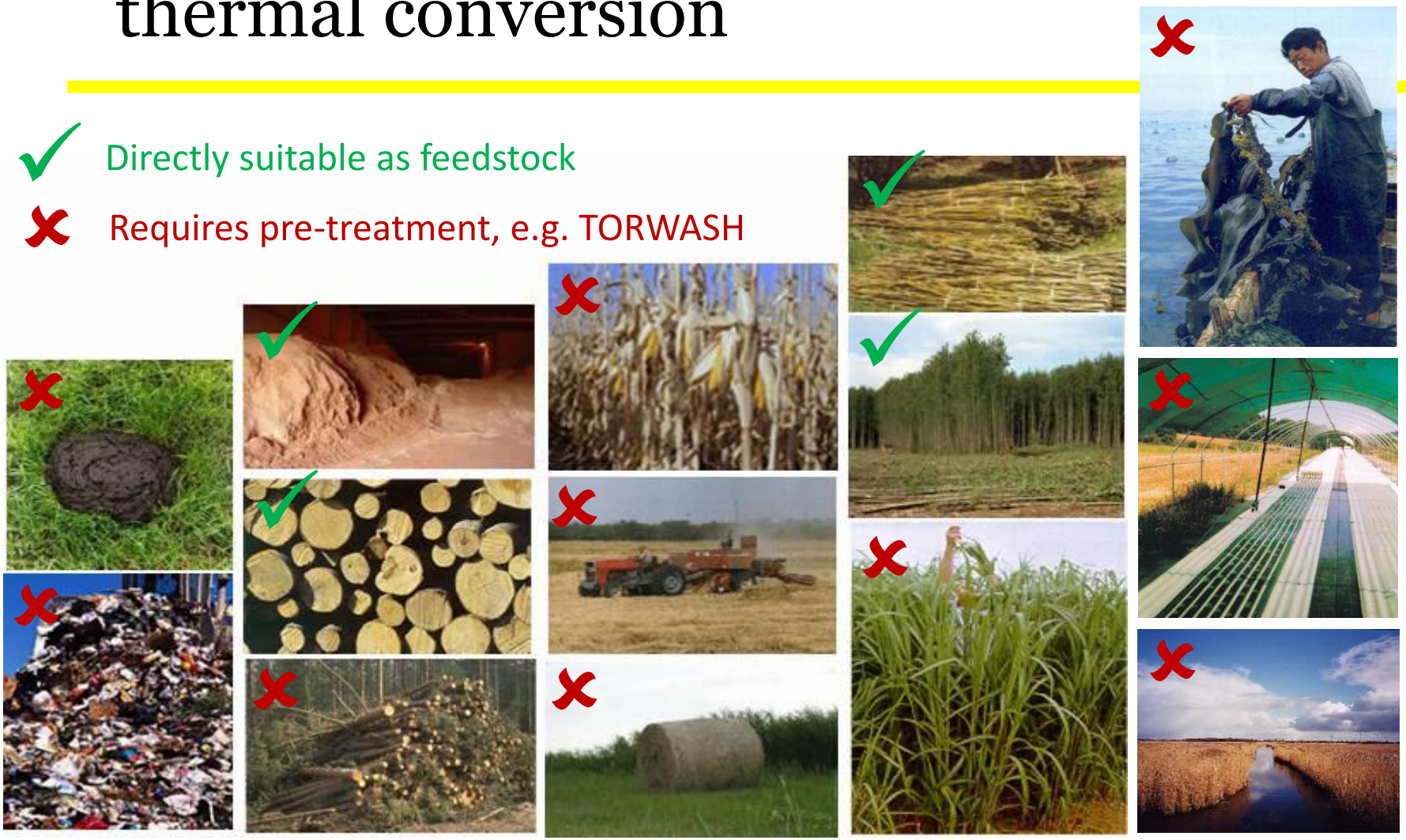
DONG Studstrup-3 experience

Upgrading of herbaceous biomass

Biomass feedstocks for thermal conversion

✓ Directly suitable as feedstock

✗ Requires pre-treatment, e.g. TORWASH



waste | wood | (agricultural) residues | energy corps | aquatic biomass

Combination of washing and torrefaction

- Torrefaction + Washing = TORWASH
  - upgrades low-grade feedstock into a commodity feedstock

- Combines advantages and eliminates disadvantages
  - Torrefaction → brittle structure
  - Salt removal → eases thermal conversion
  - Mechanical dewatering → higher efficiency

- Aim: maximum energy content and low mineral content in the solid phase
- Product: high value fuel as powder, pellets or briquettes
- By-product: biogas from fermentation of liquid residue

TORWASH Example: Arundo Donax (1)

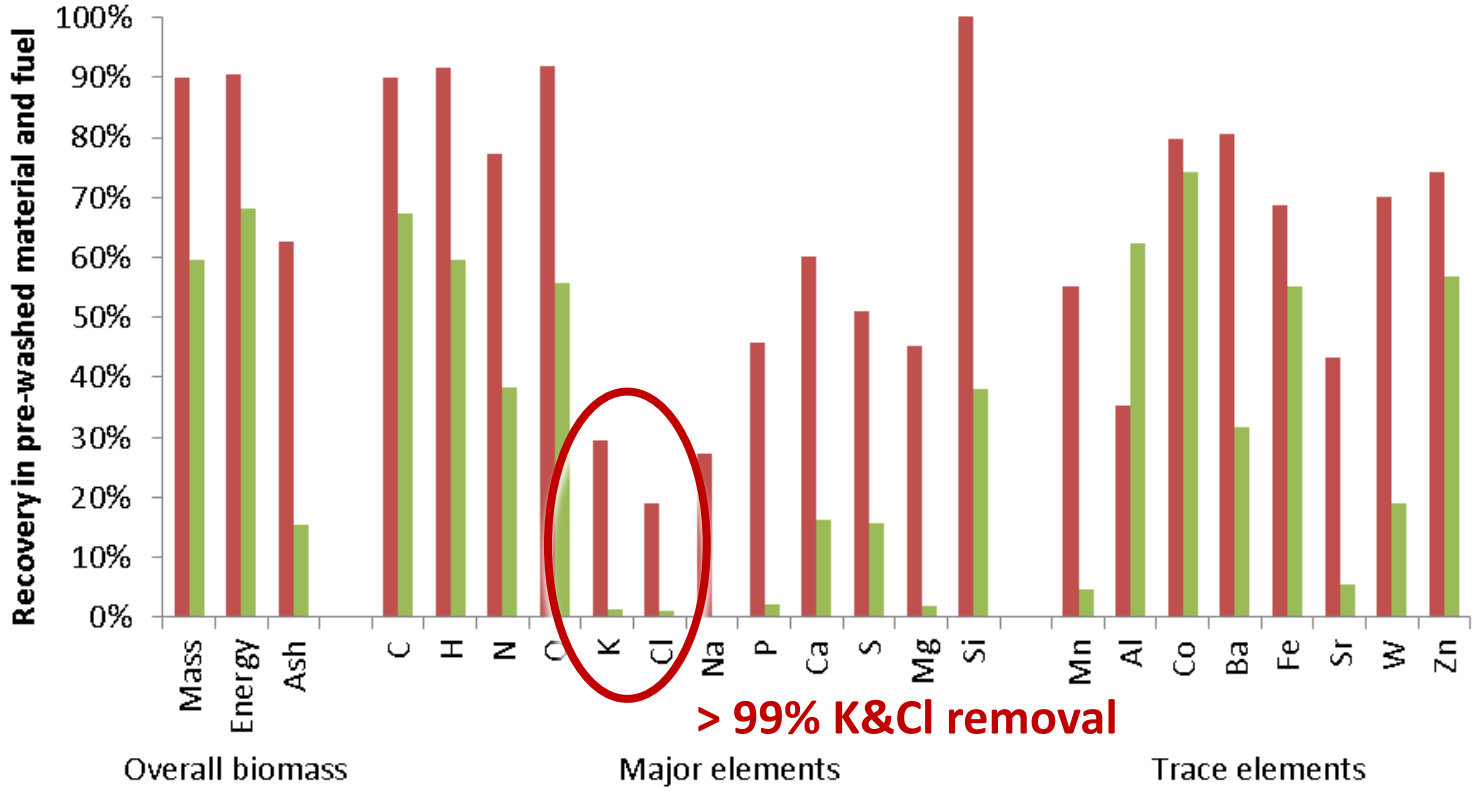
Arundo Donax/Giant Reed
Chopped

Arundo Donax/Giant Reed
Chopped and TORWASHed

Arundo Donax/Giant Reed
Chopped, TORWASHed and pelletised

TORWASH Example: Arundo Donax (2)

Presence of mass, energy, ash content and elements as function of feedstock, after pre-wash (red) and TORWASH (green)



TORWASH Example: Arundo Donax (3)

Parameter	Unit	EN plus A1	Wood pellets	Reed raw	Reed torwashed
Additives	wt% ar	0	none	none	none
Water	wt% ar	≤ 10%	8.3%	variable	7%
Bulk density	kg/m^3	≥ 600	636	-	ND
NCV	GJ/ton ar	≥ 16.5	18.6	17.9	20.6
ash	wt% DM	≤ 0.7%	0.3%	2.3%	0.6%
Cl	wt% DM	≤ 0.020%	0.012%	0.227%	0.005%
K	mg/kg DM		380	4924	116

- TORWASHed Giant Reed pellets comply with stringent white wood pellets standard
- Completion of pilot installation foreseen 2017

Future developments

- Torrefaction and steam explosion pellets produced at scale, and end use validated in industrial applications
- Gradually more commercial-scale black pellet plants will come online
- Mature black pellet technology developers are actively pursuing tangible projects
- Besides co-firing where black pellets displace fossil fuels, alternative outlets for black pellets will gain maturity where black pellets will displace white wood pellets
- Medium-term developments will probably be directed to alternative feedstocks:
  - Agricultural residues (e.g., straw, bagasse, palm oil residues)
  - Paper-plastic fractions and other “waste” streams

Thank you for your attention

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