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# Biomass co-firing experience in NL & Black pellets status update

**Michiel Carbo**

APEC Workshop on Bio-pellet Production, Handling and Energy Utilisation
Tokyo, JP, 24-25 October 2017

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

ECN

**1955** Inauguration of Reactor Centre of the Netherlands (nuclear energy)

**1975** Wind and coal power

**1985** Fuel cells

**1990** Solar power

**1994** Biomass programme

**1998** Energy Efficiency in the Industry programme

**2000** Intelligent grid programme

**2011** New strategy and consolidation of programme lines

~500 employees

~ 90 MEUR turnover

not-for-profit organisation

~500 reports (2014)

~250 publications and conference papers (2014)

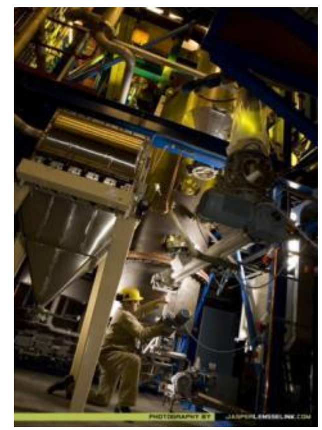
~5 technology licences per year

~20 patents per year

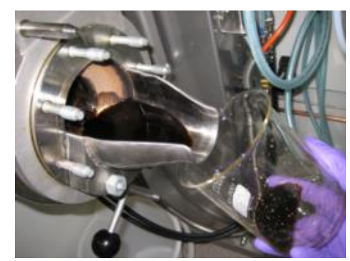
# Main biomass R&D areas

- 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



# Work and Client examples in biomass upgrading and (co-)firing services

ECN

1. **Technology Due Diligence**
   Second opinion for investors → process & product assessment
2. **Feedstock** → find optimum upgrading/conversion technology & clients
3. **Feedstock for proprietary energy generation** → Combine optimum upgradin conversion technology with energy use
4. **New feedstock for existing installation** → identify problems, define solutions
5. **Problem in current operation** (corrosion/slagging/fouling) → sampling & in-depth analysis → hands-on solutions

ECN

# ECN in Biomass (co-)firing 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

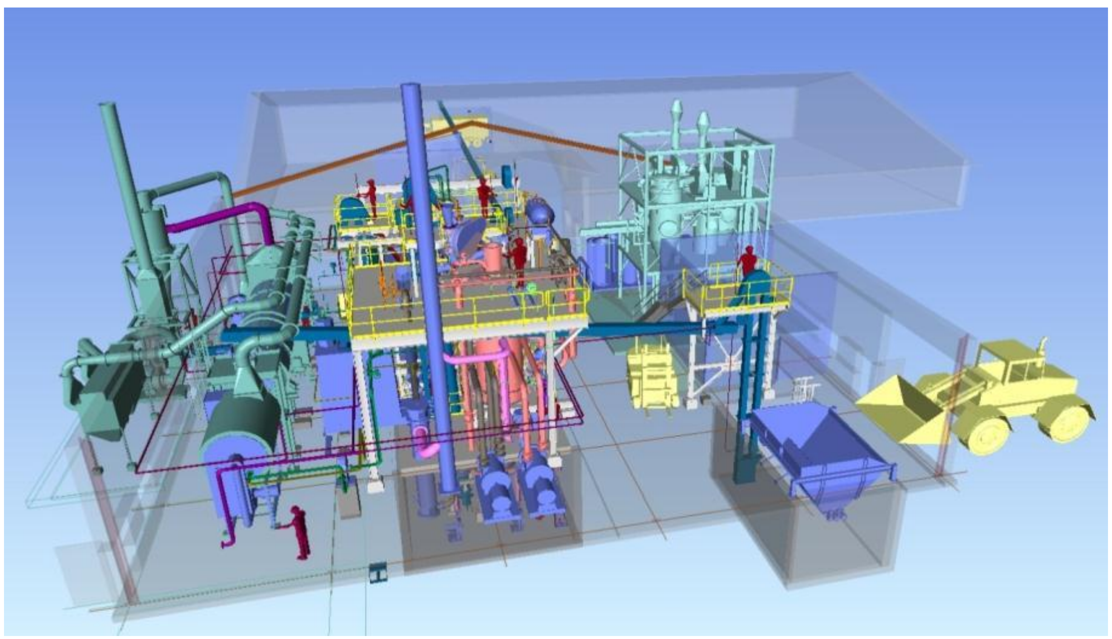
- ECN's torrefaction technology proven on pilot-scale and demonstration scale; Andritz ready for market introduction

- Contract R&D for industry to assess the torrefaction potential of specific feedstocks, produce test batches and independently assess product quality

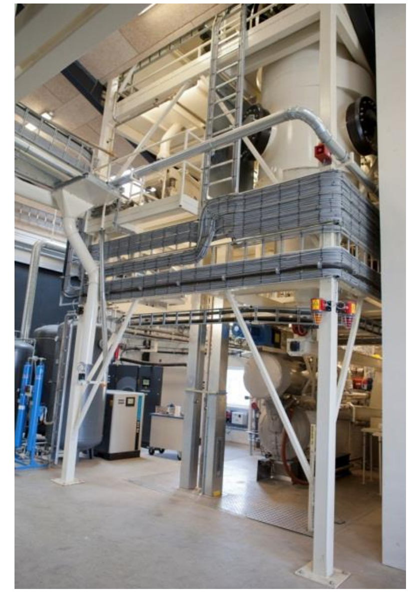
*ECN 50 kg/h torrefaction pilot-plant*

# 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



# Dutch biomass co-firing policies

# Dutch Energy Agreement for sustainable growth

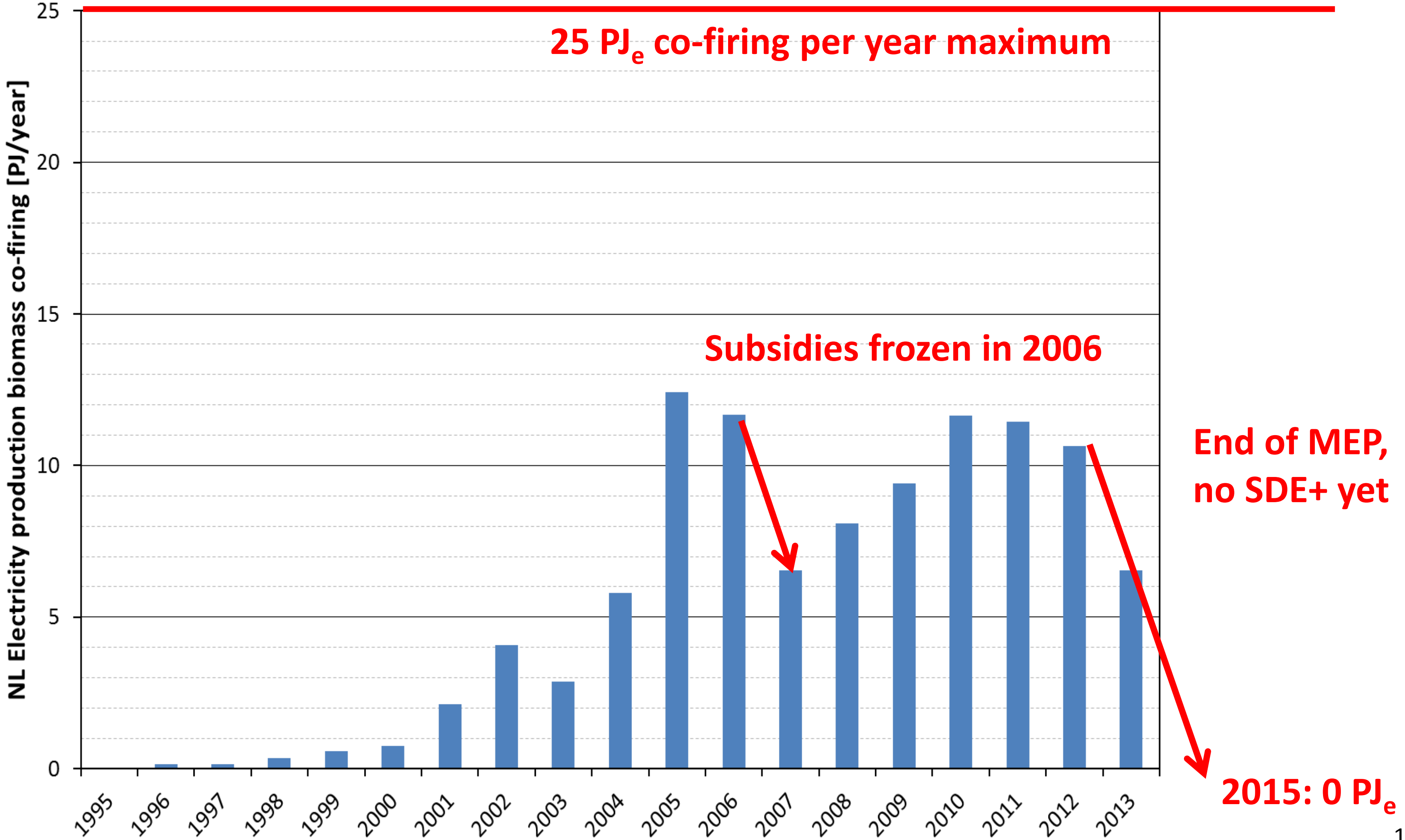
ECN

- Broad support by industry, government, NGO's, unions, etc.
- Reduction in final energy consumption averaging 1.5% annually
- Increase energy generated from renewable sources to 14% in 2020 and 16% in 2023
- Create 15,000 full-time jobs
- Improve competitive position of Dutch companies
- Investment security and innovation support
- Decrease energy costs for households (321 M€) and businesses (266-331 M€)
- Substantial investments between 2013 and 2020: subsidies (13 - 18 billion euro), infrastructure costs, private investments
- Max. 25 $PJ_e$ biomass co-firing per year (equivalent to 3.5 Mton white wood pellets), with 15% alternative streams
- Closure of older power plants (Amer-8, Borsele, Buggenum, Nijmegen, MPP 1& 2)

# Dutch co-firing incentives

- <2003: RBE → tax credit on produced electricity
- 2003-2006: (OV)MEP
  - Project subsidy contracts per kWh (10 years)
- 2008-2010: SDE
  - Feed-in premium with competitive tendering between different renewable energy project proposals; without large scale biomass co-firing, only smaller than 50 MW
- 2010-now: SDE+
  - Feed-in premium with competitive tendering between different renewable energy project proposals
  - Proposals granted starting with cheapest cost price until total budget is allocated
  - Large scale biomass co-firing included in 2015 for duration of 8 years
  - Overall 2015 budget for all renewable energy subsidies: 3.5 billion euro
  - No co-firing proposals granted in 2015 call

# Co-firing experience in the Netherlands

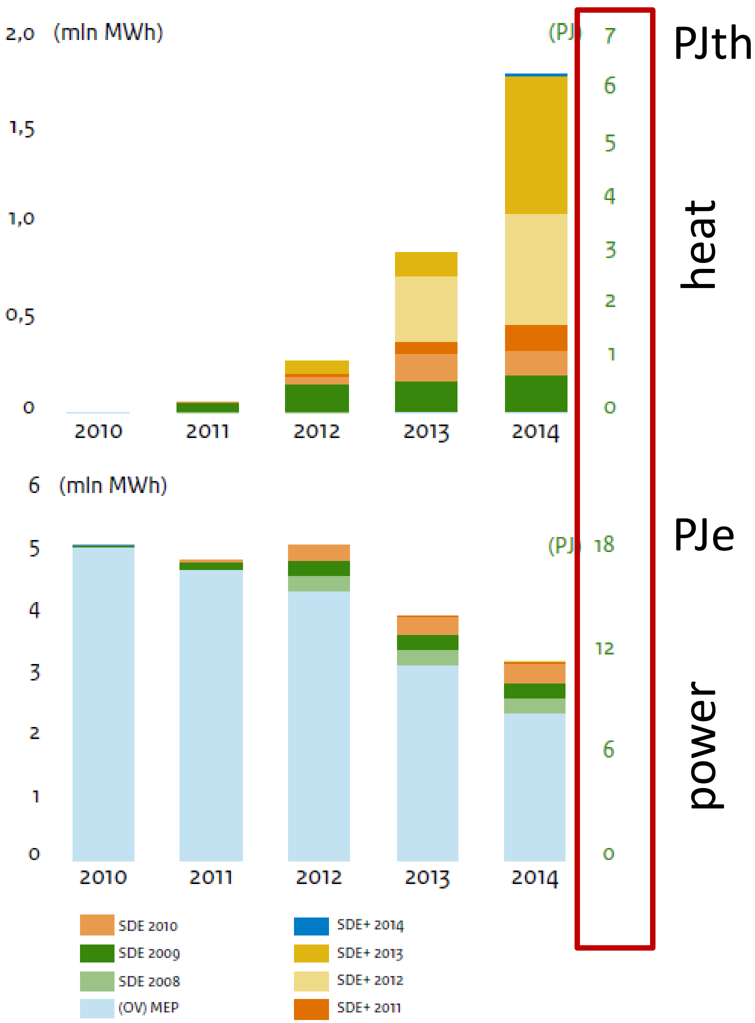


ECN

# Biomass sustainability requirements

- Biomass use must lead to substantial reduction in GHG across value chain in comparison with fossil fuels (min. 70% reduction, max. 56 g $CO_{2eq}$/MJ)
- Soil quality must be maintained and where possible improved
- Production of raw biomass may not result in destruction of carbon sinks
- Use of biomass may not result in a long-term carbon debt
- Biomass production may not result in Indirect Land Use Change (ILUC)
- Several requirements for sustainable forest management
- Chain of Custody (CoC) must be in place that covers entire chain
- Certification system requirements

# Co-firing for E vs biomass to heat in NL in 2014 - 2016




Fast growth in heat generation

2012 total approx. 18,5 PJ(e+th)

2014 total approx 17,8 PJ(e+th)

2015/2016 additional >100 heat projects, but with a total installed capacity of just **140 MWth (ca 3.6 PJ th)**

As of 01/04/2017: **24.96 PJe under contract for co-firing!**

Bron: Statusdocument Bioenergie 2015, Agentschap NL

ECN

# Biomass co-firing in NL beyond 2016 (1)

- As of 01/04/2017: 24.96 PJe under contract for co-firing!

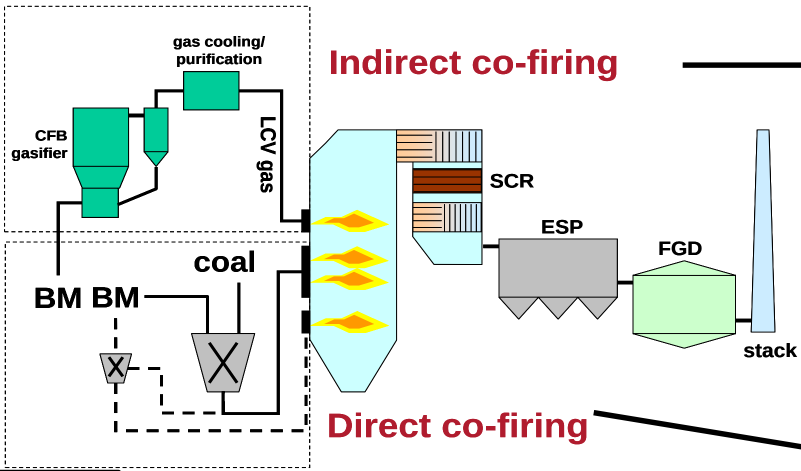
- UNIPER Rotterdam (fka E.On Benelux): USC 1070 MWe/25% co-firing (e/e)
- UNIPER (old units): 2x520MWe/20% co-firing e/e (until July 2017) and later possibly conversion/downrating to 100% heat on renewable residues

- ENGIE (Electrabel) Rotterdam : USC 736 MWe/10% co-firing (e/e)

- RWE/Essent: AMER 9/12 up to 660 MWe 80% co-firing (e/e)
- RWE/Essent: Eemshaven USC 2x736 MWe/10% co-firing (e/e)

- All systems: base fuel wood pellets but with max 15% e/e of "other renewables", including MBM, straw, bark pellets, citrus pulp, cacao

# Biomass co-firing in NL beyond 2016 (2)




Indirect co-firing

Direct co-firing

*Essent Amer wood gasifier* ***(changes to a different, lower quality fuel****)*

Amer 8 closed

AMER 9/12 and Eemshaven

*RWE/Essent Amer*

MPP1/2 closing 1/07/17

UNIPER MPP3 on-line

*UNIPER Maasvlakte*

BS12 closed

*EPZ Borssele 12*

Gelderland closed 2015

*ENGIE*

ENGIE Rotterdam on-line

Buggenum closed in 2013

*Vattenfall/NUON*

Hemweg co-firing

# Dutch lessons learned

- Fluctuations and uncertainties in support schemes do not contribute to continuous biomass co-firing in power plants
- Certainty warrants biomass co-firing by utilities
- Utilities applied for a feed-in premium of 0.068 €/kWh (or 8.5 JPY/kWh) for a total duration of 8 years and 5839 full load equivalent hours per year
- This suggests that biomass co-firing is commercially viable at this premium

- Japanese feed-in tariff and 20 years duration offers a lot of certainty
- Co-firing of white wood pellets likely requires hardware modifications
- Co-firing of torrefied wood pellets is business-as-usual: simply substitute coal

# 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

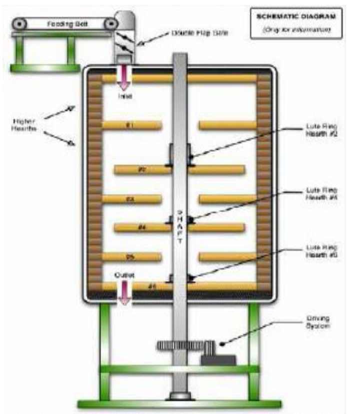
- First developments aimed at pulp production in the 1920's
- Later on recognised as pre-treatment/fractionation step in e.g. 2$^{nd}$ generation bioethanol production
- Potential as bioenergy carrier identified early 2000's

# Black Pellet Technology Overview

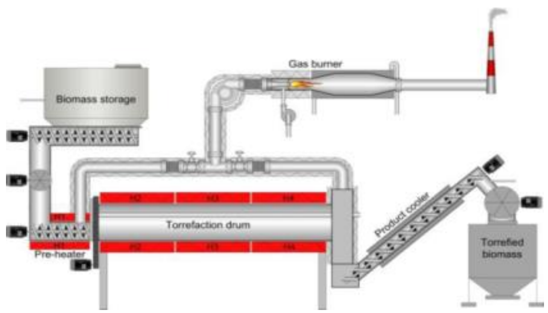
# Torrefaction technology

- 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

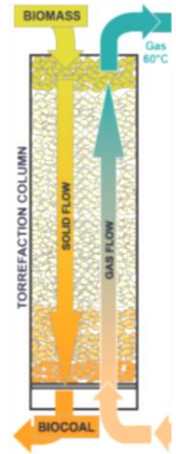
# Torrefaction technology – many reactor concepts considered



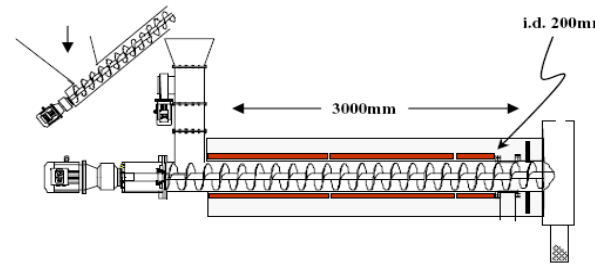

*Multiple hearth furnace*



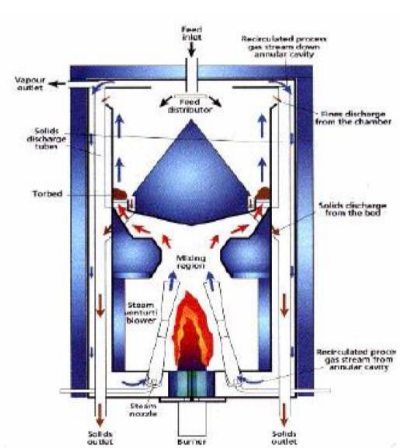

*Rotary drum reactor*



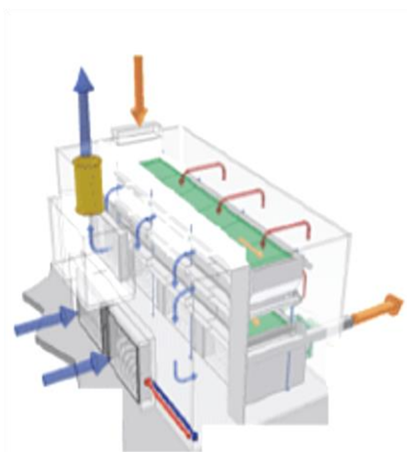

*Moving bed reactor*



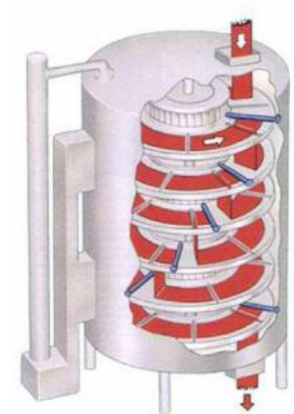

*Screw conveyor reactor*



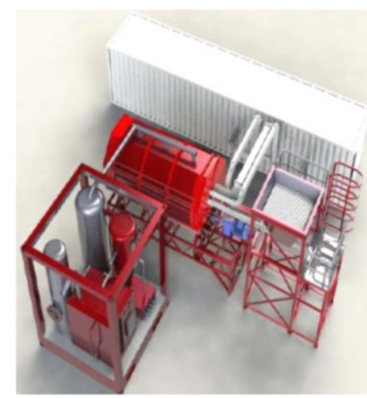

*Torbed reactor*



*Oscillating belt reactor*



*TurboDryer*



*Microwave reactor*

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

# Torrefaction initiatives (1)

| Developer | Technology | Location | Production capacity (ton/a) | Scale | Full Integration | Status |
|---|---|---|---|---|---|---|
| American Biocarbon | Rotary drum (TSI) | White Castle LA (USA) | 20,000 | Commercial | Unknown | Available |
| Clean Electricity Generation (UK) | Oscillating belt | Derby (UK) | 30,000 | Commercial | Yes | Available |
| Hip Lik Green Energy Ltd. | Unknown | Indonesia | 100,000 | Commercial | Yes | Relocated from MY |
| New Biomass Energy/Heet way (USA) | Screw reactor | Quitman MS (USA) | 40,000 | 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

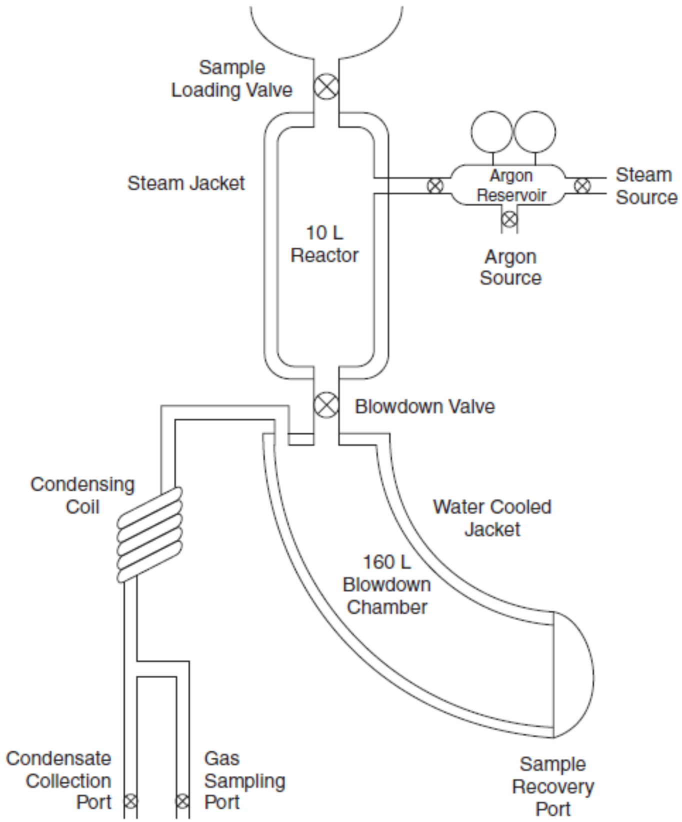
# Torrefaction initiatives (3)

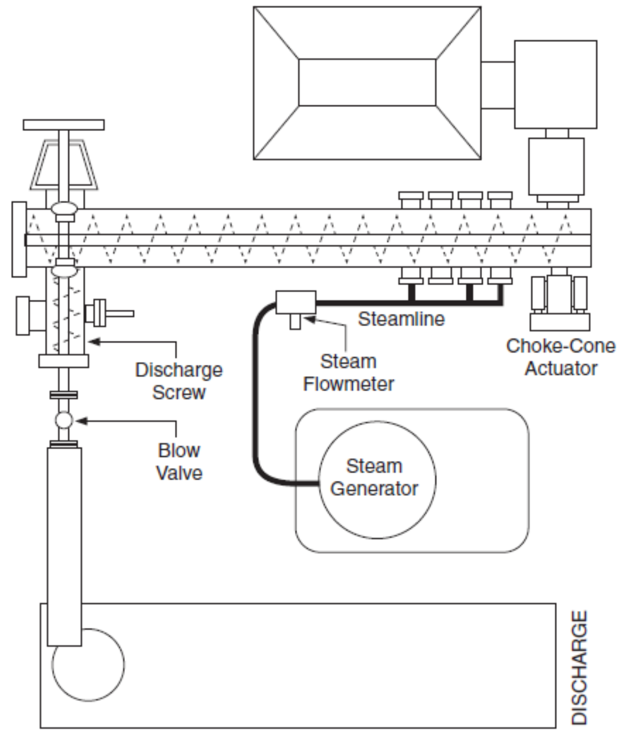
| Developer | Technology | Location | Production capacity (ton/a) | Scale | Full Integration | Status |
|---|---|---|---|---|---|---|
| Grupo Lantec (ES) | Moving bed | Urnieta (ES) | 16,000 | Demonstration | | Unknown |
| Integro Earth Fuels, LLC (US) | Multiple hearth | Greenville SC (USA) | 11,000 | 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 |

# 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 larger-scale plants established

# 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 | Unknown |
| Arbaflame (NO) | Batch | Kongsvinger (NO) | 40,000 | Commercial | Yes | Available |

Sources: Press releases Zilkha and Arbaflame

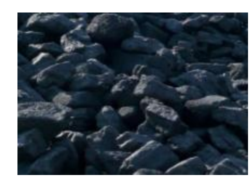
# Mapping black pellets characteristics

# 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 |



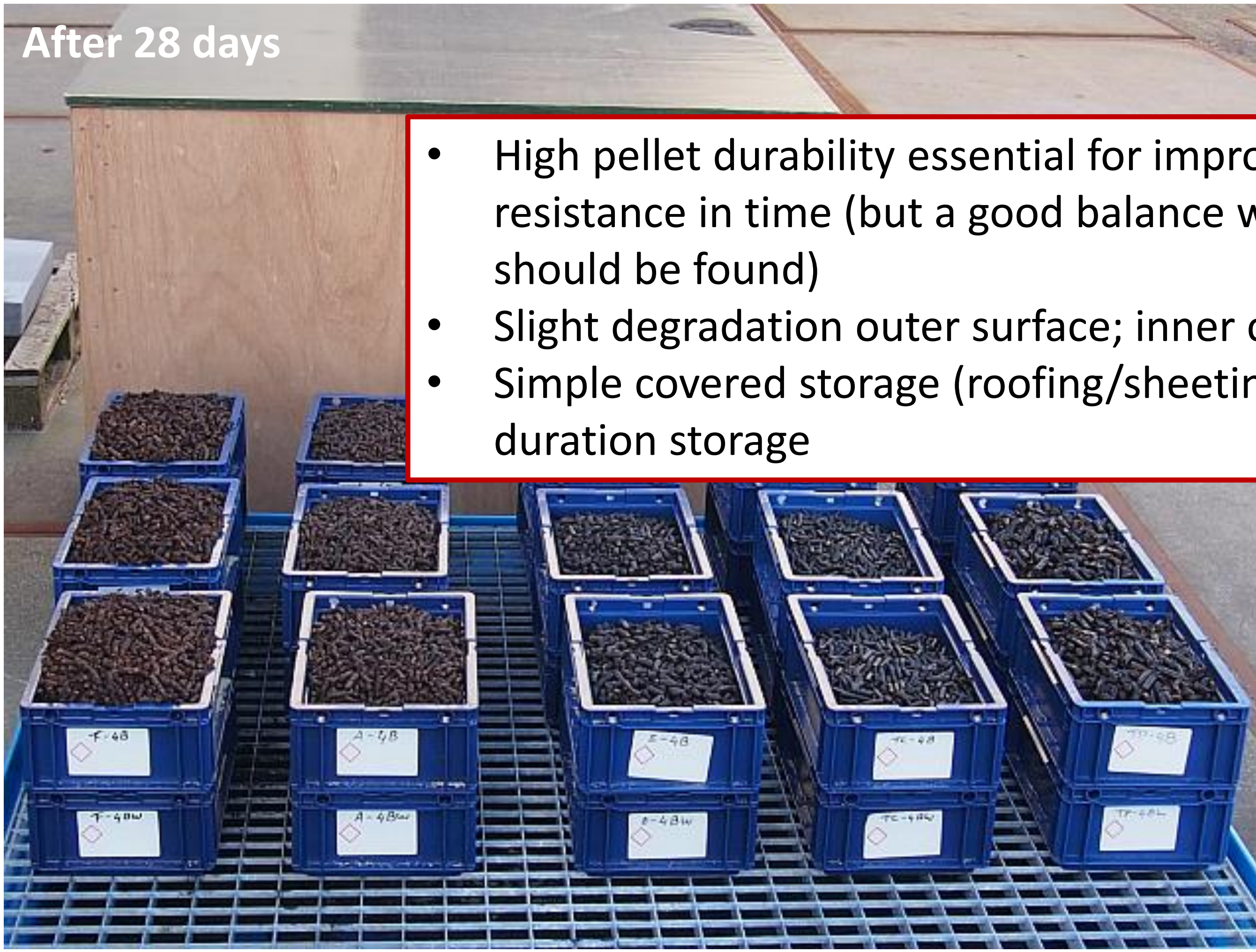


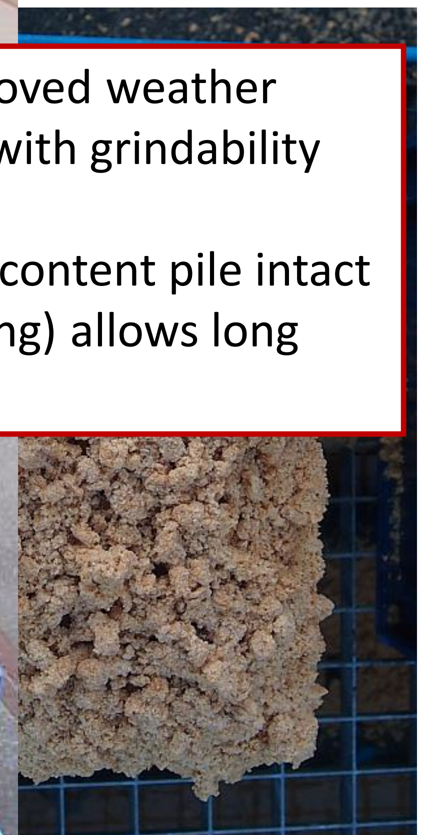



Abbreviations:
db = dry basis
LHV =Lower Heating Value

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

# Small-scale outdoor storage



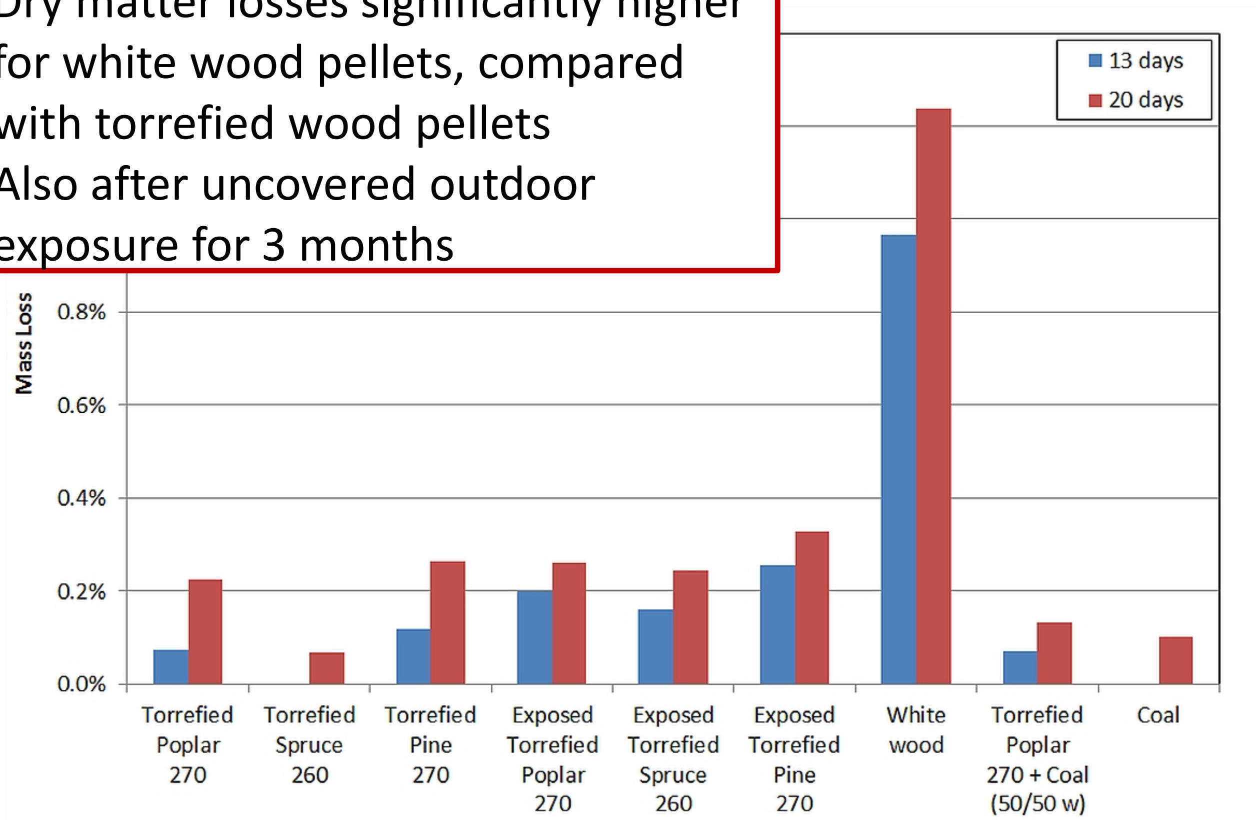



- High pellet durability essential for improved weather resistance in time (but a good balance with grindability should be found)
- Slight degradation outer surface; inner content pile intact
- Simple covered storage (roofing/sheeting) allows long duration storage

# Biological degradation

Pellets stored 20 days at 20 °C at 95% relative humidity

- Dry matter losses significantly higher for white wood pellets, compared with torrefied wood pellets
- Also after uncovered outdoor exposure for 3 months




Source: Carbo et al. "Fuel pre-processing, pre-treatment and storage for co-firing of biomass and coal" in "Fuel Flexible Energy Generation" ed. J. Oakey, 2015

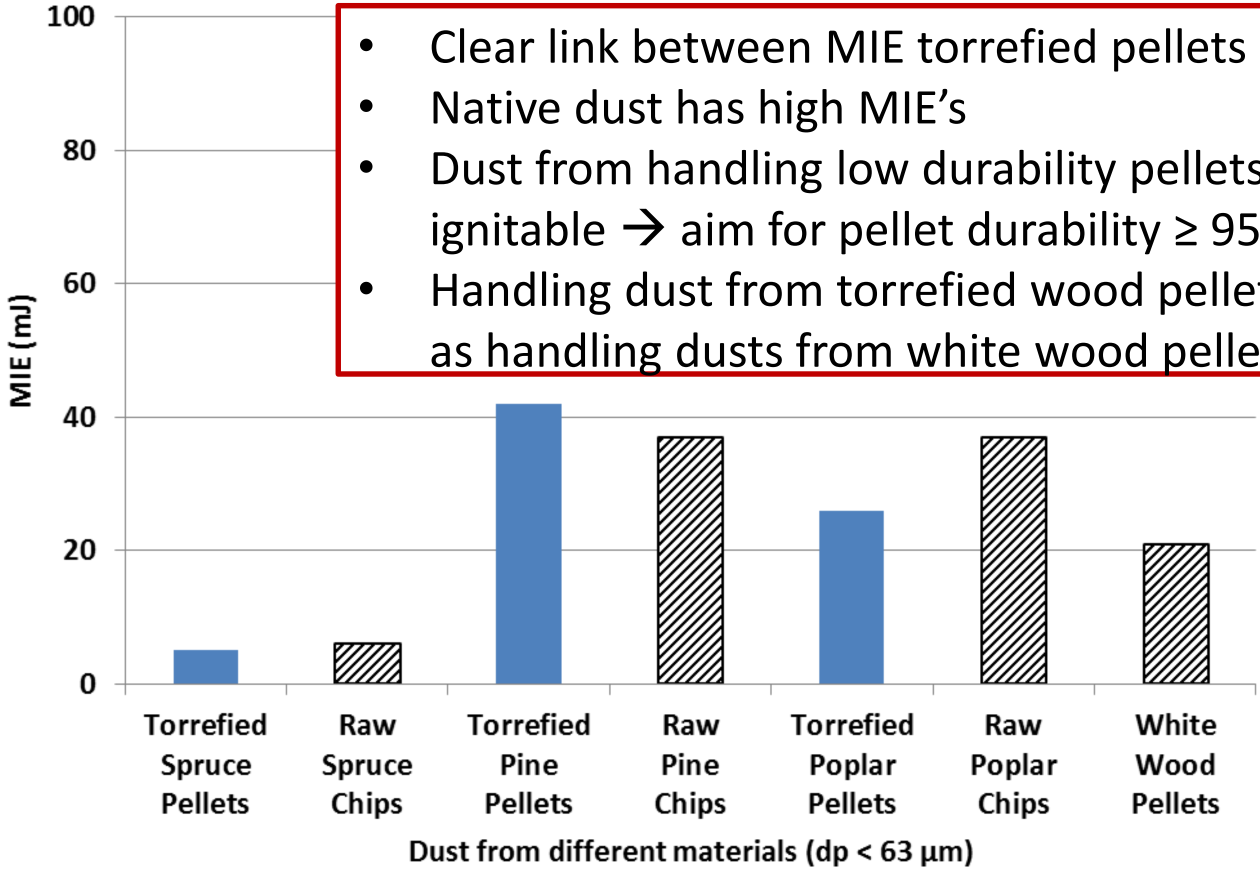
# Durability and explosivity

- Durability (EN 15210)
  - Torrefied wood pellets typically 96.5-98.5%
  - Steam explosion pellets sometimes > 99%

- Minimum ignition energy
  - Pellets were pulverised using disc impaction mill to replicate commercial roller mill
  - Fraction below 63 μm used in accordance with EN 13821
  - Torrefied wood pellets have MIE's within 30-100 mJ range, both with and without inductance

# Minimum Ignition Energy (MIE)

- Pulverised torrefied pellets vs. pulverised raw biomass chips (ind. off)

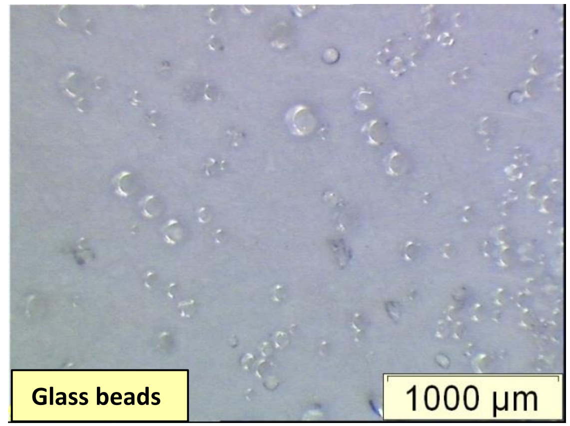



- Clear link between MIE torrefied pellets with MIE raw material
- Native dust has high MIE's
- Dust from handling low durability pellets (< 93%) is easier ignitable → aim for pellet durability ≥ 95%
- Handling dust from torrefied wood pellets is equally ignitable as handling dusts from white wood pellets

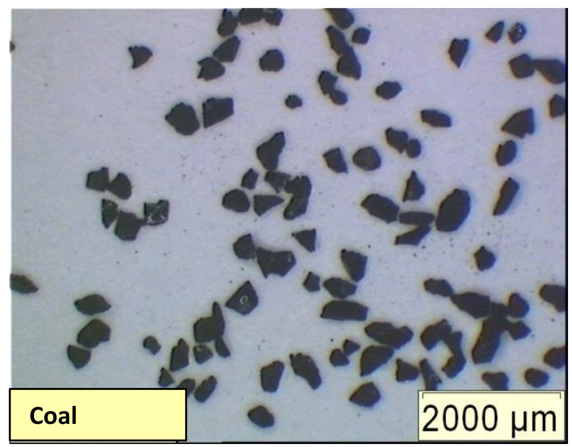
Source: Carbo et al. "Fuel pre-processing, pre-treatment and storage for co-firing of biomass and coal" in "Fuel Flexible Energy Generation" ed. J. Oakey, 2015

# Fuel morphology after milling (1)

- Glass beads:

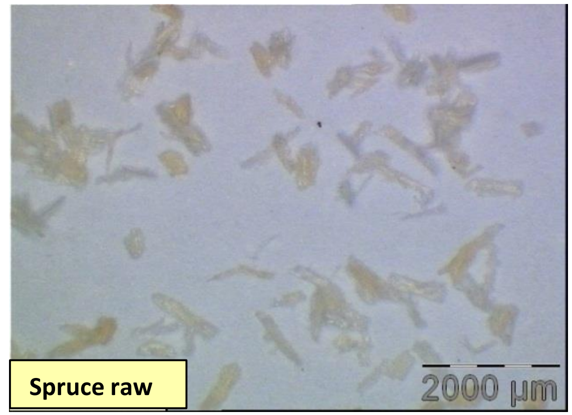



- Coal:

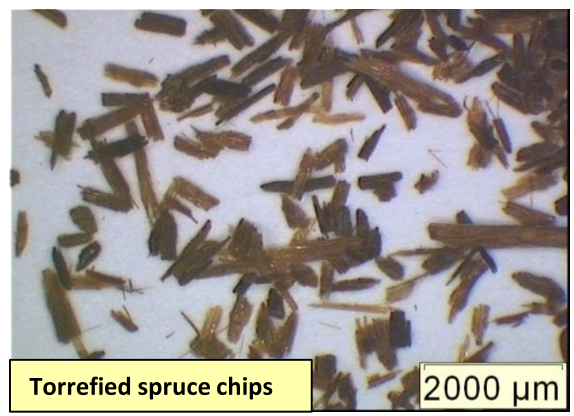


# Fuel morphology after milling (2)

- Raw spruce:

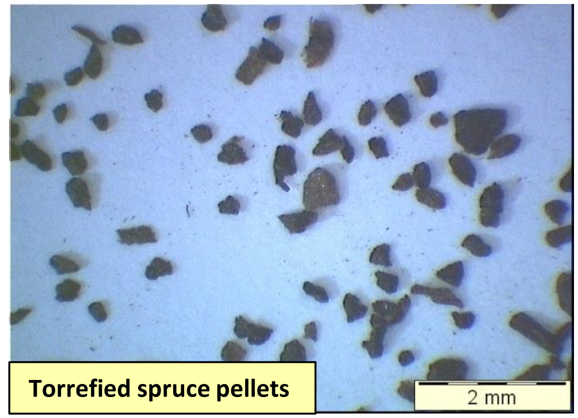



- Torrefied spruce chips:



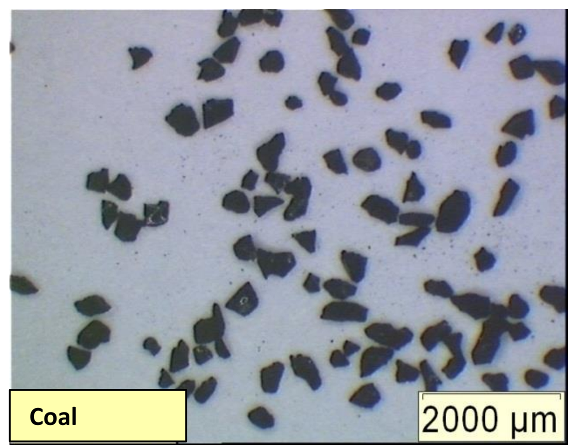
# Fuel morphology after milling (3)

- Torrefied spruce pellets Andritz/ECN demo:




- Particle "sphericity" pulverised torrefied wood pellets comparable to pulverised coal

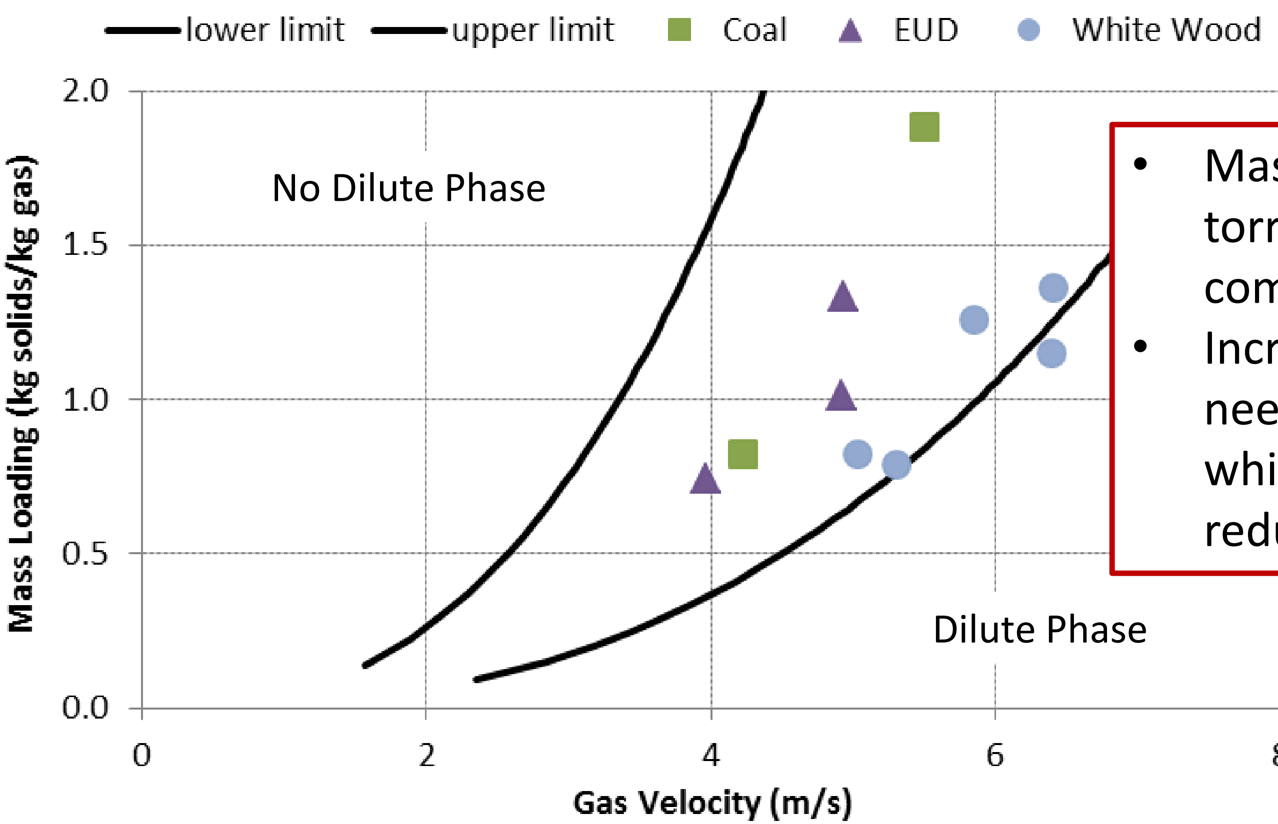
- Coal:



# 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 black pellets 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 Blackwood, RWE, Vattenfall, ENGIE 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)

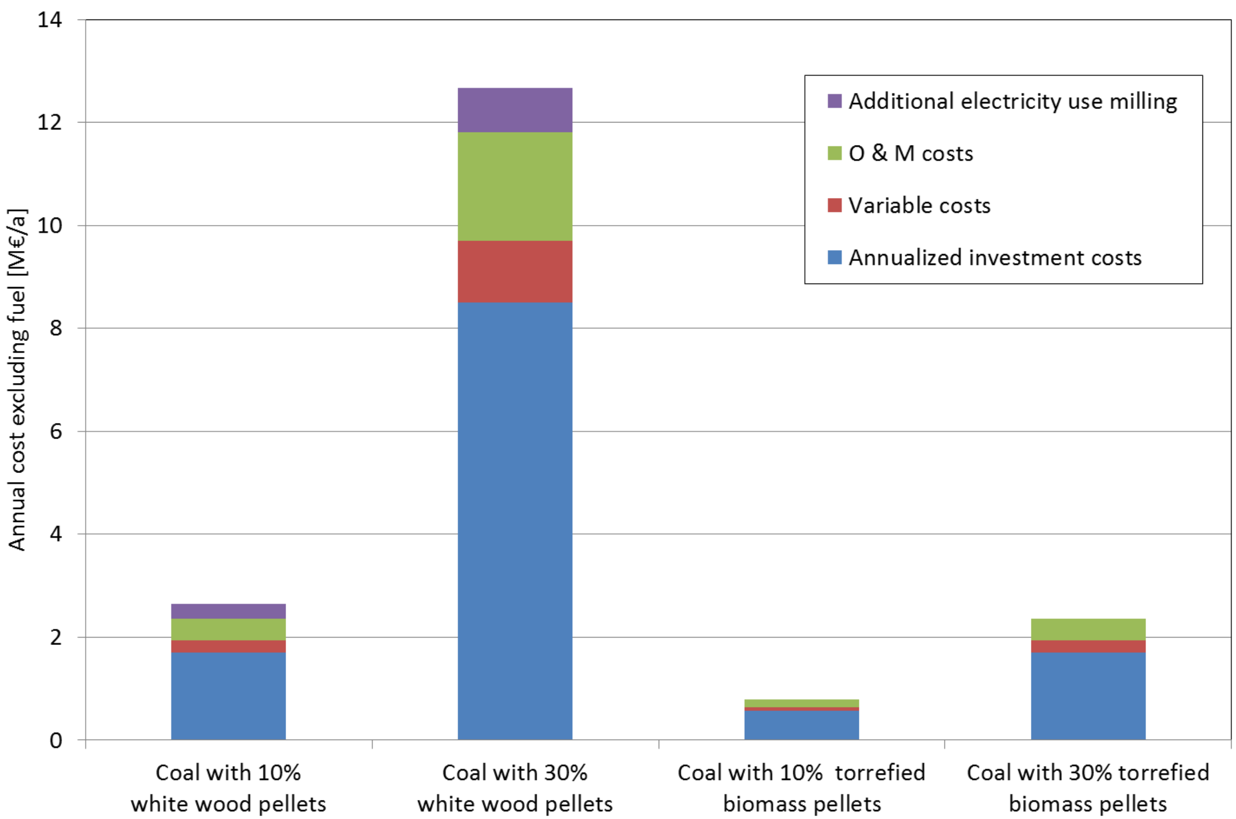
- ECN conducted lab-scale characterisation of pellets

# DONG Studstrup-3 experience

# Black pellets costs

# Black pellets end use economics

- Annual costs excluding fuel costs white wood pellets vs. black pellets in different co-firing scenarios:




  - 400 $MW_e$
  - 10 and 30% co-firing (e-basis)
  - 6,000 operating hours
  - Annuity: 14%
  - Economic lifetime: 10 years

# Purchasing power

Black pellets particularly interesting to establish increased co-firing ratios at power plants without co-firing infrastructure (or with limited current shares)

- White wood pellet price of 150 €/ton or 30 €/MWh

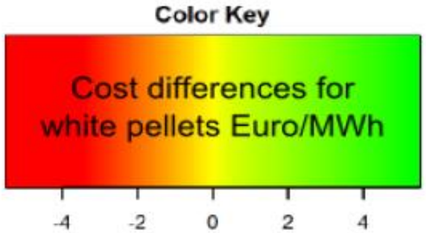
| | | 10% co-firing | 30% co-firing |
|---|---|---|---|
| Annual cost difference: white wood pellets minus torrefied wood pellets | M€/y | 1.86 | 10.31 |
| Pellets used | PJ/y | 2.16 | 6.48 |
| **Acceptable price difference for torrefied wood pellets** | **€/GJ (€/MWh)** | **0.86 (3.10)** | **1.59 (5.72)** |
| Case 1: price difference at higher rate of return (12% → 15%) | €/GJ (€/MWh) | 1.08 (3.89) | 2.02 (7.27) |
| Case 2: price difference at reduction of economic lifetime from 10 to 5 years | €/GJ (€/MWh) | 1.24 (4.46) | 2.34 (8.42) |

ECN

# Production and logistic cost black pellets

- Both torrefied and steam explosion pellets display increased volumetric energy content (read: 30-40% more energy per barge)
- Recent studies indicate that production costs are 10-15% higher for black pellets compared to white pellets (VTT/Pöyry, 2014 and FutureMetrics LLC, 2014)
- The FutureMetrics LLC white paper (2014) states:
  - Provided black pellets are waterproof the net benefit of using torrefied and steam explosion pellets over white wood pellets amounts 1.41 and 0.81 USD/GJ, respectively
  - In case dry storage is needed the net benefit of using torrefied pellets over white wood pellets still amounts 0.50 USD/GJ
- Slightly higher production costs for black pellets pay off during logistic chain as well as end use

# Value chains: Selected results




Average costs (number in the boxes, Euro2013/MWh) for torrefied pellets based on saw dust for selected biomass-to-end-use chain constellations

| | 100km EU-transport, large end use | 400km EU-transport, large end use | 800km EU-transport, large end use | 100km EU-transport, small end use | 400km EU-transport, small end use | 800km EU-transport, small end use |
|---|---|---|---|---|---|---|
| US/CA,low supply dist., Pellet plant size <101kt | 39.7 | 43.8 | 49.2 | 42.5 | 46.5 | 52 |
| EU,low supply dist., Pellet plant size <101kt | 35.8 | 39.8 | 45.3 | 38.5 | 42.6 | 48 |
| US/CA,high supply dist., Pellet plant size <101kt | 41.8 | 45.9 | 51.3 | 51.2 | 55.3 | 60.7 |
| EU,high supply dist., Pellet plant size <101kt | 38 | 42 | 47.5 | 47.4 | 51.4 | 56.9 |
| US/CA,low supply dist., Pellet plant size >199kt | 39.2 | 43.3 | 48.7 | 42 | 46 | 51.5 |
| EU,low supply dist., Pellet plant size >199kt | 35.4 | 39.5 | 44.9 | 38.1 | 42.2 | 47.7 |
| US/CA,high supply dist., Pellet plant size >199kt | 44 | 48 | 53.5 | 53.4 | 57.4 | 62.9 |
| EU,high supply dist., Pellet plant size >199kt | 40.3 | 44.4 | 49.8 | 49.7 | 53.8 | 59.2 |

Source: DBFZ, Stefan Majer

This project has received funding from the European Union's Seventh Programme for research, technological development and demonstration under grant agreement n° 282826

# Black pellet market development

- First large-scale (capacity > 100,000 ton per year) black pellet plants are operational or under construction
- Total global production capacity is not large enough to call it a market
- Black pellet technologies are ready for broad commercial market introduction and the basic drivers to use these pellets are still in place
- However, several factors slowed down this introduction:
  - European utility sector is facing difficult times – co-firing perhaps not the best launching end-user market (also in view of scale) – smaller-scale industrial or district heat perhaps a better option?
  - It takes time and effort to build end-user confidence
  - Instead of yielding immediately the ideal feedstock, black pellet technology development had to follow a learning curve, in parallel with white wood pellets
  - Biomass in general is under debate and opinions on biomass use are subject to change

# Upgrading of herbaceous biomass

# Biomass feedstocks for thermal conversion

✓ Directly suitable as feedstock

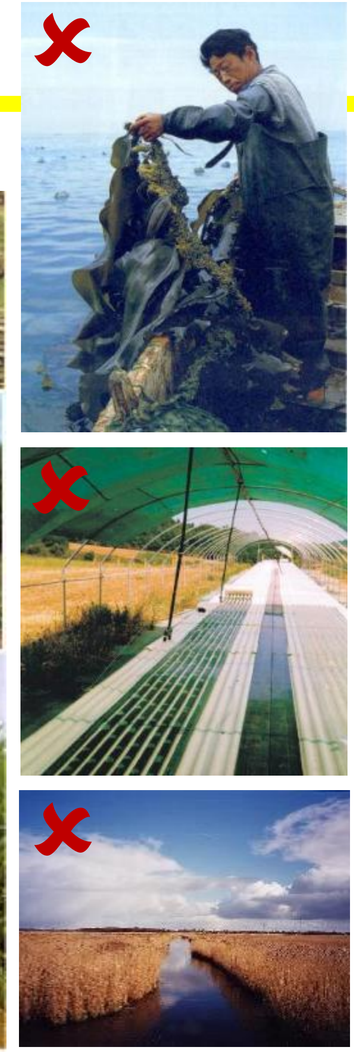
✗ Requires pre-treatment, e.g. TORWASH

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)

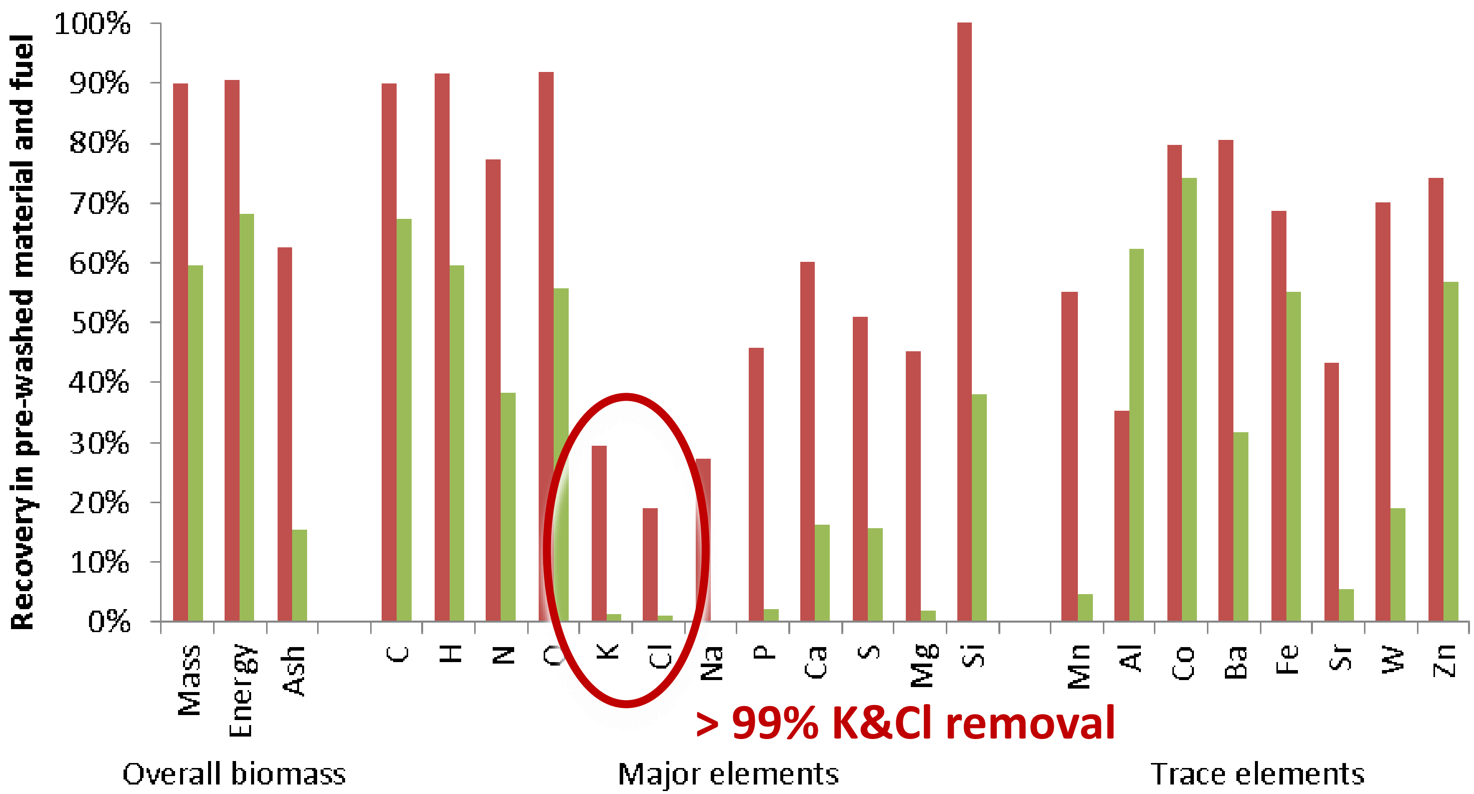
Arundo Donax/Giant Reed
Chopped

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)



ECN

# 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

**Michiel Carbo**
Innovation Manager Biomass Upgrading
Biomass & Energy Efficiency

T +31 88 515 47 92
F +31 88 515 84 88

Westerduinweg 3, 1755 LE PETTEN
P.O. Box 1, 1755 ZG PETTEN
The Netherlands

carbo@ecn.nl
www.ecn.nl