Handling and storage of torrefied biomass pellets

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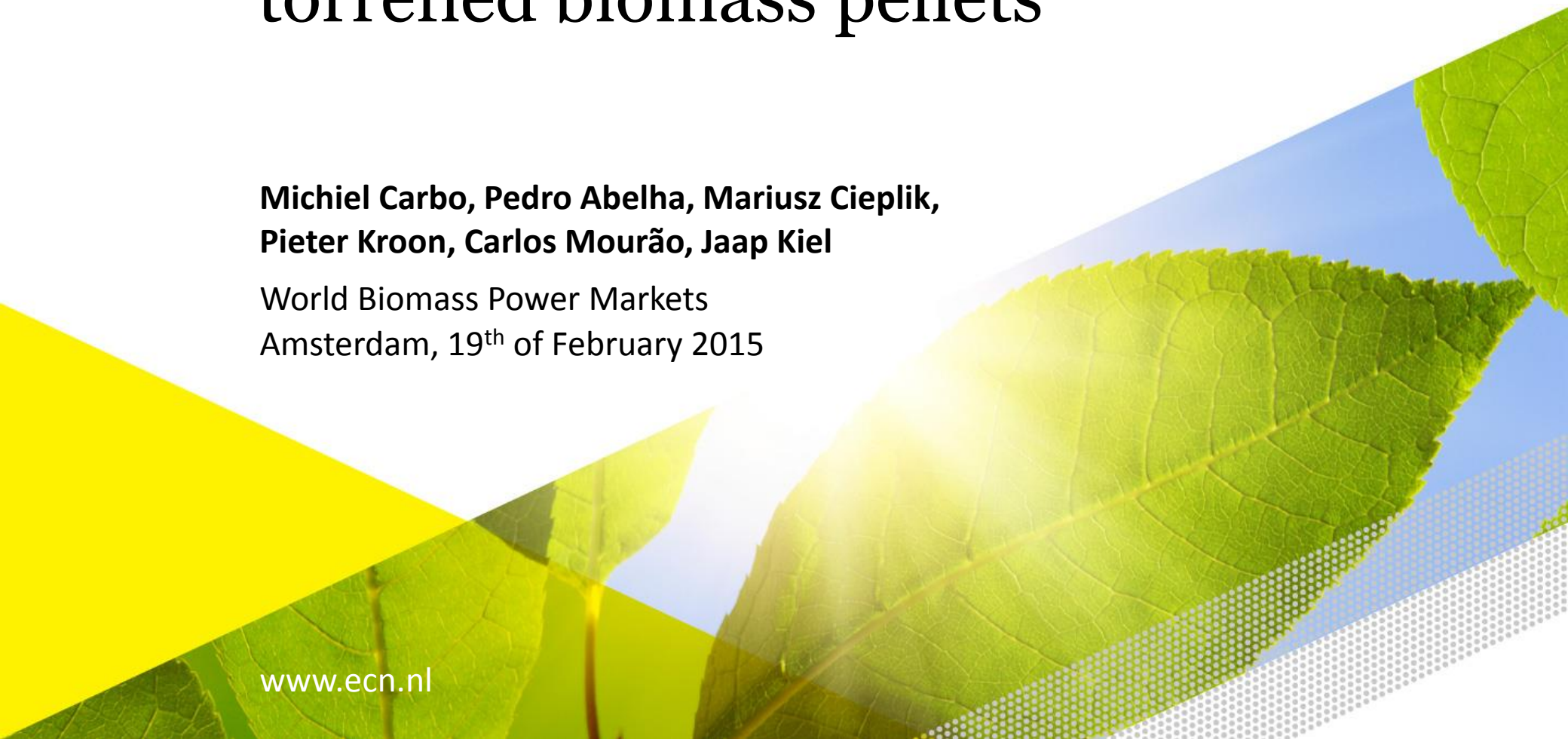

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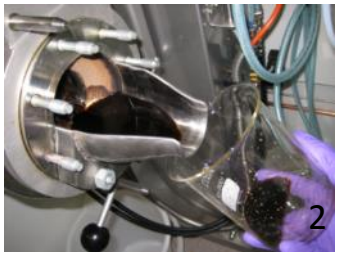
Main biomass R&D areas

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

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



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 optimise product quality

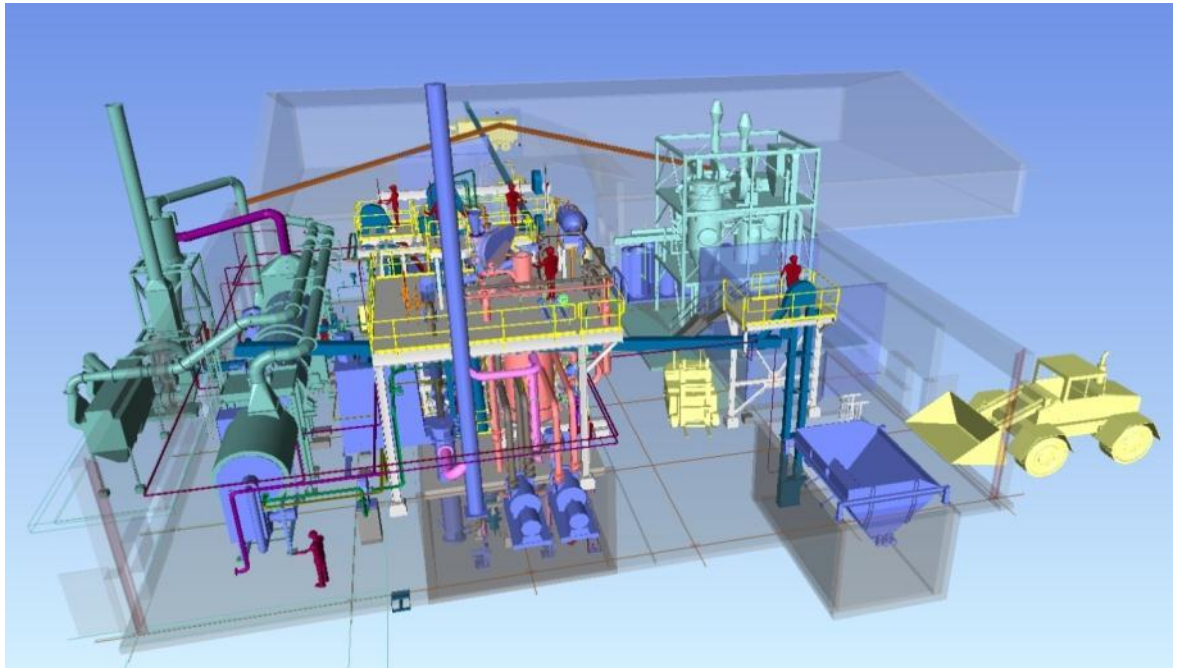
ECN 50 kg/h torrefaction pilot-plant

Torrefaction – Observations

- Often proven reactor technologies in other applications (e.g. 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; strongly depends on heat integration design
- 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 (e.g. die dimensions)
  - Good control of torrefaction conditions is essential
  - Without binder, window for tuning product quality to logistics and end-use requirements can be small
  - Special attention to safety issues (e.g. self heating, dust explosions)

Technology licensed to Andritz

- Industrial demo plant in Sønder Stenderup, Denmark
  - Operational since 2012
  - Capacity 1 ton/hour torrefied pellets
- Strong combination of industry and R&D



Torrefaction demo plant

- Demo plant comprises pre-drying, torrefaction and pelletisation
- Blends ECN and Andritz technologies
- Torrefaction pressurized for more effective heat transfer, reduction of equipment sizes
- Torrefaction reactor contains separate zones for final drying and torrefaction
- Torrefaction reactor design suitable to scale up to large single unit capacities
- All individual equipment units built at large-scale

Torrefaction section of the demo plant

Torrefaction demo plant

Experience and outlook

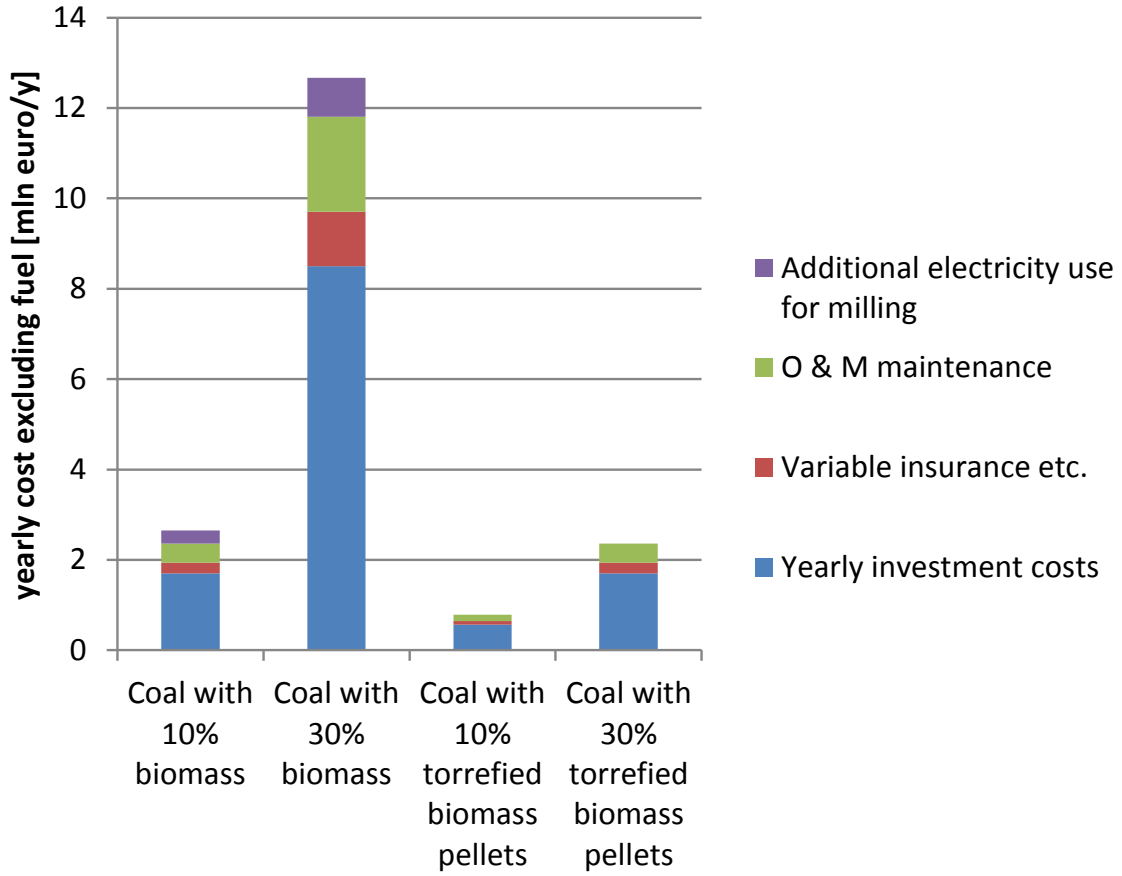
- Development of dedicated torrefaction and densification recipes:
  - Demo plant: eucalyptus, beech, spruce, pine, poplar, mixed woods, etc.
  - Lab- and pilot plants: many different wood species and mixed woods, bamboo, PKS, EFB, OPF, miscanthus, etc.

- Tailor torrefied products to meet end-user requirements:
  - ECN in-house characterization
  - Logistics, storage and safety
  - Grindability, pneumatic feeding and conversion

Mapping torrefied biomass pellet characteristics

Why torrefaction?

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



Purchasing power

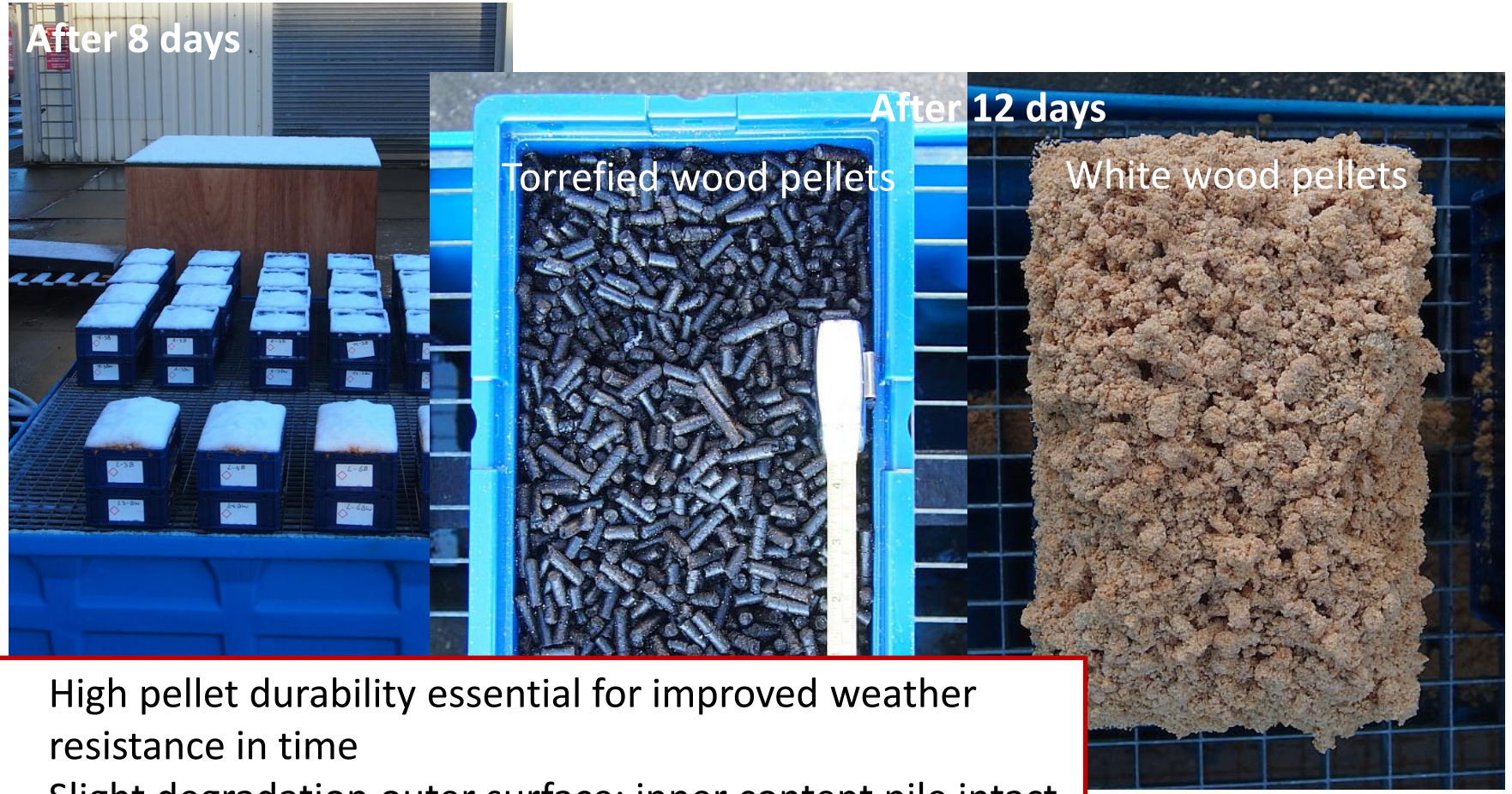
- Torrefied wood pellets particularly interesting to establish increased co-firing ratios at power plants w/o co-firing (or at existing low % capabilities)

		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**	**0.86**	**1.59**
Case 1: price difference at higher rate of return (12% → 15%)	€/GJ	1.08	2.02
Case 2: price difference at reduction of economic lifetime from 10 to 5 years	€/GJ	1.24	2.34

Small-scale outdoor storage (1)

- Ongoing experiments simulating pile surface
- Durability determined at set intervals
- Detailed monitoring weather conditions

Small-scale outdoor storage (2)

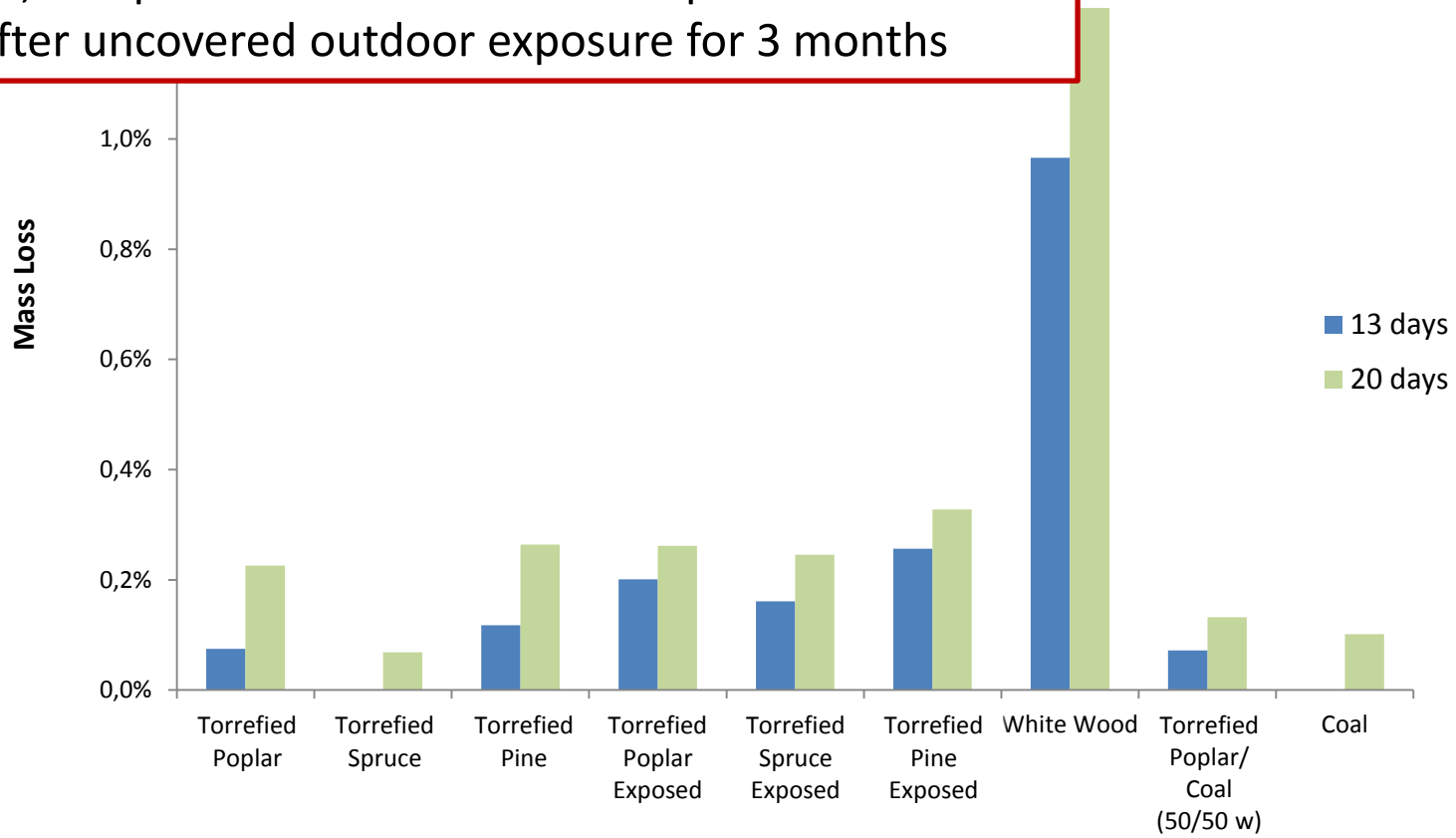


- High pellet durability essential for improved weather resistance in time
- Slight degradation outer surface; inner content pile intact

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

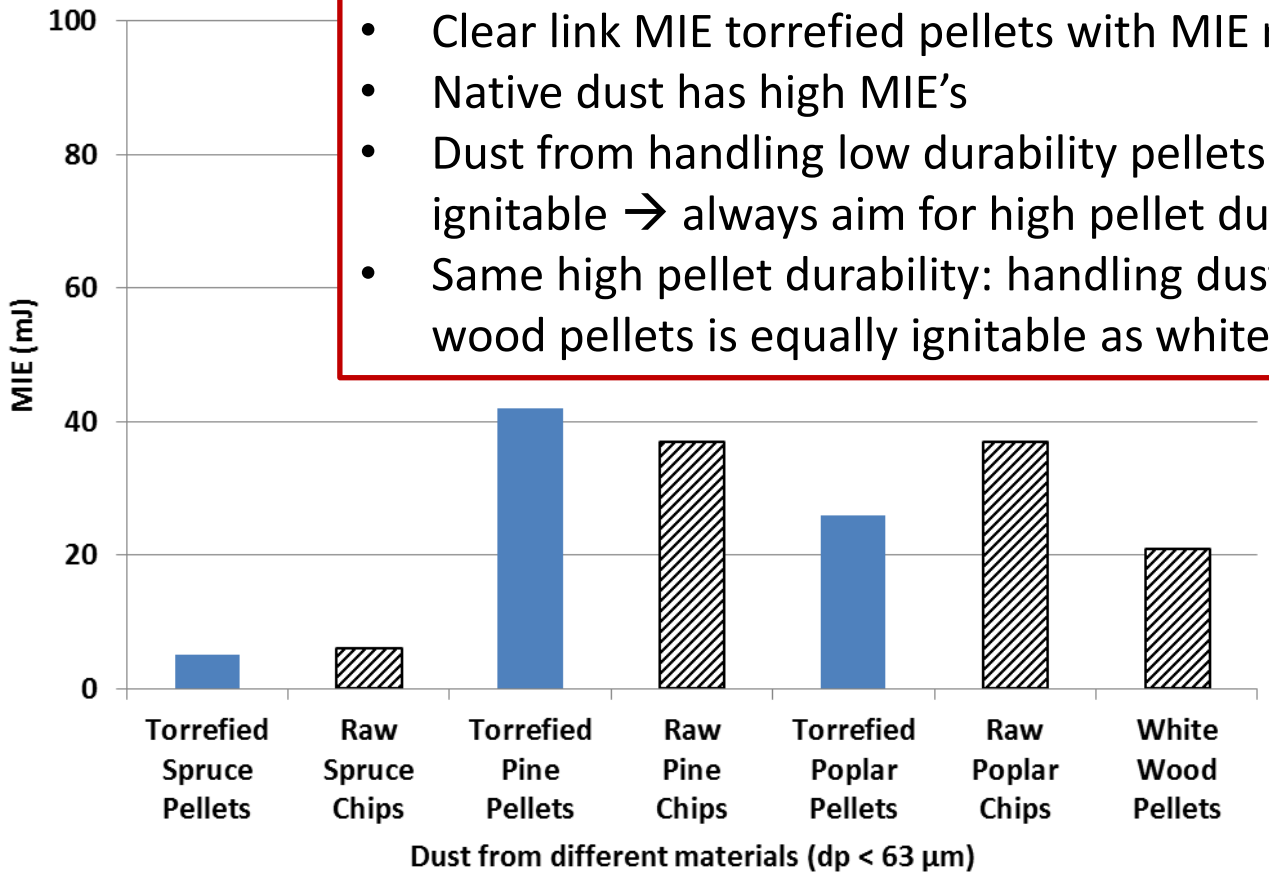


Durability and explosivity

- Durability (EN 15210)
  - Andritz/ECN demo pellets typically 96.5-98.0%
- Minimum ignition energy
  - Torrefied pellets were pulverised using disc impaction mill to replicate commercial roller mill
  - Fraction below 63 µm used in accordance with EN 13821
  - Andritz/ECN demo 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)

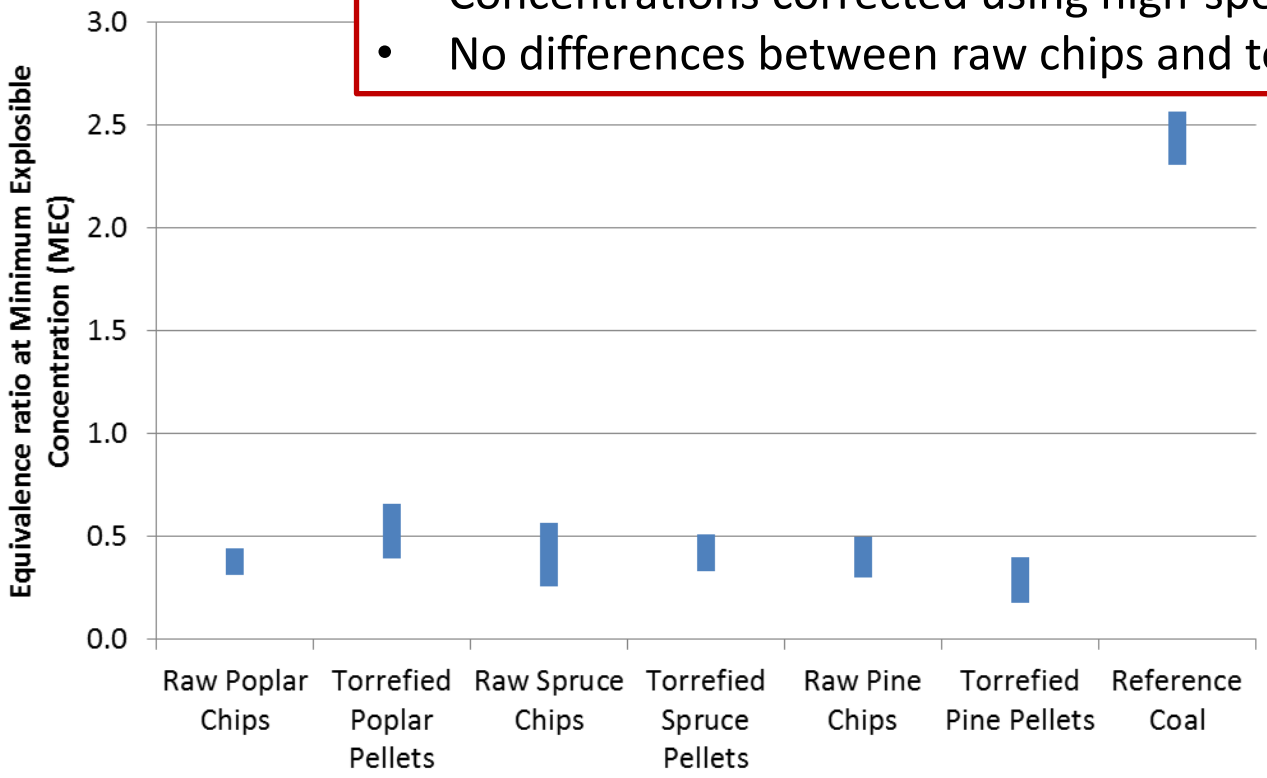


- Clear link MIE torrefied pellets with MIE raw material
- Native dust has high MIE's
- Dust from handling low durability pellets (< 93%) is more ignitable → always aim for high pellet durability
- Same high pellet durability: handling dust from torrefied wood pellets is equally ignitable as white wood pellets

Minimum Explosible Concentration (MEC)

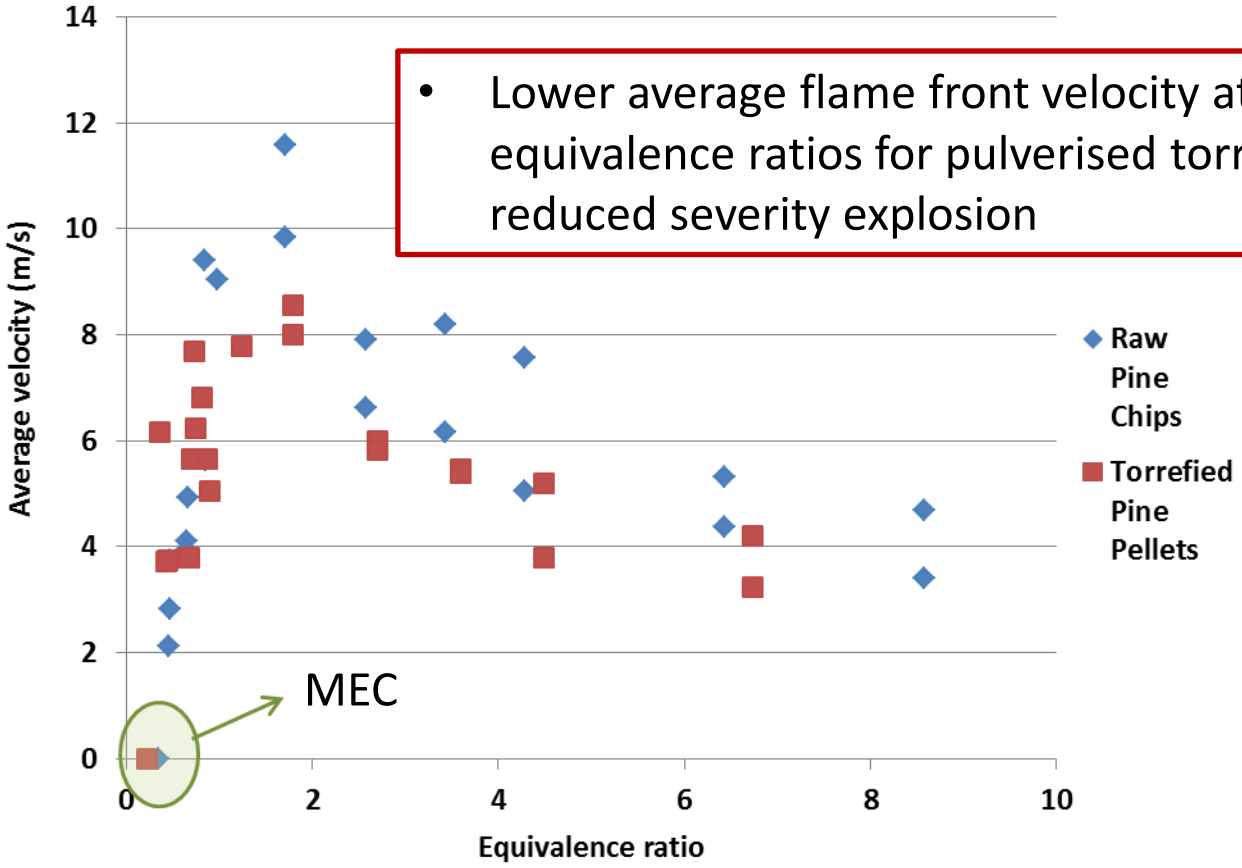
- Pulverised torrefied pellets vs. pulverised raw biomass chips

- Concentrations corrected using high-speed camera
- No differences between raw chips and torrefied pellets



Explosion Flame Front Velocities

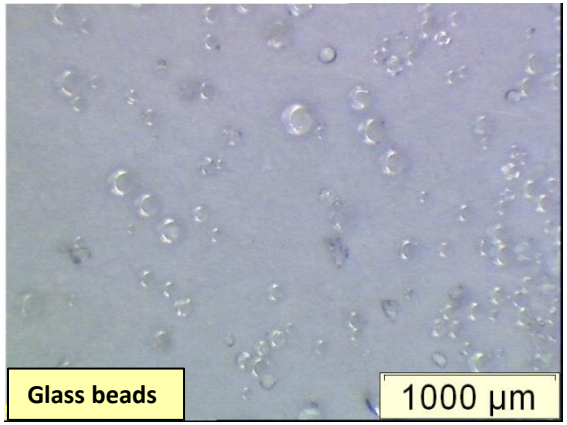
- Torrefied pellets vs. raw biomass chips



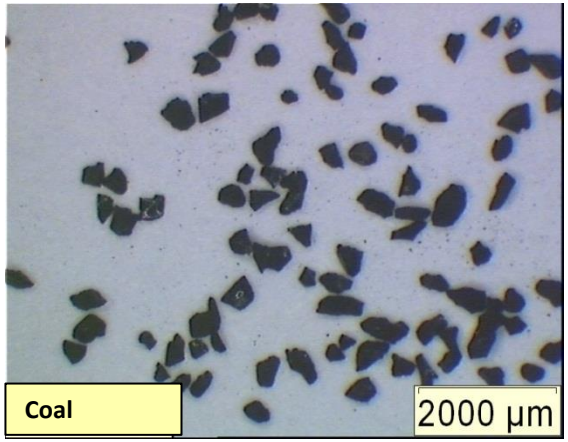
- Lower average flame front velocity at higher equivalence ratios for pulverised torrefied pellets → reduced severity explosion

Fuel morphology after milling (1)

- Glass beads:

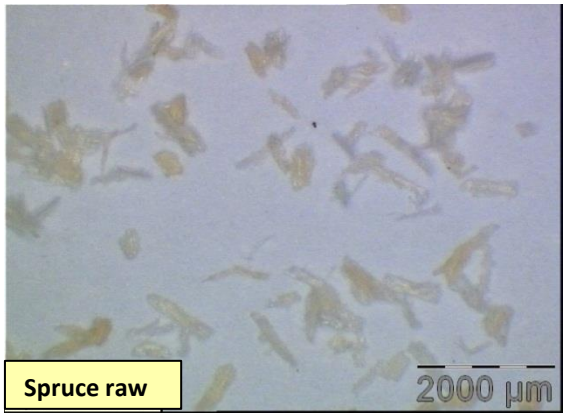


- Coal:

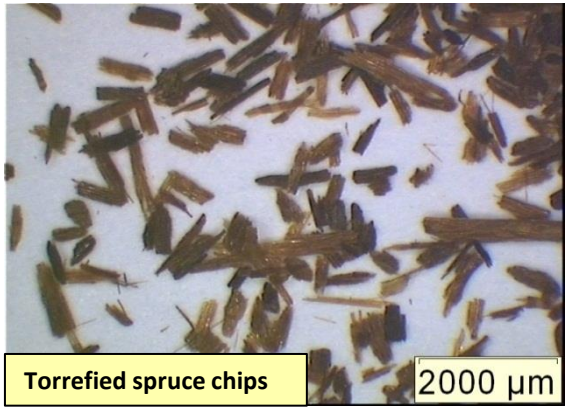


Fuel morphology after milling (2)

- Raw spruce:

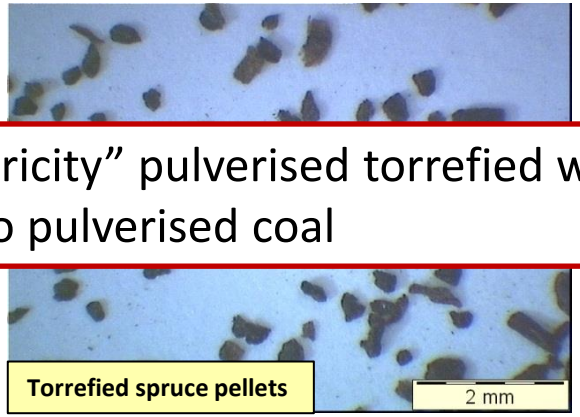


- Torrefied spruce chips:



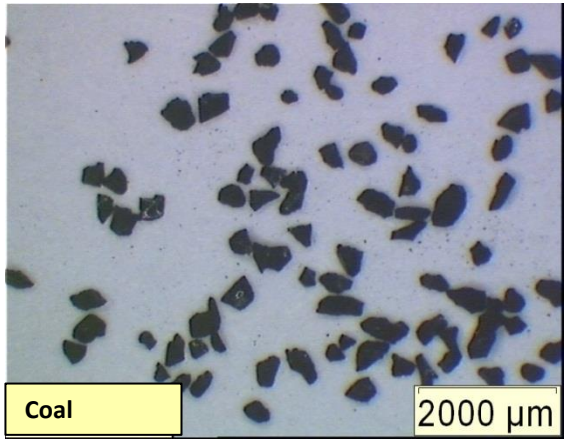
Fuel morphology after milling (3)

- Torrefied spruce pellets Andritz/ECN demo:



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

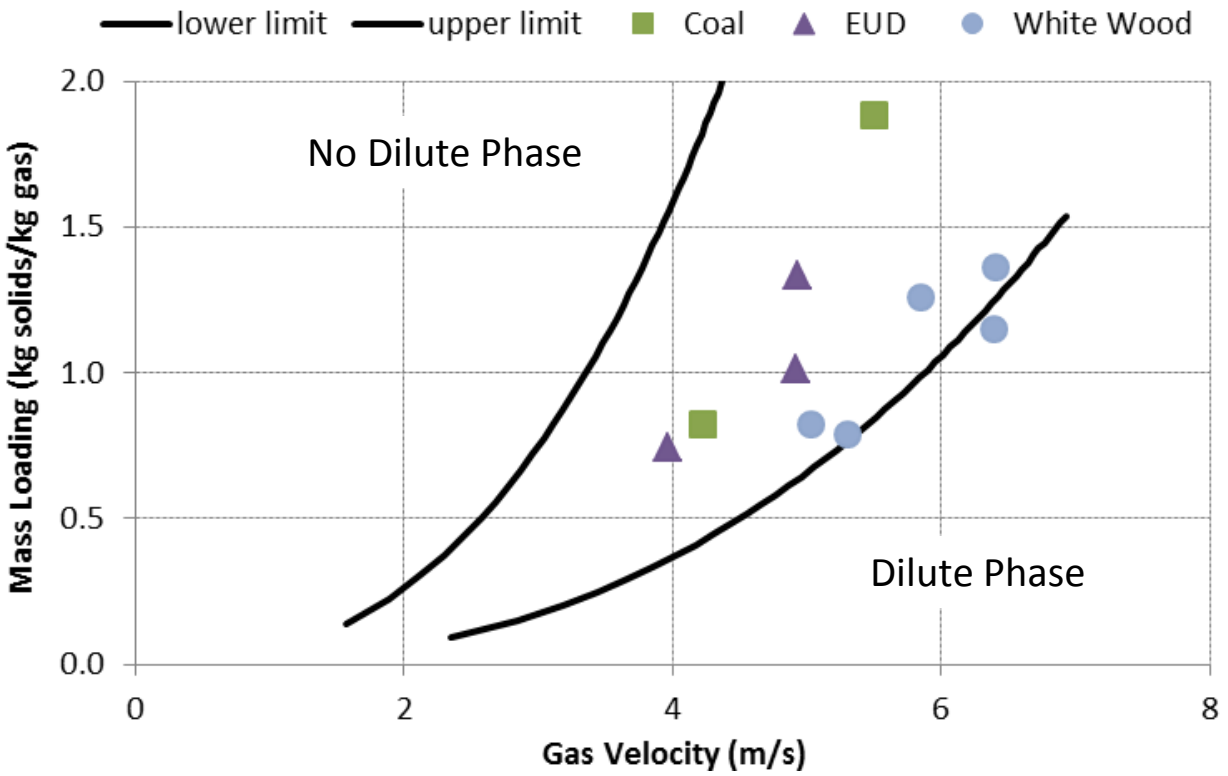
- Coal:



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
- Setup used to determine solids loading/entrainment during dense/lean phase feeding

Pneumatic lean-phase transport (2)



EUD: Torrefied eucalyptus pellets

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

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:
  - Low durability led to significant dust formation
  - Low durability disadvantageous during outdoor storage
  - Low Minimum Ignition Energy (MIE)

- 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 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

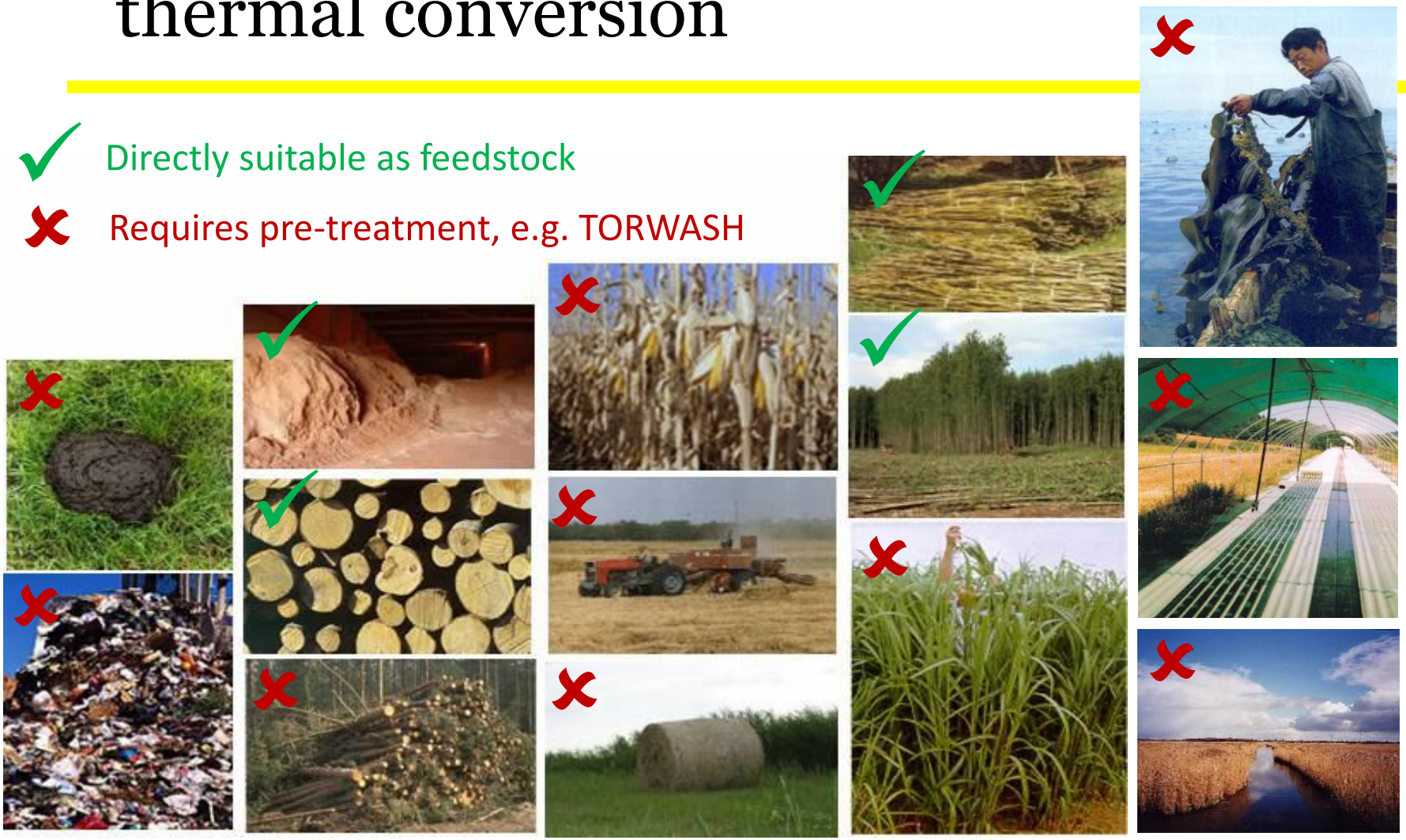
DONG Studstrup-3 experience

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
  - Salt removal
  - Dewatering

- 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)

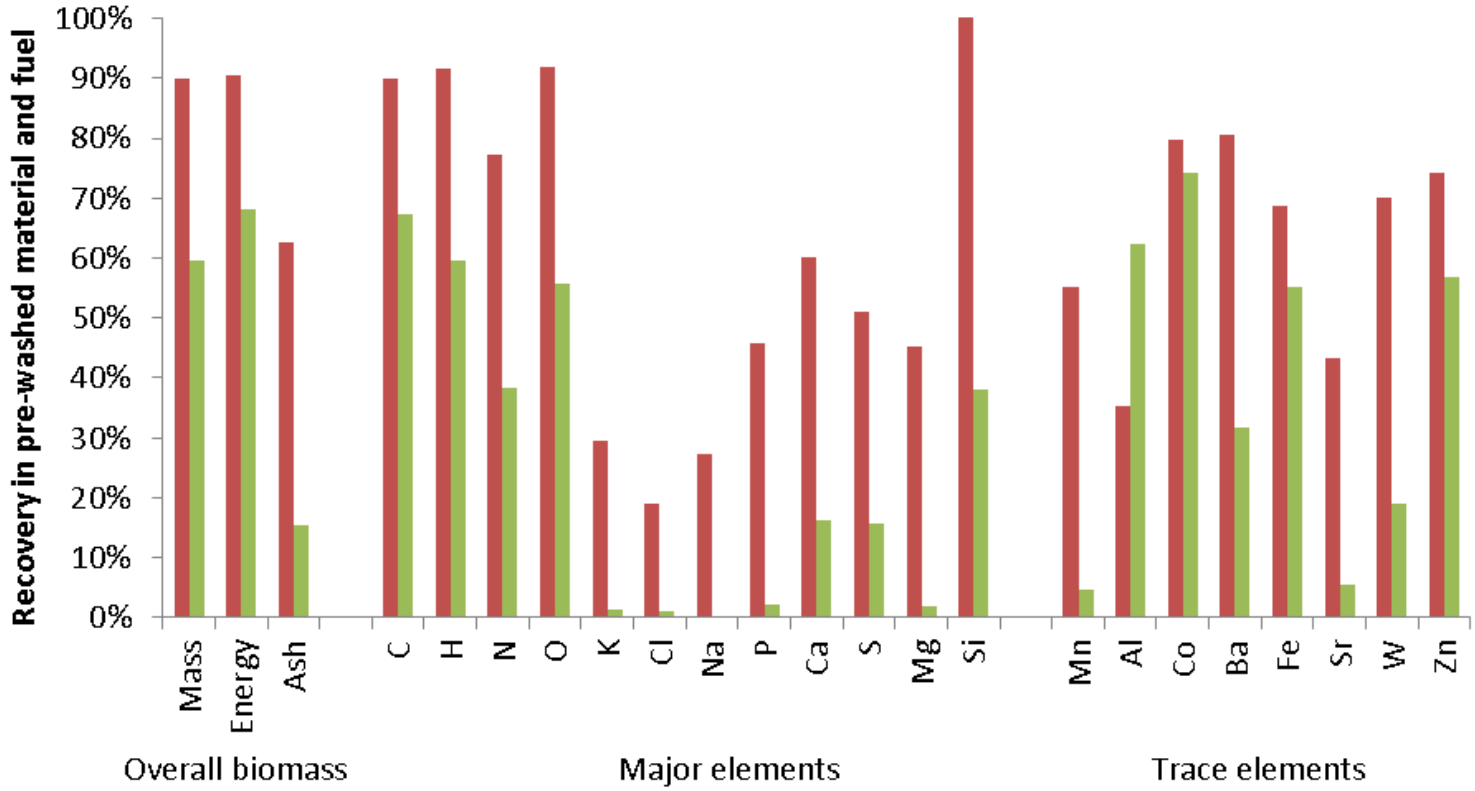
Arundo Donax/Giant Reed
Chopped

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

Thank you for your attention

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