Experience in biomass pre-treatment

BiOxySorb Final Workshop

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Stuttgart, Germany
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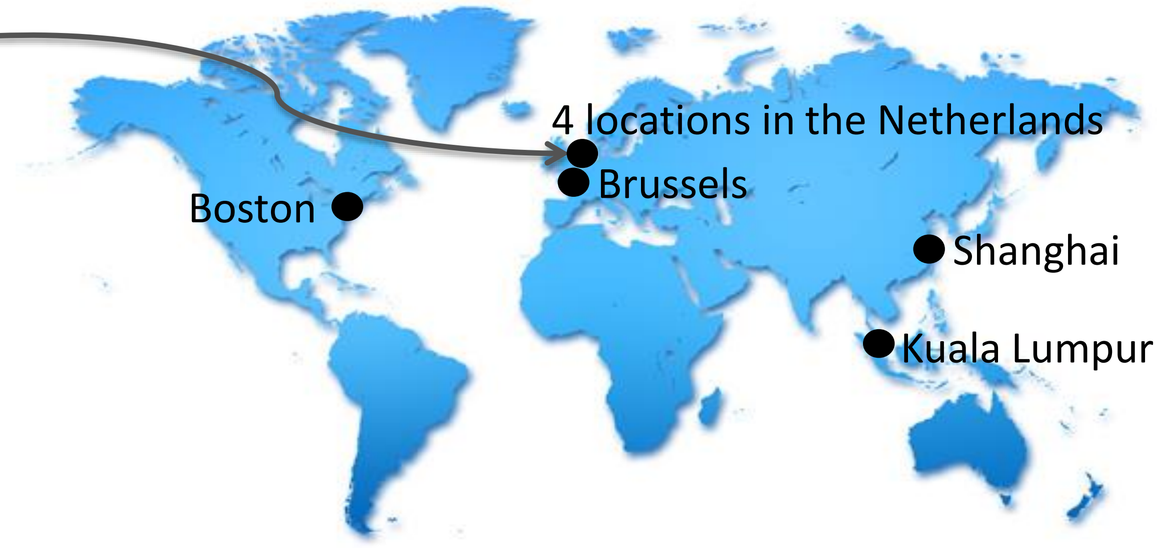
ECN at a glance

Mission:
To develop expertise and technology that enables the transition to sustainable energy management

Not-for-profit Research Institute
Founded in **1955**
5 Commercial licensing deals / year
500 Employees
+/-20 patents a year
€ 80 M annual turnover



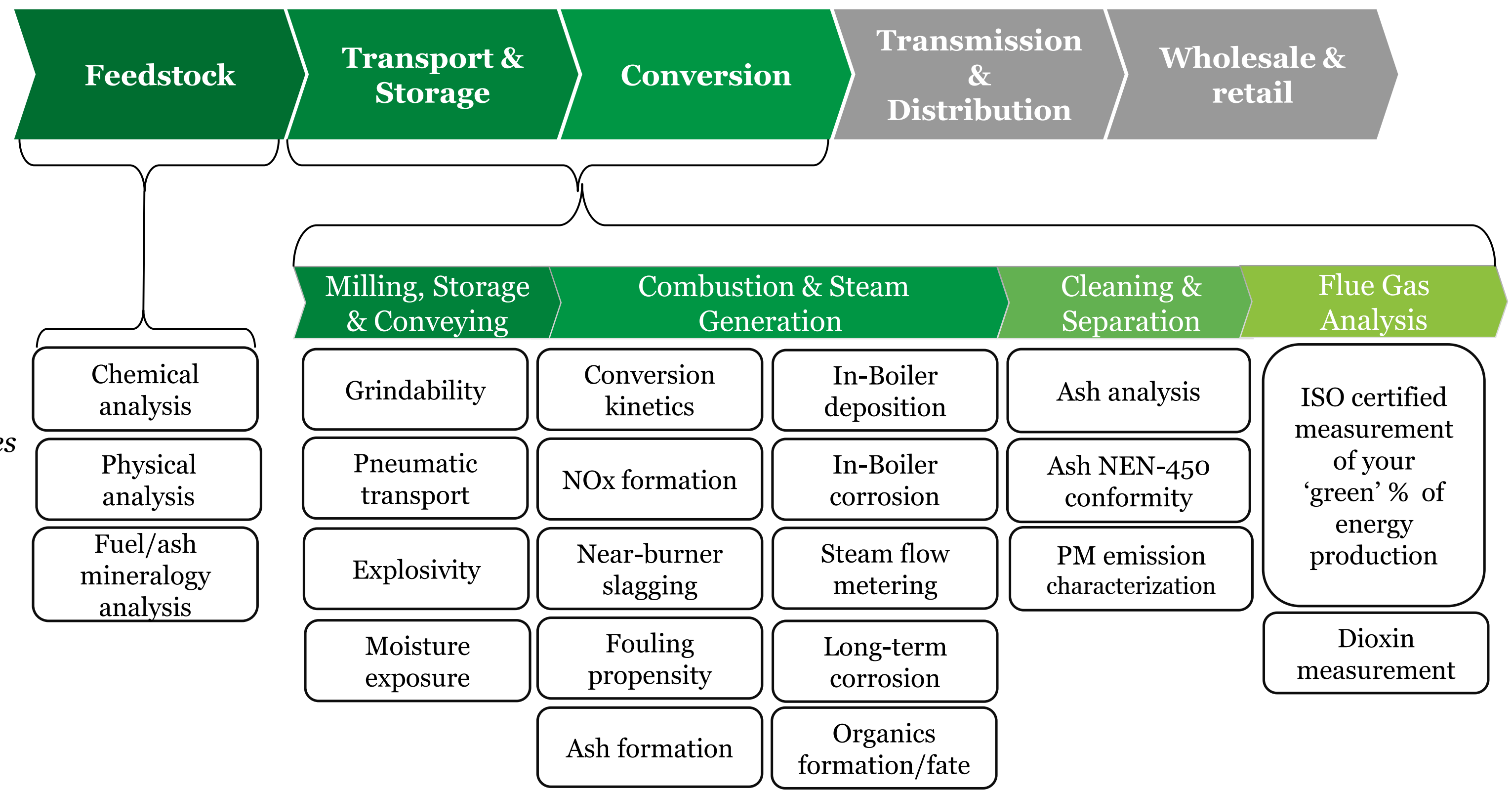
ECN in biomass (co-)firing and torrefaction

- 20+ years experience in biomass co-firing R&D, identified the potential of torrefaction and played a pioneering role in torrefaction development since 2002
- ECN's torrefaction technology proven on lab-, pilot- and demonstration scale;
  Andritz ready for market introduction
- ECN offers:
  - Complete portfolio of risk mitigating tools/solutions tailored and validated for various thermal conversion processes (logistics, handling, co-firing, gasification, grate furnaces, etc.)
  - Elaborate test infrastructure to assess feedstock suitability for torrefaction, TORWASH and densification

ECN 50 kg/h torrefaction pilot-plant

ECN (co-)firing services

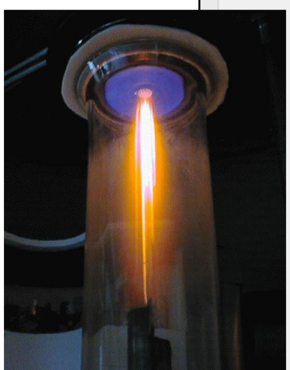
ECN scope of biomass tests and services

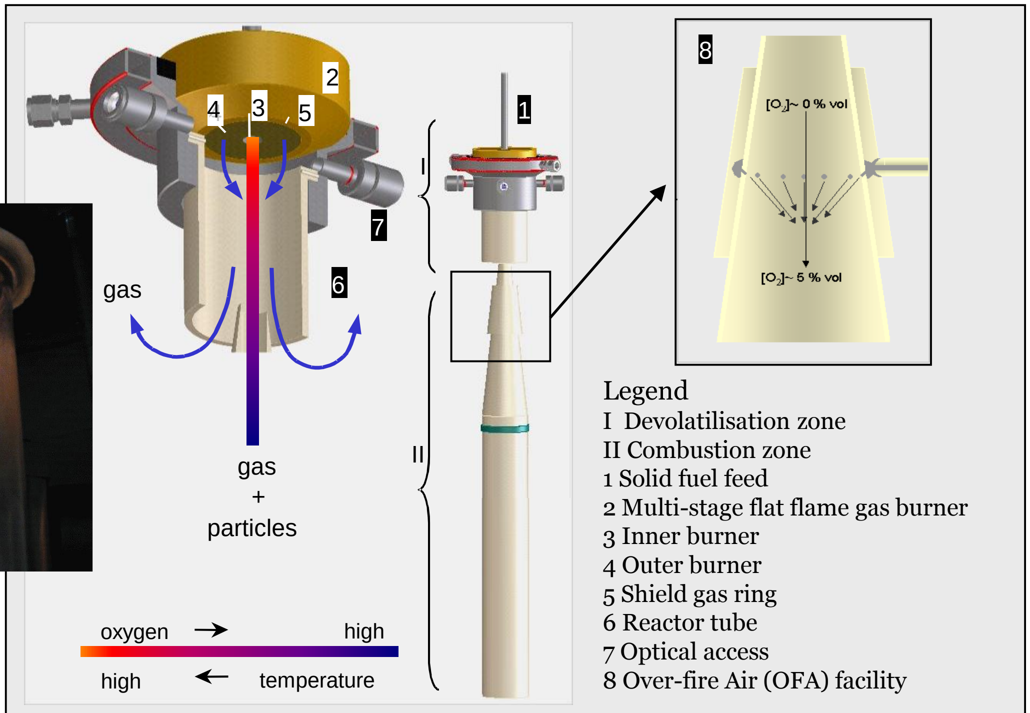


ECN's LCS provides a complex analysis of fuel behaviour during combustion

ECN

Lab Combustion Simulator (LCS)





Features:

- Advanced simulation capabilities
- High particle heating rates
- High flame/particle temperature
- Realistic gas temperature / environment history
- Controllable, long particle residence time

Benefits:

- Feedstock optimization
- Sustainable plant management optimization
- Energy output optimization
- Corrosion reduction
- Ash/gypsum revenue management
- Industry regulation management

Torrefaction

Biomass – a difficult energy source

- In view of:
  - Logistics (handling, transport and feeding)
  - End-use (combustion, gasification, chemical processing)

- Difficult properties are:
  - Low energy density (LHV_{ar} = 10-17 MJ/kg)
  - Hydrophilic
  - Vulnerable to biodegradation
  - Tenacious and fibrous (grinding difficult)
  - Poor "flowability"
  - Heterogeneous

Bioenergy – major challenge

- Enable decoupling of biomass production and use
  - Place
  - Time
  - Scale

- By converting biomass in high-quality bioenergy carriers (solid, liquid or gas), that:
  - Better fit in (existing) logistic infrastructures
  - Allow efficient, reliable and cost effective conversion into electricity and heat, transport fuels and chemicals

Solve biomass related problems at the source

Torrefaction – What is it?

- Pre-drying to moisture content typically below 15%
- Thermal treatment decomposes hemi-cellulose content at 250-300 ˚C
- Either in absence of oxygen or at very limited concentrations
- Volatile components are partially driven off and are 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

Added value of torrefied biomass pellets

- Torrefaction 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 and waste

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	0.70-0.75	0.18 – 0.24	0.80 – 0.85
Vol. energy dens. (GJ/m^3)	1.4 – 3.6	8 – 11	13 – 19	13-15	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
ND = Not Determined
sources: ECN (table, fig.1, 3), Pixelio (fig. 2, 6), Valmet (fig. 4), OFI (fig. 5), ISO/TC 238 WG2 (table)

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
- SECTOR project: 1.59 €/GJ benefit torrefied pellets at 30% co-firing
- Slightly higher production costs for black pellets pay off during logistic chain as well as end use

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 > 750,000 tpy, 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

Alternative outlets for torrefied pellets

Besides large-scale power generation, alternative end use could be in:

- Small- and medium-scale combustion
- Small-scale CFB gasification
- Entrained flow gasification for syngas production (fuel or chemical synthesis)
- But also in other industries such as iron & steel, cement, etc.

- These routes could offer more distinct economic and technological advantages for the use of black pellets compared to white wood pellets

Experience with torrefied pellets at large-scale

RWE/Essent AMER-9 experience*

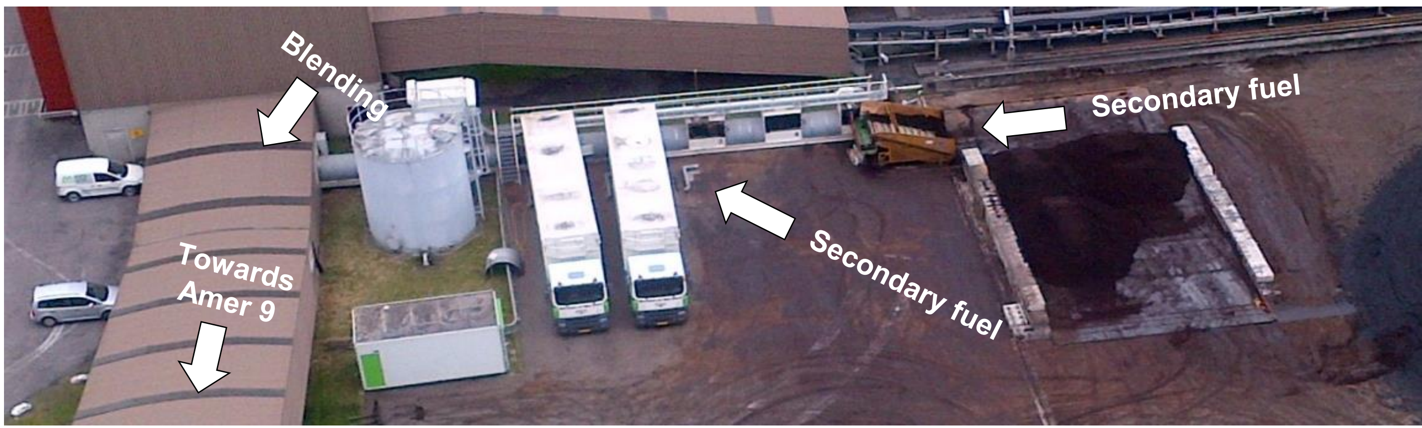
- Consortium of Topell, Essent, NUON, GdF Suez and ECN as part of Dutch TKI Pre-treatment Project
- Maximum 25 wt% co-milling on weight basis; 5 wt% co-firing
- 2300 tons of Topell torrefied pellets during November & December ‘13
- Observations:
  - No significant issues

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

* Source: Carbo & Bouwmeester, INVENT/Pre-treatment Eindrapport, juli 2016

RWE/Essent AMER-9 experience

- During the test at RWE/Essent AMER-9 power plant, the torrefied wood pellets were blended with coal via a dedicated biomass blending facility:



- Topell torrefied wood pellets unloaded through tipping and “potato” trucks
- Pellets were occasionally stored outside for a couple of days
- The mixture of coal and torrefied wood pellets was co-fired from October 22nd to December 30th 2013

RWE/Essent AMER-9 experience

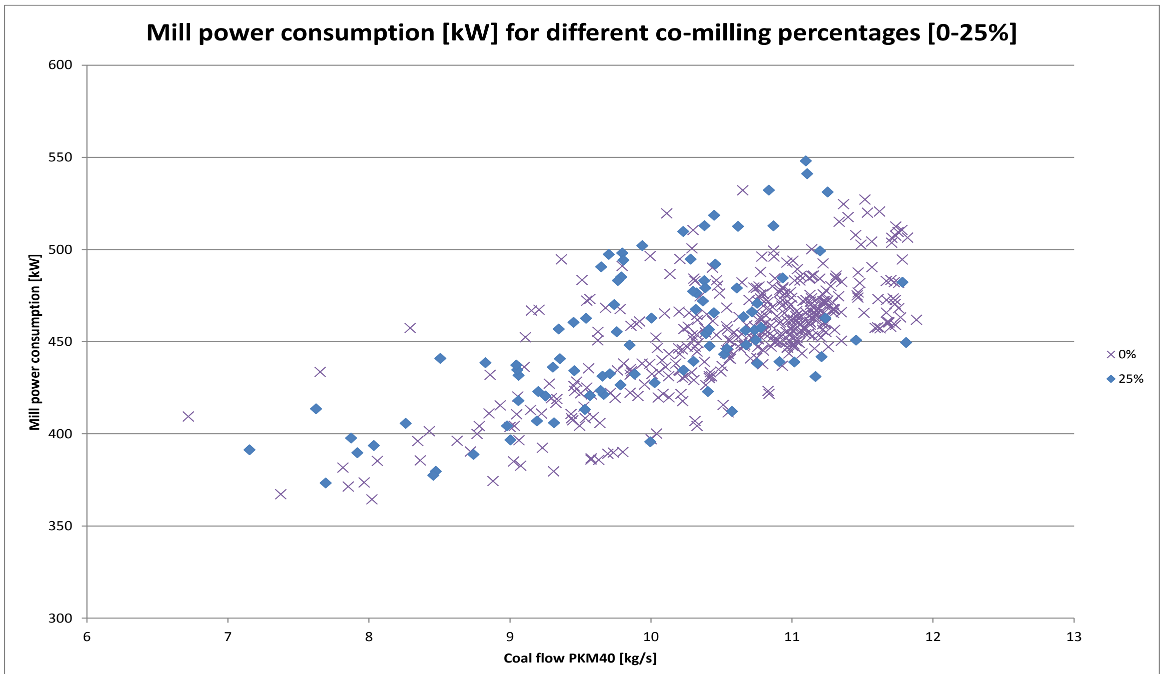
- During the test, the torrefied wood pellets have been processed at several co-milling percentages together with coal

Test	Topell pellets on mill 40	Topell pellets in furnace	Coal	White wood pellets	Wood gas (gasifier)	Bentonite	Coal HGI	Coal volatiles	Coal moisture
base	0%	0%	76%	18 %	5 %	1%	49-52	31-33%	8-12%
A	4-6%	1%	75%	18 %	5 %	1%	43-49	32-36%	8-14%
B	9-11%	2%	74%	18 %	5 %	1%	43-52	31-36%	8-13%
C	23-25%	4%	72%	18 %	5 %	1%	52	31%	8%

- Topell pellets contained 68-70 % volatiles and 7.5-9.0 % moisture
- An risk assessment demonstrated no additional risks and measurements for co-milling percentages

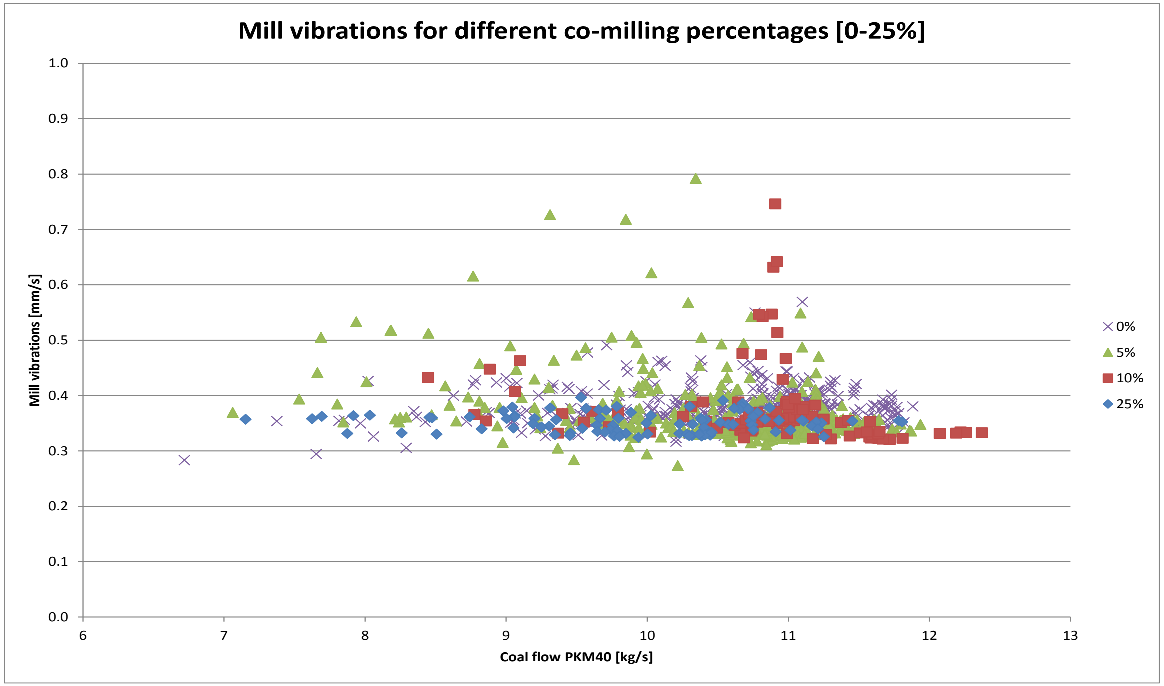
RWE/Essent AMER-9 experience

- During all co-milling tests, the milling process proved to be stable
- At increasing co-milling percentage, no significant effect on power consumption could be found (effect of coal in blend is dominant):



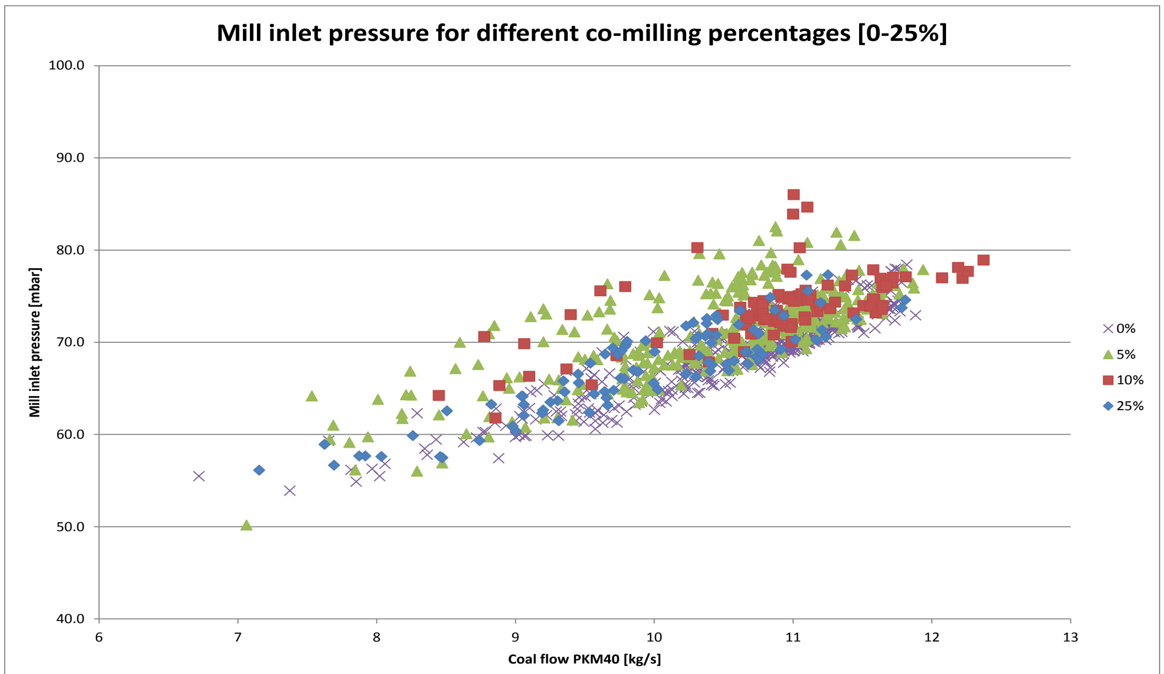
RWE/Essent AMER-9 experience

- Increasing the amount of torrefied wood pellets did not have a significant effect on mill vibrations:



RWE/Essent AMER-9 experience

- Increasing the amount of torrefied wood pellets did not significantly increase the mill pressure drop:



RWE/Essent AMER-9 experience

- During the tests no flame stability issues have been detected
- At 25% co-milling (4% overall co-firing), the average amount of carbon in fly-ash is slightly higher than during tests at a lower percentage:

Test	Min	Max	Average
0%	1.5%	3.0%	2.3%
5%	1.0%	6.2%	1.9%
10%	0.9%	2.7%	1.7%
25%	2.5%	3.1%	2.8%

- Difficult to draw conclusions on combustion effects, but these are probably limited

Future developments

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 likely directed to alternative feedstocks:
  - Agricultural residues (e.g., straw, bagasse, palm oil residues)
  - Paper-plastic fractions and other “waste” streams

Biomass feedstocks for TORWASH

- Difficult materials:
  - High moisture content
  - Seasonal variations and bio-degradable
  - High salt content
  - Bulky material with low energy density
  - Fibrous and resilient
- Essentially the growing parts of plants
- Some attractive but difficult feedstocks
  - Grass, reeds, park maintenance
  - OPF, EFB, sugar cane leaves
  - Wet residues from food and agro industry, e.g. brewer's grains and digestate
  - Manure and sludges

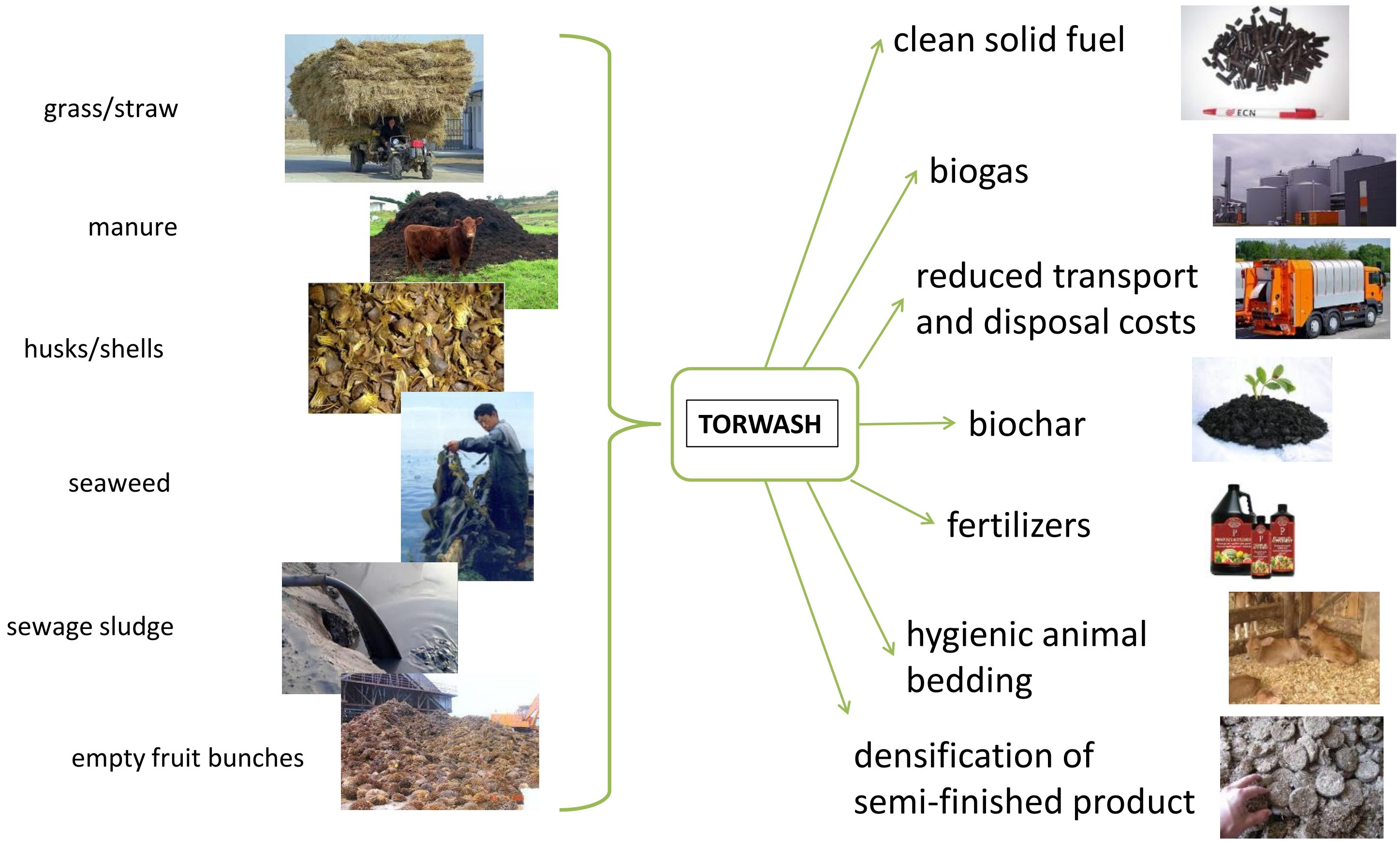
Combination of Washing and Torrefaction

- Torrefaction + Washing = TORWASH
  - Upgrades low-grade feedstock into a commodity fuel
- Combines advantages and eliminates disadvantages
  - Torrefaction & Salt removal & Dewatering

Arundo Donax/Giant Reed Chopped	Arundo Donax/Giant Reed Chopped and TORWASHed	Arundo Donax/Giant Reed Chopped, TORWASHed and pelletised

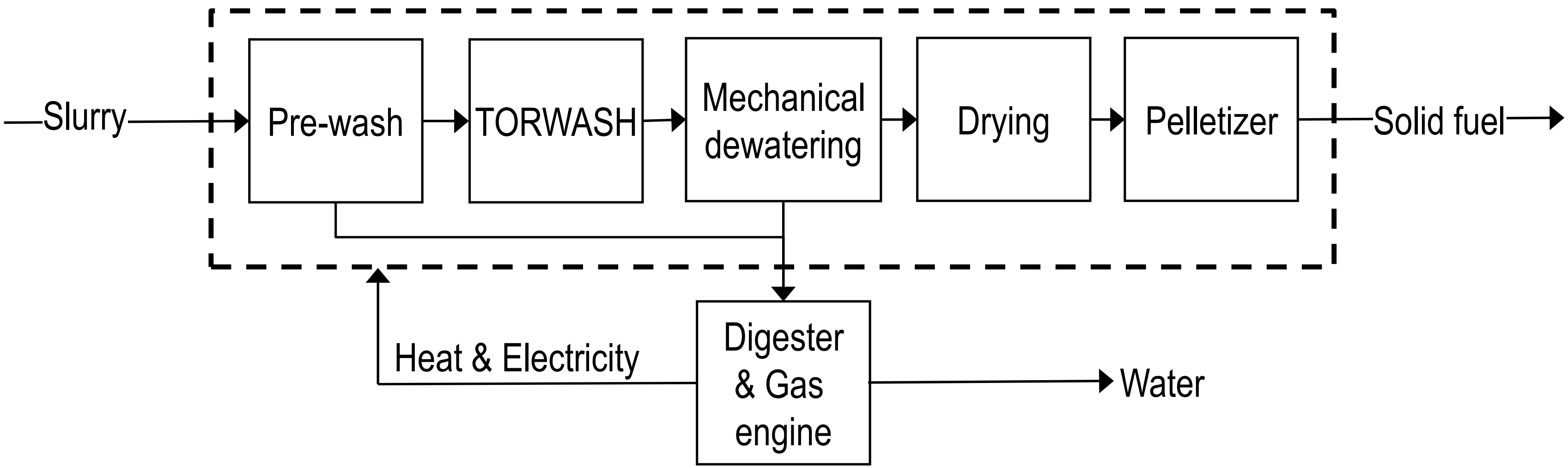
- Aim: maximum energy content and low mineral content in solid phase
- Product: high value fuel as powder, pellets or briquettes
- By-product: biogas from digestion of liquid residue

TORWASH:
A multi-purpose process for green solutions



TORWASH Process Flow Scheme

- A simple block scheme of TORWASH implemented for agricultural residues (digestate, sewage sludge, manure may not need pre-wash step)



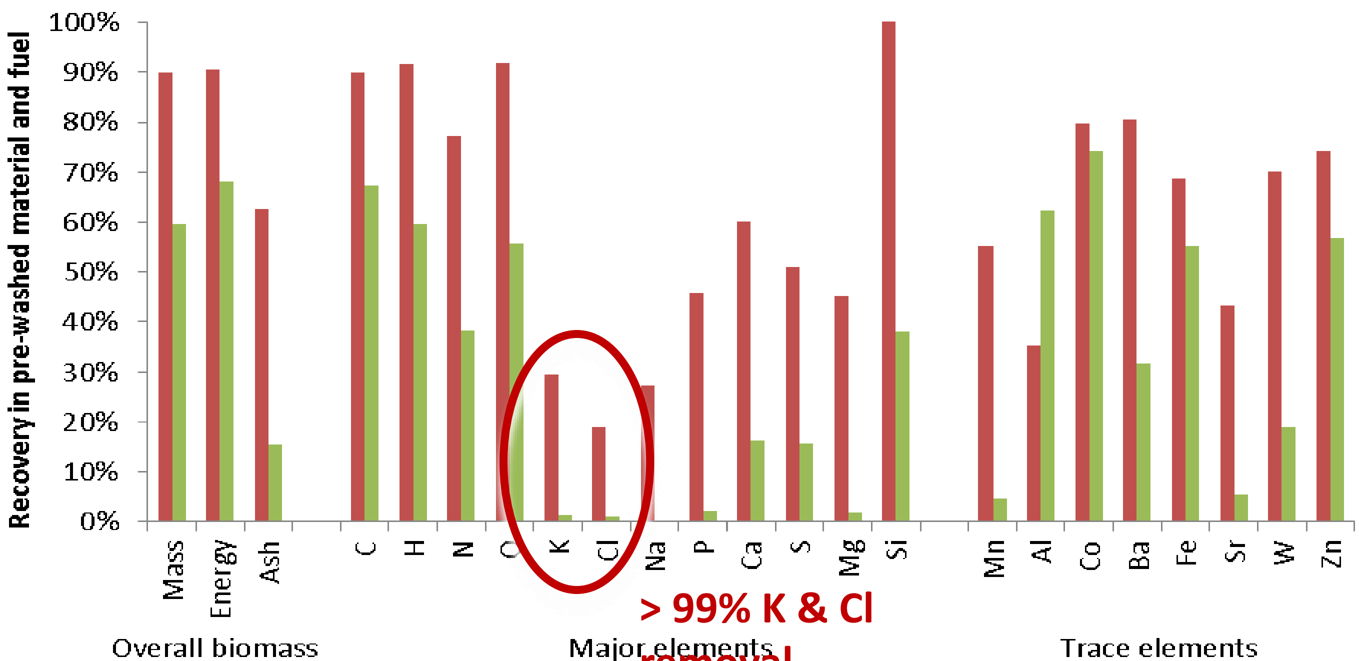
- TORWASH under pressure in liquid water 150-250°C
- Thermal drying up to 85% dry matter needed prior to pelleting
- Pelletizer optional (case specific)

Why is TORWASH unique?

- Enables efficient *mechanical* dewatering
- Opens biomass structure and enables complete removal of salts
- Mild process conditions allow digestion of the effluent to biogas
- No use of additives:
  - no catalysts
  - no pH control
  - no flocculants
  - no enzymes
- ECN patent WO 2013/162355

TORWASH Example: Arundo Donax (1)

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



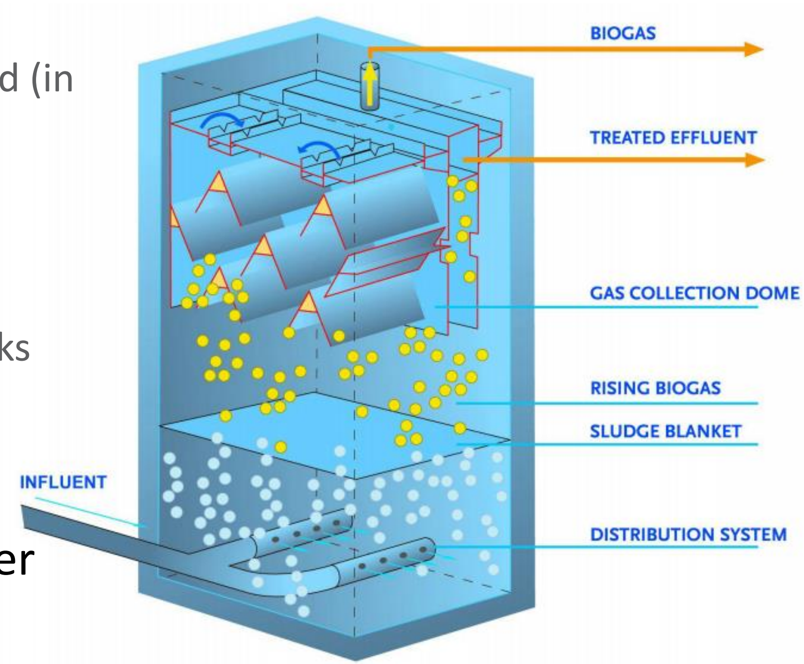
TORWASH Example: Arundo Donax (2)

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 chemically comply with white wood pellets standard
- Completion of pilot installation foreseen late 2016

UnAerobic Sludge Blanket Digester

- Biogas from digestion of *effluent*
  - More than 50% of organic dry matter dissolved (in case of non-disgested sewage sludge)
  - Digestion of dissolved organic matter is fast
- High-rate UASB
  - Efficient: residence time hours instead of weeks
  - Smaller volume, higher biogas yield
  - Cost effective (low CAPEX, OPEX)
- Optimization of biogas production is under investigation



BIOPAQ®UASB
source: Paques

TORWASH technology – current status

- TORWASH process concept proven on bench scale (batches 10-20 kg)
  - Grass, reeds, straw, water plants, digestate, bamboo, brewer's grains
  - Typically 60-70% mass yield, 65-75% energy yield
  - Wet and "salty" biomass can be transferred into high-quality energy pellets compliant to standards for white wood pellets
  - Mechanical dewatering reduces energy consumption for drying
  - Effluent allows anaerobic digestion (no expensive waste water treatment)
- Economically attractive feedstocks are wet and contain salts (K and Cl)
  - Best case for NW-Europe: road-side grass
  - Residues from plantations (Tropics), manure, sludge or food industry waste (Worldwide)

Empty Fruit Bunches

TORWASH technology – the way forward

- Scale-up for ***grasses*** (NW-Europe)
  - Mobile pilot-installation 10-30 kg/hr input dry matter ready late 2016
  - Subsequent demonstration at 10-30 kton/yr
- Scale-up and demonstration for ***empty fruit bunches*** (oil palm plantation in Malaysia, 2 ton/h) in 2017-2018
- Additional feedstocks under investigation:
  - Second generation TORWASH for ***digestate***
  - ***Sludges*** from food industry and sewage treatment (without pre-wash)
  - Manure
- Ongoing R&D co-production of energy carriers and higher added-value products (e.g. nutrient recovery)

Thank you for your attention

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