ECN

Energy research Centre of the Netherlands

Overview of thermal pre-treatment processes for large-scale biomass application

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Presentation overview

- Thermal pre-treatment / upgrading options
- Pyrolysis (bio-oil)
- Torrefaction (biocoal)
- Gasification (bioSNG)
- Conclusions

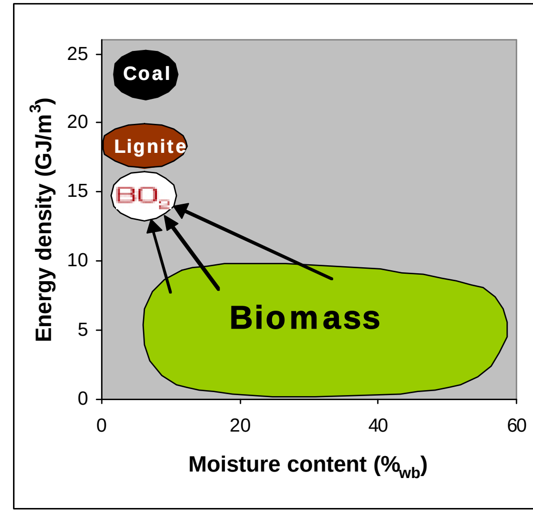
Biomass – a difficult energy source ….

- … 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

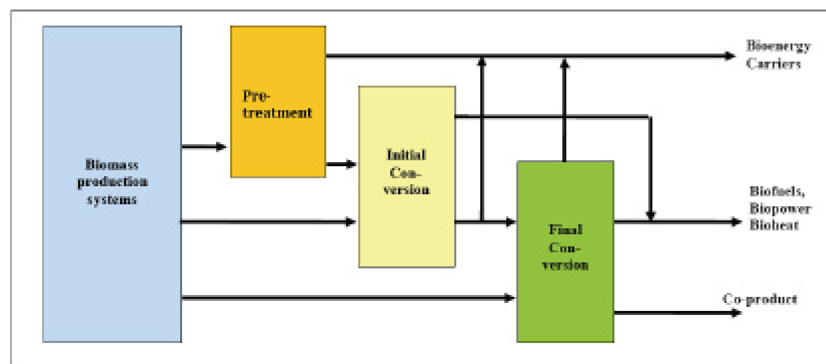
Biomass pre-treatment into bioenergy carriers

- Convert biomass into high-energy density biomass fuels (bioenergy carriers) with favourable logistic and end-use properties
- Deal with the difficult biomass properties at the source
- Allow de-coupling availability and end-use in scale, time and place
- Relate to existing logistic infrastructures (coal, oil, gas)
- Allow conventional trading schemes – commodity fuels



BO_2 = ECN torrefied pellets

Bioenergy carriers play a key role in the bioenergy value chain approach of the EU SET-plan instruments EERA and EIBI



Biomass pre-treatment options (1)

- Dry biomass (< 50% moisture)
  - Densification (pellets/briquettes)
  - Torrefaction + densification (biocoal pellets/briquettes)
  - Carbonisation (charcoal)
  - Pyrolysis (bio-oil)
  - Gasification (bioSNG)

Typical product distribution for wood (dry wood basis). Source: www.pyne.co.uk

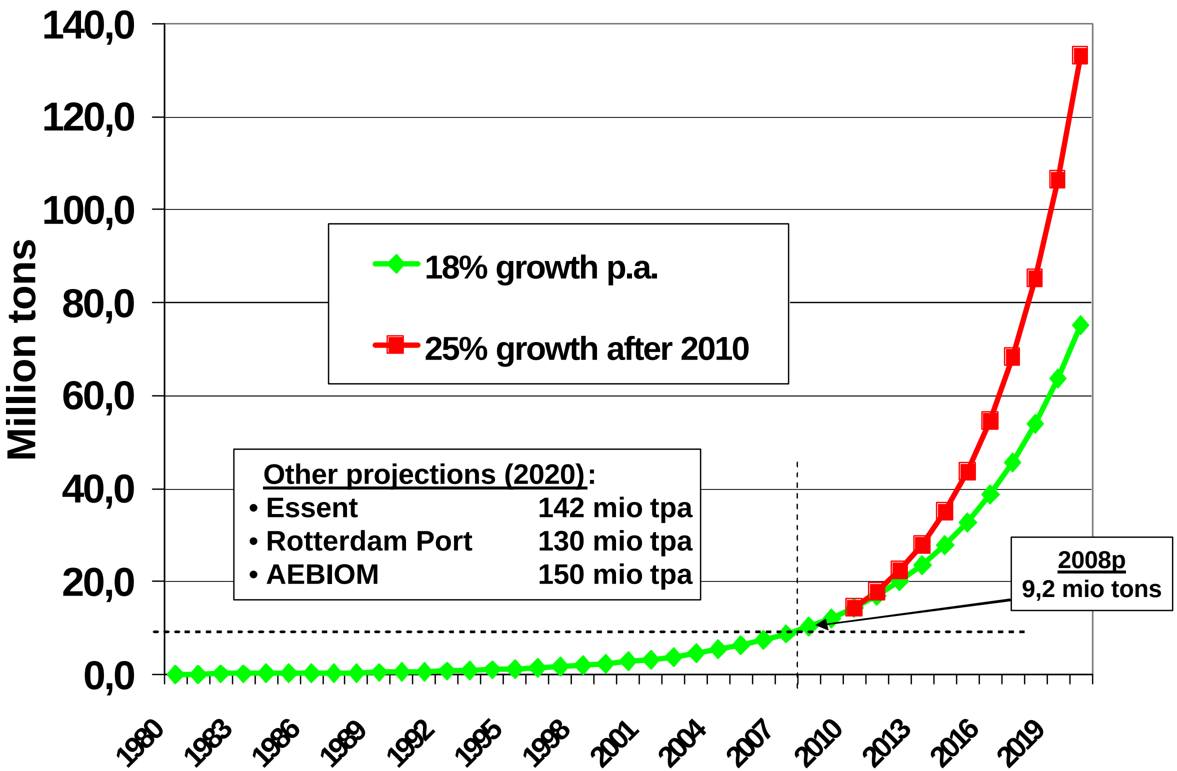
Mode	Conditions Wt %	Liquid	Char	Gas
Fast	~ 500°C, short hot vapour residence time ~ 1 s	75%	12%	13%
Intermediate	~ 500°C, hot vapour residence time ~ 10-30 s	50%	25%	25%
Slow - Torrefaction	~ 290°C, solids residence time ~30 mins	-	82% solid	18%
Slow - Carbonisation	~ 400°C, long vapour residence time hrs → days	30%	35%	35%
Gasification	~ 800°C	5%	10%	85%

Biomass pre-treatment options (2)

- Wet biomass (> 50% moisture)
  - – Digestion
  - – Hydrothermal processing
    - – TORWASH (biocoal)
    - – Hydrothermal Carbonisation (charcoal-like product)
    - – HydroThermal Upgrading – HTU (bio-oil)
    - – Hydrothermal Gasification (bioSNG)

Bioenergy carriers – increasingly popular ….

- Scenarios for European pellets consumption



Source: ProPellets analysis 2008 + presentations by Essent, Rotterdam Port & AEBIOM

Bioenergy carriers – … but what is the preferred option?

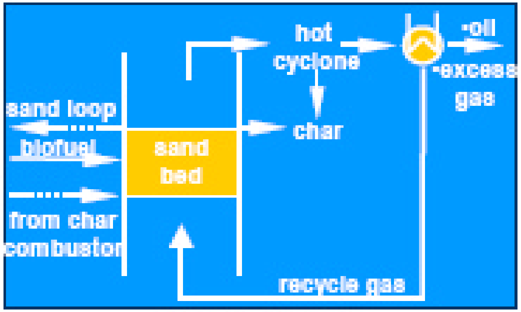
- Often no direct competition, different bioenergy carriers may serve different markets
- If direct competition, then supply chain studies show that overall supply chain efficiency is an important cost factor (given high biomass feedstock price)
- Most technologies still in development stage – substantial uncertainties

Pyrolysis

- Emphasis on fast pyrolysis – maximum liquids production (bio-oil)
- Options:
  - Renewable fuel for boilers, engines and gasifiers
  - Feedstock for the secondary conversion into transport fuels or chemicals
  - Upgrading of lignin fractions in biorefinery concepts

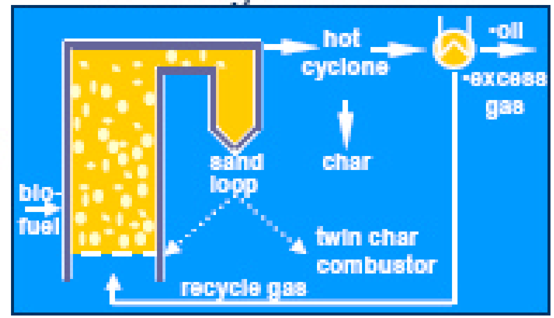
Fast pyrolysis – different reactor concepts considered

fixed bed

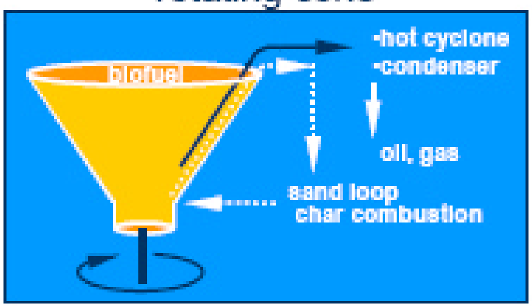


pneumatically fluidized

circulating fluidized bed

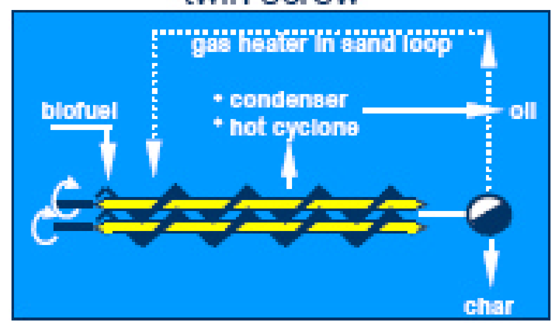


rotating cone

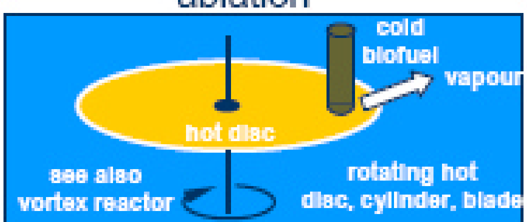


mecanically fluidized

twin screw



ablation



direct contact heating

vacuum

Source: D. Meier, 2004

Pyrolysis – development in demonstration stage

Dynamotive
100 t/d fluid bed
fast pyrolysis
plant, Canada

PyTec
50 t/d ablative
pyrolysis plant,
Germany

BTG
50 t/d rotatin
cone fast
pyrolysis pla
Malaysia

Source: IEA Task 34 brochure, 2007

Crude bio-oil – as bioenergy carrier still some drawback

Typical properties and characteristics of wood derived crude bio-oil

Physical property		**Typical value**
Moisture content		20-30%
pH		2.5
Specific gravity		1.20
Elemental analysis	C	55-58%
	H	5.5-7.0%
	O	35-40%
	N	0-0.2%
	Ash	0-0.2%
HHV as produced		16-19 MJ/kg
Viscosity (40 °C and 25% water)		40-100 cp
Solids (char)		0.1-0.5%
Vacuum distillation residue		up to 50%

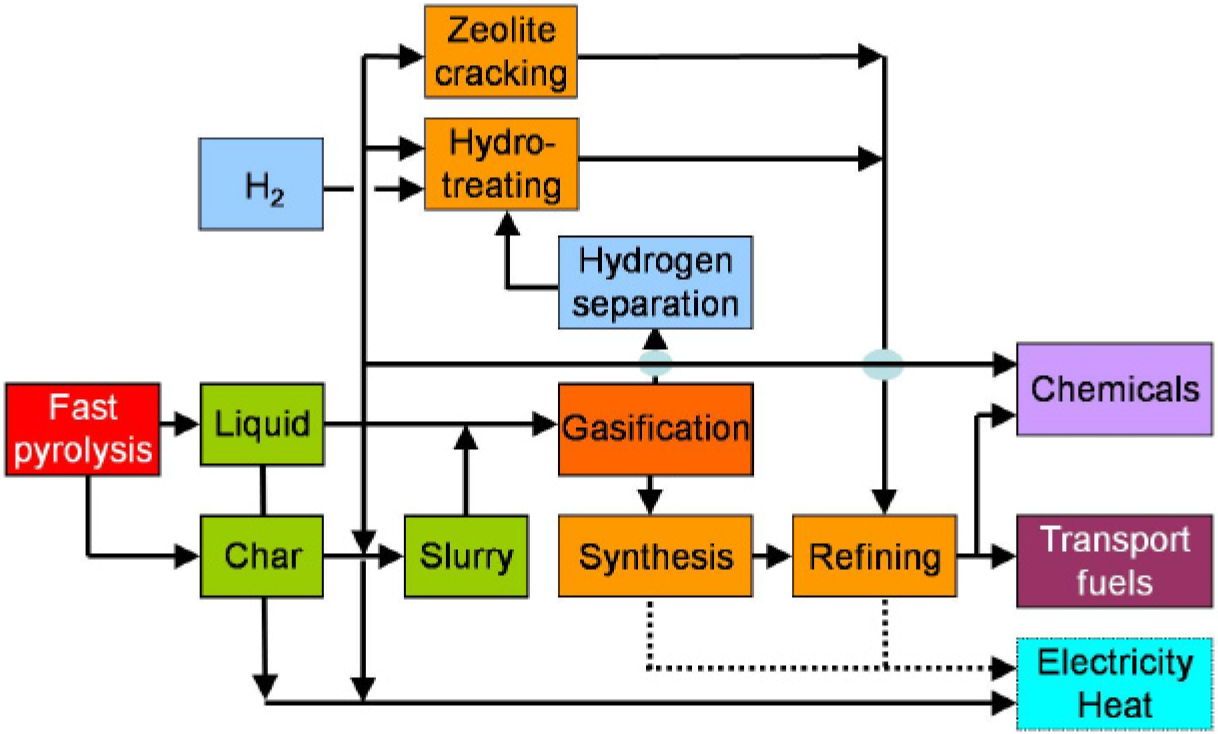
Characteristics

Liquid fuel
Ready substitution for conventional fuels in many stationery application
Heating value of 17 MJ/kg at 25% wt. water, is about 40% that of fuel oil/diesel
Does not mix with hydrocarbon fuels
Not as stable as fossil fuels
Quality needs definition for each application

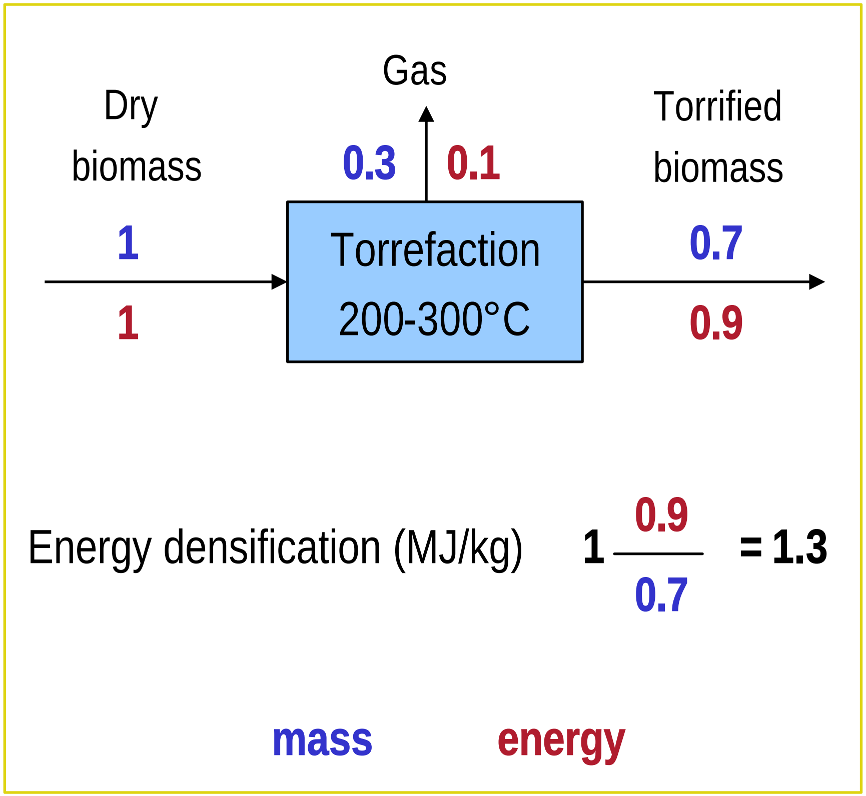
Source: www.pyne.co.uk

Bio-oil upgrading

- Co-refining in standard refineries (“drop-in fuels”)
- Joint effort in EU FP6-project BioCoup



Torrefaction for upgrading biomass



Process parameters

– Temperature: 200-300°C

– Residence time: 10-30 minutes

– Particle size: < 4 cm

– Absence of oxygen

– Pressure: near atmospheric

Why torrefaction: from biomass/waste to commodity fuel

Woody biomass

Agricultural residues

Friable and less fibrous
19 - 22 MJ/kg (LHV, ar)
Hydrophobic
Preserved
Homogeneous

Superior fuel properties:

- Transport, handling, storage
- Milling, feeding
- Gasification, combustion
- Broad feedstock range
- Commodity fuel

Mixed waste

Torrefaction and pulverisation

Fuel powder

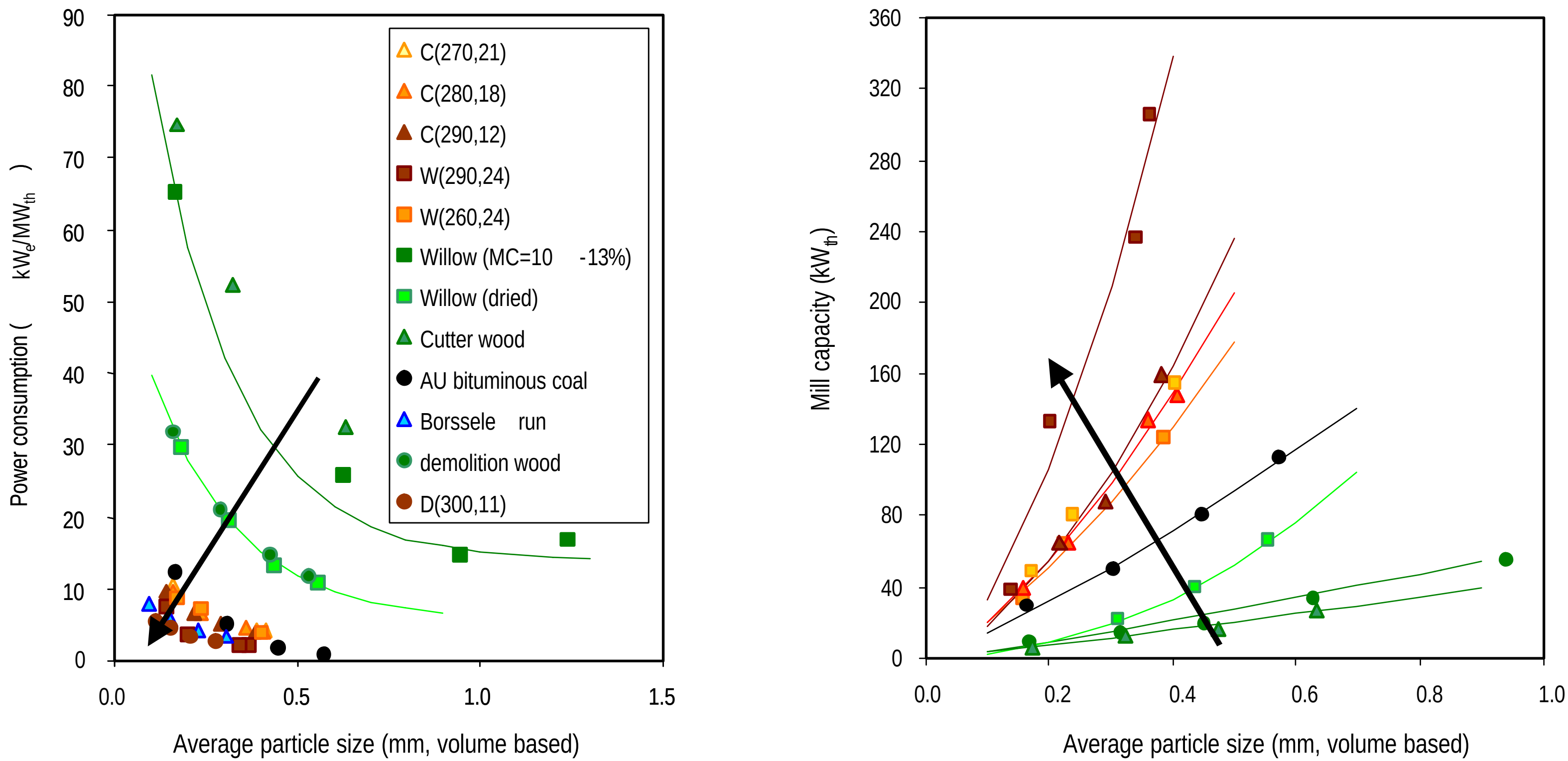
Tenacious and fibrous
10 - 17 MJ/kg (LHV, ar)
Hydrophilic
Vulnerable to biodegradation
Heterogeneous

Pelletisation

Bulk density 650-750 kg/m^3
Bulk energy density 13-17 GJ/m^3

Fuel pellets

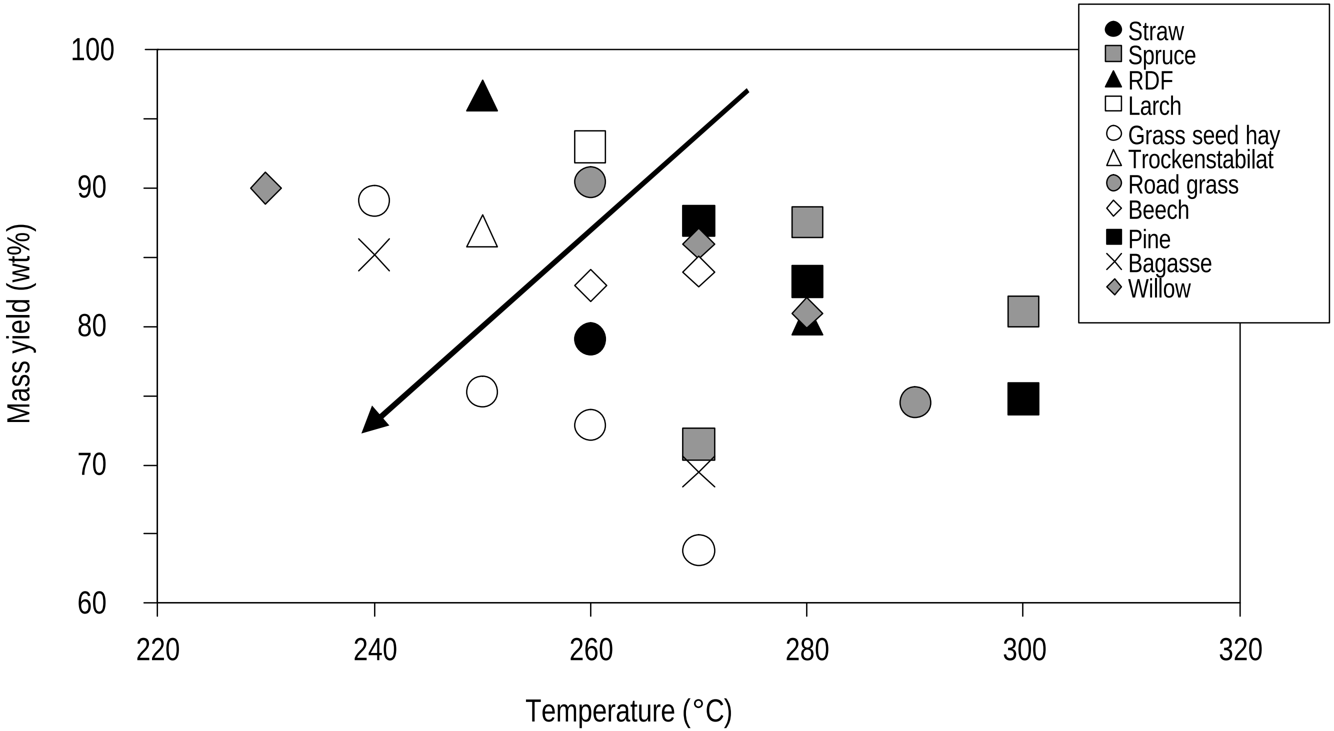
Grindability of (torrefied) woody biomass



Torrefaction leads to a dramatic decrease in required milling power and increase in milling capacity

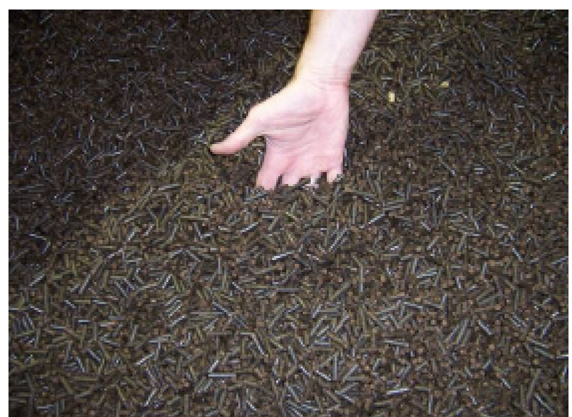
Torrefaction of agro residues and mixed wastes

- Agro residues: torrefaction behaviour comparable to woody biomass, determining factor is hemicellulose content
- Good prospects for mixed wastes as well (e.g., RDF, SRF): plastic fractions may become brittle and easily grindable



ECN pelletisation testing

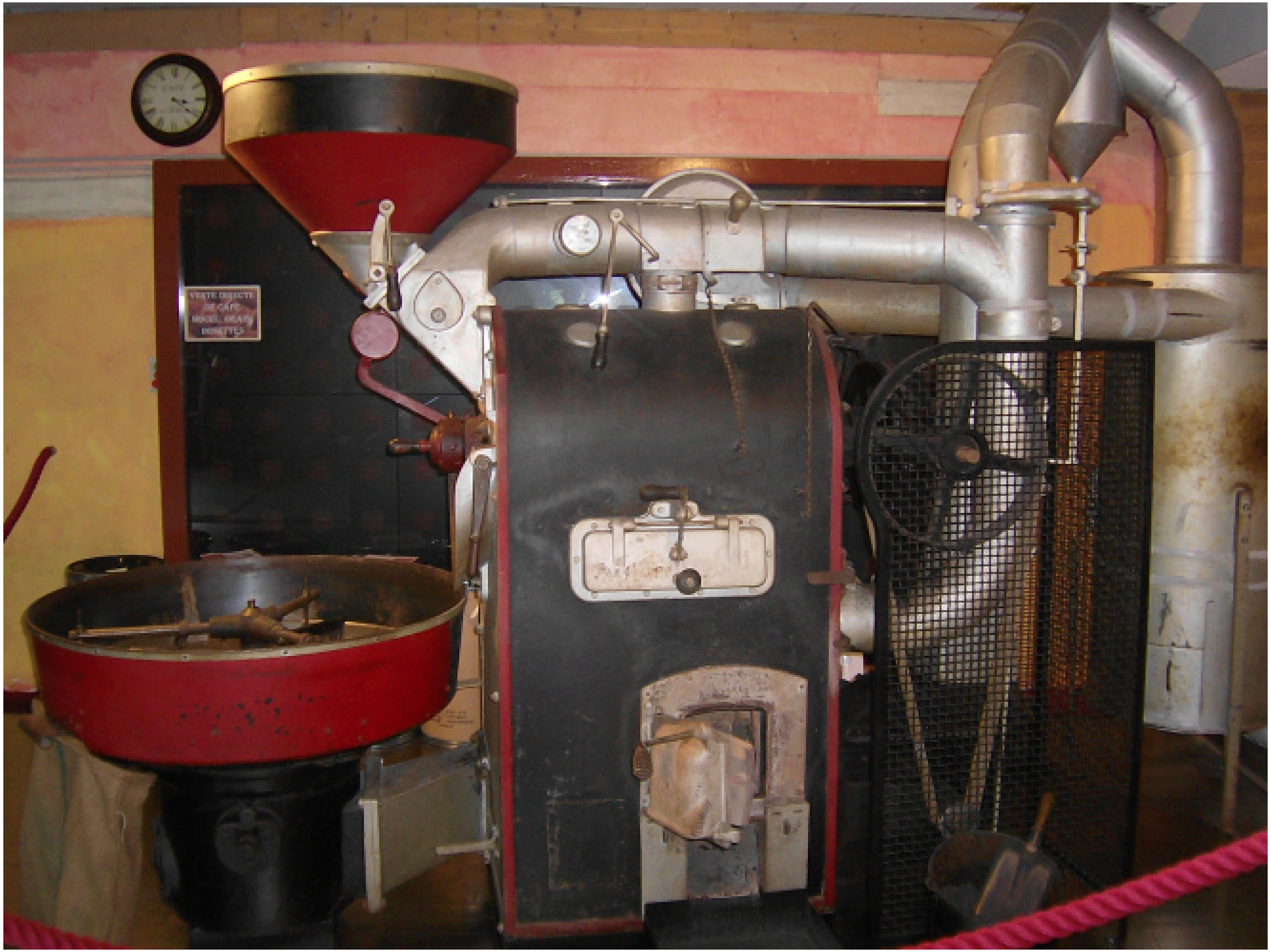
- Torrefied material from pilot-plant subjected to semi-industrial-scale pelletisation tests at CPM:
  - Good quality pellets can be produced *without additional binder*, despite heterogeneous nature of the biomass
  - But case-by-case tuning of the pelletisation conditions (e.g. die type) required
  - Good control of torrefaction conditions essential for proper pelletisation performance



Torrefaction pellets in perspective

Properties (willow, typical values)	unit	Wood	Torrefied Wood	Wood pellets	Torrefaction pellets
Moisture content	wt.%	35	0	10	3
Calorific value (LHV)					
Dry	MJ/kg	17.7	20.4	17.7	20.4
As received	MJ/kg	10.5	20.4	15.6	19.9
Mass density (bulk)	kg/m^3	475	230	650	750
Energy density (bulk)	GJ/m^3	5.0	4.7	10.1	14.9
Pellet strength				Good	Very good
Hygroscopic nature		Hydrophilic	Hydrophobic	Hydrophilic	Hydrophobic
Biological degradation		Fast	Slow	Fast	Slow
Handling properties		Normal	Normal	Good	Good

Torrefaction ….. how difficult can it be?



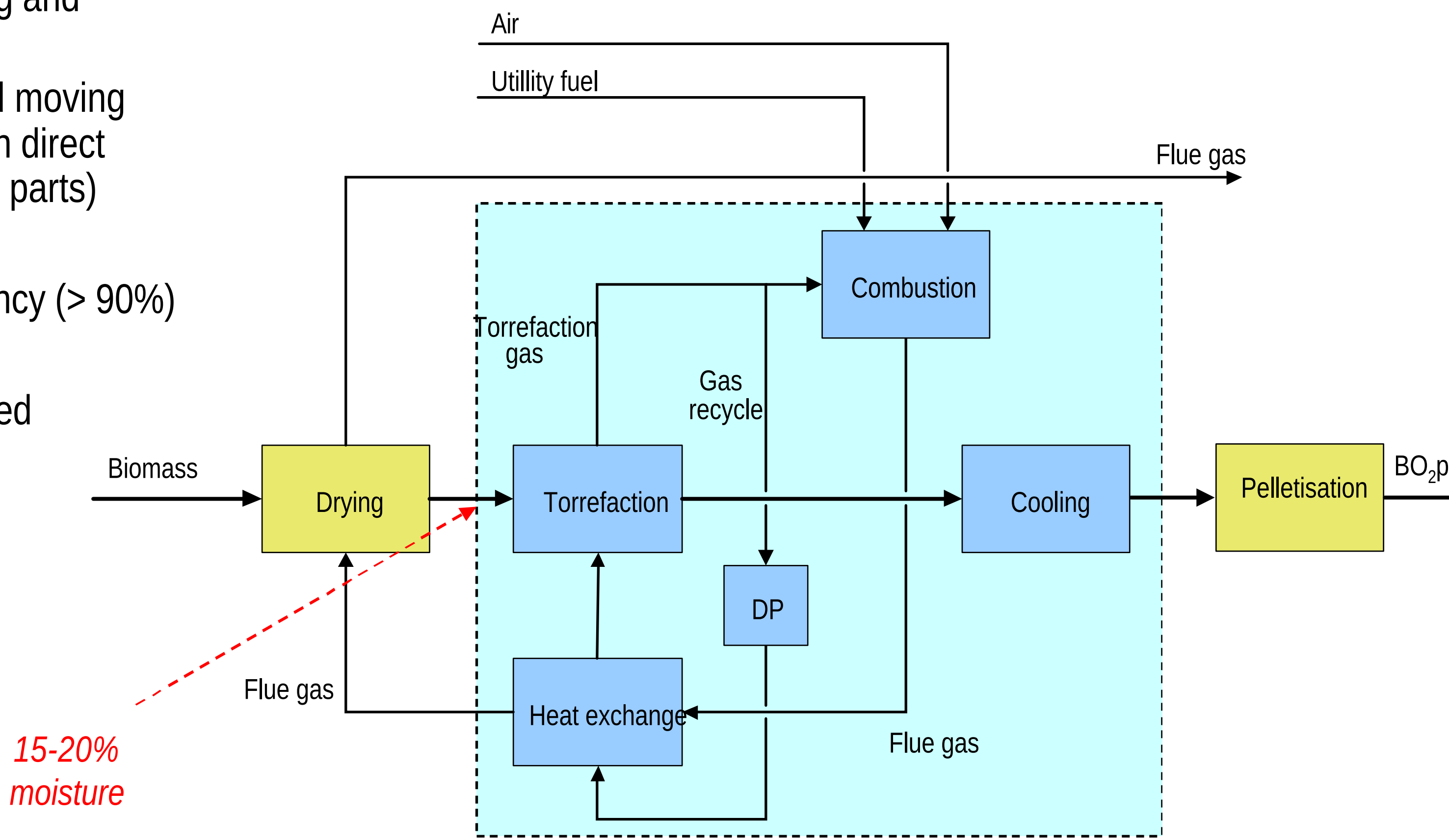
Design challenges for torrefaction plants

- Torrefaction process control – condensables, exothermicity, product quality control (in view of subsequent densification and end-use)
- Cost – CAPEX, OPEX, availability
- Energy efficiency (also in view of CO_2 footprint) → heat integration → use energy content torrefaction gas
- Feedstock flexibility
- Environmental impact (avoid waste streams)
- Plant capacity (5-15 tonne/h dry input)
- Energy densification: torrefaction + pelletisation

Technology example – ECN BO_2-technology

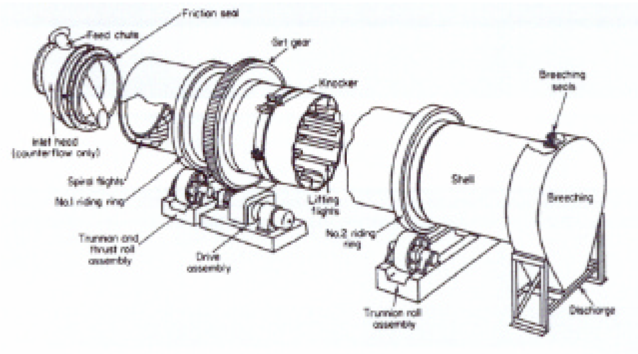
Features:

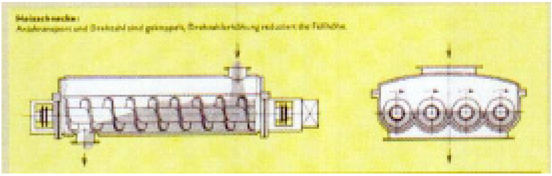
- Conventional drying and pelletisation
- Compact dedicated moving bed technology with direct heating (no moving parts)
- Heat integration
- High energy efficiency (> 90%)
- Cost effective
- IP is patent protected

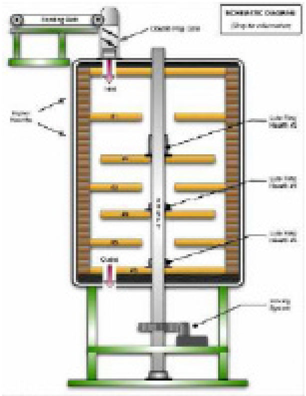


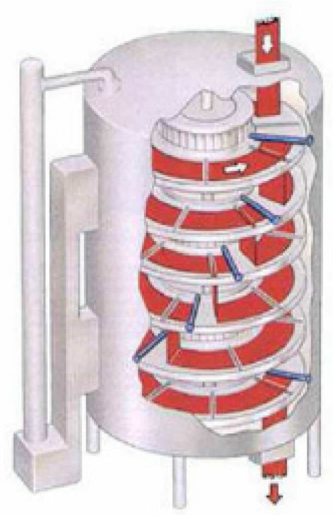
Torrefaction reactor concepts – many considered

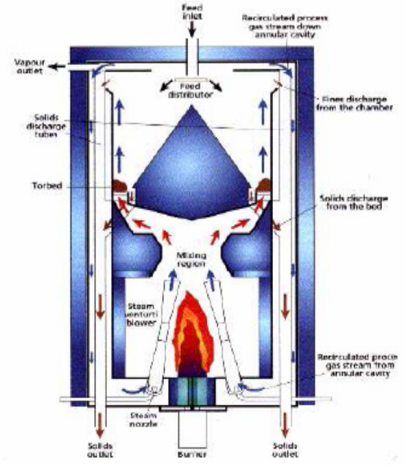
- Rotating drum (different heating concepts)
- Moving bed
- Belt reactor
- Torbed reactor
- Multiple hearth furnace
- Screw reactor (Auger reactor)
- ……











Torrefaction reactor concepts – many limitations

- Derived from drying or pyrolysis technology (e.g. other thermo-chemical regimes)
- Difficult/limited process control (e.g., temperature, residence time distribution)
- Limited efficiency
- Limited fuel flexibility / robustness
- Limited scale-up

- Other observations:
  - Often limited bench-/pilot-scale testing; directly to demo
  - Often limited attention to energy efficiency through heat integration
  - Process control / product quality control underestimated

Torrefaction – a Dutch technology?

- Pioneering role ECN (although building on earlier French experience)
- Several Dutch technology developers, several demo-plants under construction / starting up (ECN, Stramproy Green, Foxcoal, Torrcoal, Topell)
- Dutch Torrefaction Association established

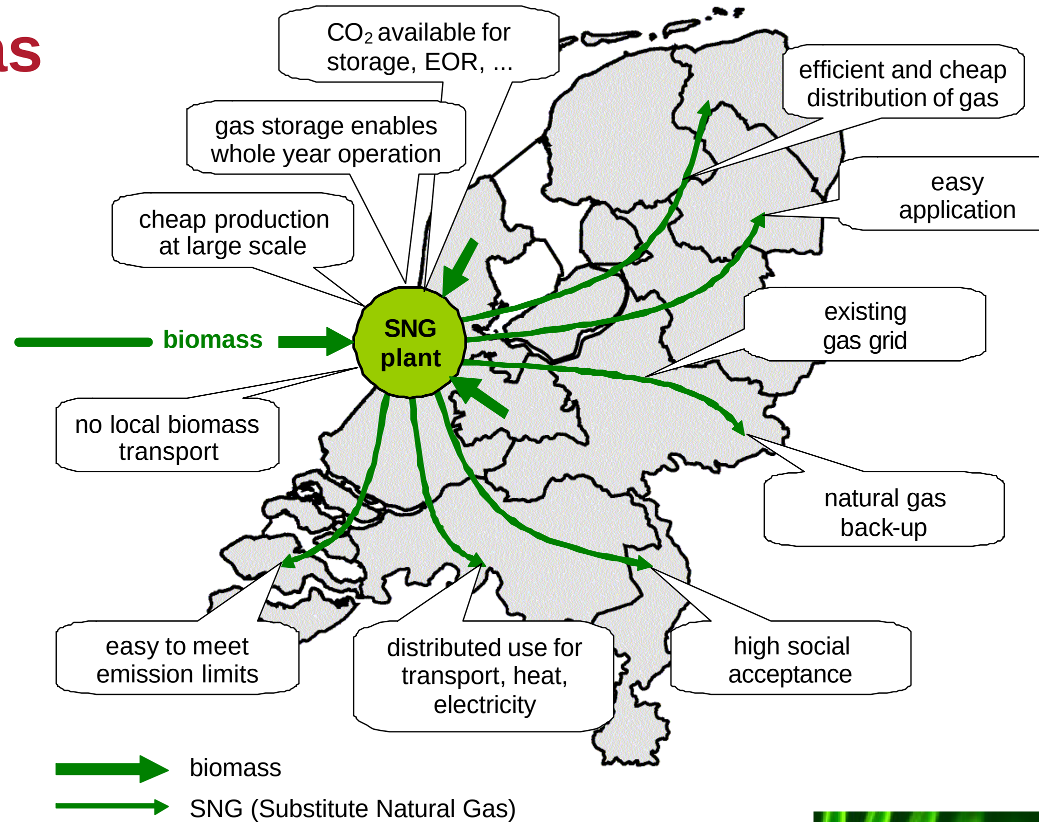
DTA
Dutch Torrefaction Association

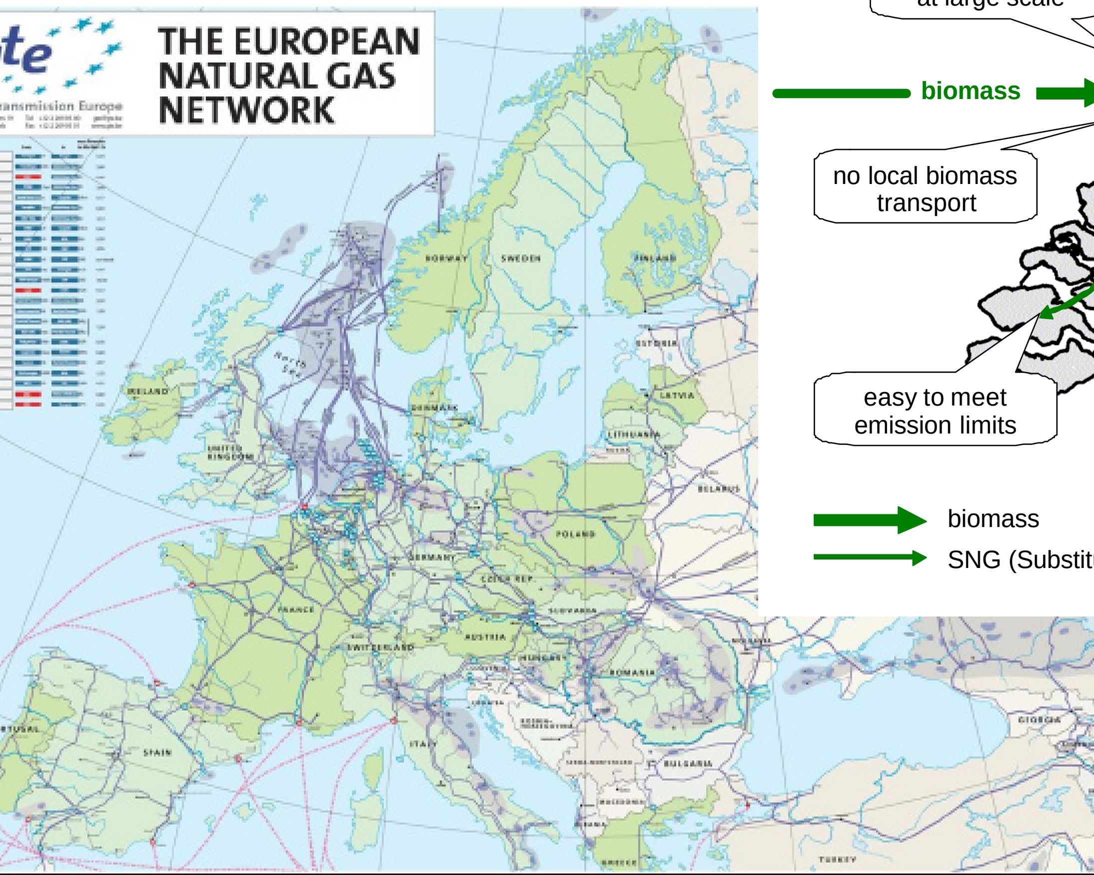
STRAMPROY GROUP

TORR COAL

TOPELL

Substitute Natural Gas (bioSNG)

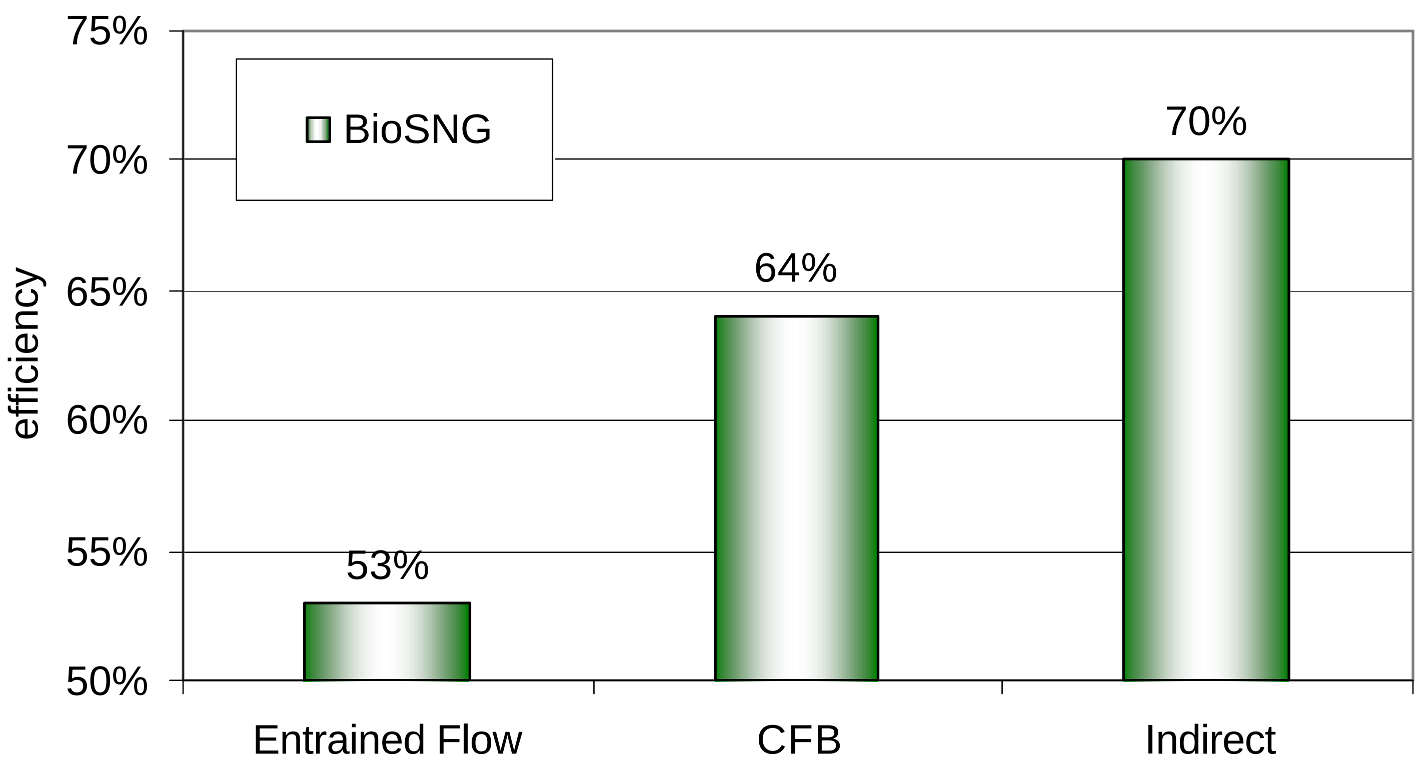




Production of bioSNG – different gasification options

• Oxygen-blown entrained-flow:	operated at elevated pressure	?
	no tars in product gas	?
	no methane in product gas	?
	complicated feeding	?
• Oxygen-blown CFB:	operated at slightly elevated pressure	?
	methane in product gas	?
	tars and organic sulphur in gas	?
	“limited” char conversion	?
• Indirect/allothermal:	methane in product gas	?
	no oxygen plant required	?
	tars and organic sulphur in gas	?
	atmospheric, compression required	?

Production of bioSNG – overall conversion efficiency

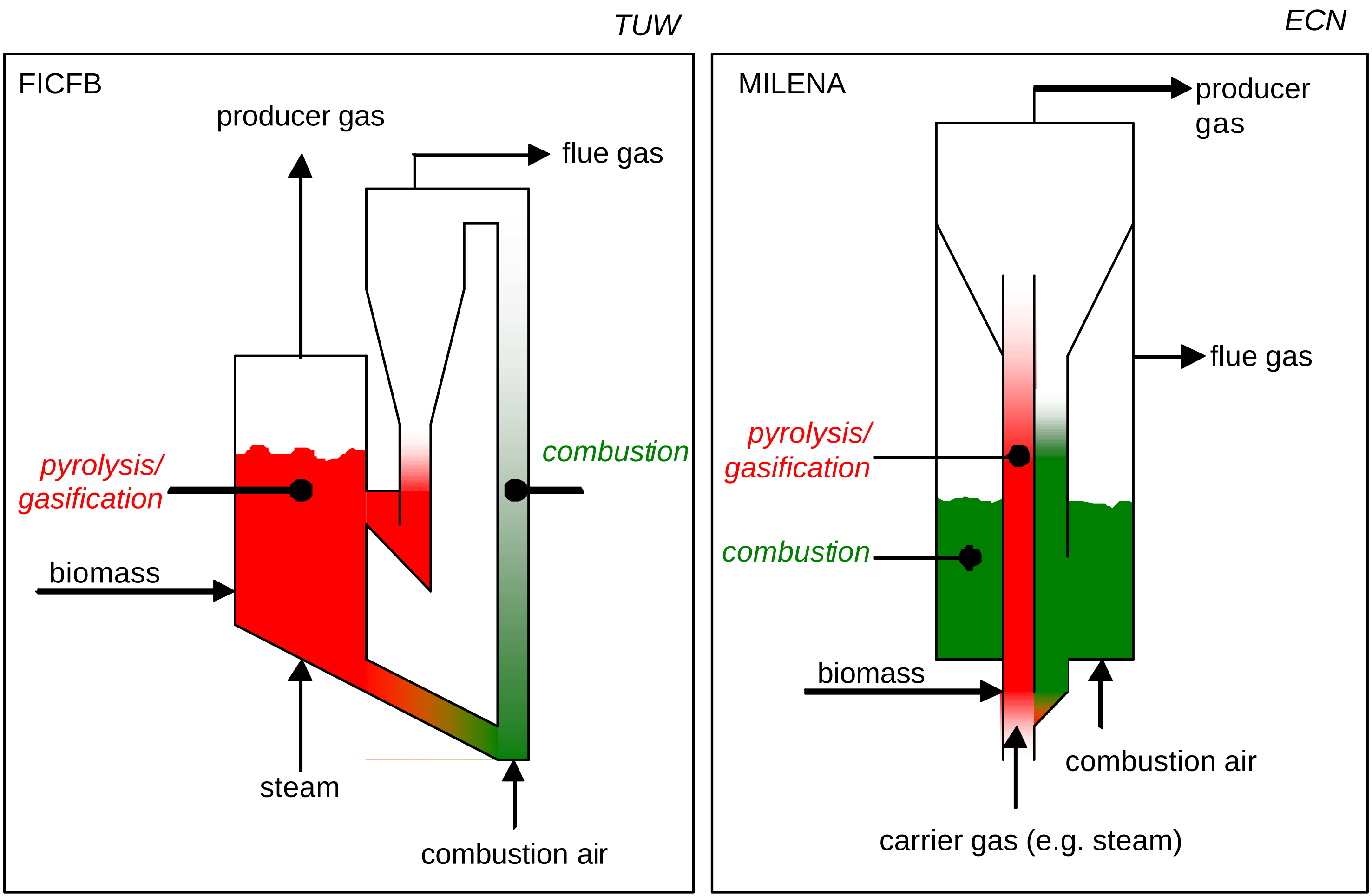


C. M. van der Meijden et.al., Biomass and Bioenergy 34, pp 302-311, 2010.

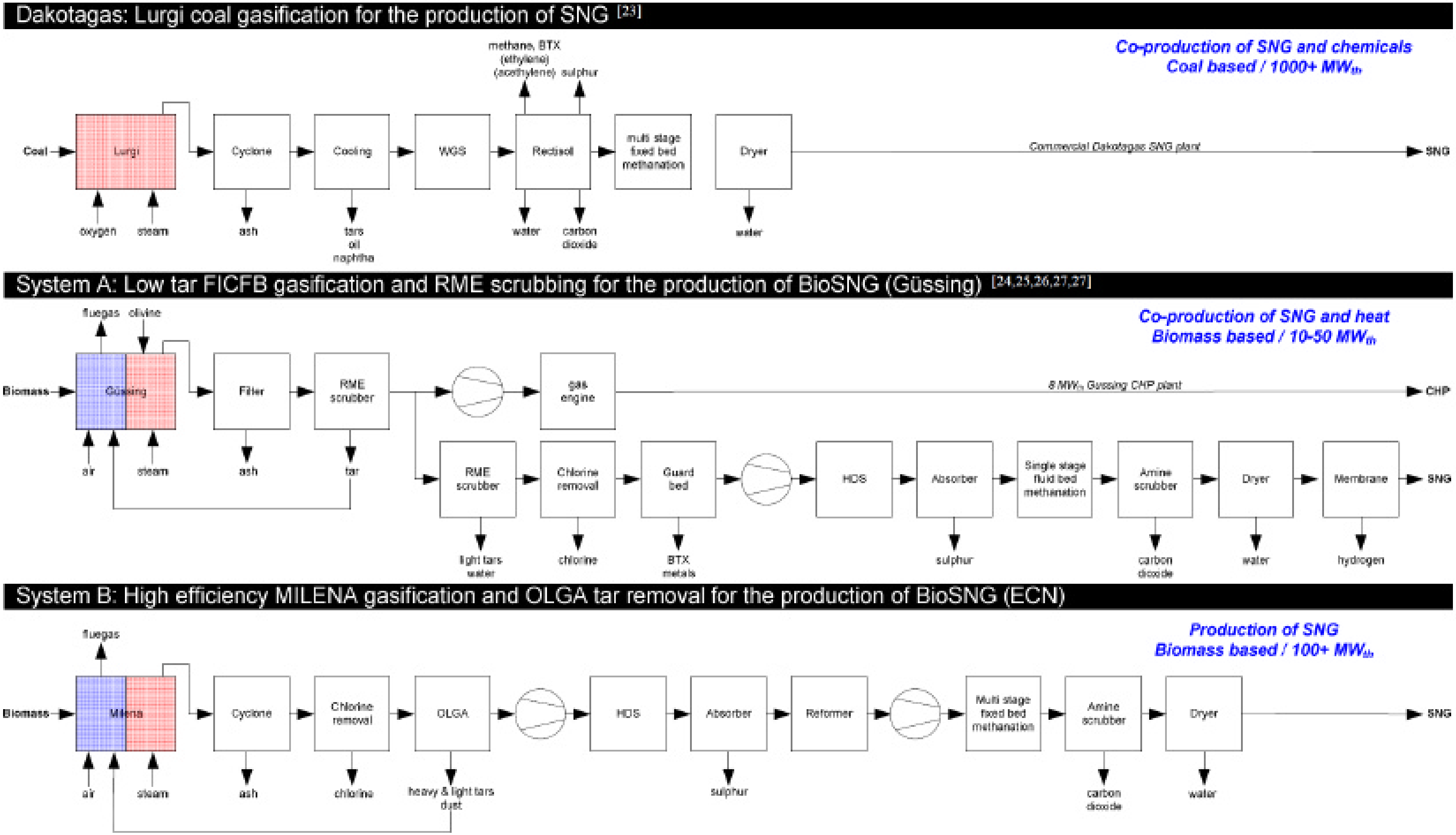
Two indirect-gasification based bioSNG technologies

- Austria (TUW) / Switzerland (PSI)
  - – based on the success of “Güssing”
- Netherlands (ECN)
  - – based on the success of OLGA tar removal

Two different indirect gasification technologies

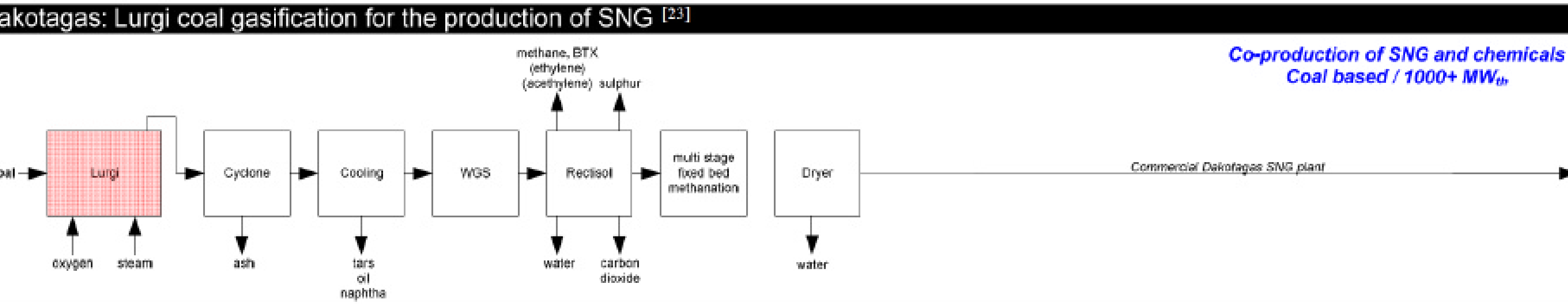


Production of bioSNG



Production of SNG

Dakotagas (USA): Lurgi coal gasification



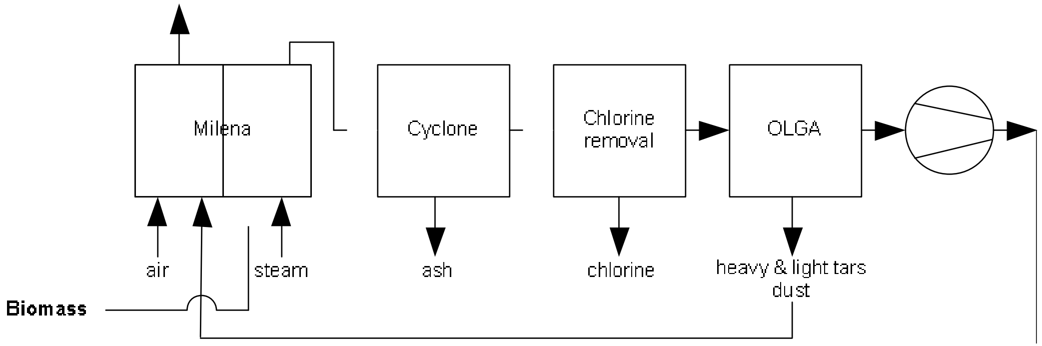
<u>Large scale coal based SNG production</u>:

- The gasifier is not suitable for conversion of biomass and/or tars
- The gas cleaning and conditioning applied is operating at pressure levels and sulphur loads being (for the moment) not realistic for biomass based systems
- The Rectisol unit removes to many high-value gas components

ECN

R&D needs bioSNG via indirect gasification

Upscaling gasification and tar removal

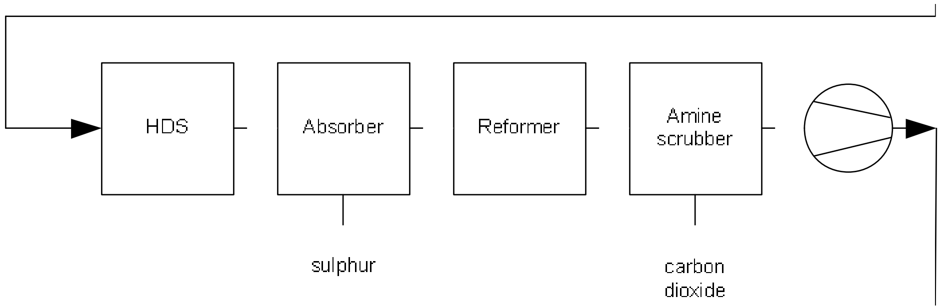


<u>(Indirect) biomass gasification has still not yet matured</u>:

- Commercial G?ssing gasifier has a capacity of 8 MW_{th}
- Pilot MILENA gasifier has a capacity of 1 MW_{th}
- Goteborg Energi wants 20-100 MW_{th}
- HVC starts with 50 MW_{th}
- E.ON wants 200+ MW_{th}

R&D needs bioSNG via indirect gasification

Demonstrating the critical gas cleaning steps

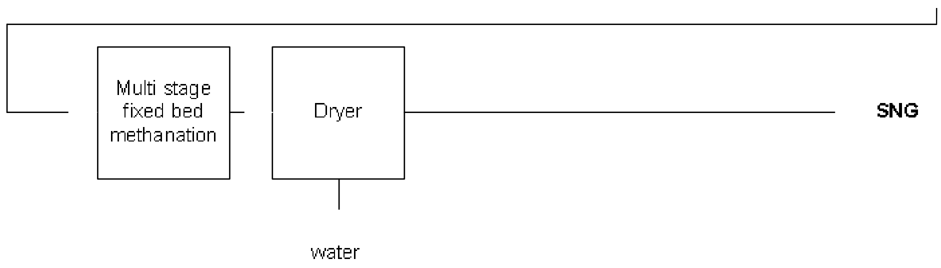


<u>Cleaning was developed for fossil-fuel based systems</u>:

- The critical gas cleaning systems did not have to handle unsaturated hydrocarbons, tars, organic sulphur, nor were optimised for being able to handle these components
- Demonstration of the critical gas cleaning steps up till now has been limited to lab and pilot scale testing for a limited period of time

R&D needs bioSNG via indirect gasification

Adjusting the methanation catalyst



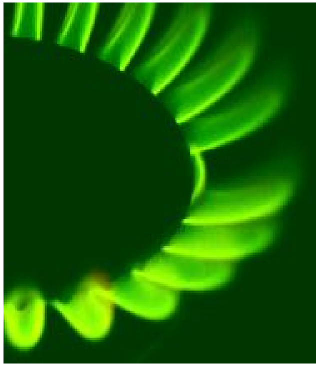
<u>There is only 1 commercial methanation unit in operation</u>:

- The methanation catalyst was optimised for this specific coal based application and has over the last 25 years hardly been improved
- Optimisation of the catalyst, either in order to be able to handle specific biomass related contaminants in the product gas or in order to produce CH_4 more efficiently will require realistic long-term testing

In conclusion

- General trend towards conversion of biomass into bioenergy carriers to facilitate logistics, trading and end-use
- Rapid growth in application of 1st generation bioenergy carriers (e.g. wood pellets, SNG via digestion)
- Many 2nd generation technologies for biomass upgrading into bioenergy carriers under development, most of them linking to existing infrastructures for coal, oil and gas
- Development of 2nd generation technologies in pilot-to-demo phase with torrefaction maybe closest to large-scale market introduction





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