Biofuels

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NTNU
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Biofuels are hot again - this time it's the global warming

Outline

- Introduction
  - Characterisation, resources
  - Fuel prices, trade, politics
- Process routes and options
- Technologies and cycles
  - Combustion/Co-combustion
  - Gasification/gasification-combustion
- Producer gas impurities and gas/particle cleaning
- Examples of projects at NTNU/Sintef
- Biofuels for transport
- Poly/tri-generation biomass systems
- Conclusions

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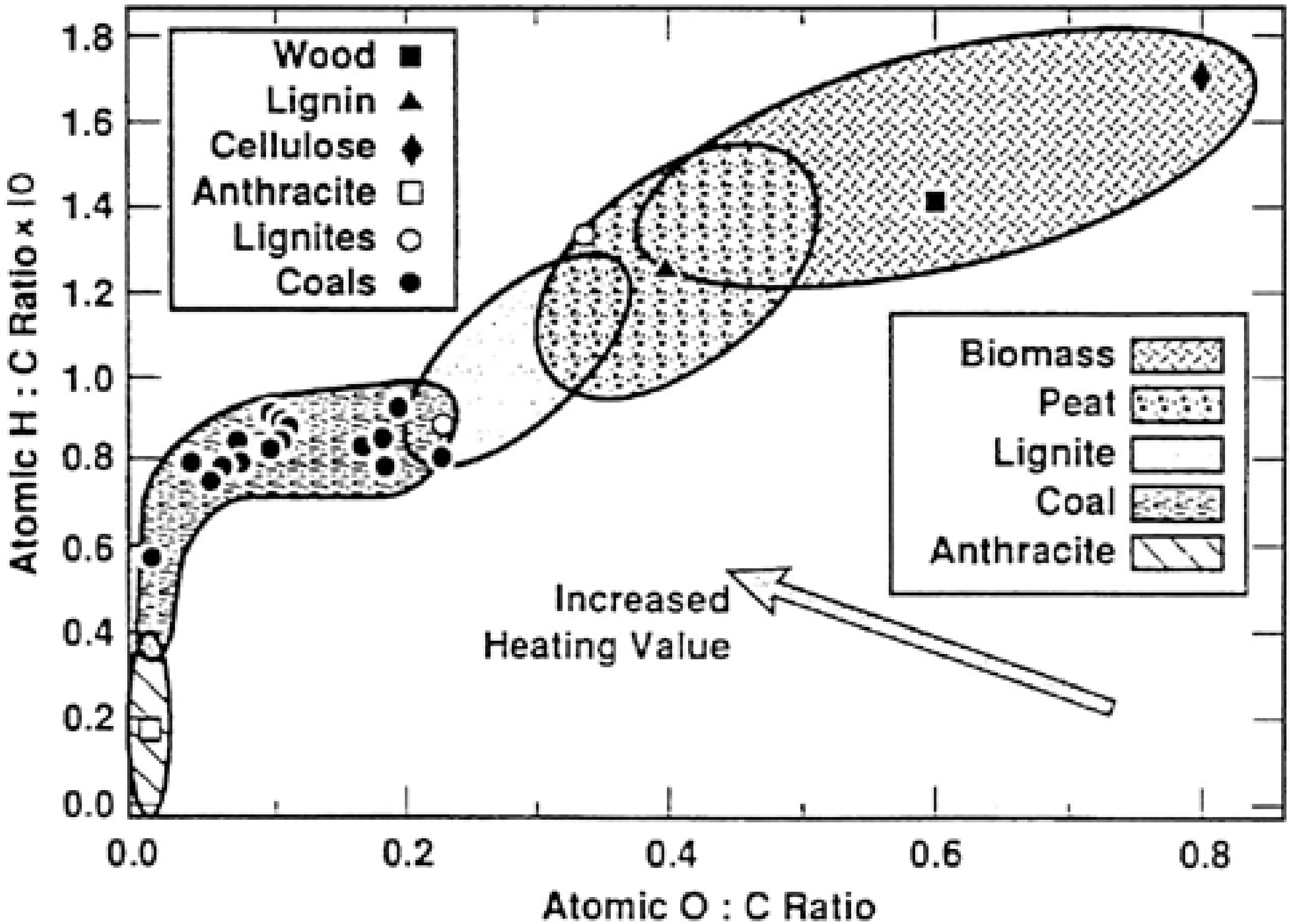
Biofuels – some examples

Wood

Pellets

Chips

Charcoal



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Brenselanalyser

Direkte Analyse (*Proximate Anlysis*)

- Fuktighet (*moisture content*) [vekt%]
- Flyktige Bestanddeler (*volatile matter*) [vekt%]
- Fast Karbon (*fix-C*) [vekt%]
- Aske (*ash*) [vekt%]

Analysen gjøres på rått brensel

Elementanalyse (*Ultimate Analysis*)

- Karbon C [vekt%]
- Hydrogen H [vekt%]
- Oksygen O [vekt%]
- Nitrogen N [vekt%]
- Svovel S [vekt%]

Analysen gjøres på tørr og askefri basis (DAF)

Brennverdi *(Heating Value)* [MJ/kg]

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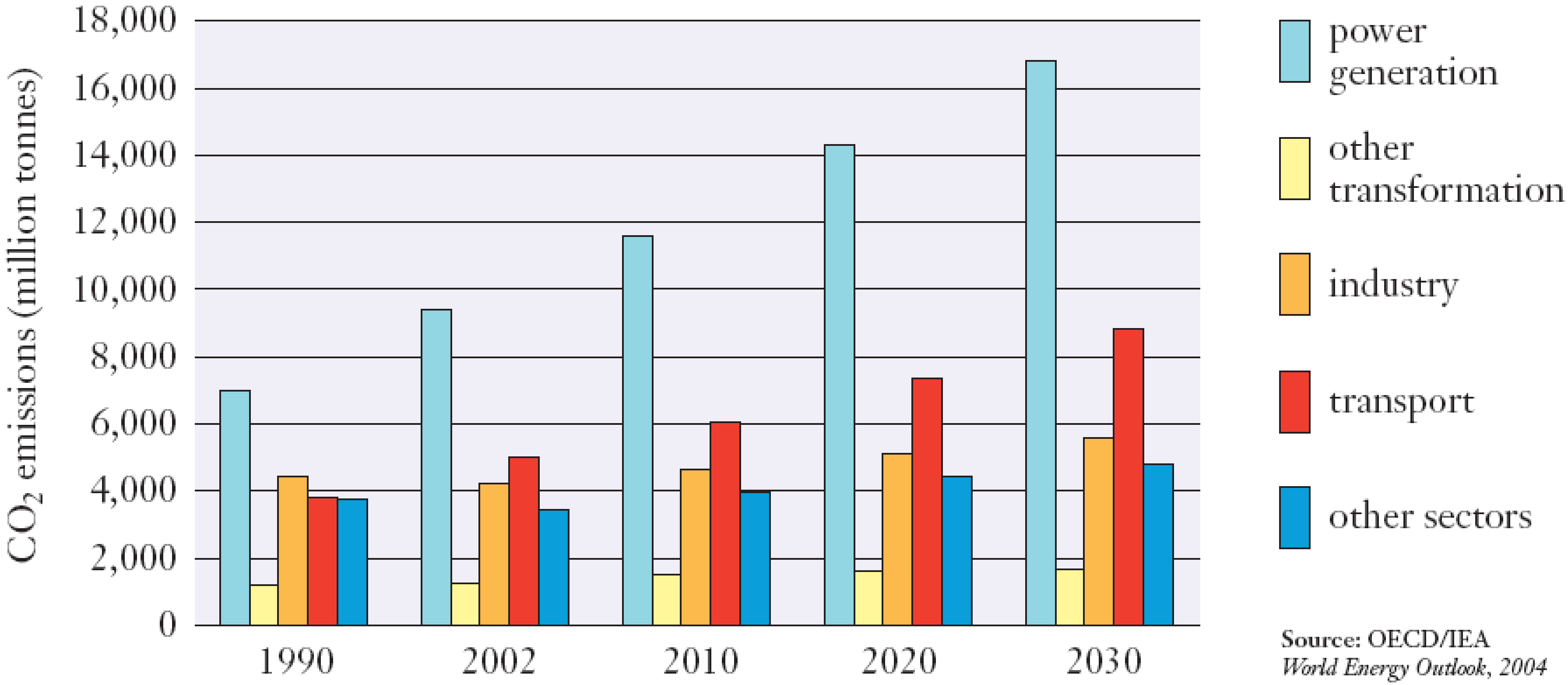
Main properties of coal, natural gas and various woody and herbaceous raw materials and feedstocks

	Bituminous Coal	Natural gas	Wood[8]	Bark	Willow	Forest residues[10]	Wood chips	Wood pellets	Cereal straw	Dedicated energy crops
Ash, d%	8.5-10.9	0	0.4-0.5	3.5-8	1.1-4.0	1-3	0.8-1.4	0.4-1.5	3-10	6.2-7.5
Moisture, w%	5-10	0	5-60	45-65	50-60	50-60	20-50	7-12	14-25	15-20
NCV, MJ/kg	26-28.3	48	18.5-20	18.0-23	18.4-19.2	18.5-20	19.2-19.4	16.2-19	16.5-17.4	17.1-17.5
Density, kg/m3	1100-1500	n.a.[11]	390-640	320	120[12]	n.a.[13]	250-350, 320-450[14]	500-780	100-170[15]	200[9]
Volatile matter, w%	25-40	100	>70	69.6-77.2	>70	>70	76-86	>70	70-81	>70
Ash melting point, T°C	1100-1400	-	1400-1700	1300-1700	n.a.	n.a.[16]	1000-1400	>1120	700-1000	700-1200
C, d%	76-87	75	48-52	48-52	47-51	48-52	47-52	48-52	45-48	45.5-46.1
H, d%	3.5-5	24	6.2-6.4	4.6-6.8	5.8-6.7	6.0-6.2	6.1-6.3	6.0-6.4	5.0-6.0	5.7-5.8
N, d%	0.8-1.5	0.9	0.1-0.5	0.3-0.8	0.2-0.8	0.3-0.5	<0.3	0.27-0.9	0.4-0.6	0.50-1.0
O, d%	2.8-11.3	0.9	38-42	24.3-42.4	40-46	40-44	38-45	≈40	36-48	41-44
S, d%	0.5-3.1	0	<0.05	<0.05	0.02-0.10	<0.05	<0.05	0.04-0.08	0.05-0.2	0.08-0.13
Cl, d%	<0.1	-	0.01-0.03	0.01-0.03	0.02-0.05	0.01-0.04	0.02	0.02-0.04	0.14-0.97	0.09
K, d%	0.003	-	0.02-0.05	0.1-0.4	0.2-0.5	0.1-0.4	≈0.02	n.a.	0.69-1.3	0.3-0.5
Ca, d%	4-12	-	0.1-1.5	0.02-0.08	0.2-0.7	0.2-0.9	≈0.04	n.a.	0.1-0.6	9

Motivation



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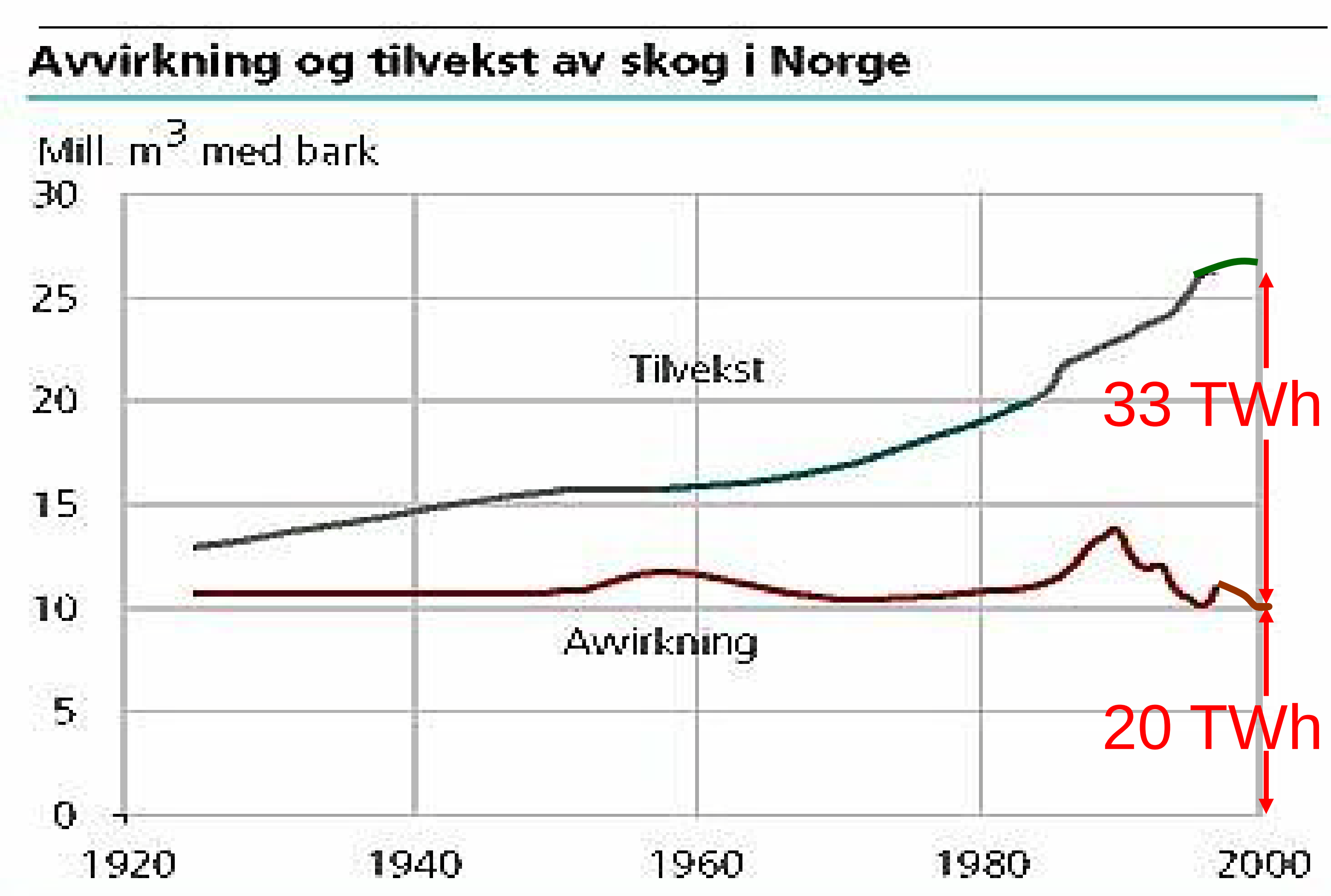
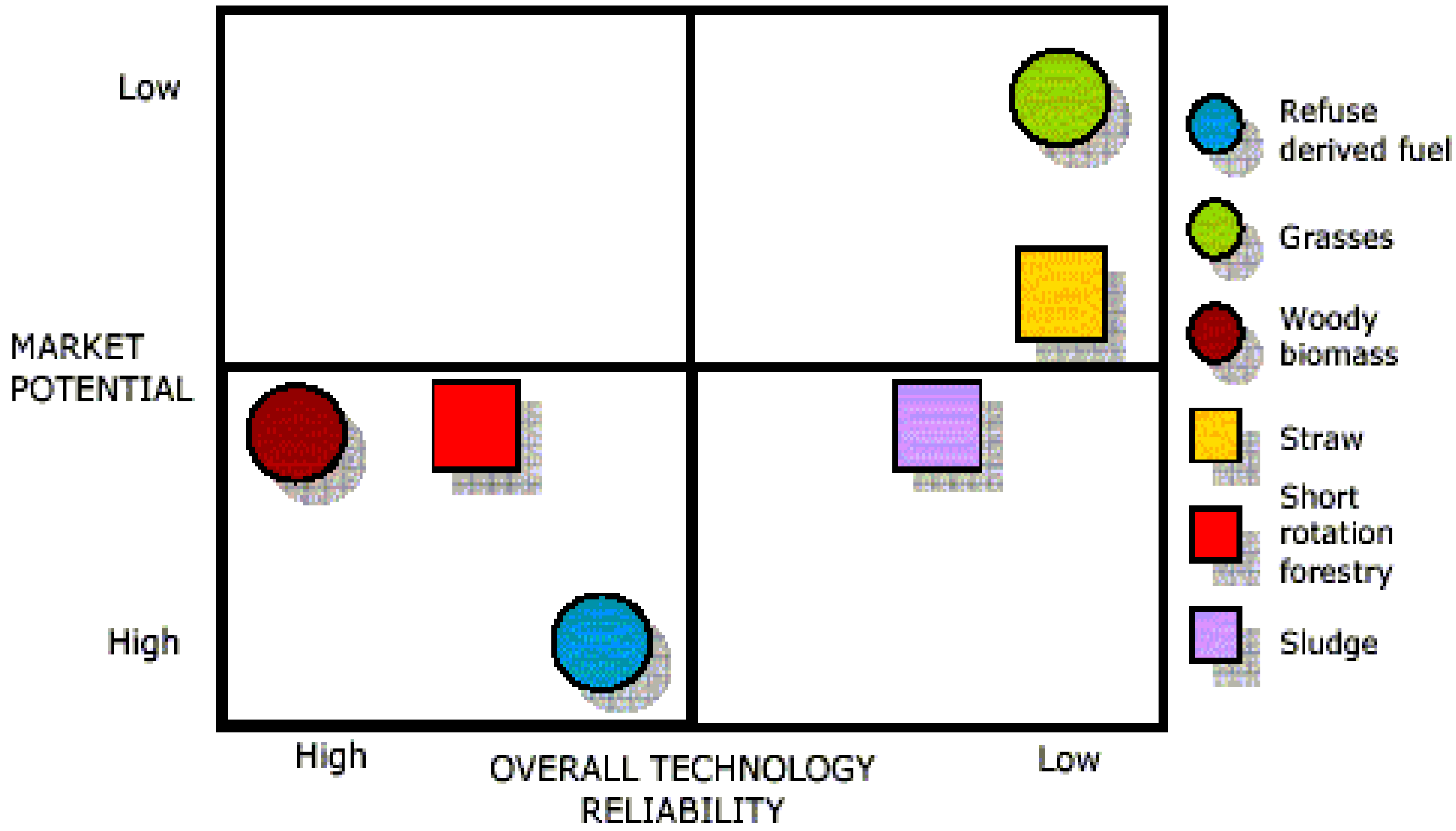
Forest Biofuels in Norway

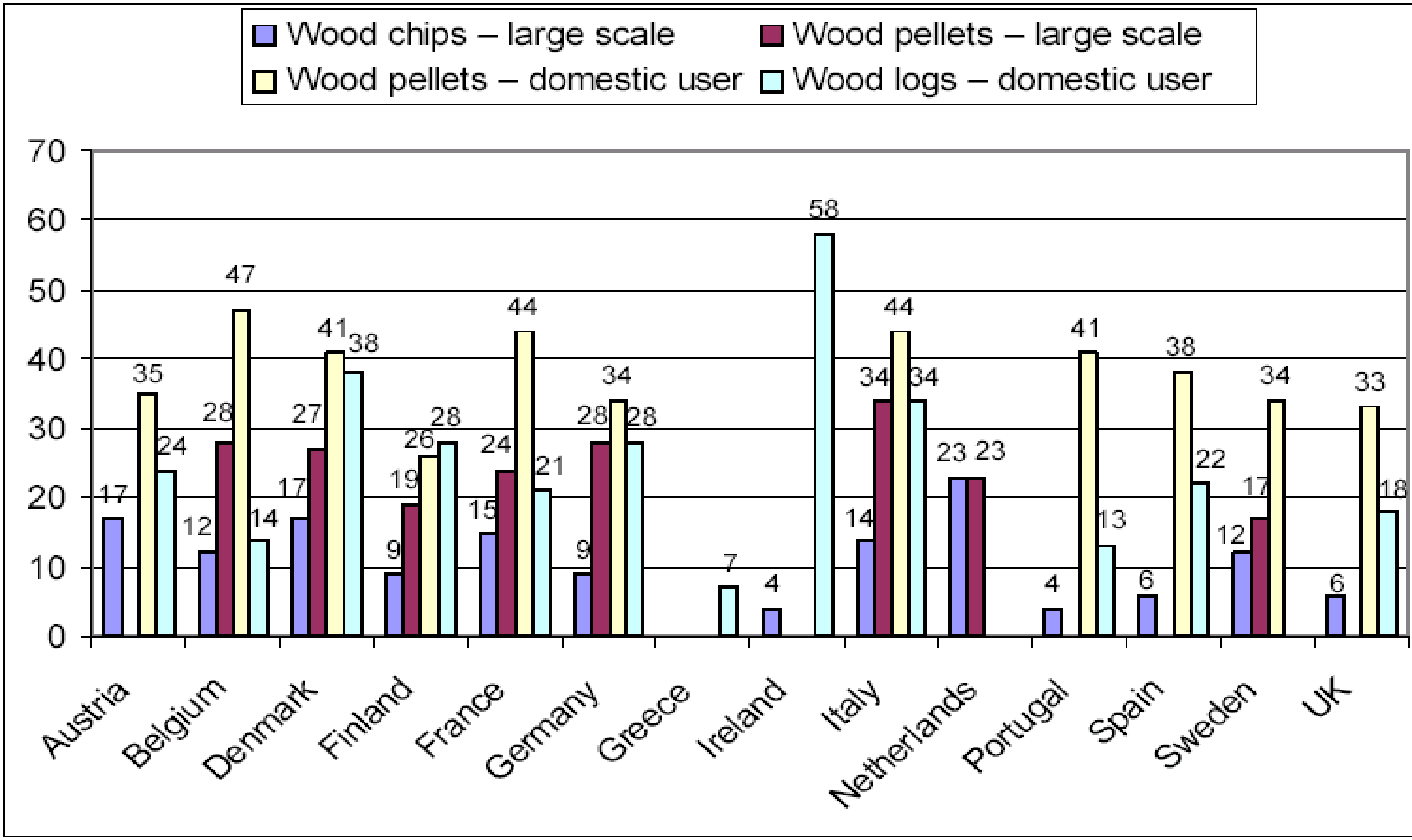


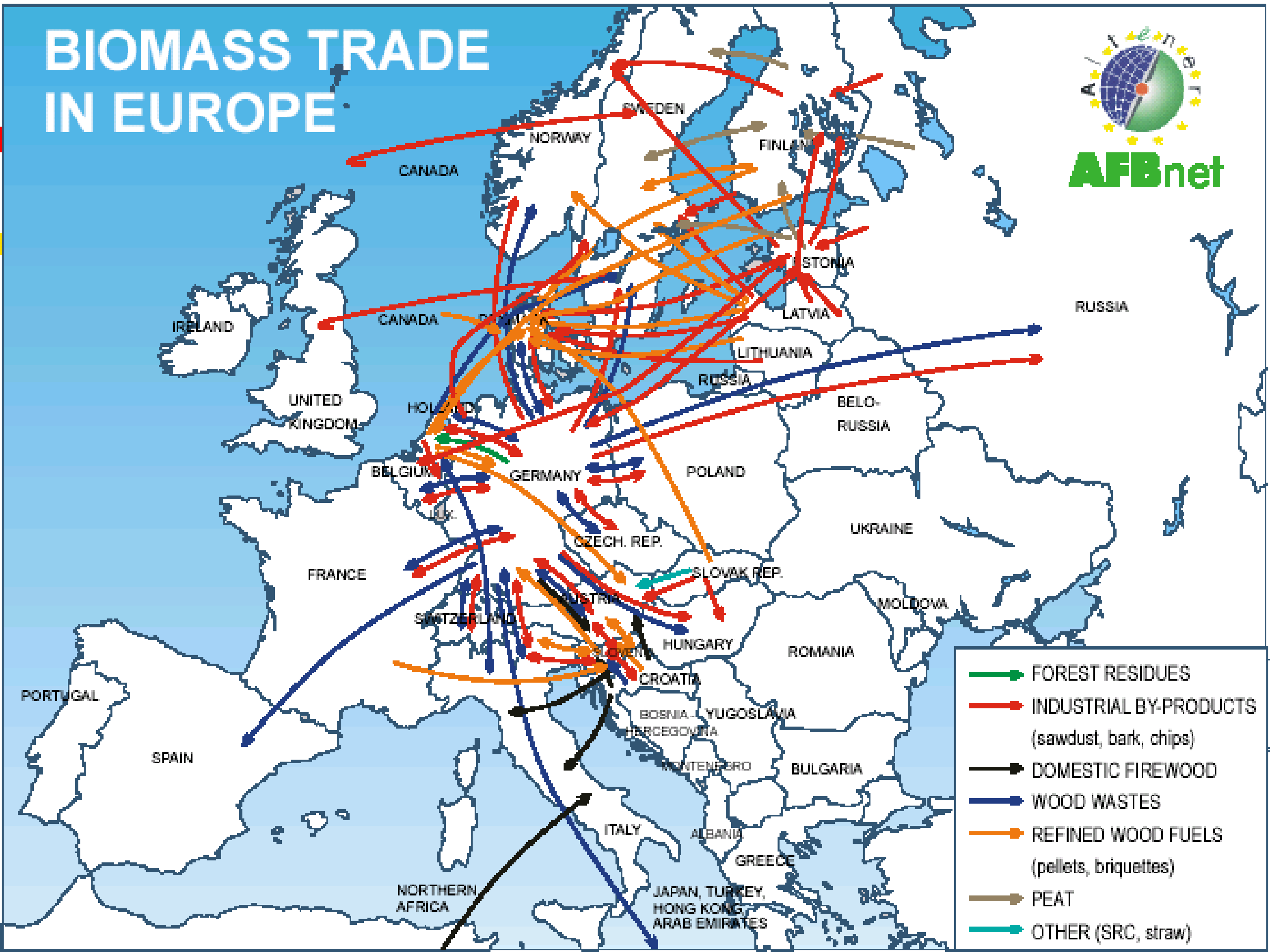
Kilde: SSB, NIJOS, Petter Heyerdahl (UMB)

FUEL MARKET POTENTIAL



WOOD FUEL PRICES (Euro/MWh)




BIOMASS TRADE IN EUROPE
AFBnet
SWEDEN
NORWAY
CANADA
FINLAND
ESTONIA
RUSSIA
IRELAND
CANADA
DENMARK
LATVIA
LITHUANIA
RUSSIA
UNITED KINGDOM
HOLLAND
BELO-RUSSIA
BELGIUM
GERMANY
POLAND
LUX.
CZECH. REP.
UKRAINE
FRANCE
SLOVAK REP.
AUSTRIA
MOLDOVA
SWITZERLAND
HUNGARY
SLOVENIA
ROMANIA
CROATIA
PORTUGAL
BOSNIA - HERCEGOVINA
YUGOSLAVIA
SPAIN
MONTENEGRO
BULGARIA
ITALY
ALBANIA
GREECE
NORTHERN AFRICA
JAPAN, TURKEY, HONG KONG, ARAB EMIRATES
FOREST RESIDUES
INDUSTRIAL BY-PRODUCTS (sawdust, bark, chips)
DOMESTIC FIREWOOD
WOOD WASTES
REFINED WOOD FUELS (pellets, briquettes)
PEAT
OTHER (SRC, straw)

EU-Politics, regulations

•RES increase from 6% (1997) to 12% (2010)

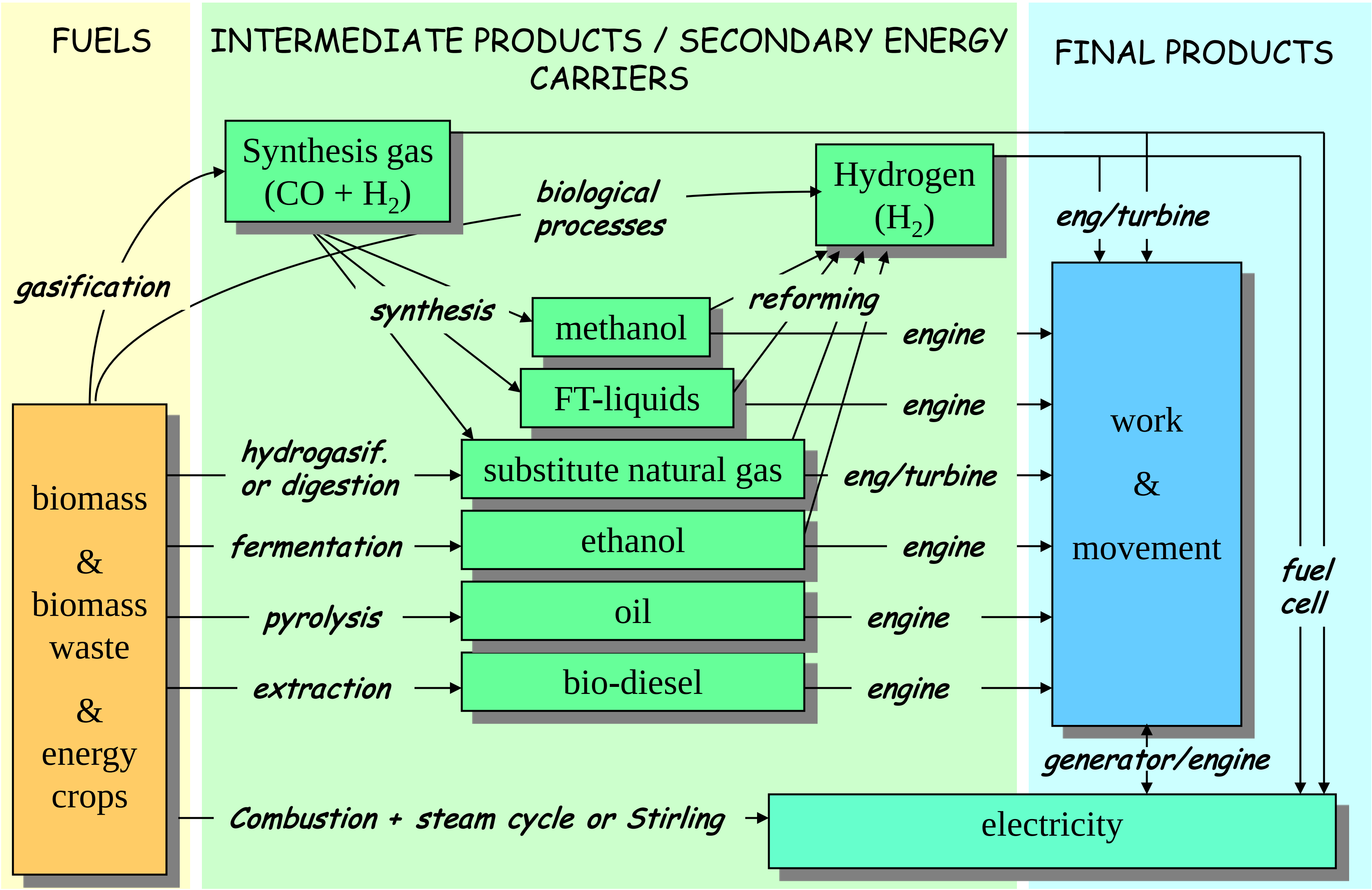
RES-E incr. from 14% (1997) to 22% (2010)

Energy Performance Certificate in Buildings (Savings, Space Heat., DH, reduce FF)

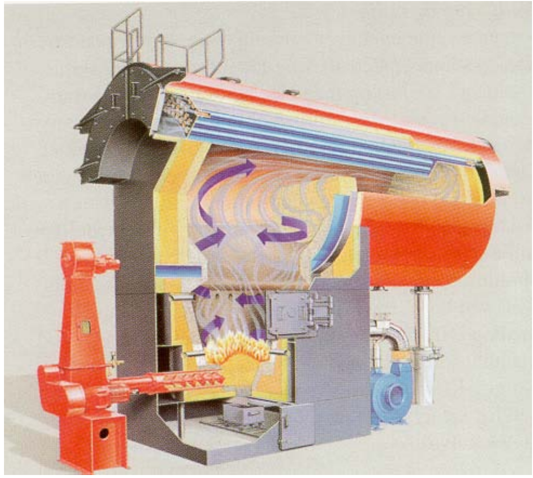
Solid Biofuel Standardisation – CEN TC-335

Biofuels Directive to replace gasoline and diesel by 2% in 2005, 5.75% in 2010 and 20% in 2020

Energy from biomass. Routes and options



Small scale combustion



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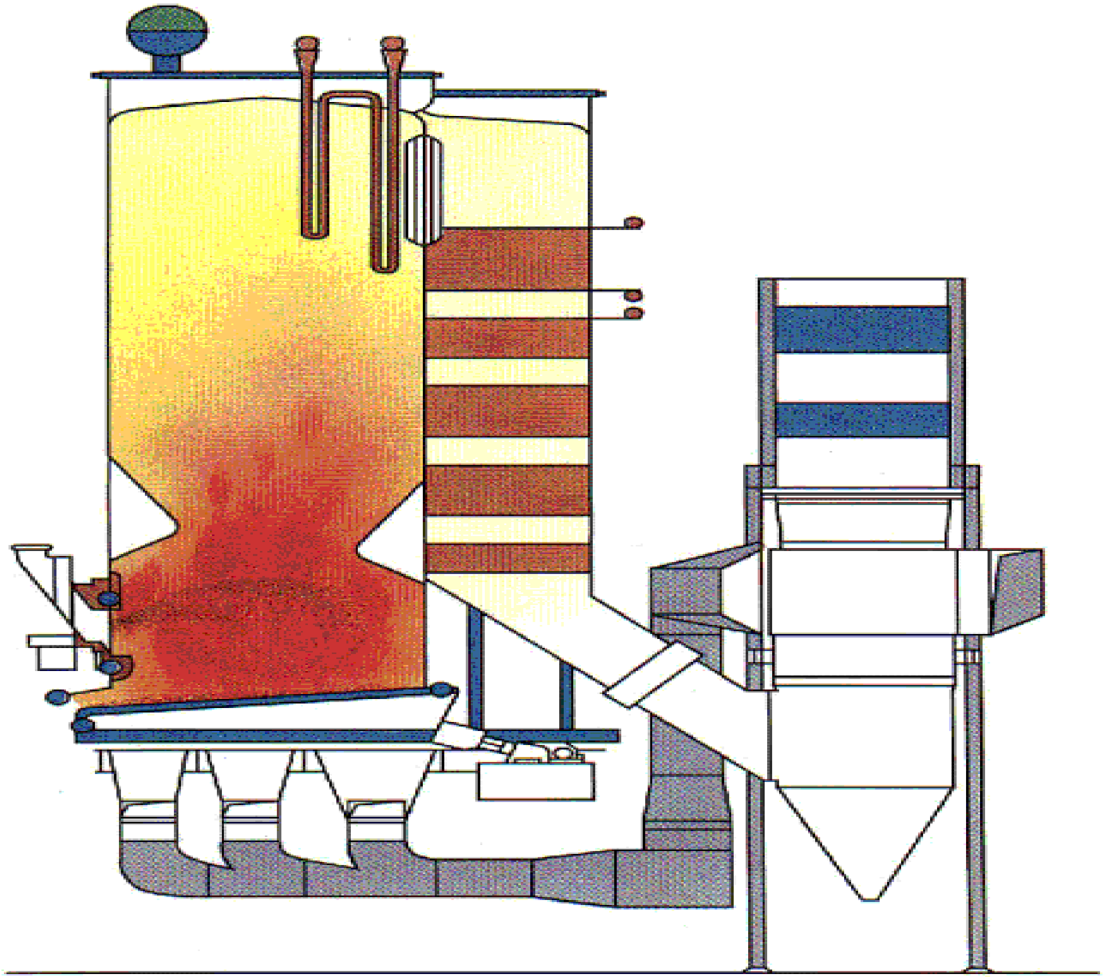
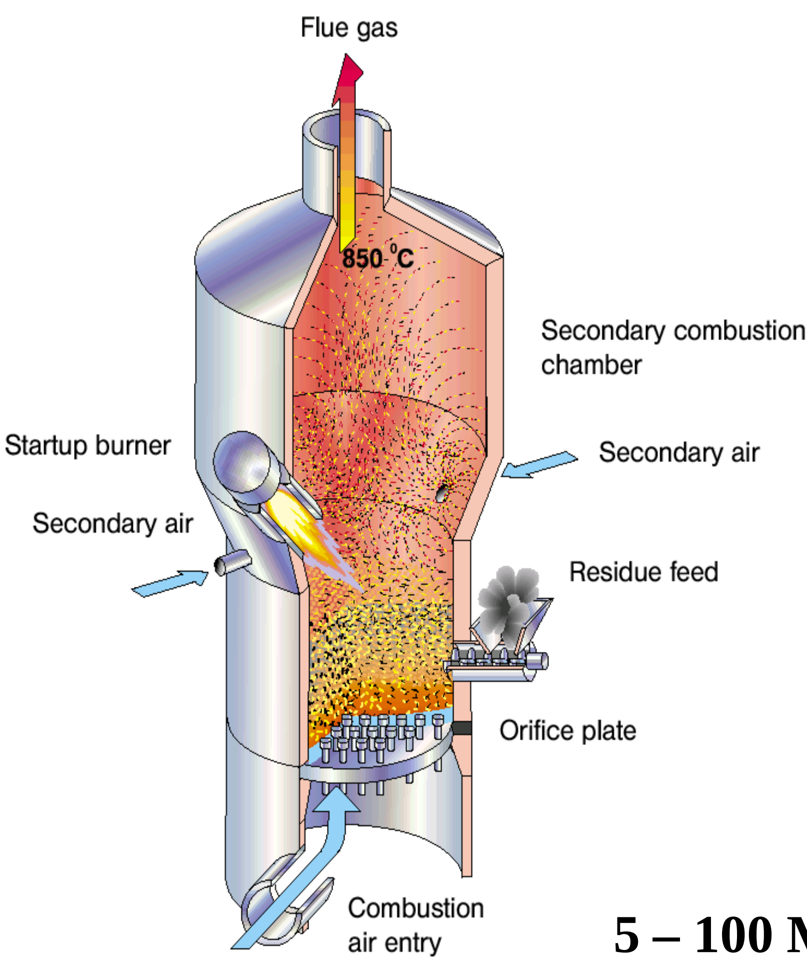
Medium/Large scale combustion

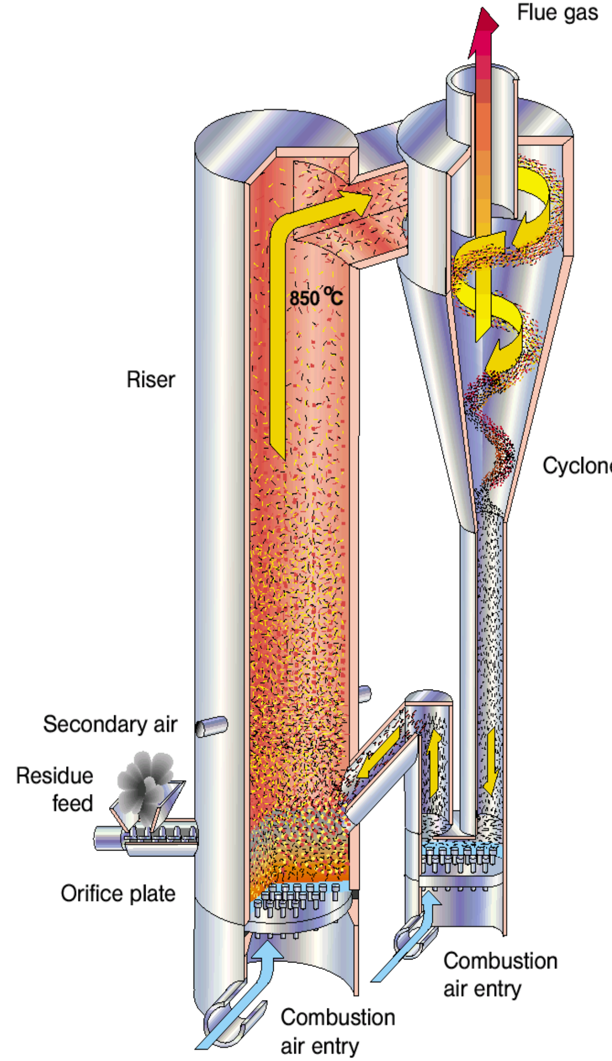


Fluidized bed

Stationary fluidized bed.

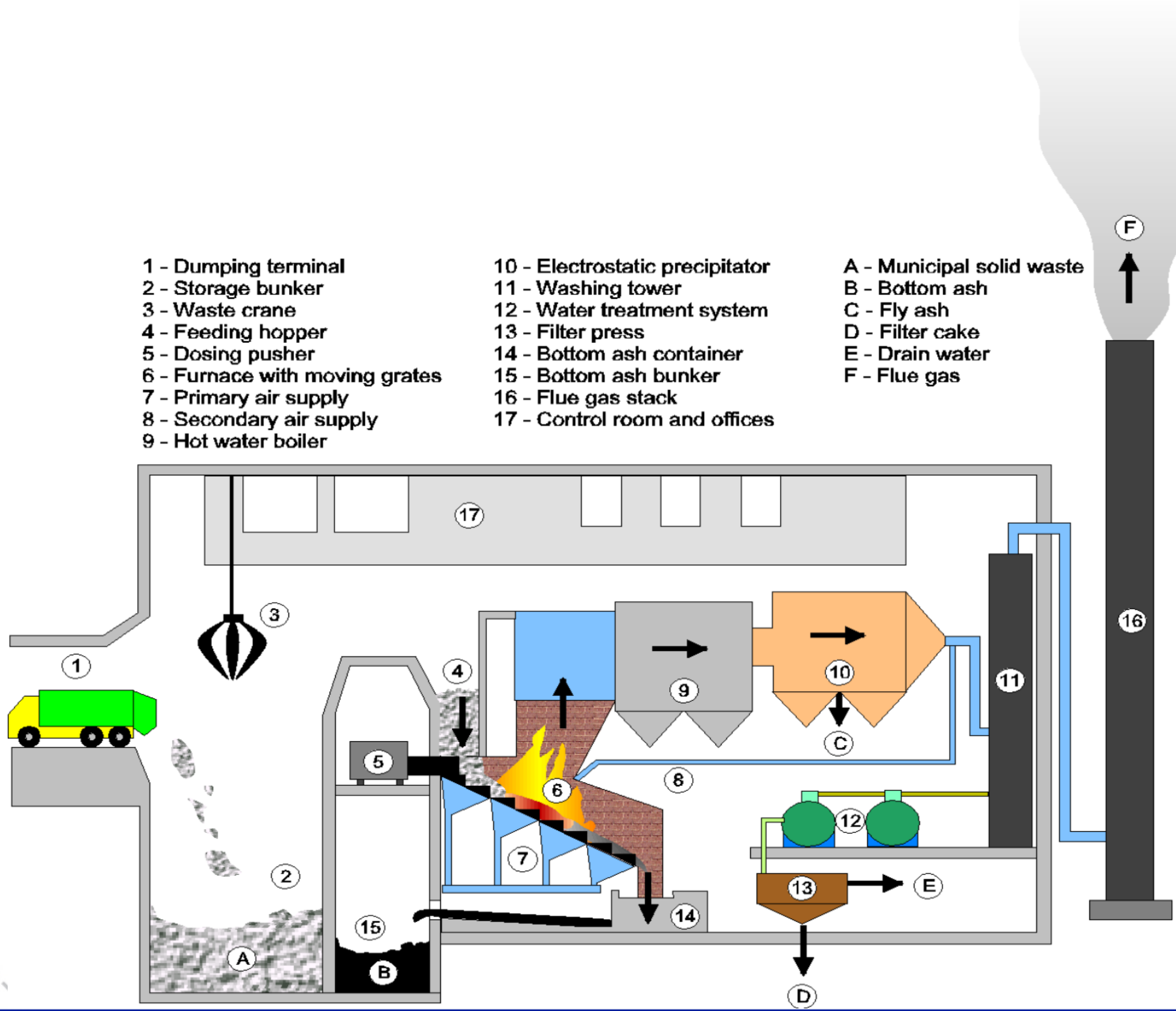


Circulating fluidized bed.

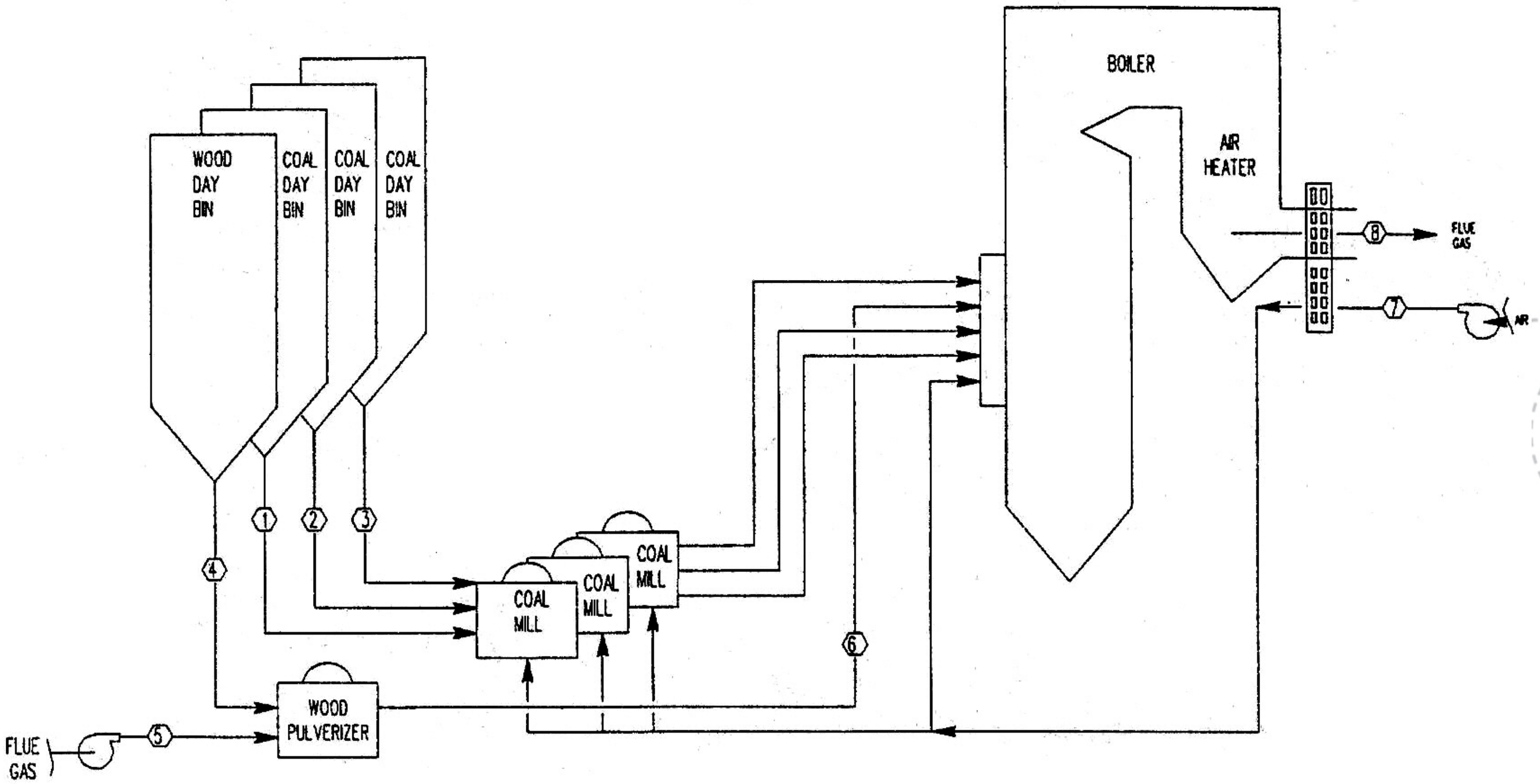


5 – 100 MW

Waste combustion



Co-combustion – Pulverized fuel



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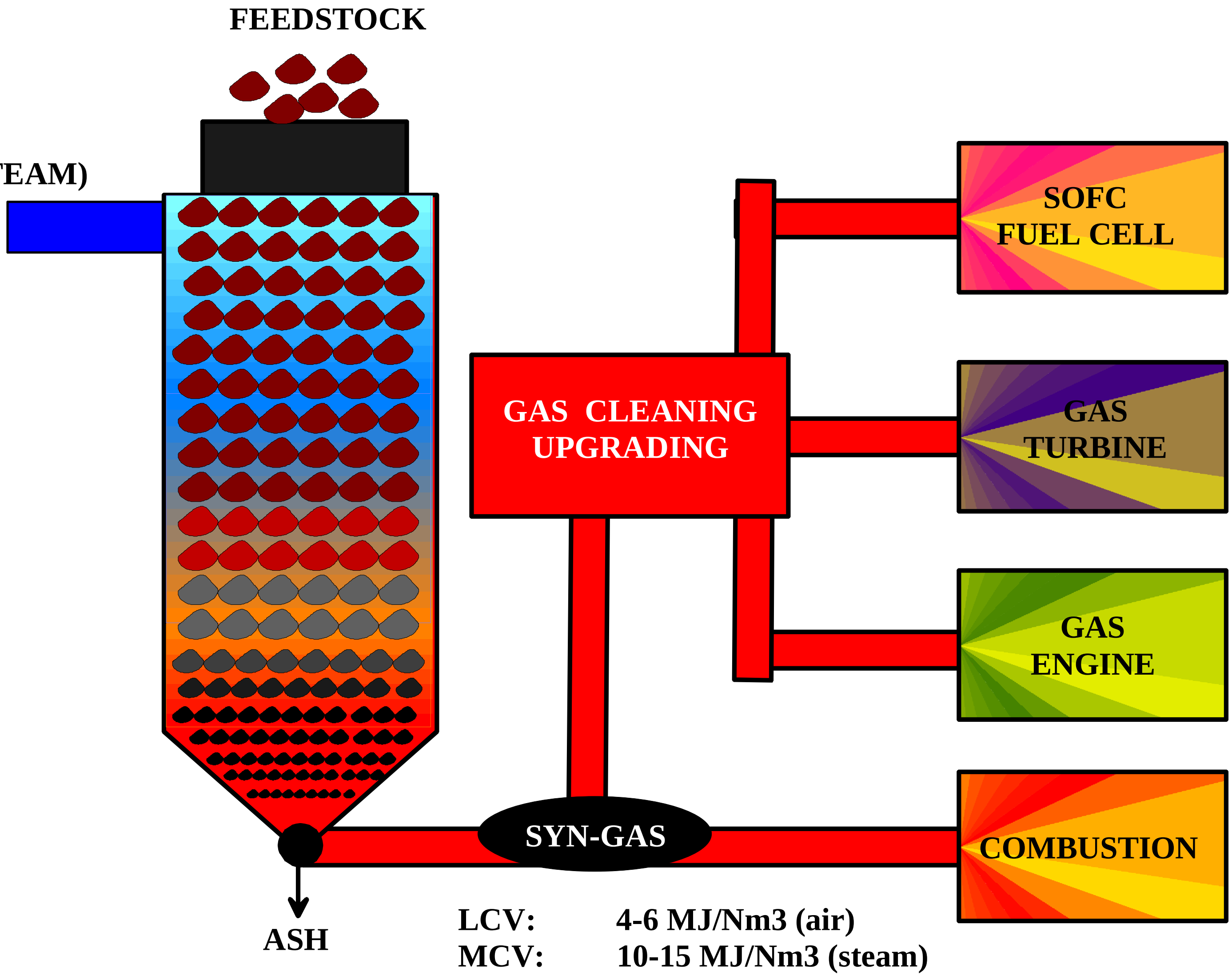
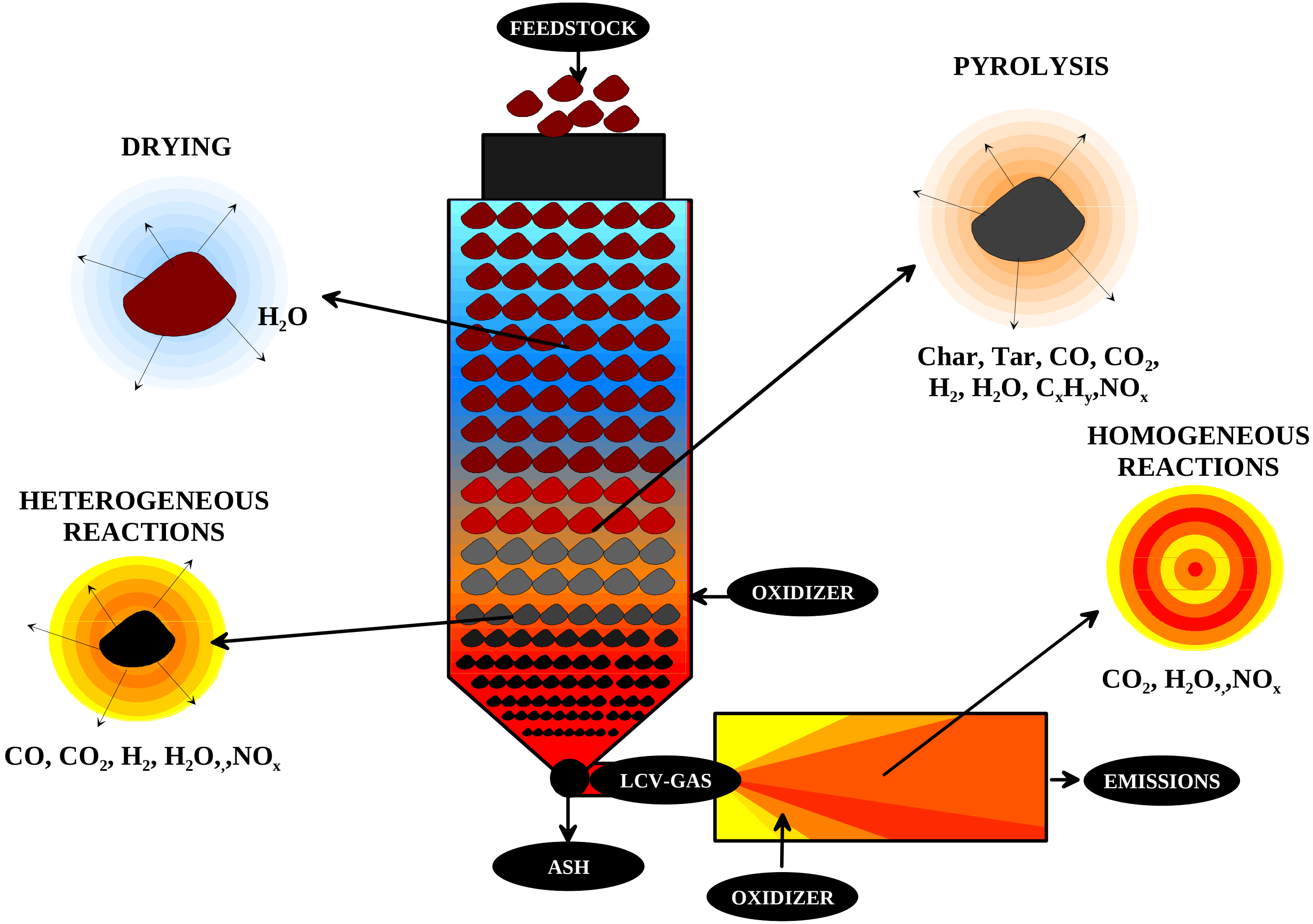
Gasification

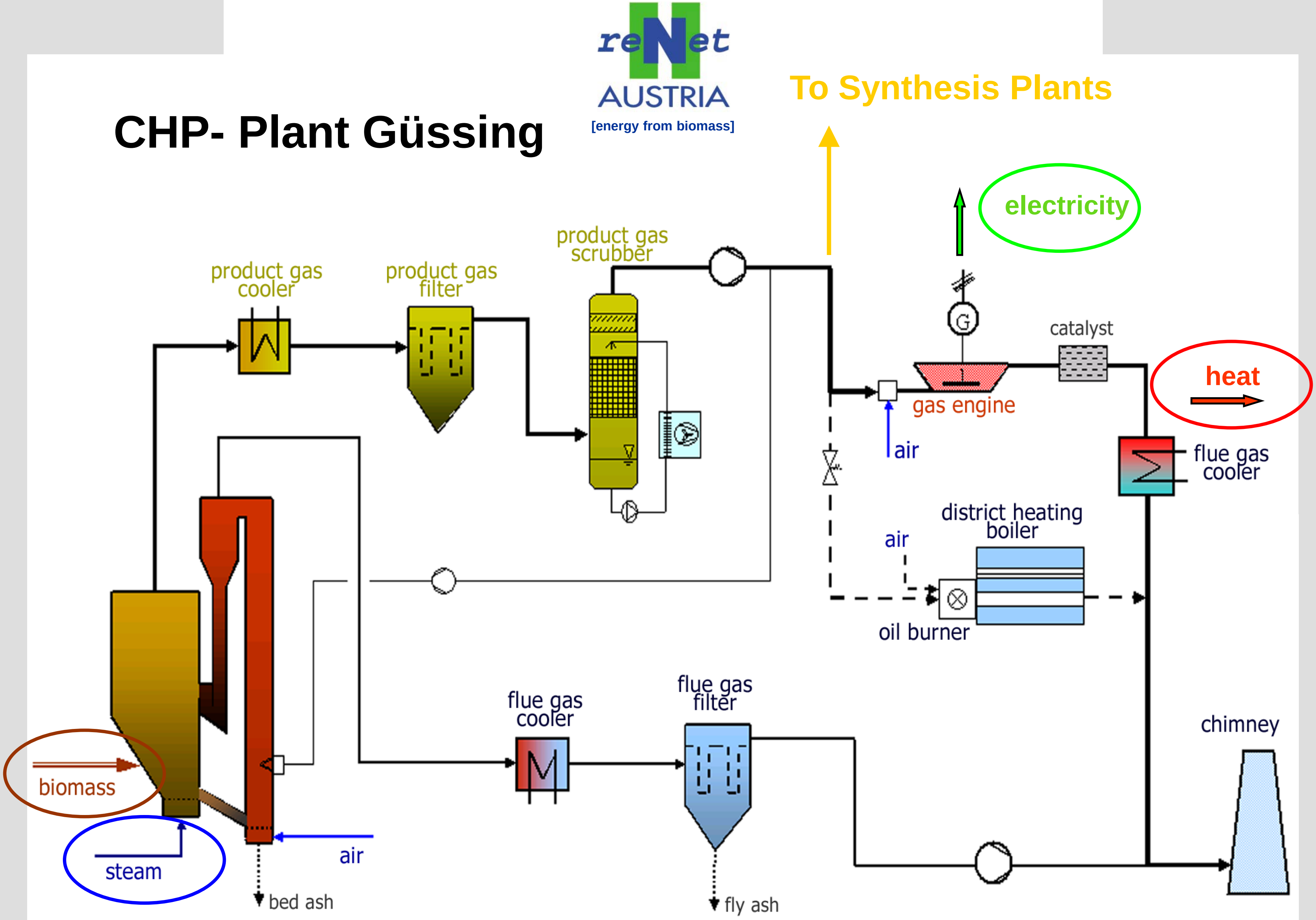


LCV: 4-6 MJ/Nm3 (air)
MCV: 10-15 MJ/Nm3 (steam)
Naturgass: 40 MJ/Nm3

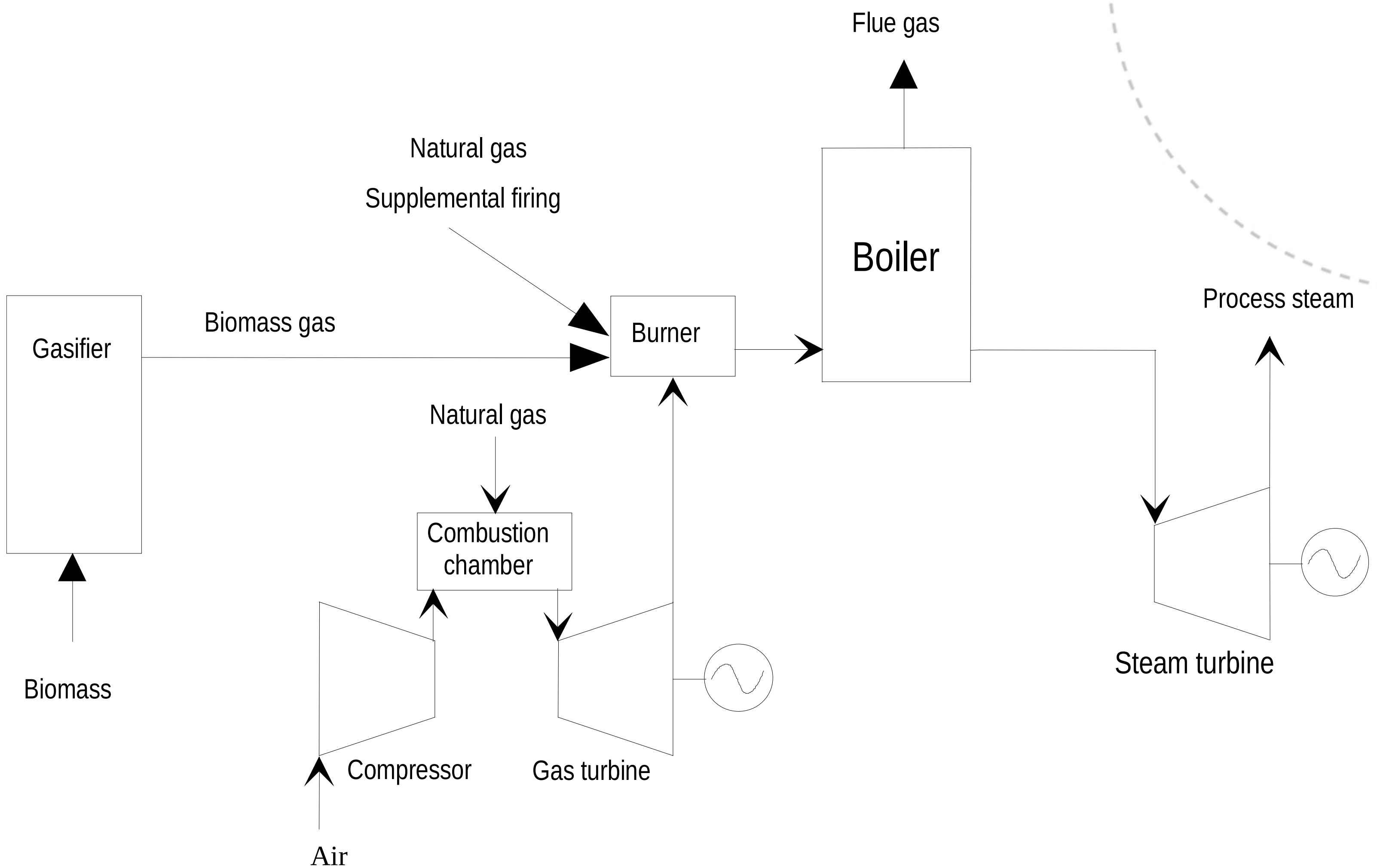
SNTEF project - CFD-modeling of gasification/combustion



CHP- Plant Güssing



Gasification – co-combustion natural gas



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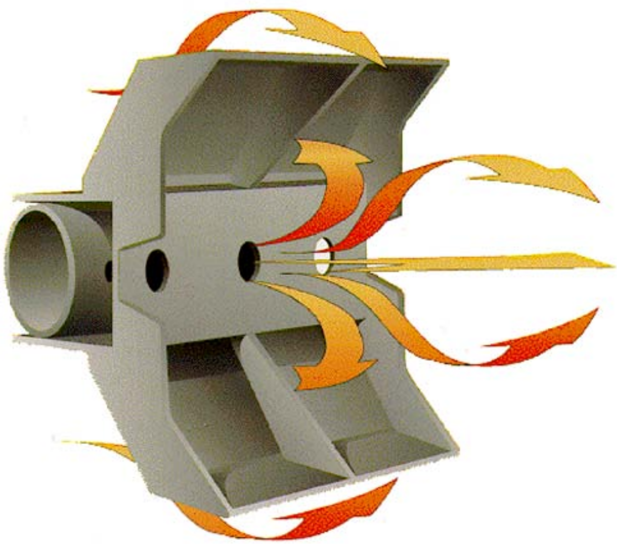
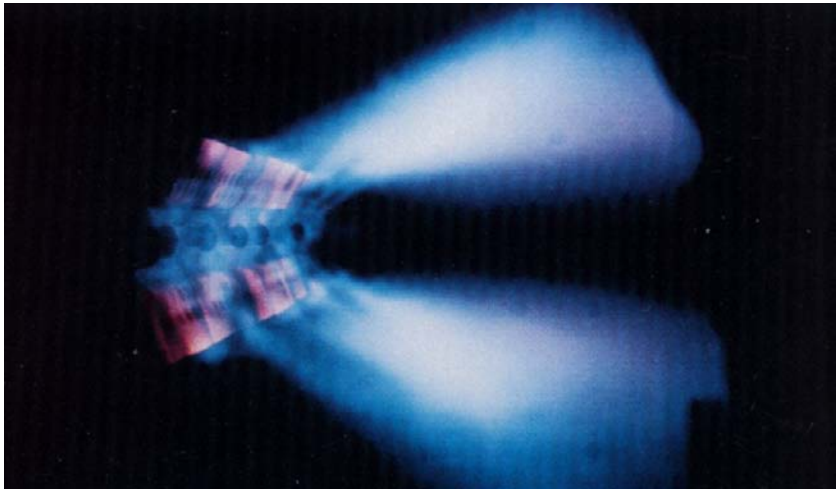
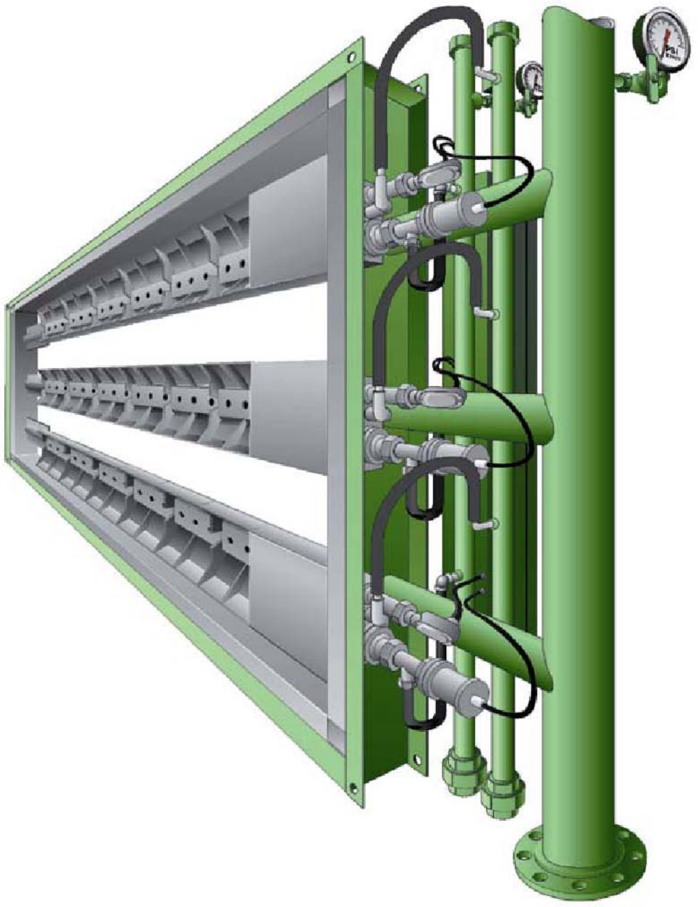
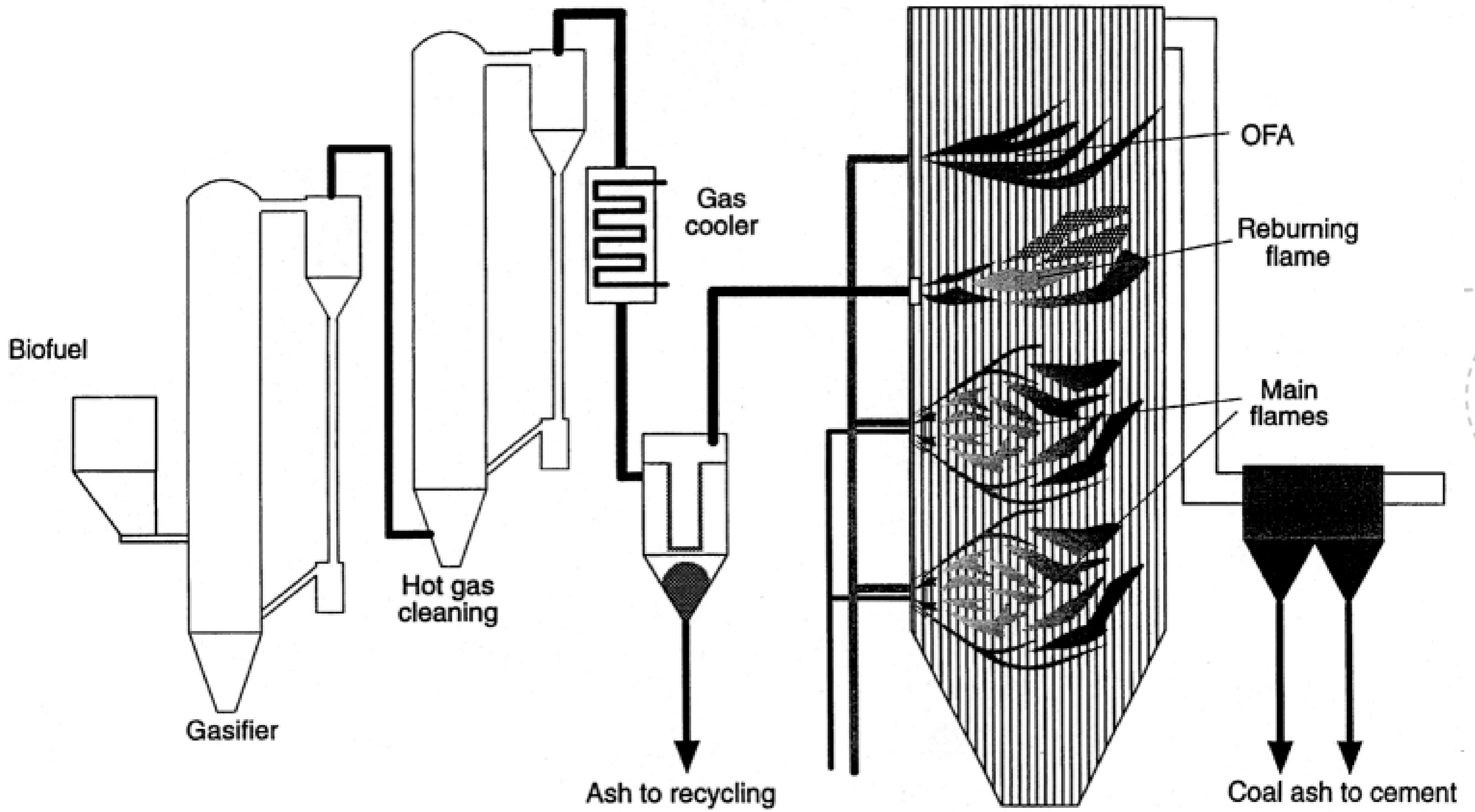
SINTEF project - Duct burner*: Co-fire of natural gas and syngas*







Gasification –co-combustion coal



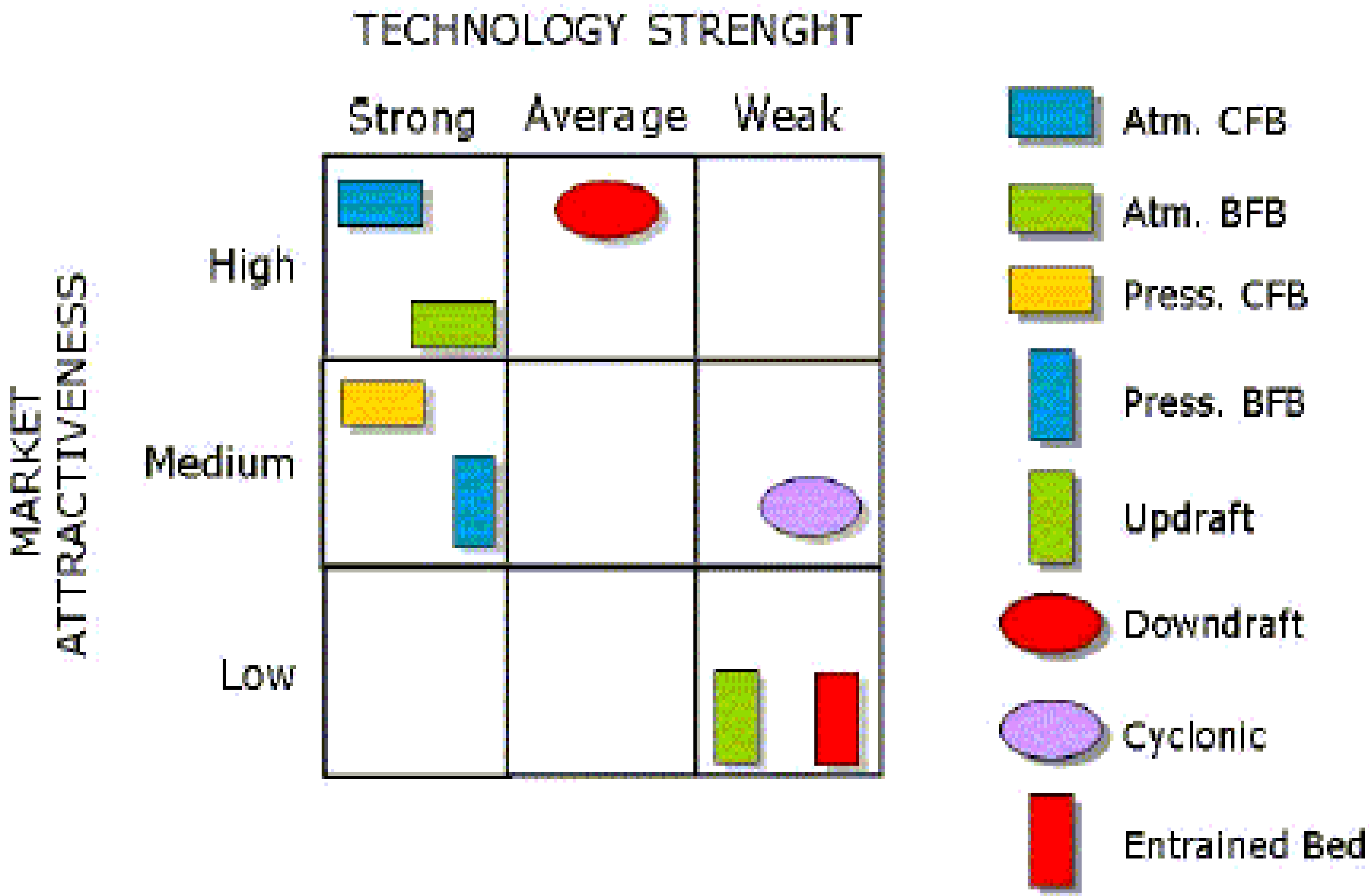
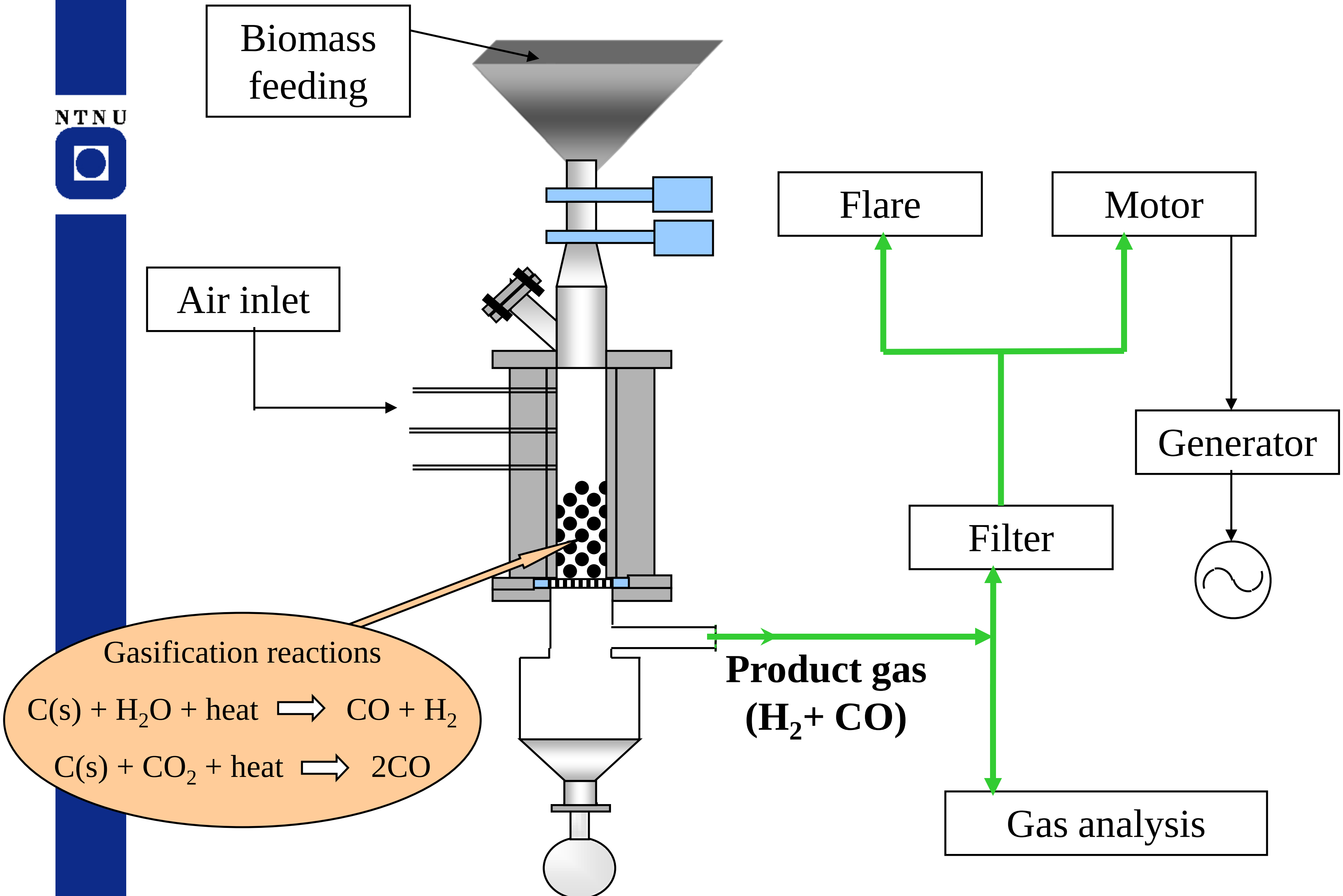


Figure 1.21: Status of gasification technologies (Modified from Maniatis, 2000).

Biomass gasification for heat and power production



Stratified downdraft gasifier

Reactor dimensions

Diameter: 100 mm

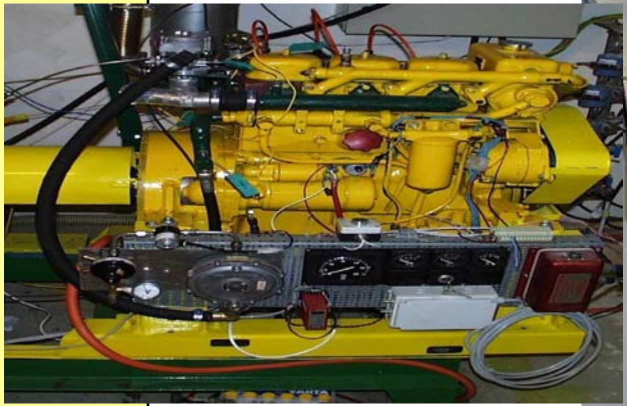
Height: 500 mm

Feeding rate

4-6 kg/h wood pellets

Air supply

6-8 Nm^3/h (8-10 kg/h)



- Controlled and stable operation.
- Air excess ratio: 0.25-0.30
- 23-26% CO, 14-16% H_2, 1.5%CH_4, 46-49%N_2, 8-11%CO_2
- 10 -14 Nm^3/h of product gas.
- Energy output: ~18 kWth
- Low heating value: 5.3 - 5.7 MJ/Nm^3
- Cold gas efficiency: 52-64 %
- Tar content: 3 g/Nm^3

Reaction kinetics and models

$$C_f + CO_2 \underset{k_{1b}}{\overset{k_{1f}}{\rightleftharpoons}} 2C(O)$$

$$C(O) \xrightarrow{k_3} CO + C_f$$

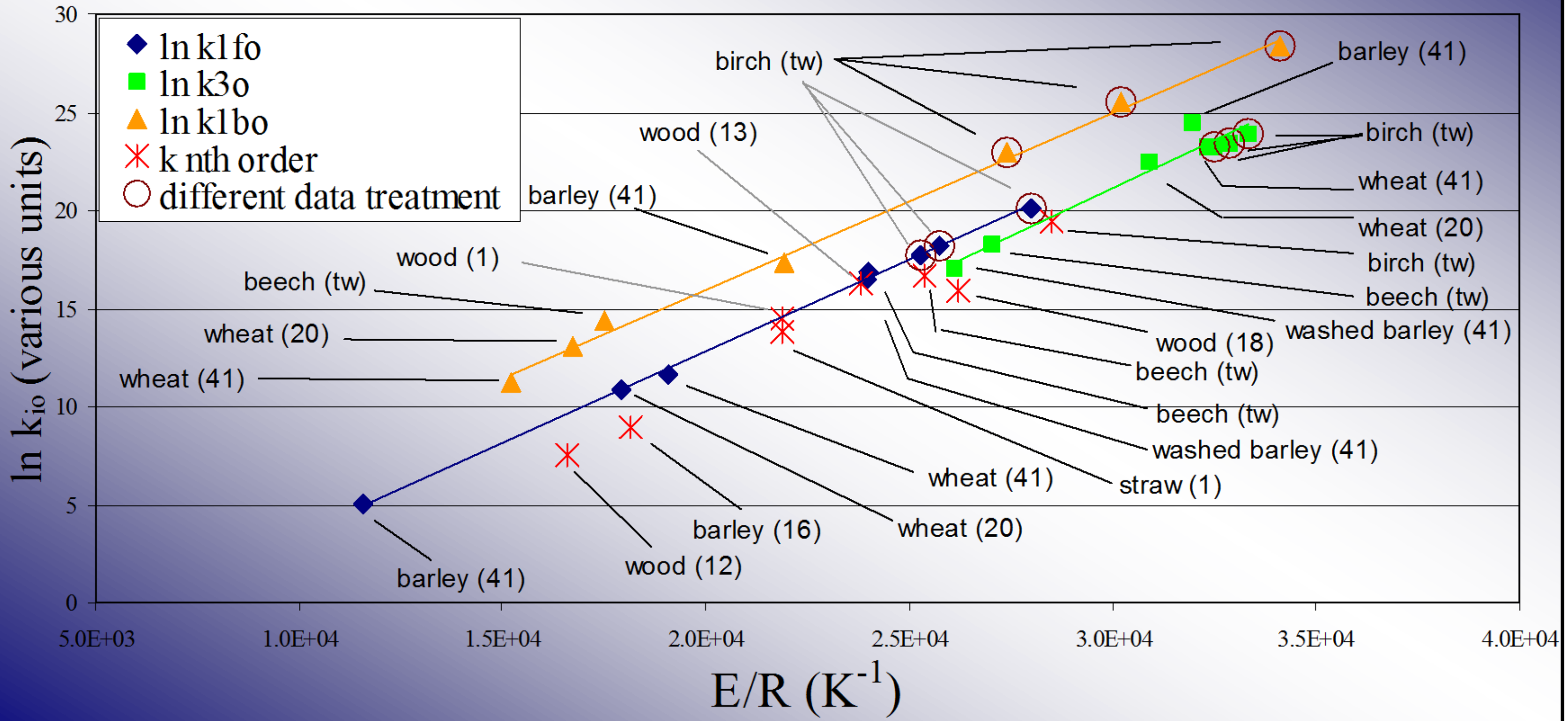
n[th] order

$$r_c = k\left(p_{CO2}\right)^n$$

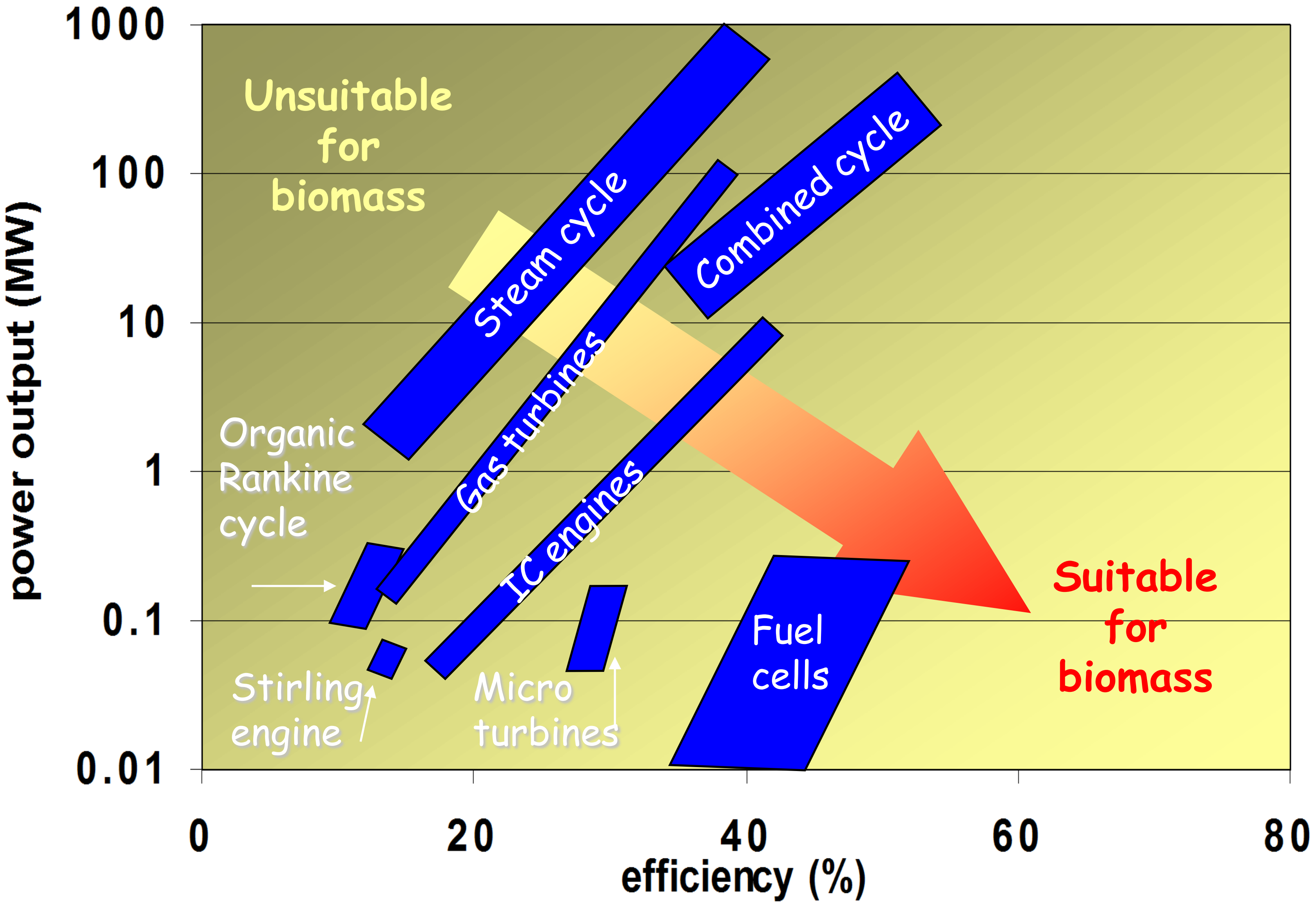
Langmuir-Hinshelwood

$$r_c = \frac{k_{1f}\, p_{CO2}}{1 + \frac{k_{1f}}{k_3} p_{CO2} + \frac{k_{1b}}{k_3} p_{CO}}$$

Kinetic compensation diagram for H_2O and H_2O/H_2 gasification.

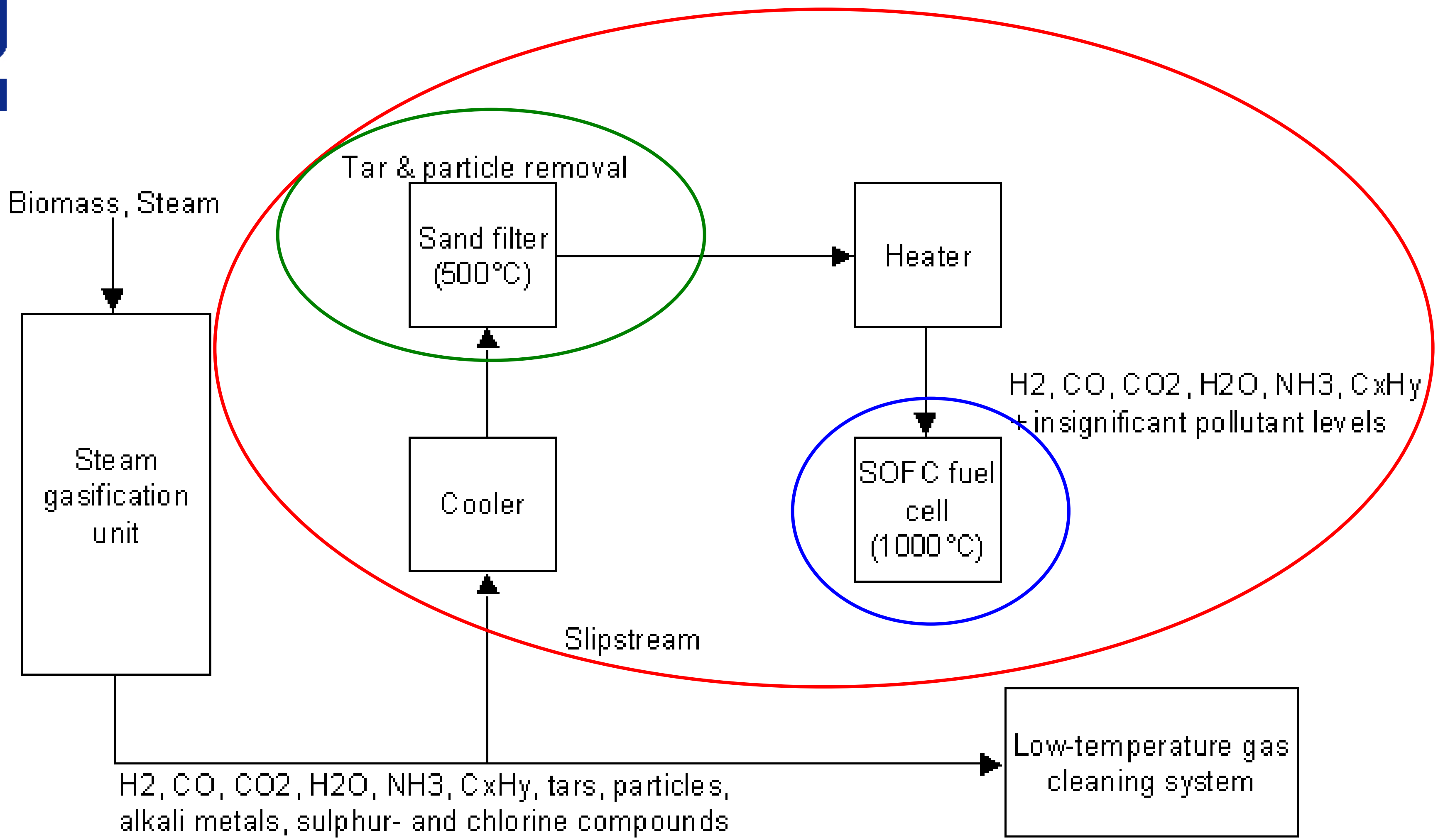


COMBINED HEAT & POWER



BioSOFC – Project contents and goal

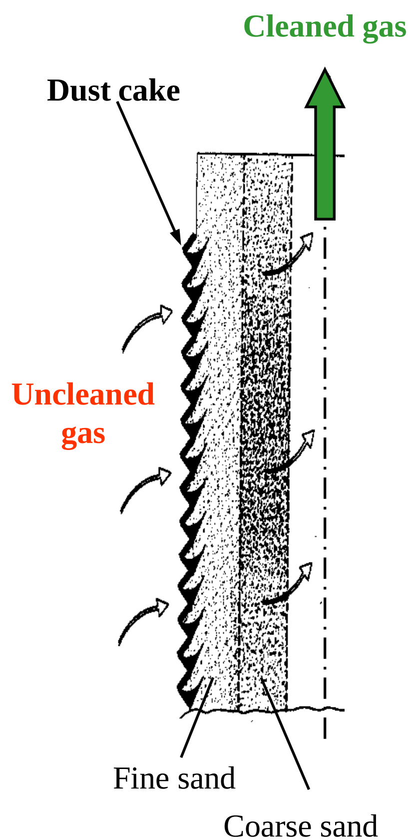
Goal: Technology development for integrated SOFC, biomass gasification and high temperature gas cleaning



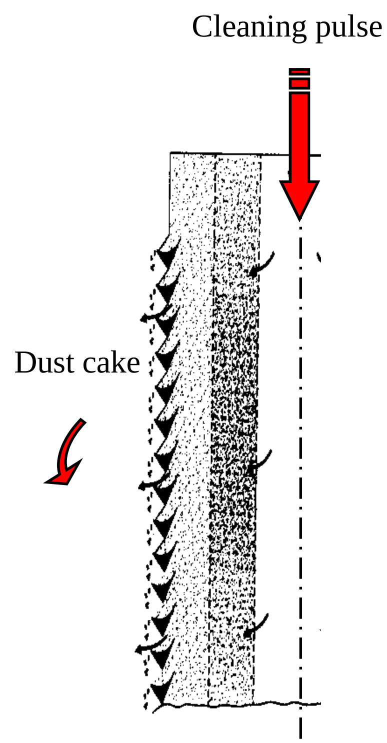
Particulate gas cleaning in combustion and gasification processes

- The Panel Bed Filter, working principle -

Normal operation



Regeneration



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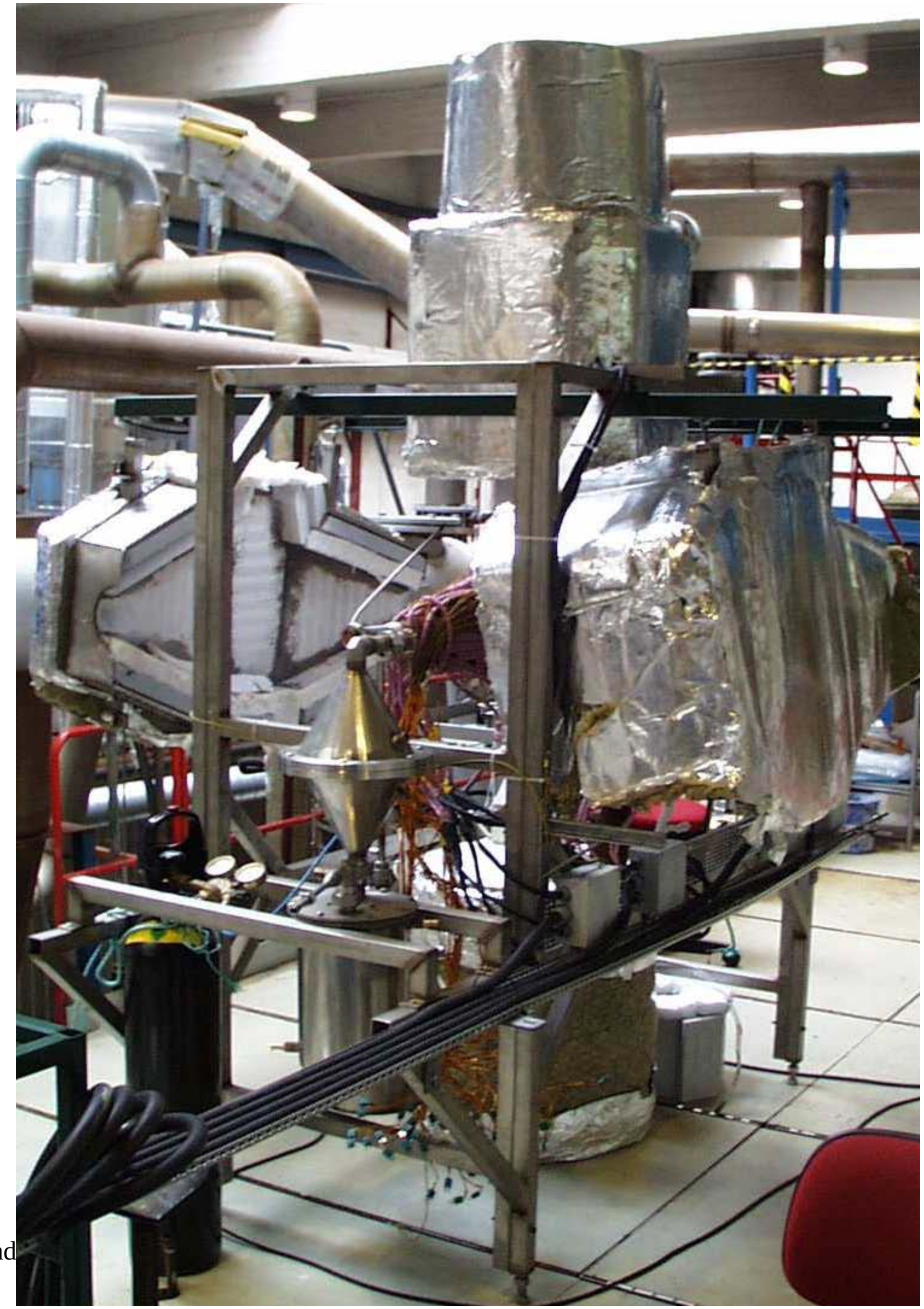
Panel Bed Filter

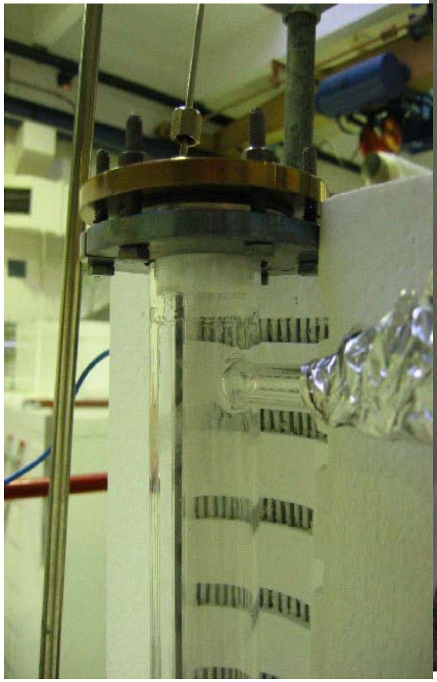


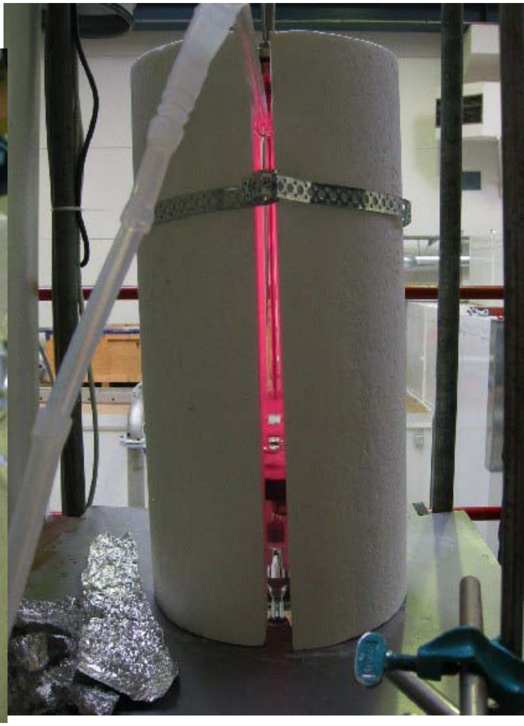
H_2S removal reactor

Sorbent screening:

- Temperture curves, flow rates, fuel gas concentrations, influence of water

- Glass cover for the thermocouple
- Glass disc to avoids flow towards top/gasket



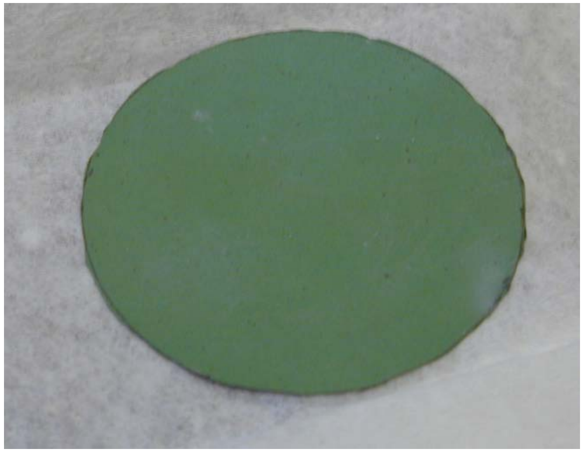


Single cell test I - Setup

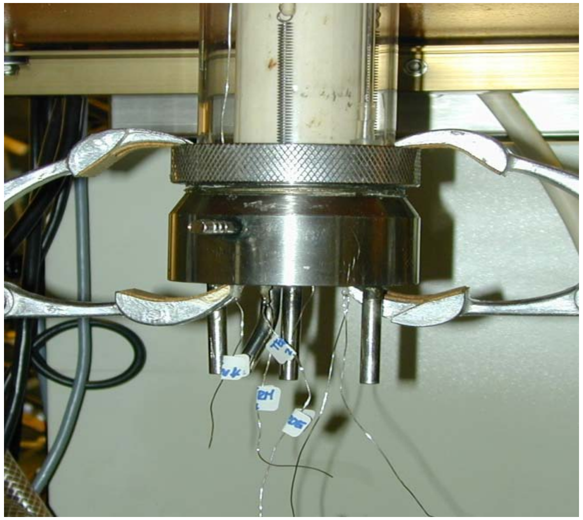
SOFC unit

Detail of the upper part

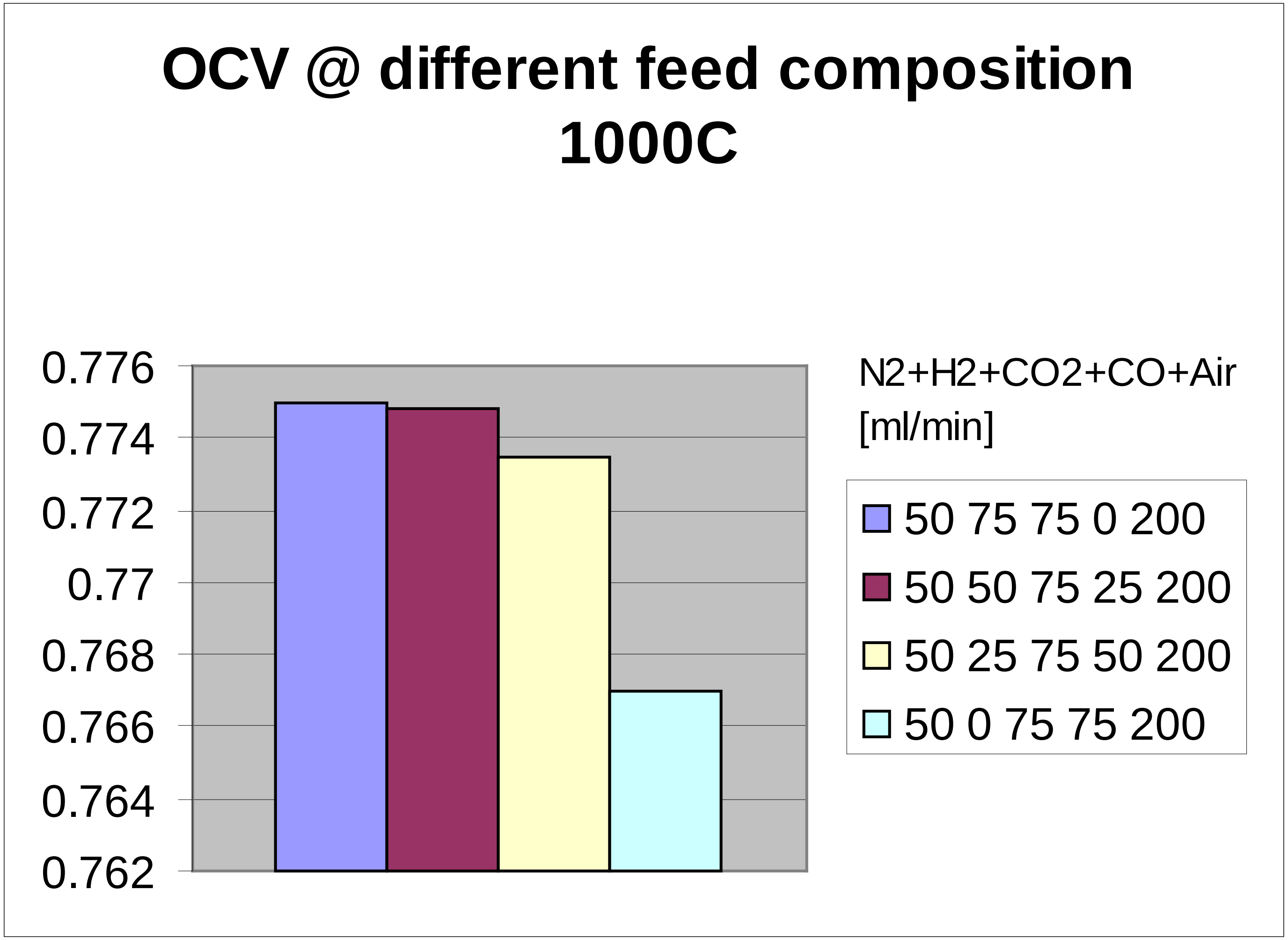
SOFC



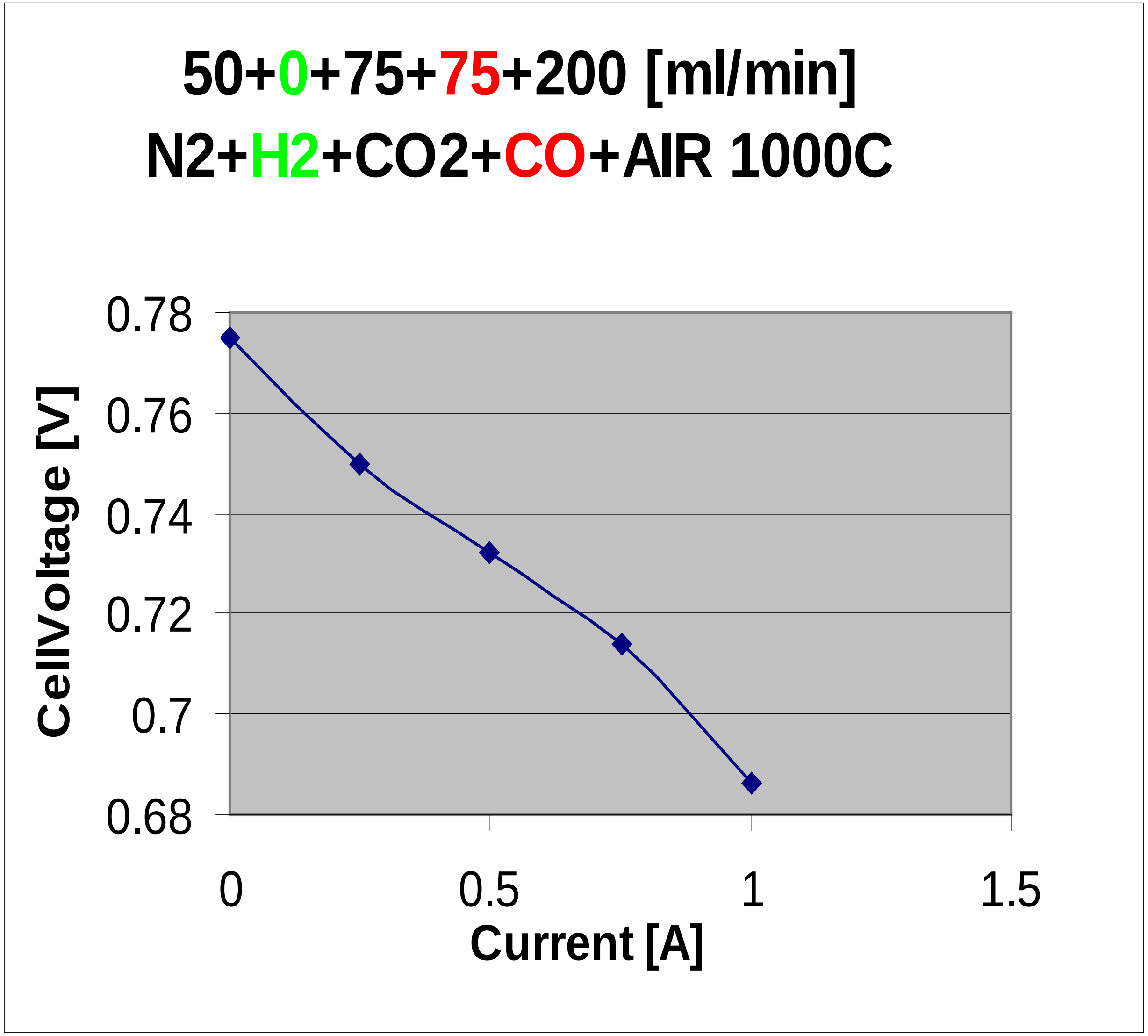
Cooling cup



Single cell test I - Results



Single cell test I - Results



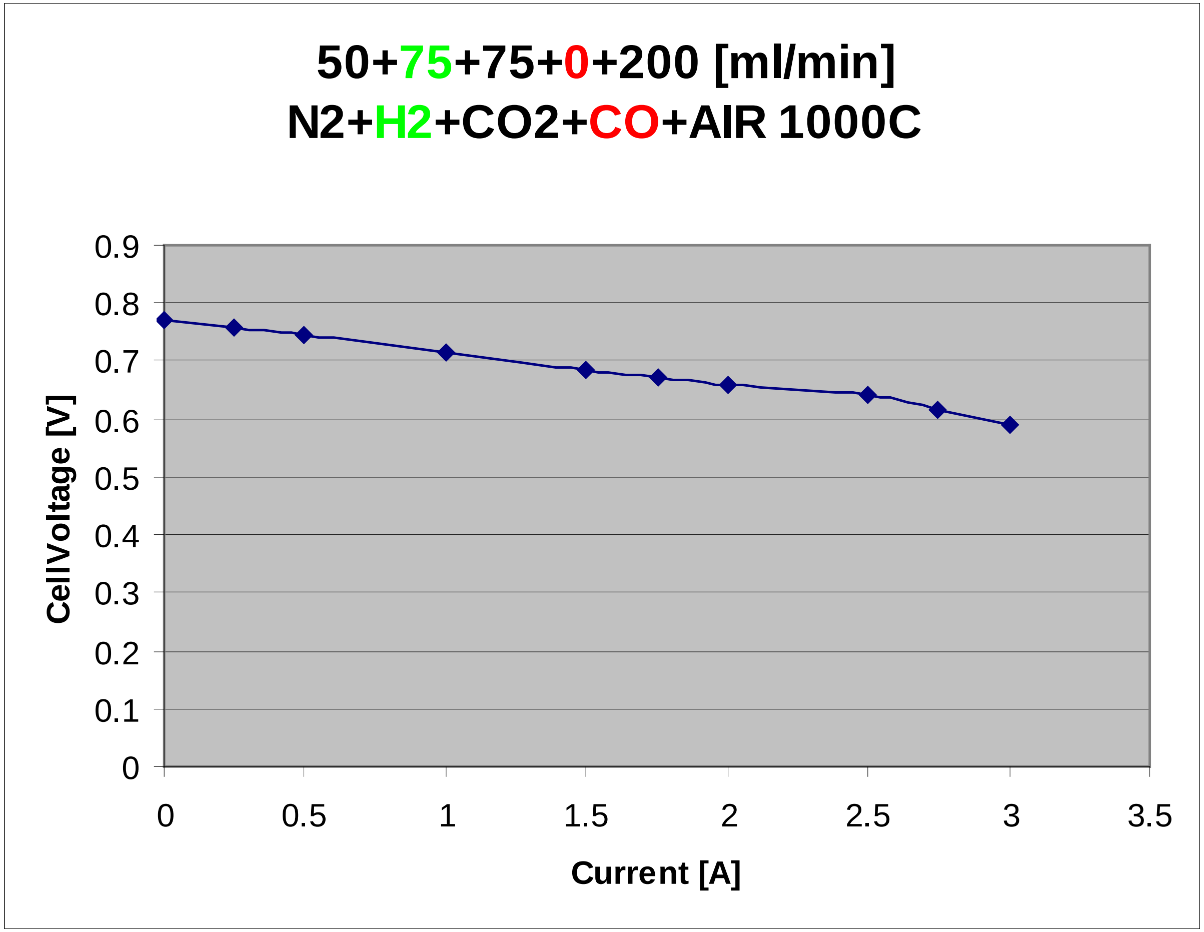
Voltage drop:

0.089V per 1A

Power:

0.69W @ 1A

Single cell test I - Results



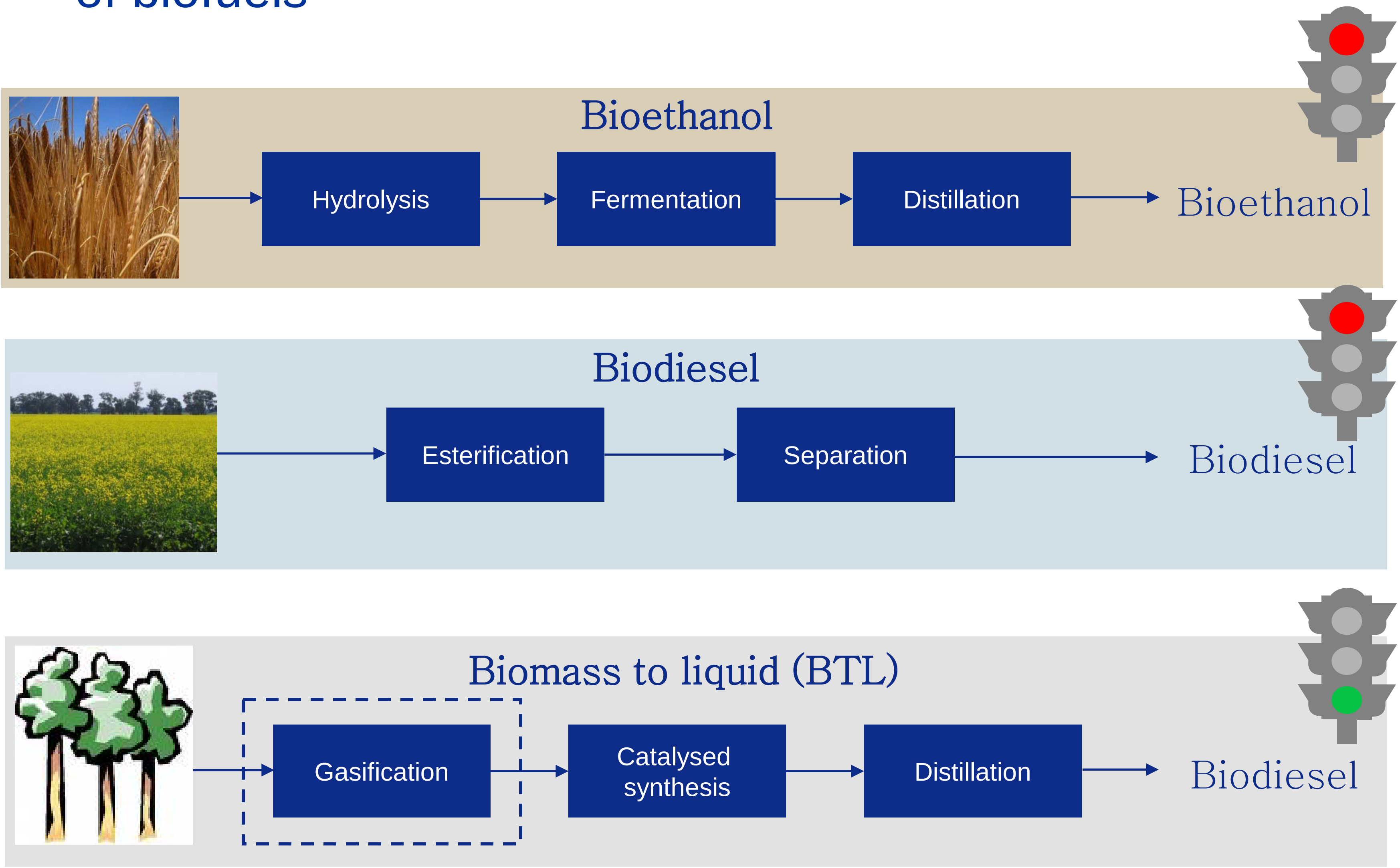
Voltage drop:

0.054V pr 1A

Power:

0.72W @ 1A

Three different technologies will coexists for production of biofuels



Both agricultural and wood based materials are involved in biofuels production

Bioethanol

Sugar cane

Brazil, India, China, Colombia

Sugar beet

Europe, China

Corn

US, China

Wheat

Europe, India, China, US

Biodiesel

Rapeseed

Europe, Canada, China, Russia

Palm

Indonesia, Malaysia, Nigeria

Jatropha

Africa, South Eastern Asia, India

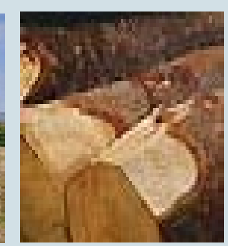
Biomass to liquids (Second generation)

Switchgrass

Miscanthus

Bagasse

Straw



Wood

Bioethanol and biodiesel have different properties

Bioethanol

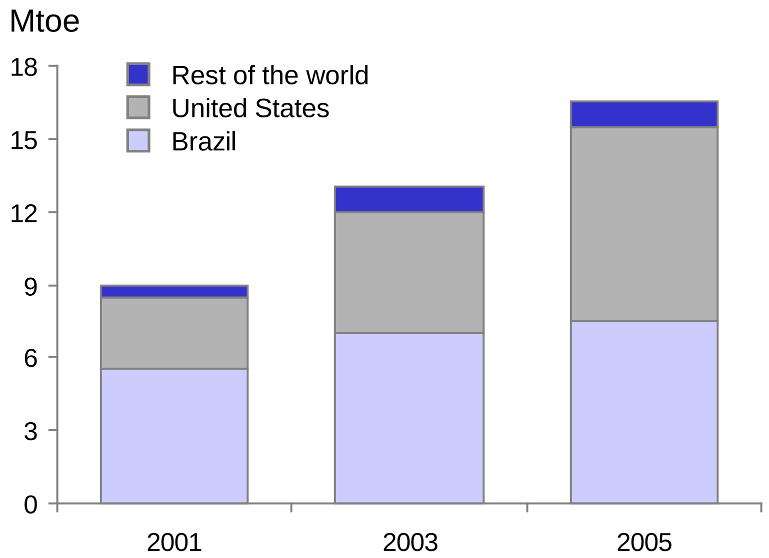
- CH_3CH_2OH
- Can be blended with gasoline (up to ~10%) or used in special cars
- Commercially available
- Brazil is the largest consumer

Biodiesel

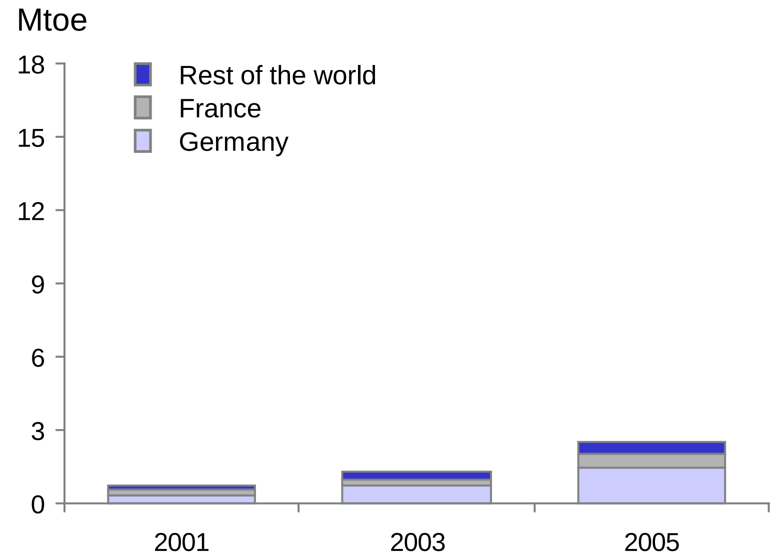
- Depends on raw material, typically $C_{10}H_{22}$ to $C_{15}H_{32}$
- Can be used in today’s diesel cars
- Commercially available from agricultural crops
- Germany is the largest consumer

World production of bioethanol eight times that of biodiesel

Production of bioethanol dominated by Brazil and US



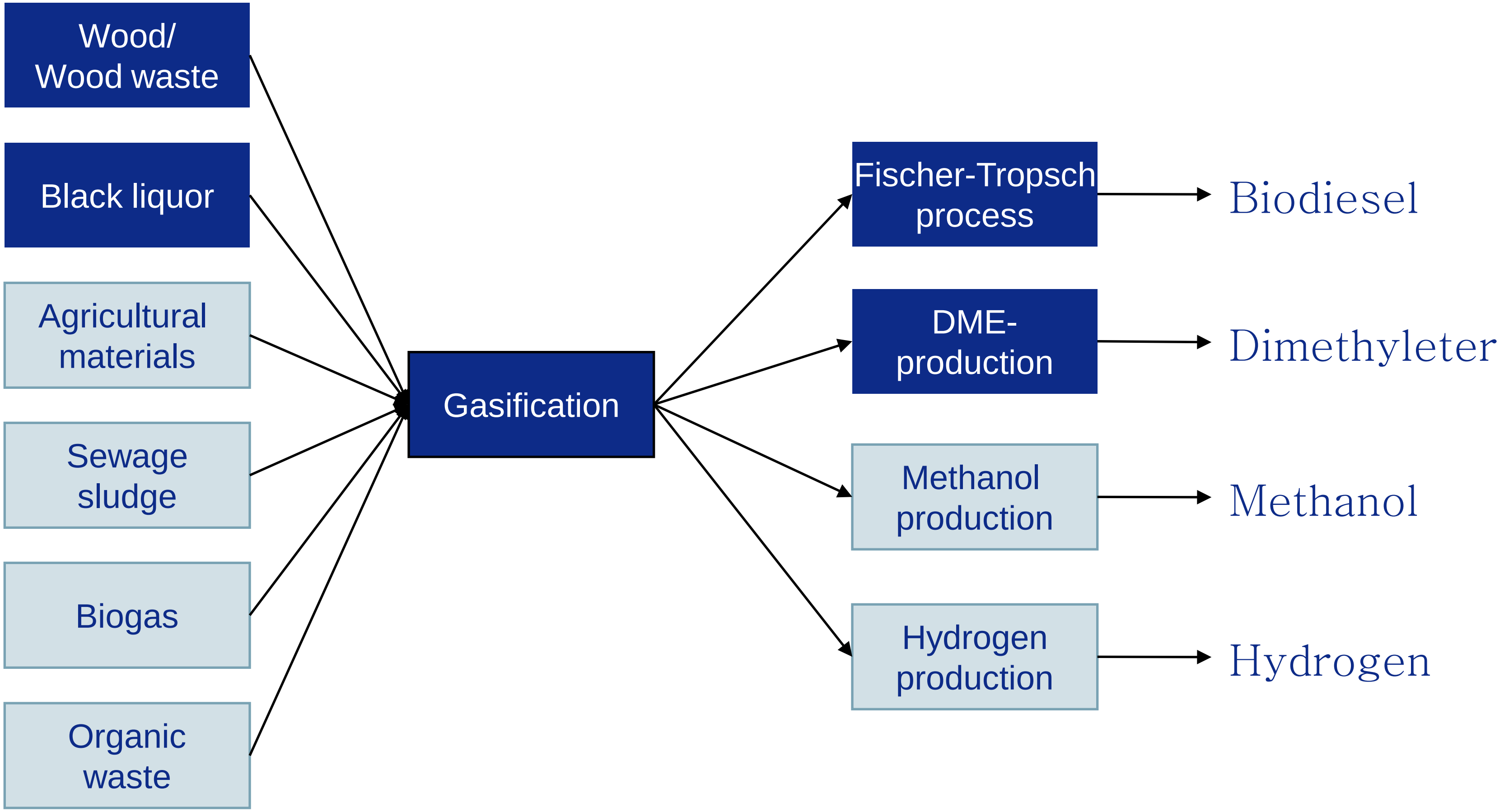
Production of biodiesel dominated by Europe



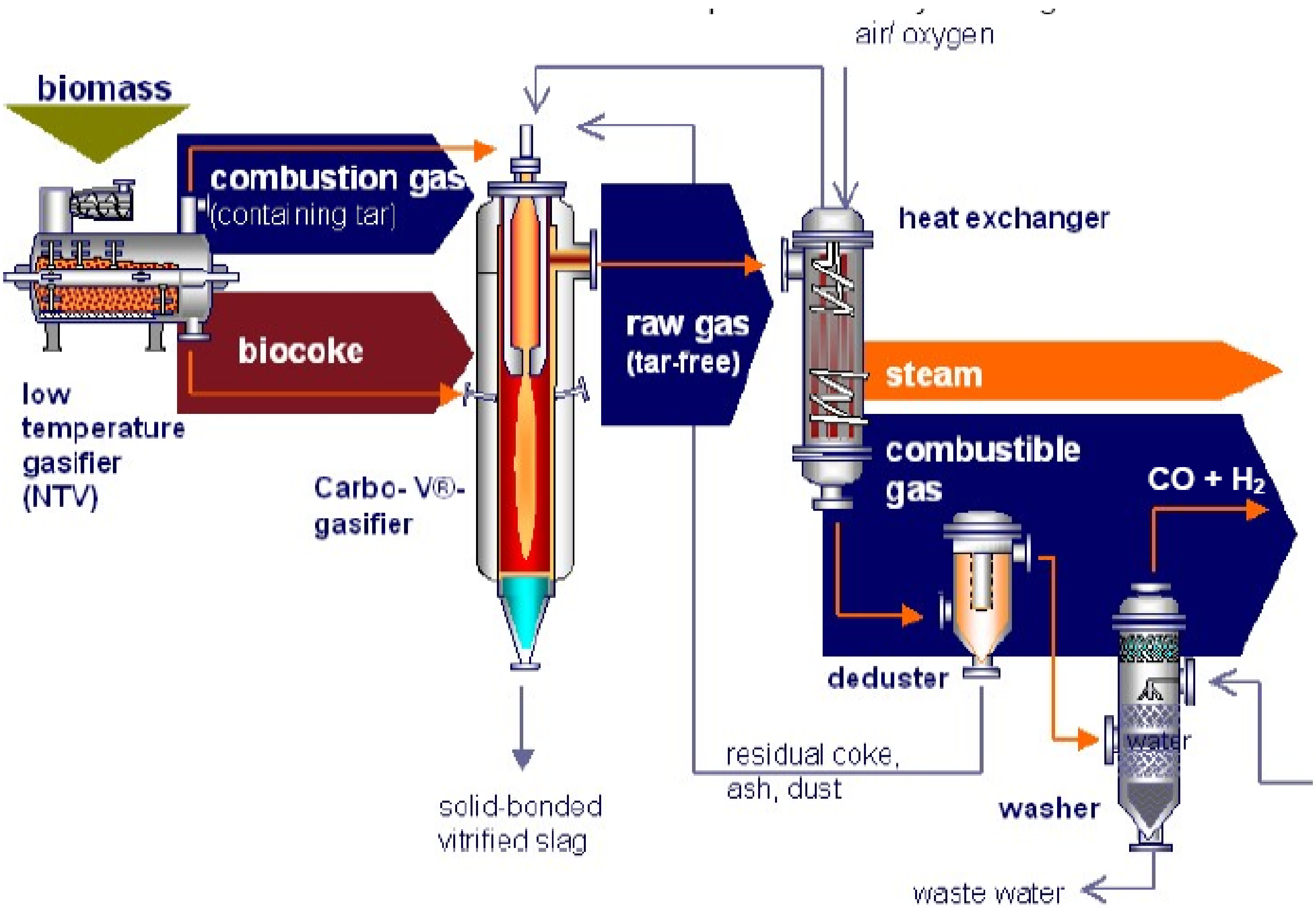
Source: IEA World Energy Outlook 2006

1

Gasification of biomass is flexible with respect to raw materials and end products

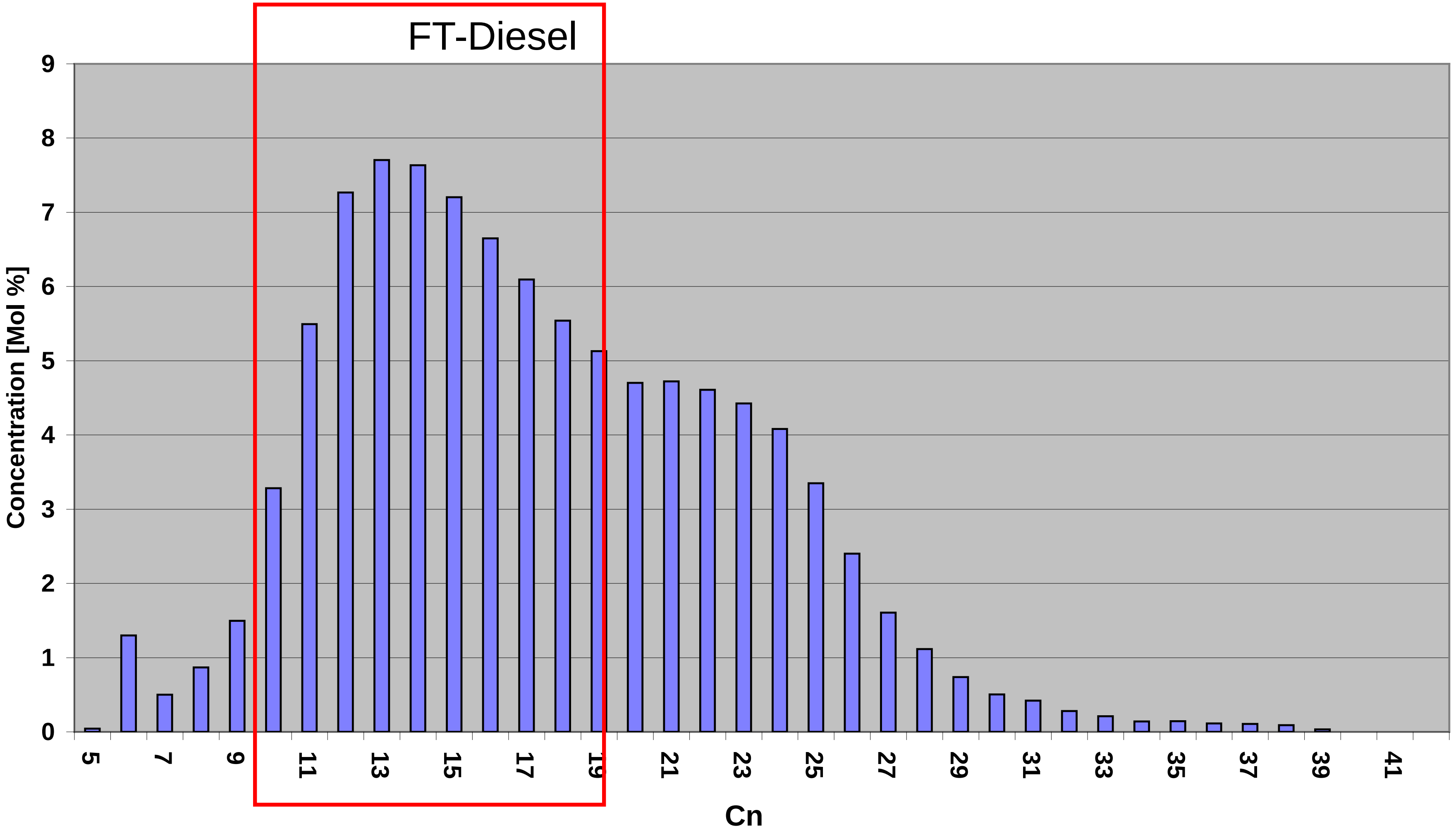


Syntetic fuels - Choren

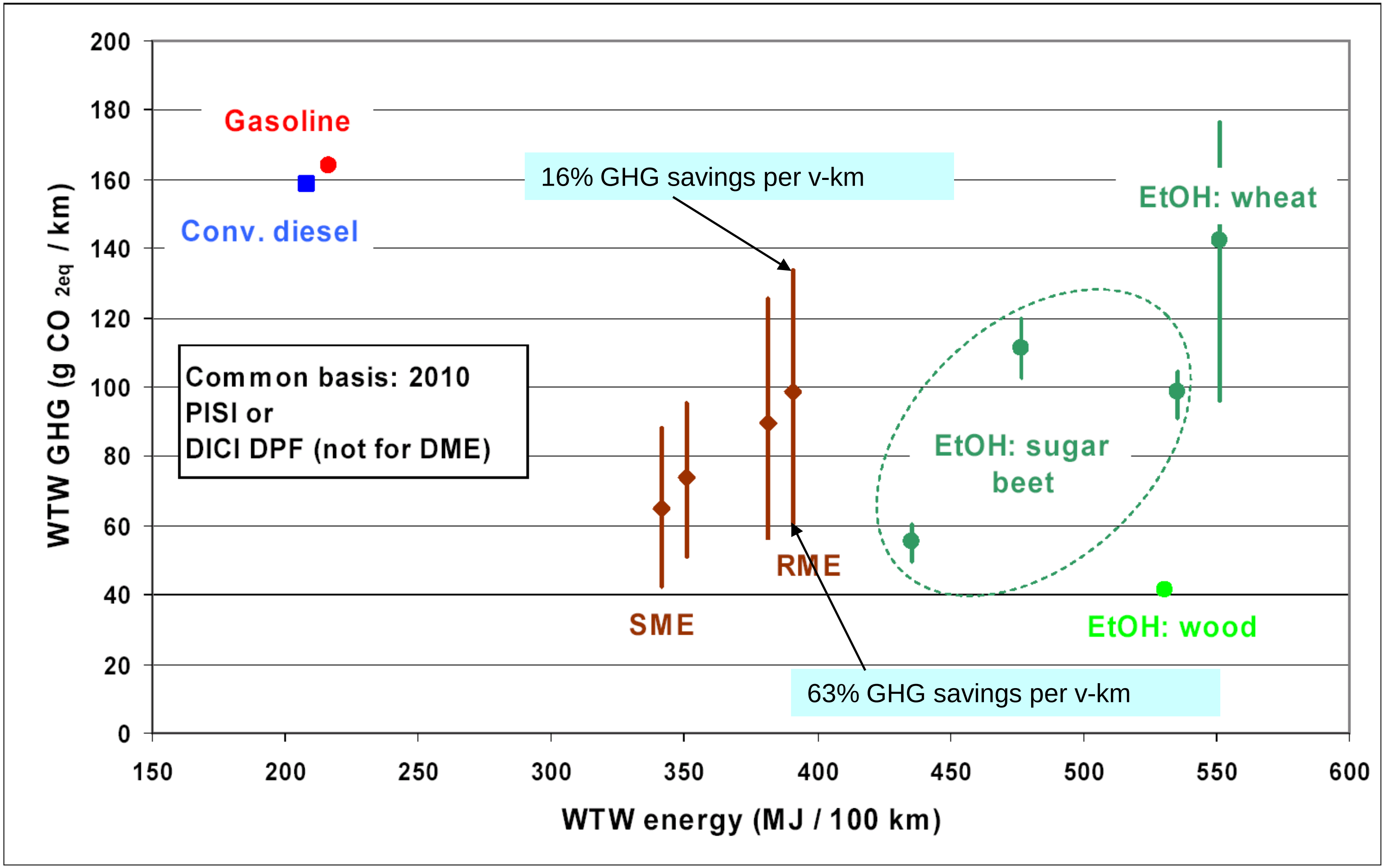


[energy from biomass]

FT-product in off gas (condensed)

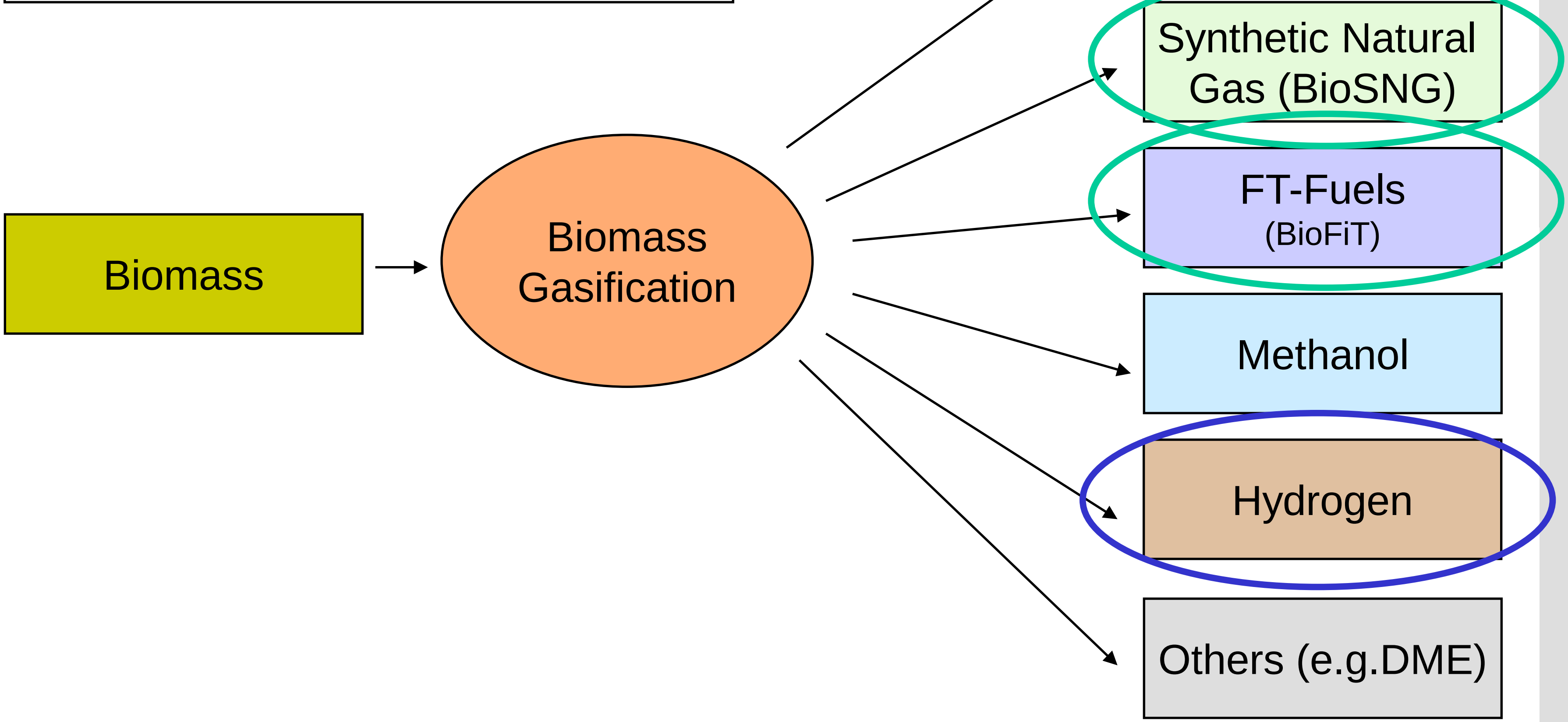


Wide range in LCA results (1)

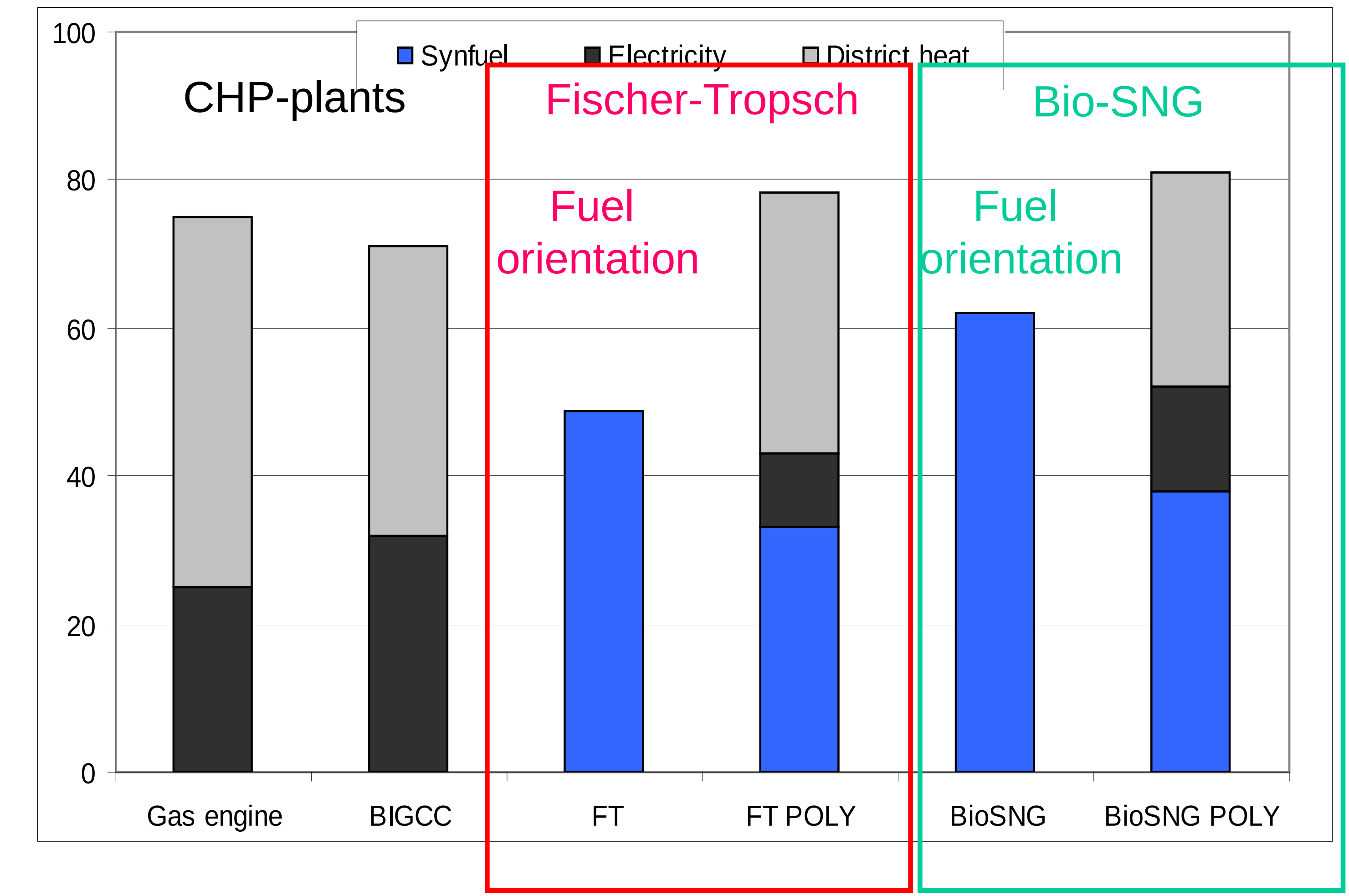


Concawe, et al., 2004.

The basic concept – "Green Chemistry"



Efficiencies in Case of Polygeneration



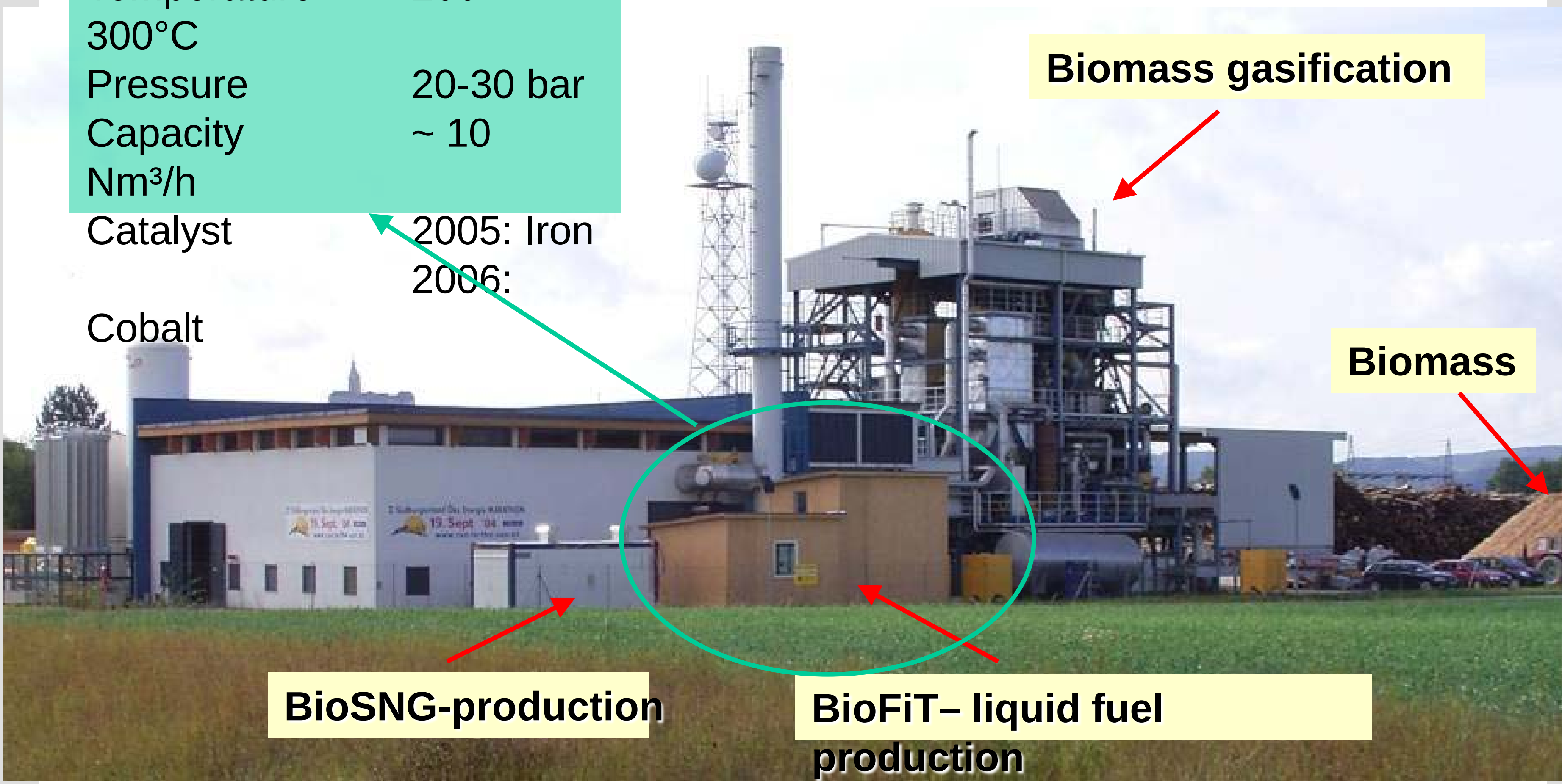
reNet AUSTRIA [energy from biomass]

$$nCO + 2nH_2 = nCH_2 + nH_2O$$

<u>Fischer-Tropsch BioFiT</u>

Slurry bed reactor

Temperature	200-300°C
Pressure	20-30 bar
Capacity	~ 10 Nm³/h
Catalyst	2005: Iron 2006: Cobalt



Conclusions

- Biofuels can be utilised in a large range of processes and by the use of many different technologies at different scales.
- Biofuels will play an increased importance in the energy system in the future.
- Biofuels is the only renewable energy resource which can be used in both heat, electricity and transport applications.
- The most important processes will be combustion and gasification.
- Combustion and co-combustion will be most important for heat, power and CHP applications.
  - Particles, UHC, CO small plants
  - Fouling/slagging (Cl, K, S, Na) larger plants
- Gasification/combustion/co-gasification can be the source of both (heat), electricity and transport fuels including hydrogen
  - Gas cleaning like tars, H_2S, particles, alkali metals and chlorine compounds
- Gasification also has the potential for advanced processes like high temperature fuel cells.