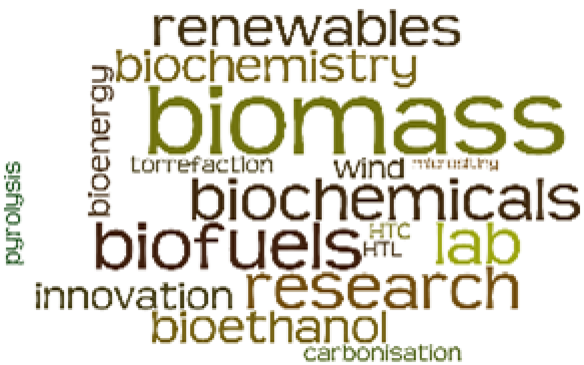
Small scale CHP for decentralised energy generation and grid balances: which challenges and opportunities for gasification?

David Chiaramonti

RE-CORD

Renewable Energy Consortium for Research and Development

Florence, Italy



RE-CORD: Who we are

UNIVERSITÀ DEGLI STUDI FIRENZE

- ✓ **Public-private no profit research center**, participated by the **Univ.of Florence**
- ✓ focused on **R&D in Biomass / Bioenergy /Bioproducts**
- ✓ **Pilot/demo plants, chemical lab**

MEMBERS

Public

- **Univ. of Florence**
  - ***CREAR*** *– Interdepartmental Center led by the Industrial Engine.Dept.*
  - ***Montepaldi*** *–Univ. Special Farm.*
- **Pianvallico**
  Municipalities of Scarperia & San Piero and Borgo San Lorenzo (Florentine Metropolitan area).

Private

- **Spike Renewables**
  Engin. company specialized in energy projects.
- **Bioentech**
  Innovative Start-up on thermochem.conversion.
- **ETA-Florence**
  Communication, Dissemination, Intern.projects.

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Main areas of work

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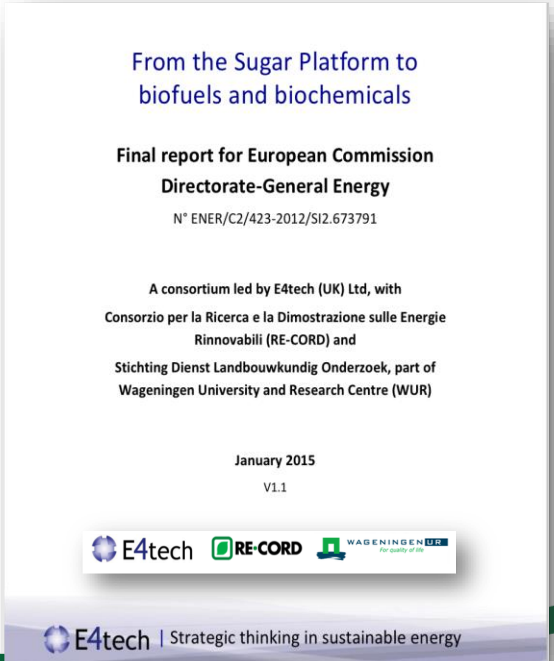
Budget (contributions) from R&D activities on Biomass/Renewables:	
CREAR (2002-2015)	> 6.1 M€
RE-CORD (2012-2015)	≈ 2.3 M€
EU/Intern. Projects	14 *(3 coord)*
National projects	11 *(6 Coord)*

Patents related to the research work of RE-CORD/CREAR personnel	
Nr of patents	7

Publications	
Journal papers	32
Conf.Proceedings (incl.ISI Indexed)	123
Edited Intern.Conf.Proceedings	3
Magazines	7
Thesis	>70
Studies (EC, Companies)	7

- **Fast Pyrolysis** (use in CHP and Heat)
- **Intermediate/Catalytic & Slow Pyrolysis/Carbonisation**
- **Gasification** (fixed bed, small scale)
- **HTL e HTC -** Hydrothermal Conversion of biomass
- **Liquid Biofuels** (**road & aviation**) from lipids/VO/UCO
- **Lignocellulosic ethanol chain** and coproducts
- **Algae**: engineering of cultivation system + downstream process. into **biofuels and bioproducts**
- **Biofuel Policy**
- ***Studies* (EC): Sugar Platform, Template First-of-its-kind…**


From the Sugar Platform to biofuels and biochemicals

Final report for European Commission Directorate-General Energy

N° ENER/C2/423-2012/SI2.673791

A consortium led by E4tech (UK) Ltd, with Consorzio per la Ricerca e la Dimostrazione sulle Energie Rinnovabili (RE-CORD) and Stichting Dienst Landbouwkundig Onderzoek, part of Wageningen University and Research Centre (WUR)

January 2015

V1.1

E4tech RE-CORD WAGENINGEN UR

E4tech | Strategic thinking in sustainable energy

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Renewables, cogeneration ...and.. INTEGRATION

Global scenario: Oil Prices at low end…strong fluctuations

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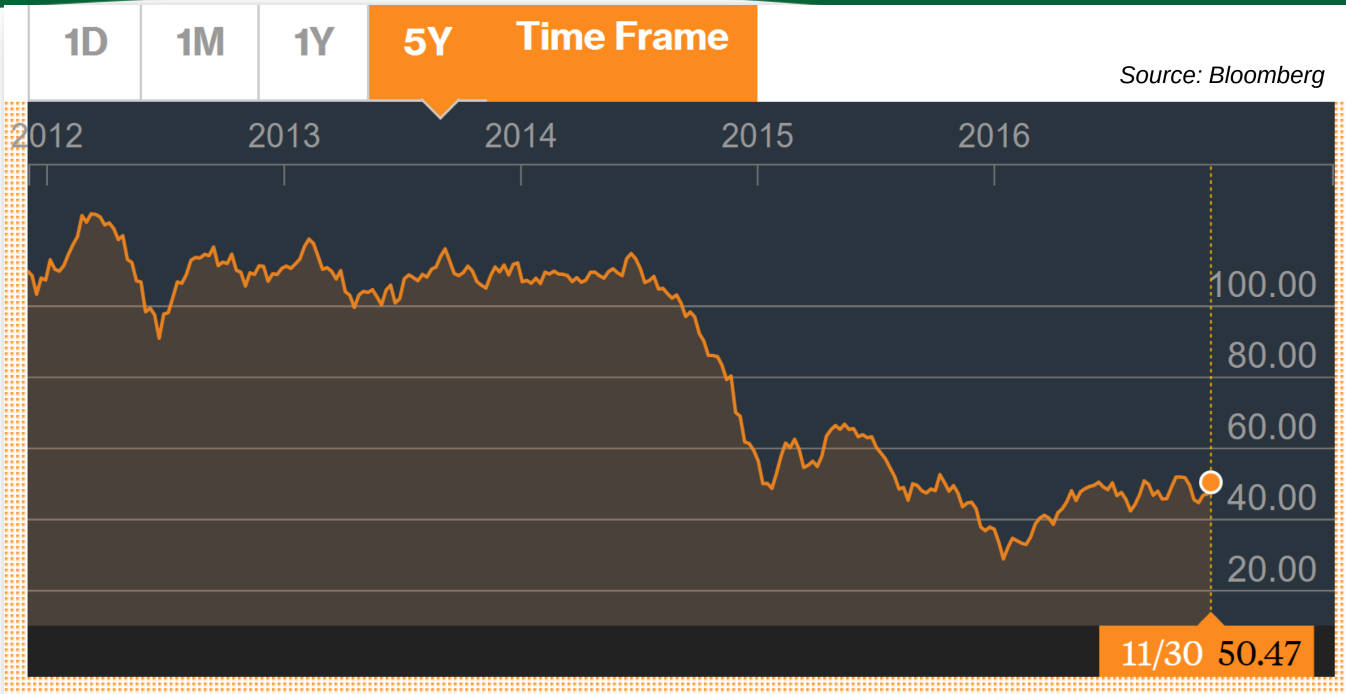

- "Brent" (UK Stock Ex) during last five years.
- 18/1/2016: <u>28.55 US$/bbl</u>. MIN for last 12 years.
- Same for WTI (North America)

✓ IRAN is the 5th largest OPEC oil producer. Lifting sanctions to IRAN → +100.000 bbl/d (3.7 % of their total prod.), and +400.000 bbl/d in 1 month

✓ This generated further drop in barrel value.

30 Nov 2016, Wien (A): agreement reached to reduce oil production by 1,2 Mbbl/d (at 32,5 Mbbl/d)

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EC TARGETS

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2020 Package

GHG Emissions Reduction
20% compared to 1990
Binding via ETS and Effort Sharing Decision

Increase of Renewable Energy Use
20% of total energy consumption
Binding via Renewable Energy Directive

Increase of Energy Efficiency
20% compared to baseline scenario
Binding via Energy Efficiency Directive

2030 Framework

GHG Emissions Reduction
40% compared to 1990
Binding via ETS and ESD methodology

Increase of Renewable Energy Use
27% of total energy consumption
Only binding at EU level

Increase of Energy Efficiency
27% compared to baseline scenario
Only binding at EU level

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IEA BIOENERGY / EC-DG ENERGY

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- Study on

BIOMASS FOR BALANCING THE GRID

- Two main focuses
  - ✓Policy development
  - ✓Opportunities for R&D
- Final document expected end 2016 (draft ready)

IEA Bioenergy

European Commission

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Share of bioenergy and other renewable sources in final energy consumption in EU 28 (2013, Mtoe)

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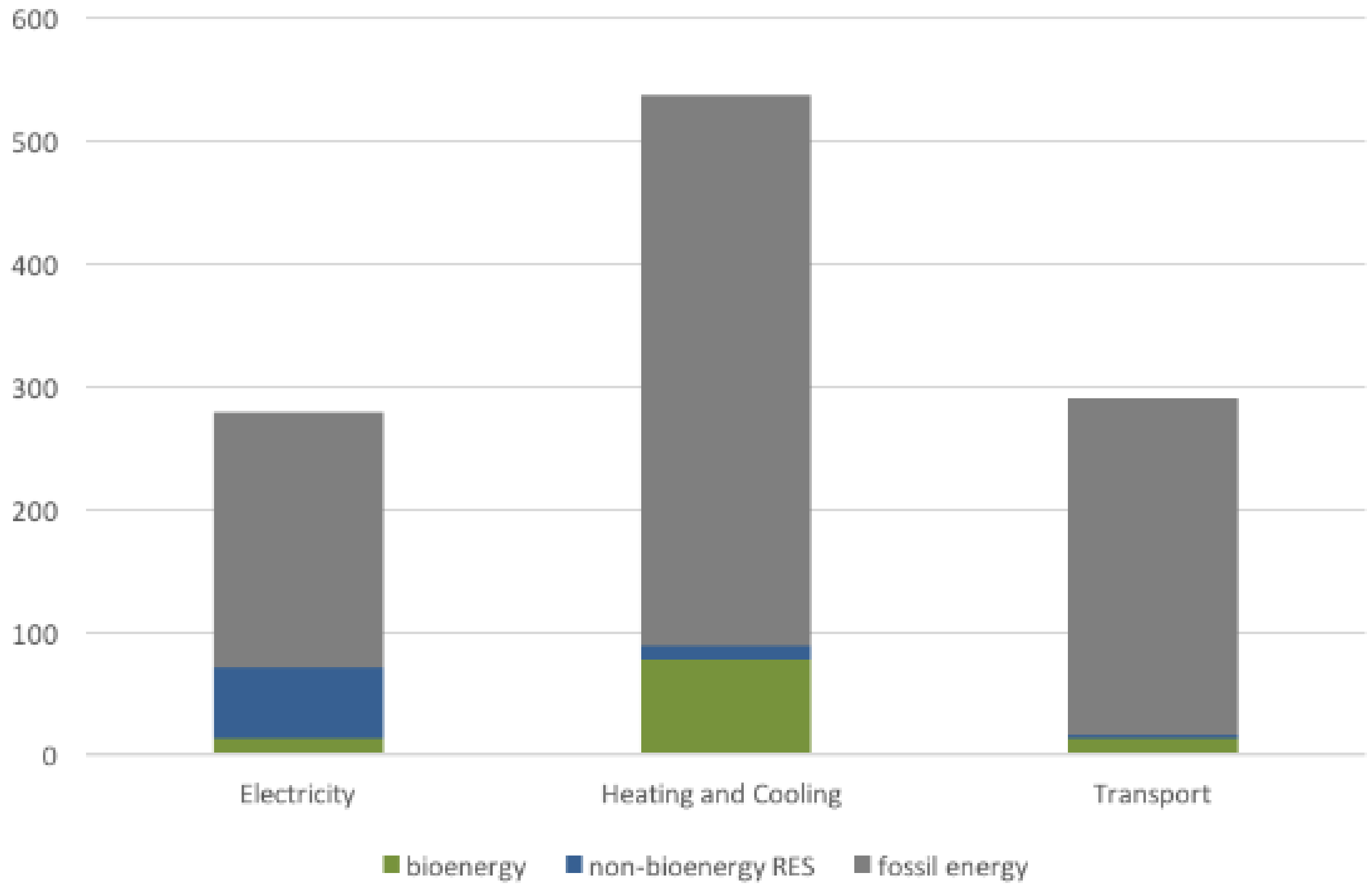

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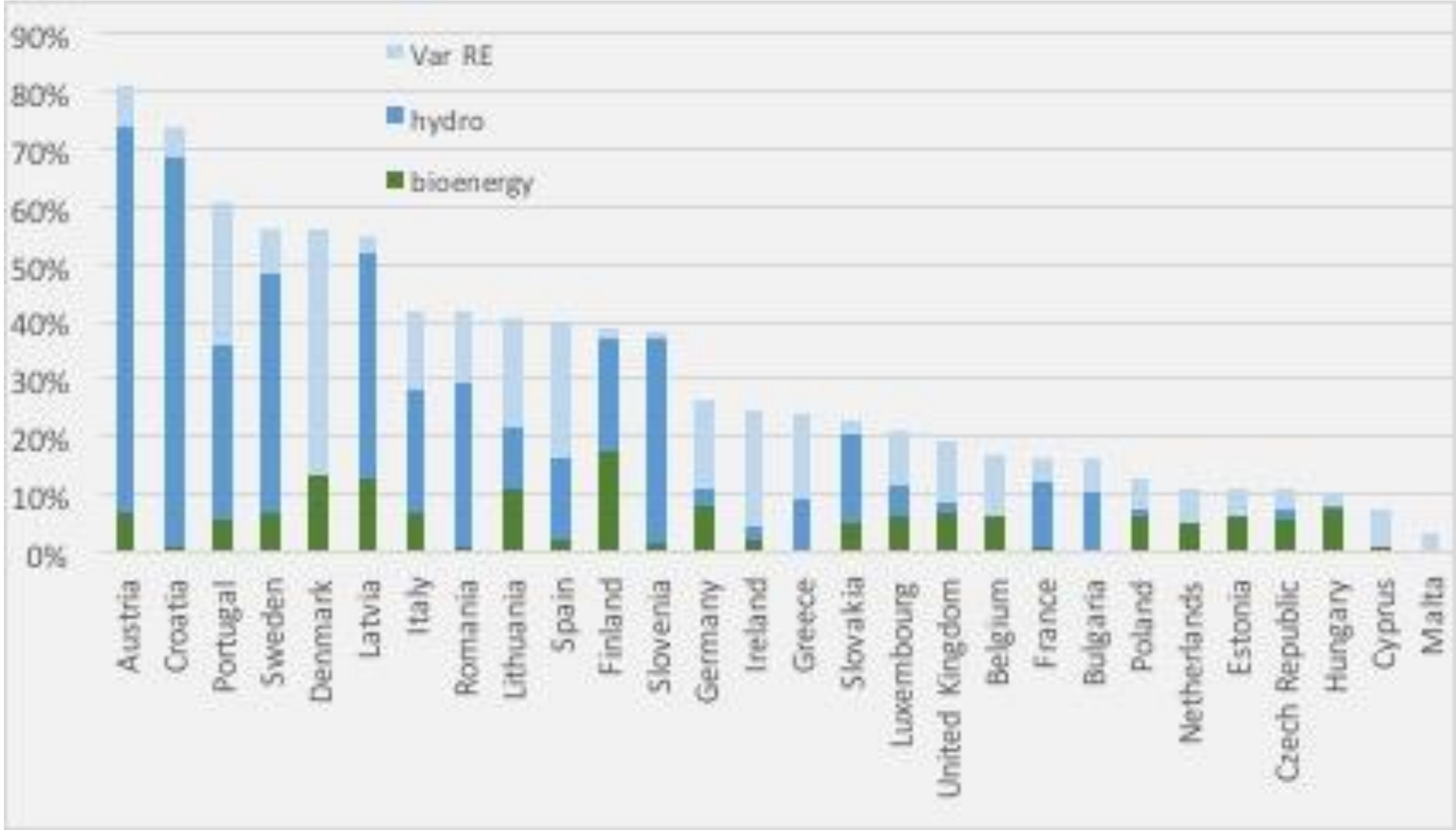
Overview of the energy sources that provide renewable electricity in total electricity generation in 2014



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Member States ranked on the share of Variable renewable energy in total electricity generation (in 2014)

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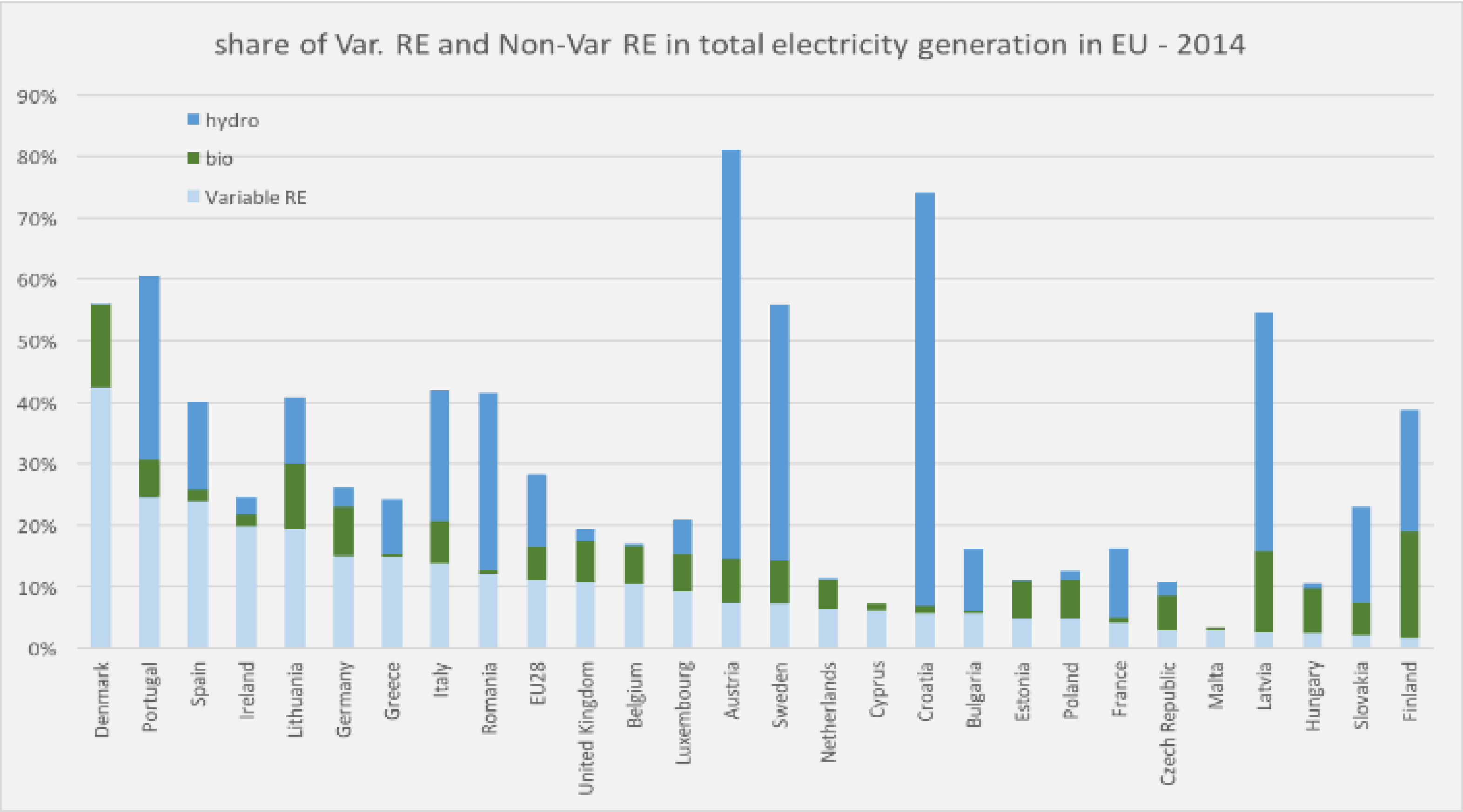

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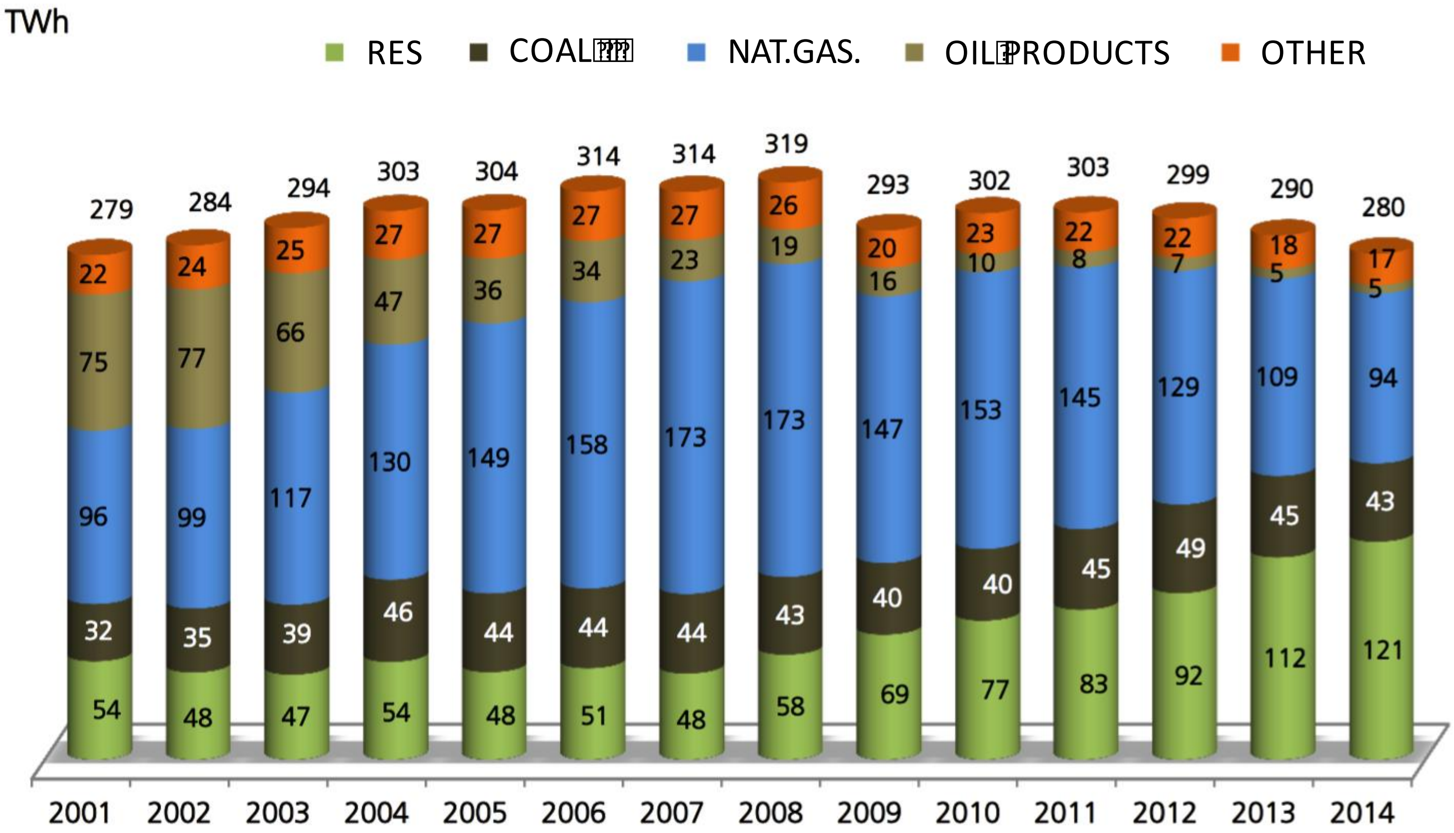
Renewable Power Generation in Italy



	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
OTHER	22	24	25	27	27	27	27	26	20	23	22	22	18	17
OIL PRODUCTS	75	77	66	47	36	34	23	19	16	10	8	7	5	5
NAT.GAS.	96	99	117	130	149	158	173	173	147	153	145	129	109	94
COAL	32	35	39	46	44	44	44	43	40	40	45	49	45	43
RES	54	48	47	54	48	51	48	58	69	77	83	92	112	121
Total	279	284	294	303	304	314	314	319	293	302	303	299	290	280

Germany: Shifting back to RES from Nuclear *(Source: GearUp, on BP Stat.Review 2013)*

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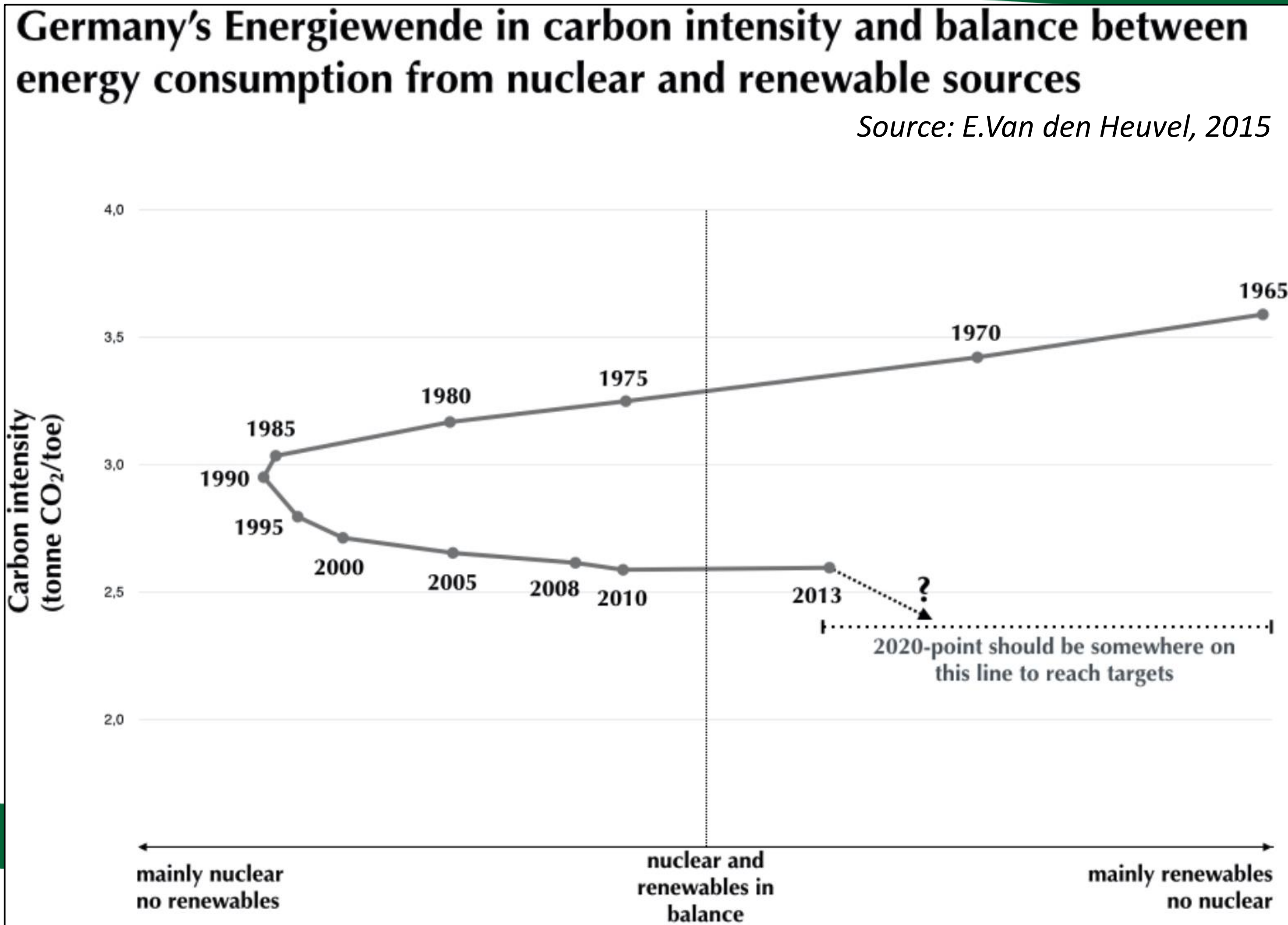

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BIOELECTRICITY IN THE EU, AND SHARE OF CHP, 2014 *(solid biomass only)*

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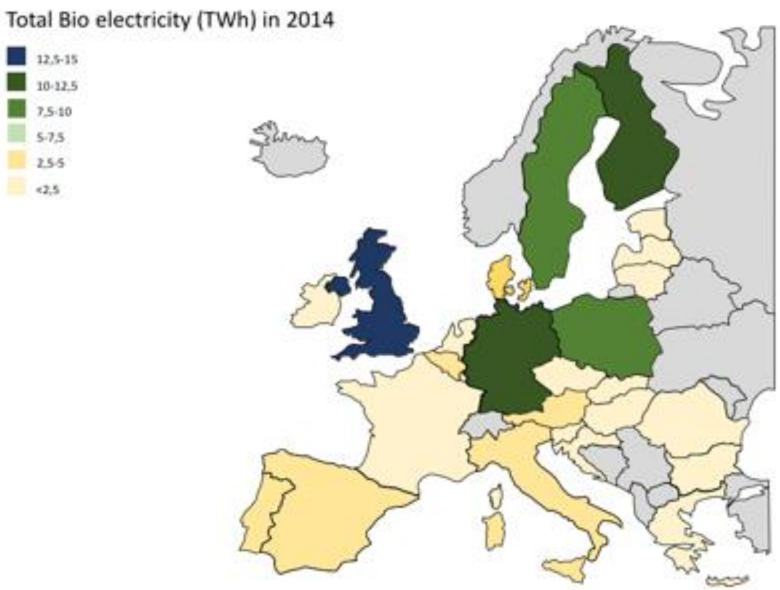
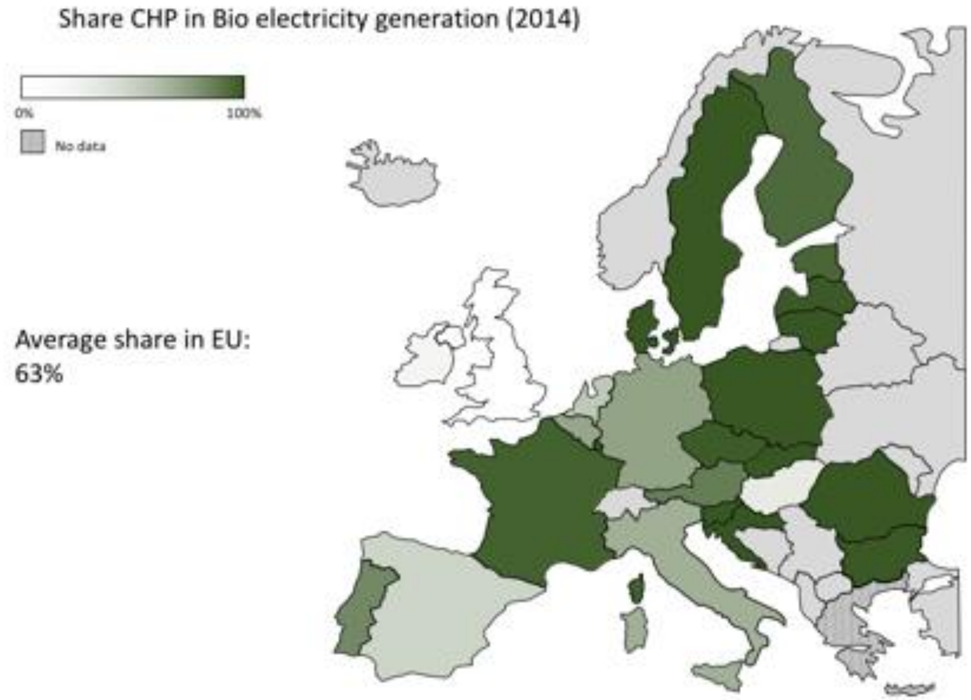


Based on: Eurobserver, 2015



Based on: Eurostat, Eurobserver, 2015

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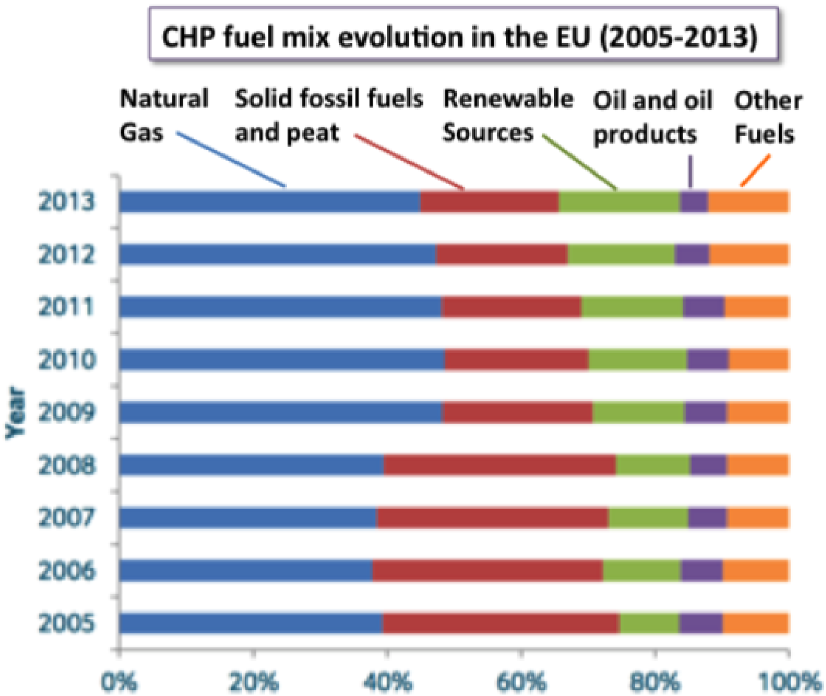
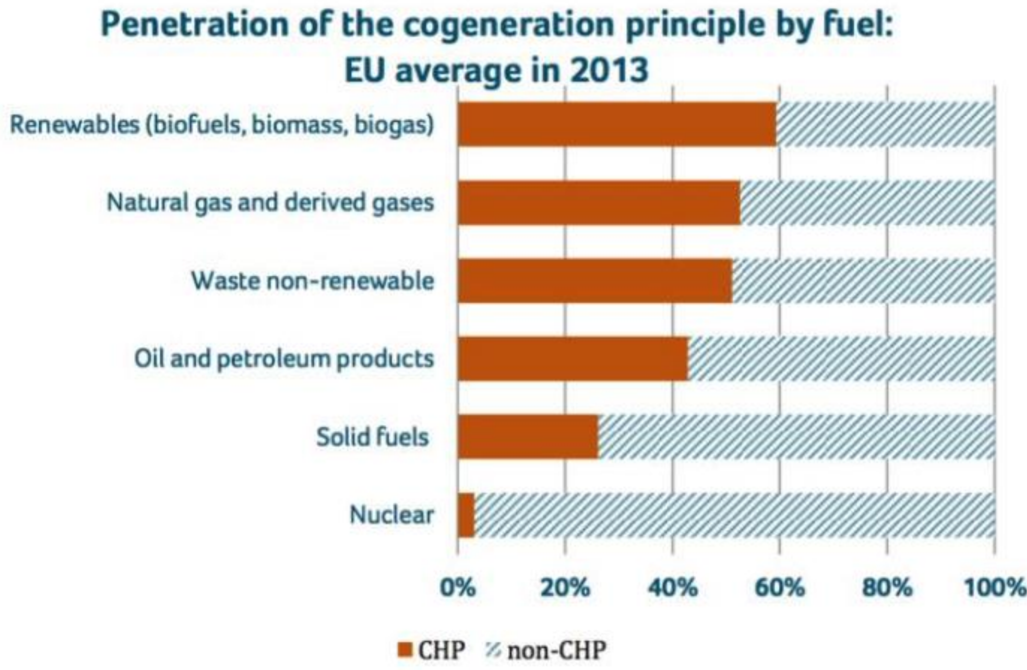
Renewables/Biomass-based CHP in the EU





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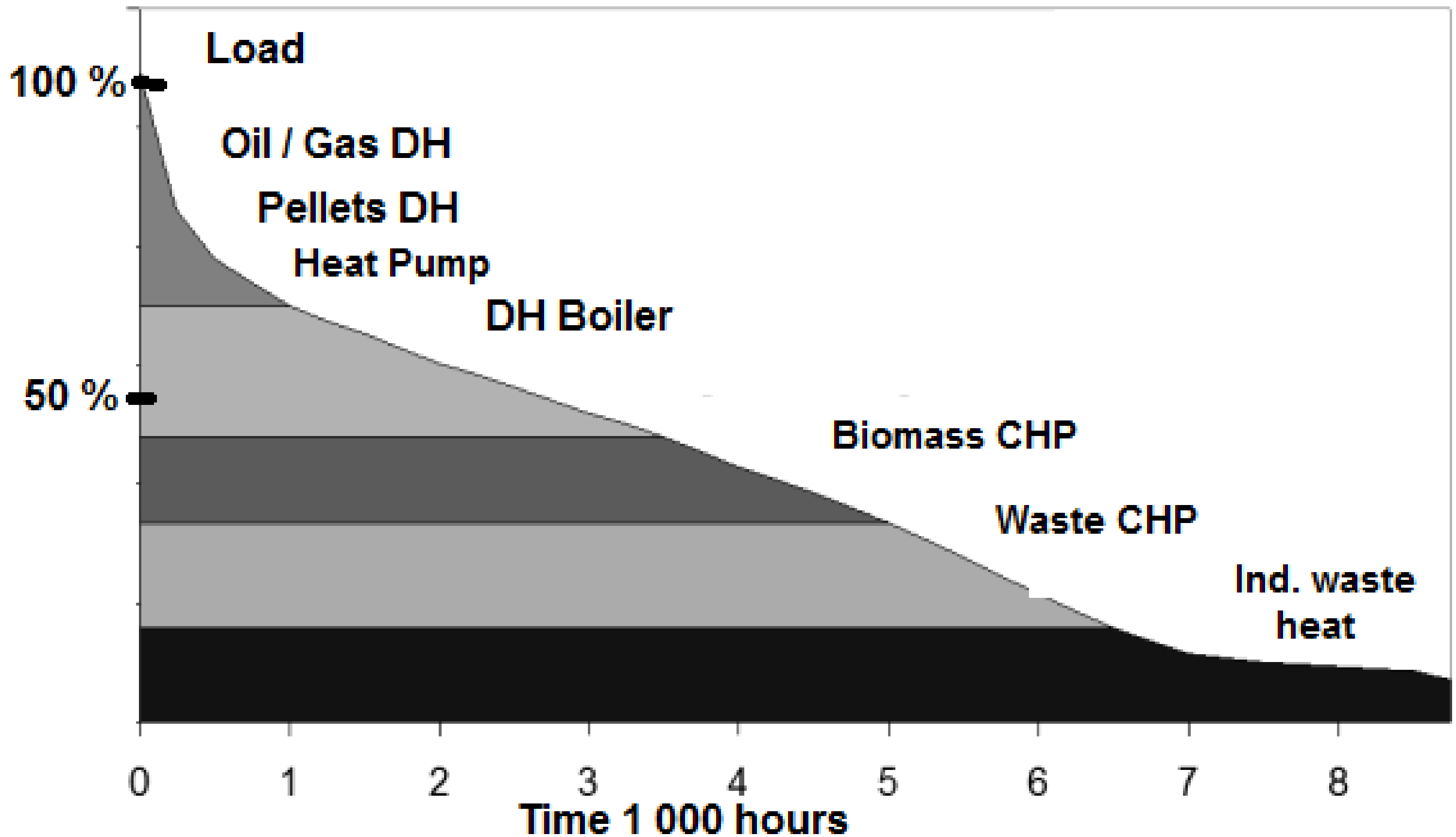
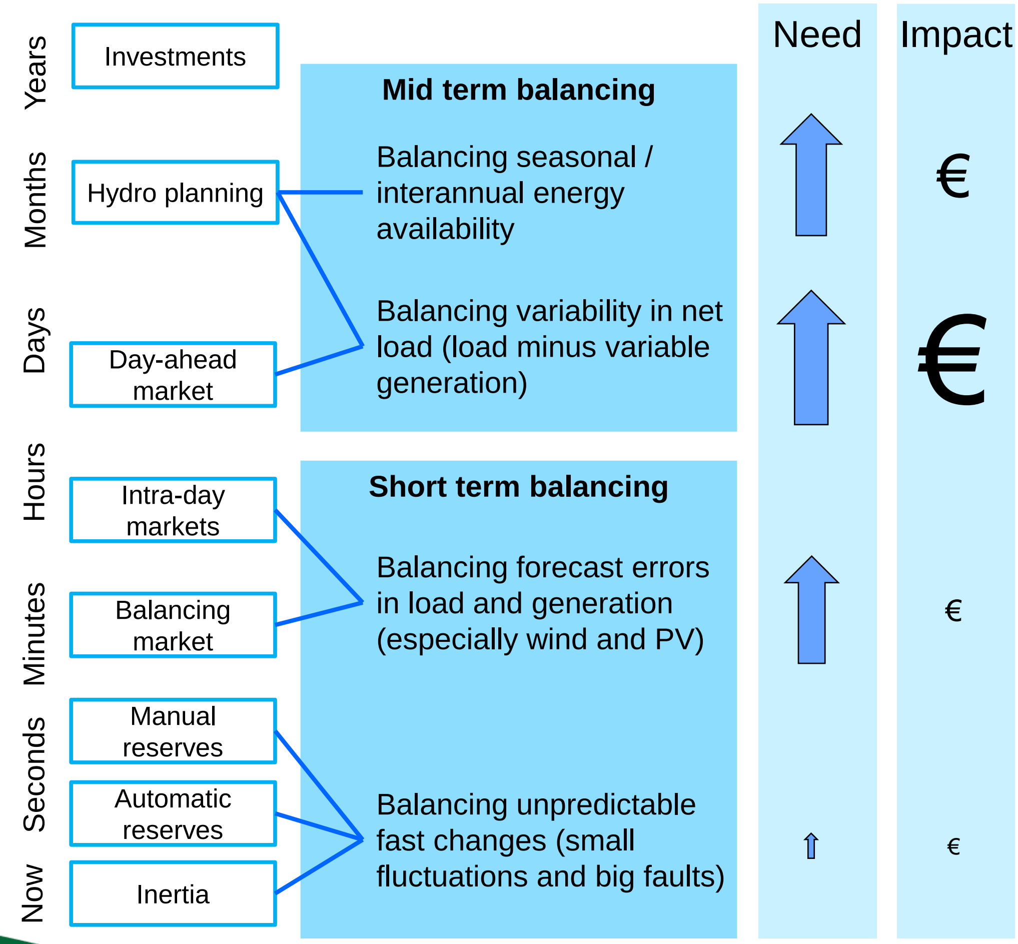
Example of DH load curve

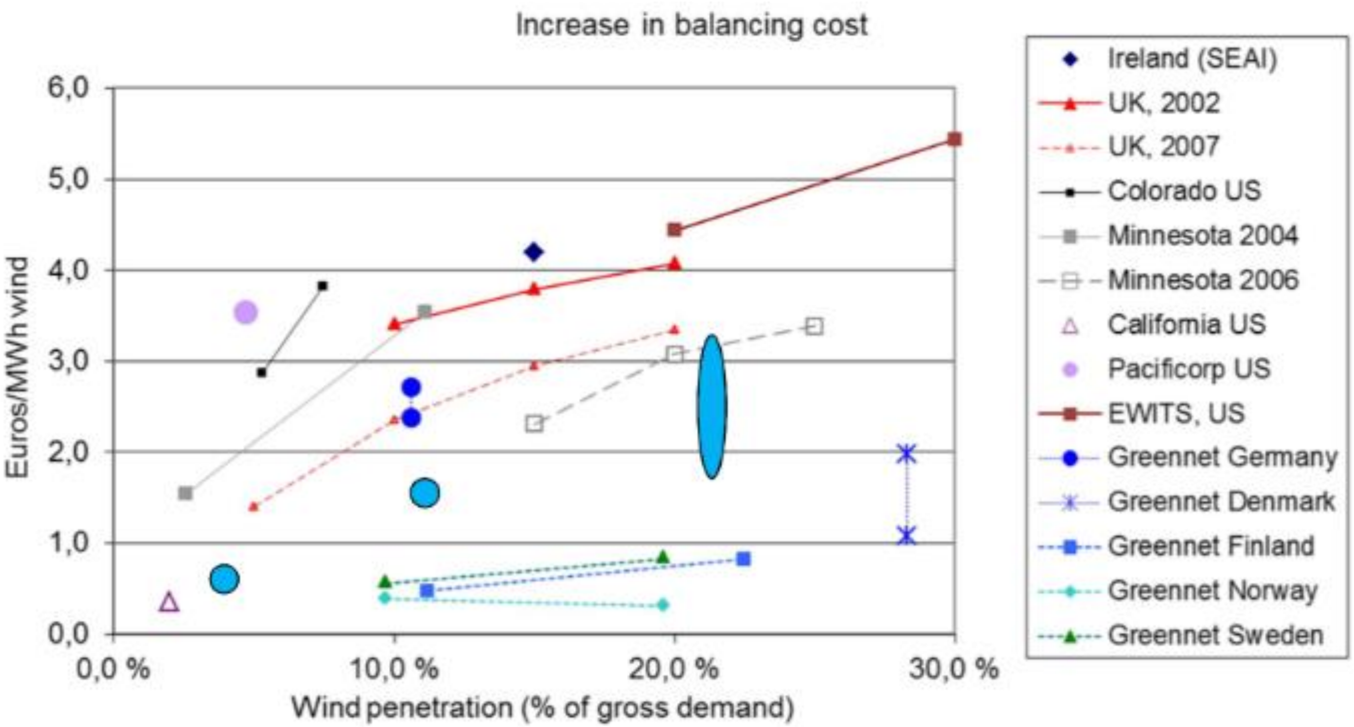


BALANCING THE GRID



BALANCING THE GRID

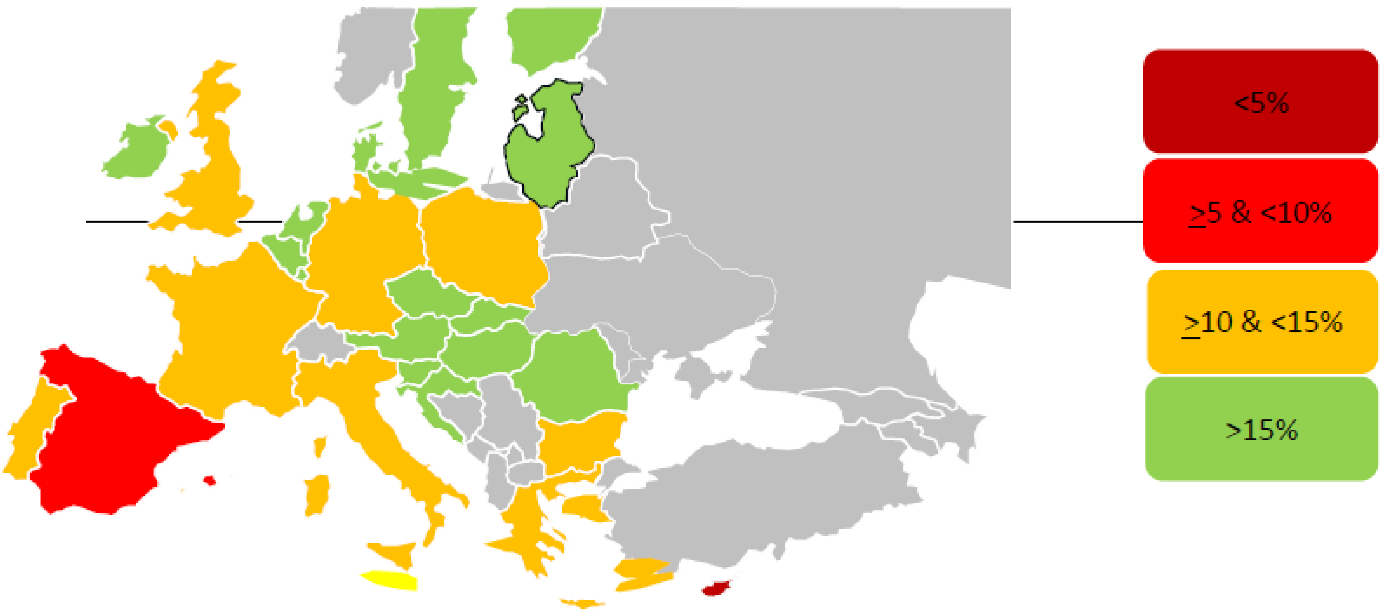
Increase in balancing costs vs wind penetration. Also the range of imbalance costs paid by wind power in the markets are shown for Denmark, Spain and the Netherlands



Holttinen et al. Design and operation of power systems with large amounts of wind power, Final summary report, IEA WIND Task 25, Phase two 2009–2011. VTT Technology 75, Espoo 2013

Interconnection

As part of the EU Energy Union a target of a minimum of 10 % interconnection capacity between the Member States has been set , and European wide transmission planning by ENTSO-E defines Projects of Common Interest (PCI) for implementation to 2020



Expected status of grid interconnection capacity level 2020 after implementation of Point of Common Interest

The Natural Gas Network - BIOMETHANE

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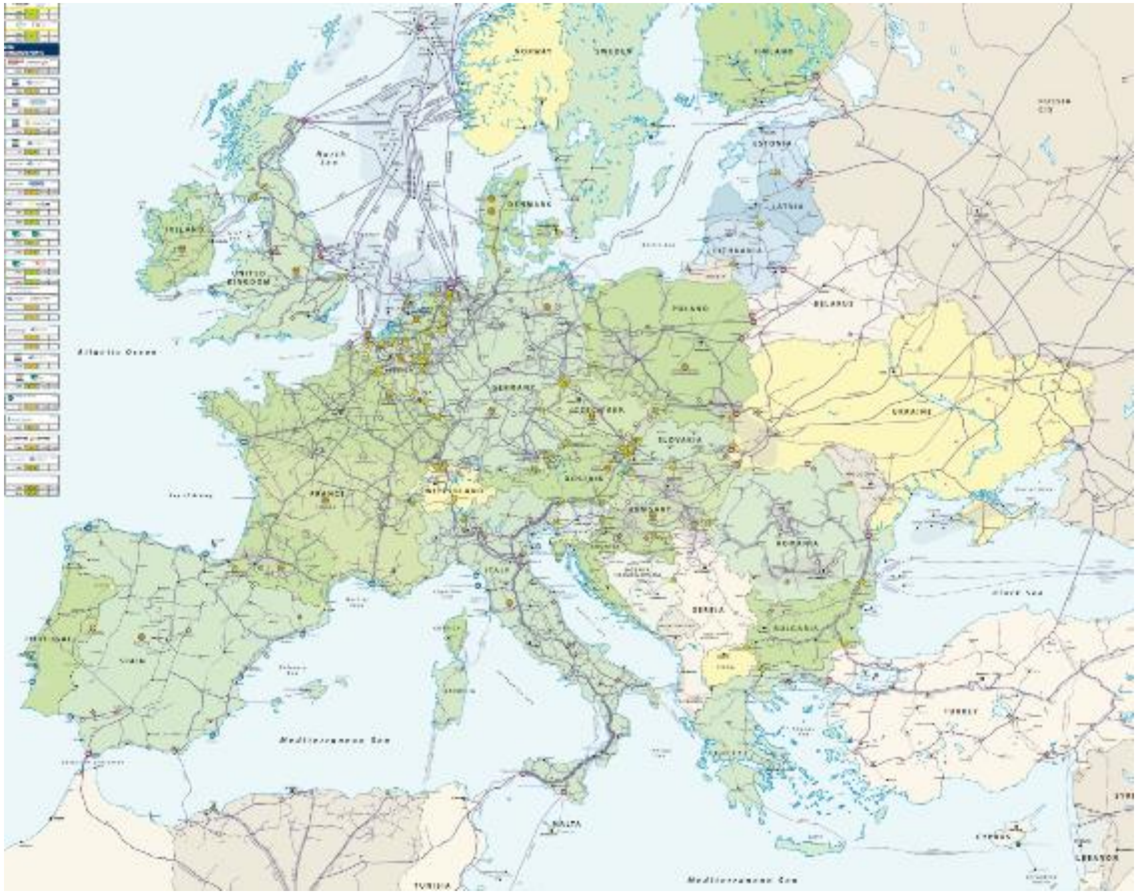

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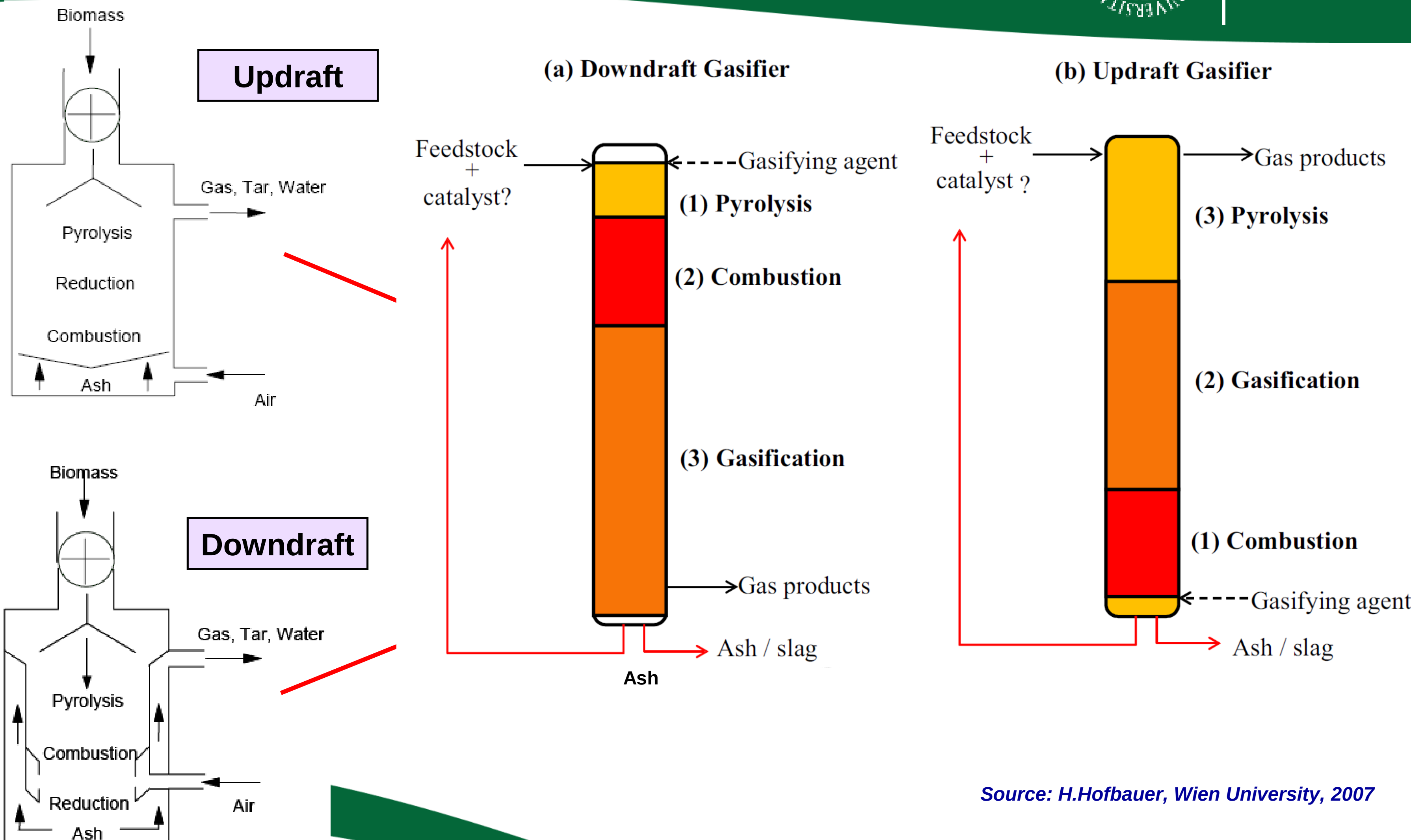
Small Scale Gasification in the CHP context

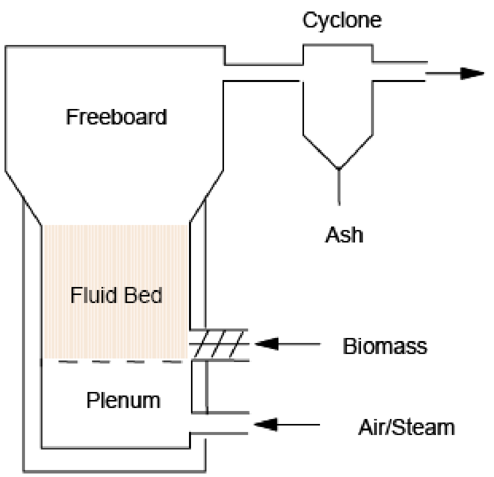
Main types of Biomass Fixed-bed Gasifiers



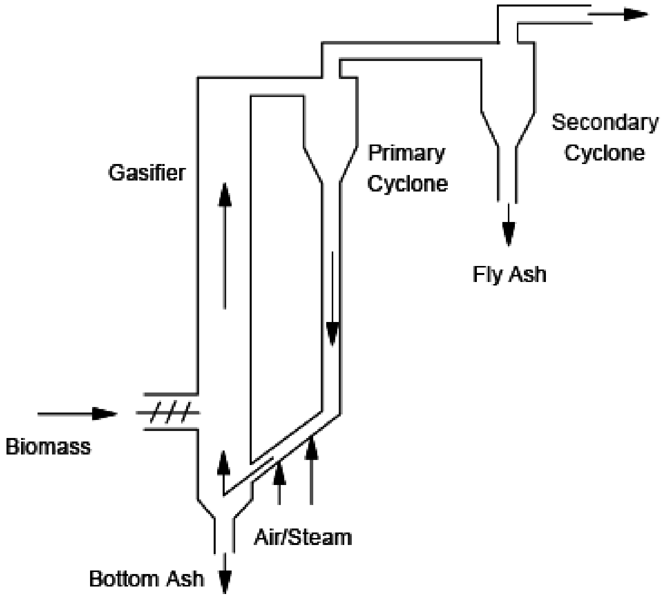
Source: H.Hofbauer, Wien University, 2007

Main types of Fluid-bed Biomass Gasifiers

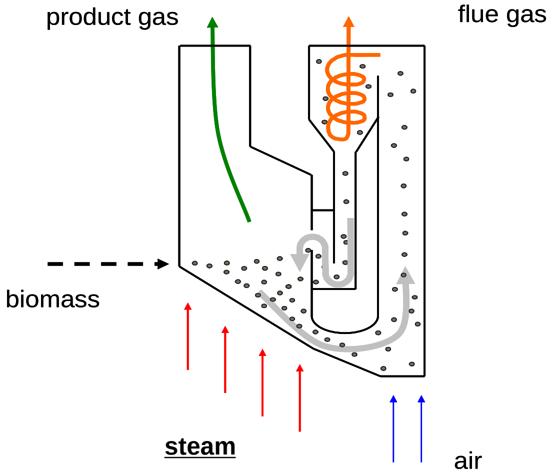
Bubbling fluidised bed gasifier



Circulating fluidised bed gasifier

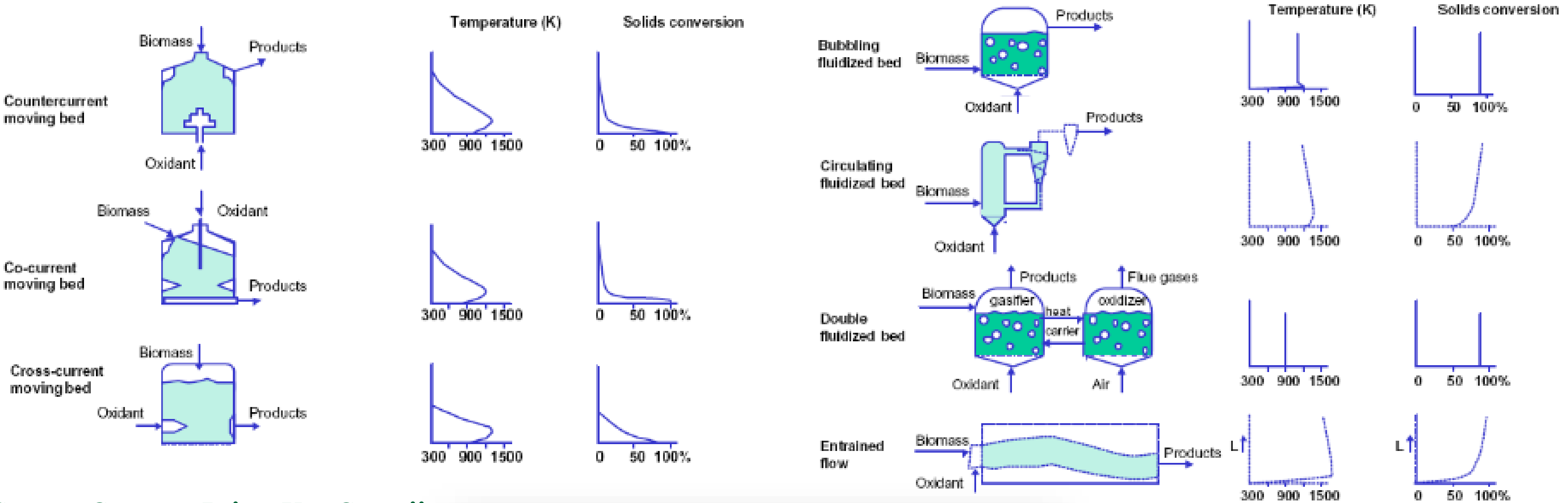


Dual fluidised bed gasifier

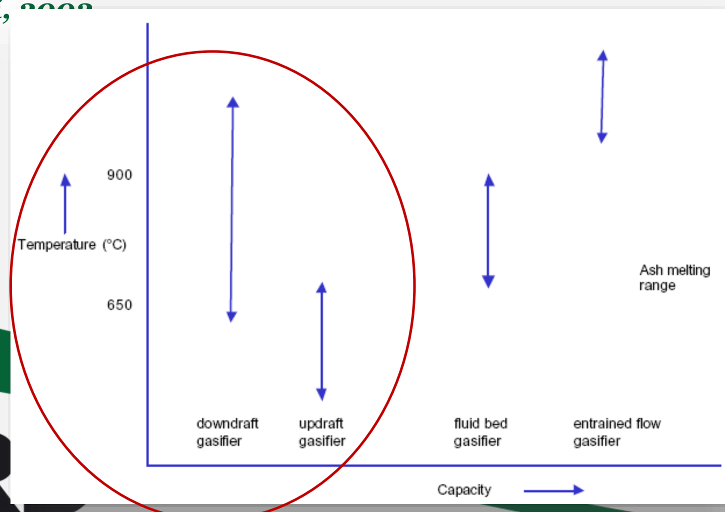


Source: H.Hofbauer, Wien University, 2007

Biomass Gasifiers – Temperature distribution



Source: Stassen, Prins, Van Swaaji, 2002



Installed capacity of gasification vs type of feedstock

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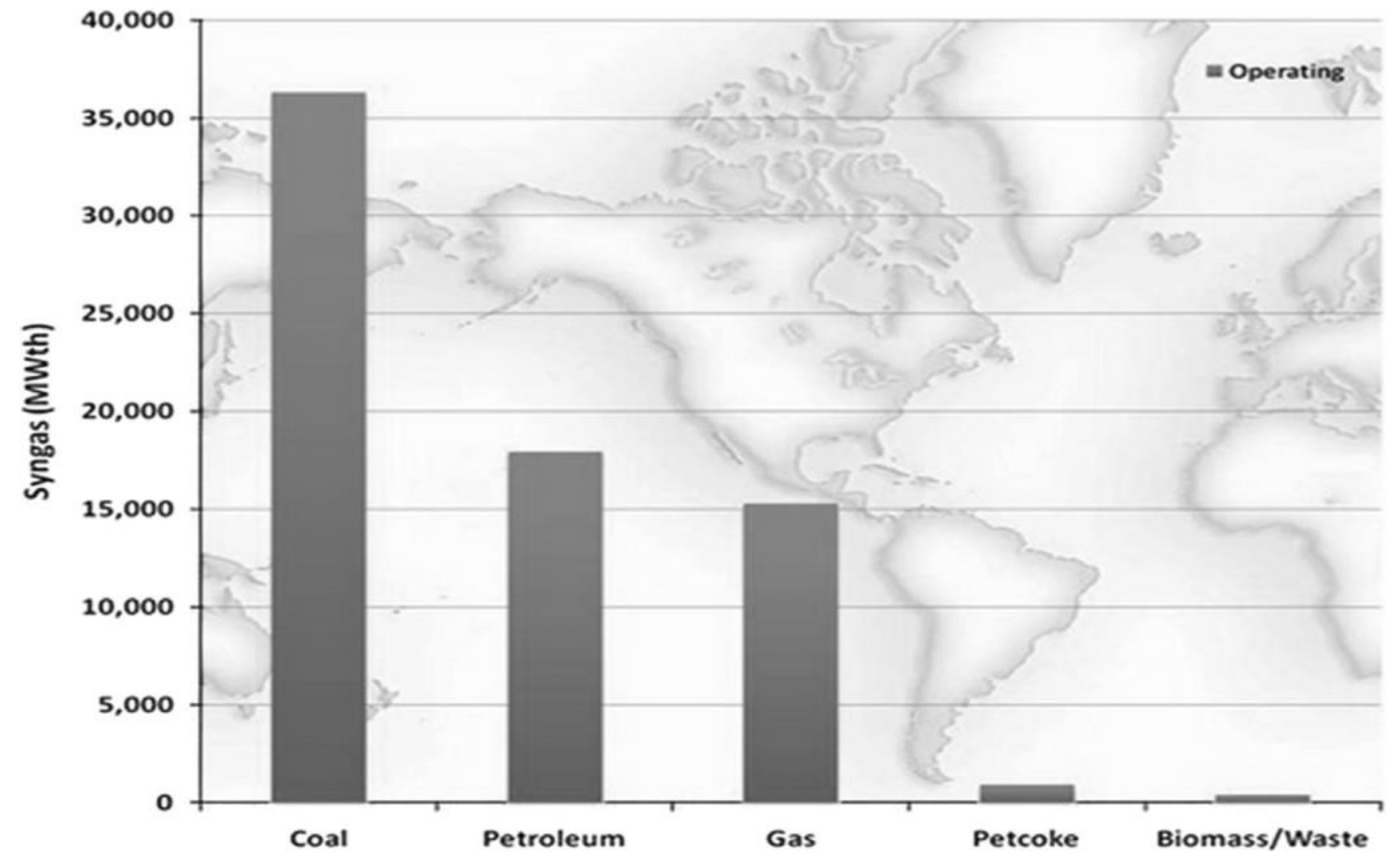

Fig. 2. World gasification operating capacity by feedstock [56].

A.A. Ahmad et al. / Renewable and Sustainable Energy Reviews 53 (2016) 1333–1347

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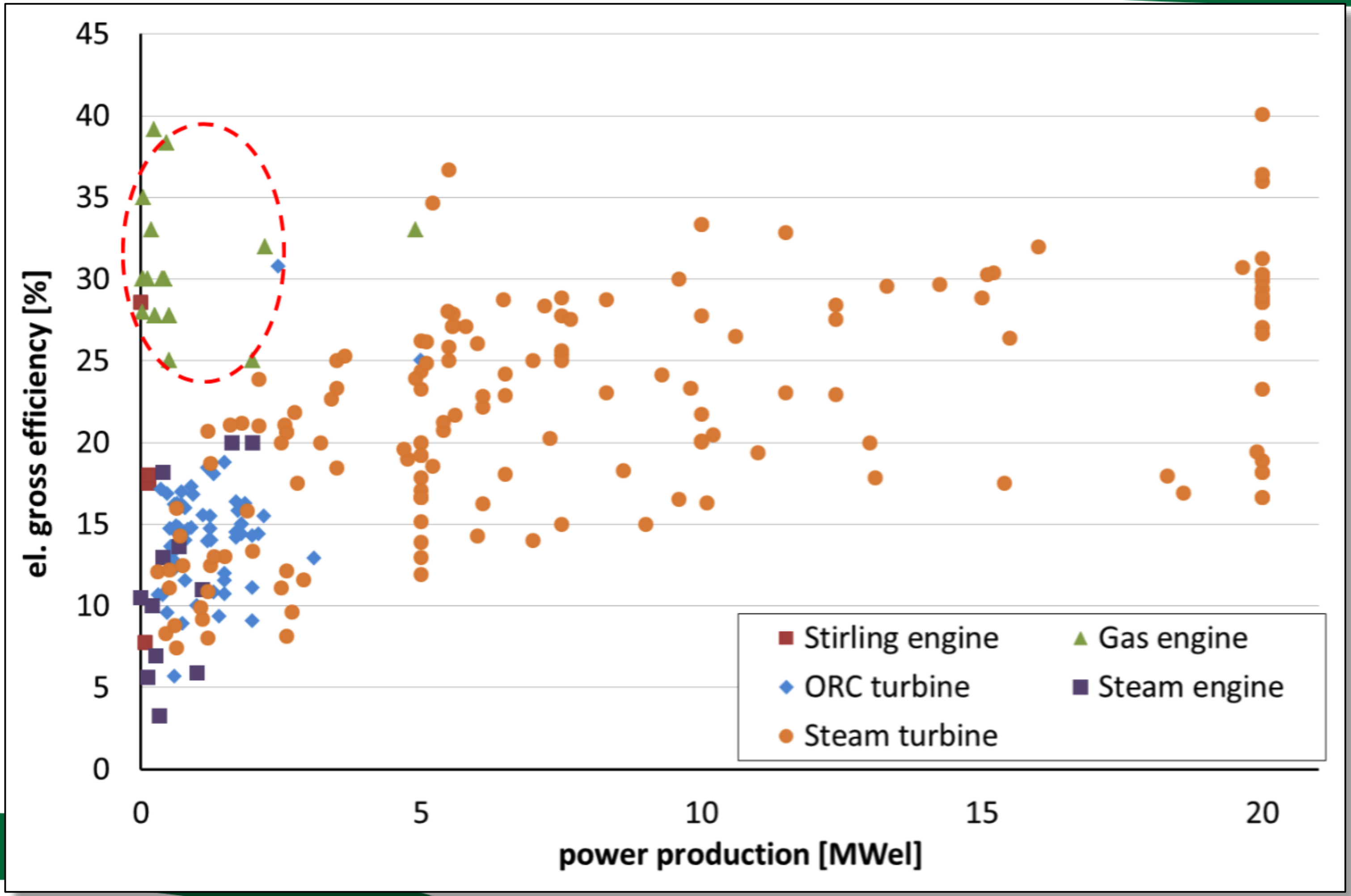
Gasification vs Steam/ORC/Stirling systems

??



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Source: Scheftelowitz M et al, DBFZ

Biomass pretreatment

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Biomass gasification steps

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- **<u>Pyrolysis</u>**: biomass heating (usually up to 700 ° C), producing char and releasing volatiles. Tars also produced when volatiles liquefy at low temperatures.
- **<u>Oxidation</u>**: Char and volatiles burnt with O2 to produce the needed gasifying agents (steam & CO_2) and CO. Exothermic reaction: heat is released for following reduction reactions.
- **<u>Reduction</u>** (mainly gasification reactions): Char + tar + hydrocarbons gasified with CO_2 & steam.
  - Producer gas mainly composed by CO, H_2, and CH_4.
  - Endothermic reactions, thus heat from oxidation reactions is used.
  - Steam reforming (*endothermic*) of char and tar, as well as water–gas shift reactions (*exothermic*).
  - Reduction of H_2O in steam gasification = the most effective way to increase H_2.
  - Boudouard reaction (endothermic) to CO. CO_2 may also be recirculated with O_2 within oxyfuel combustion/gasification.

N. Mahinpey, A. Gomez / Chemical Engineering Science 148 (2016) 14–31

Underdstanding Biomass gasification

- **<u>Feedstock</u>**: normally solid biomass (or solid fuels), of different physical & chemical characteristics, even if liquid feedstocks can also be processed.
- **<u>Reactor</u>**: it determines how solid is maintained in the reaction chamber, and the gas flow direction. CO2 and steam gasification agents.
- **<u>Heat transfer and heat source</u>**: radiation is most relevant heat transfer mechanism. Thus, expecially as scale increases, indirect heating is not sufficient. Most often direct heating through superheated steam or partial combustion (air, O2).
- **<u>Producer gas/Syngas quality</u>**: Gas Cleaning mandatory for using the gas, essential to make a difference towards direct combustion
- **<u>End use/application</u>**: heating, power, CHP, chemical synthesys

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Underdstanding Biomass gasification - reactions

Main Gasification reactions

- $C+CO_2 \leftrightarrows 2CO$ $\Delta H_{R1} = 172.5$ kJ/mol (Boudouard, Endothermic)
- $C+H_2O \rightarrow H_2+CO$ $\Delta H_{R2} = 131.3$kJ/mol (Steam Gasif., Endoth.)
- $CO+H_2O \leftrightarrows H_2+CO_2$ $\Delta H_{R3} = 41.2$kJ/mol (WGS, Exoth., Homog.)
- $C+H_2 \rightarrow CH_4$ $\Delta H_{R4} = 74.5$kJ/mol (Methane production, Exoth.)
- $CH_4+H_2O \leftrightarrows CO+H_2$ $\Delta H_{R5} = 205.8$ kJ/mol (Steam Meth Ref., Endo, Homog.)

✓ *Steam promotes (i) Steam Ref (endoth) of char & tars (ii) WGS (exoth)*

✓ *Boudouard react (taking place at T > 700 °C) : controlling step at low gasification T in CO2 gasification (<1000 °C)*

✓ *If HR>200 °C/min → no weight loss difference during pyrolysis step. Separating Pyro from Gasif maybe not the best solution (Pyro >> fast than Gasif), as it affects char reactivity*

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Char reactivity and process efficiency vs product (gas) quality

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CHAR REACTIVITY

- T and HR (more than p) in pyrolysis
  - ✓ Strong influence on char gasif. reactivity
  - ✓ ↑ T – HR → ↓ process thermal efficiency

- *If Pyrolysis (P) is part of Gasification (G), P Res.Time (Rt) is < than G Rt, as P is >> faster than G (irrespective to gasifying agent).*
- *If P and G are done in different/separated reactors, P Rt is significantly increased, and char is < reactive*

- time char held at high T is not controlled and not negligible vs tot Rt (Char "history")

→ **Kinetic models not reflecting actual behaviour at industr. scale** (as based on isothermal pyrolysis in inert gas, far from industrial scale conditions)

→ **As HR ↑ → Reactivity ↑**

GASIFICATION & GAS QUALITY

Summary of the effects of increasing temperature on syngas production and reaction rate.

Temperature	Characteristics
Low (< 1000 °C)	– CO decreases, H_2 increases, WGS reactions more dominant than Boudouard reactions – H_2/CO ratio increases for air-steam gasification due to WGS and steam reforming reactions – CO/CO_2 ratio decreases due to a balance between CO-producing and CO-consuming reactions – Slower reaction rate – Longer residence time to achieve high conversion – Tars may be produced
High (> 1000 °C)	– CO and H_2 increase due to Boudouard, steam reforming and WGS reactions – CH_4 decreases due to steam reforming – H_2/CO ratio increases for air-steam gasification – Tars decrease due to thermal cracking and steam reforming – Improved cold gas efficiency (CGE) – Higher reaction rates and carbon conversion
Very high (~1500 °C)	– H_2 and CO decrease due to sintering – Reaction shifts to combustion from gasification region – Particles collapse and shrink – Lack of surface area

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Actual operation conditions of small-scale fixed bed gasifier

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- Very often the operation of actual small scale industrial gasifiers is performed **far from design conditions**
  - It may be due to **inadequate feedstock** (moisture, size, composition…), or **gasifier design**, or **distribution of flows**, etc
- **Insufficient T** in key sections of the gasification system
- **Reduced Cold Gas Efficiency**, higher **tar load** in PG

→ *Interesting evaluation carried out by Pittaluga in 2008*

100 % wood chip

Campione N°	Contenuto idrico w (%)	Potere calorifico inferiore (kJ/kg)
1	10,05	16408,65
2	12,5	15895,21
3	11,1	16188,60
4	11,2	16167,64
5	11,8	16041,90
Valore medio	11,33	16140,40

100% clean coal

Densità (kg/m³)	Contenuto idrico w (%)	Potere calorifico inferiore (kJ/kg)
369,50	4	31395
372,25	4,25	31395
367,20	3,95	31395
370,10	4,1	31395
367,00	3,95	31395
369,21	4,05	31395

70% wood chips - 30% clean coal

Densità (kg/m³)	Contenuto idrico w (%)	Umidità u (%)	Potere calorifico inferiore (kJ/kg)
281,00	4,00	4,17	20716,78
282,50	4,50	4,71	20716,78
282,00	5,00	5,82	20716,78
281,75	3,00	3,09	20716,78
281,95	3,50	3,63	20716,78
281,84	4,00	4,28	20716,78

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Small scale imbert-type gasifier
Wood chips vs mix with coal

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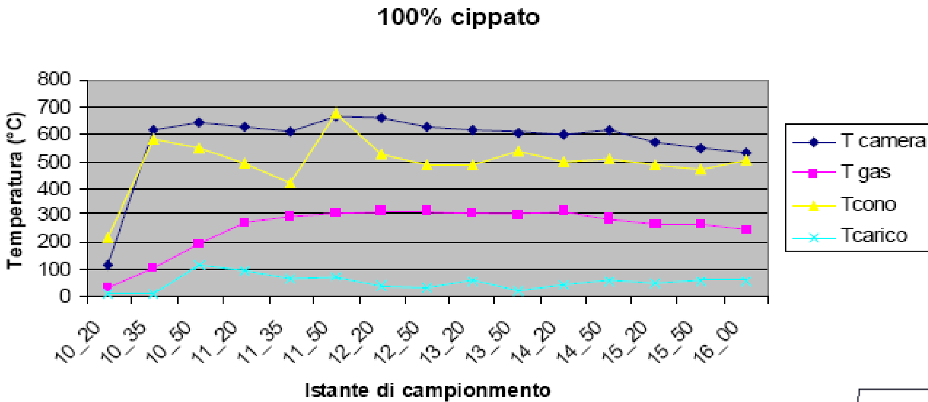
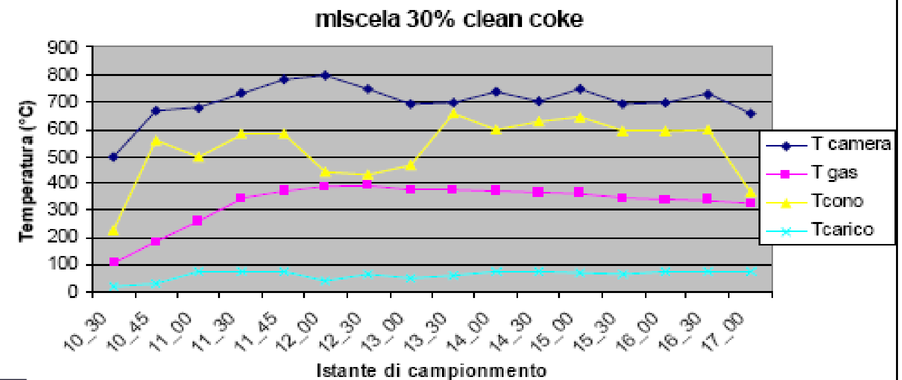
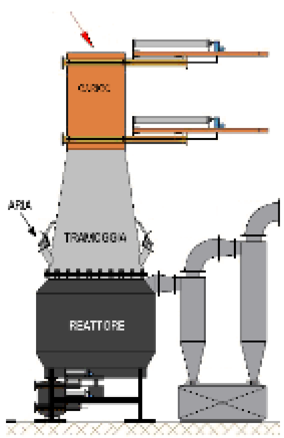
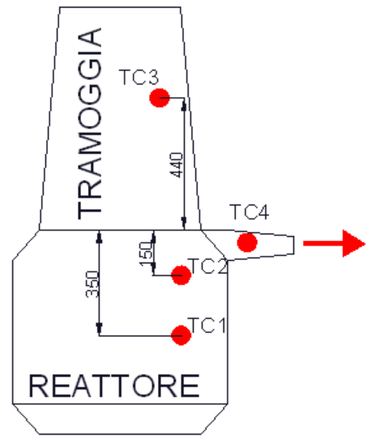
Temperatures









PARCO SCIENTIFICO TECNOLOGICO DELLA LIGURIA PSTL

Prof. Ferruccio Pittaluga
Univ. degli Studi di Genova
Facoltà di Ingegneria
DIMSET-DIPTEM

RE-CORD

Small scale imbert-type gasifier Wood chips vs mix with coal

Energy balance

100 % wood chips

biomassa in	13 kg/h	P in	58.9 kW
PCI biom	16.3 MJ/kg		

syngas out	26.7 kg/h	P out	26.6 kW
PCI syngas	4 MJ/m3		

rendimento gassificazione	45.2 %

70 % wood chips – 30 % clean-coke

miscela in	8.8 kg/h	P in	50.4 kW
PCI miscela	20.6 MJ/kg		

syngas out	30.2 kg/h	P out	33.1 kW
PCI syngas	4.4 MJ/m3		

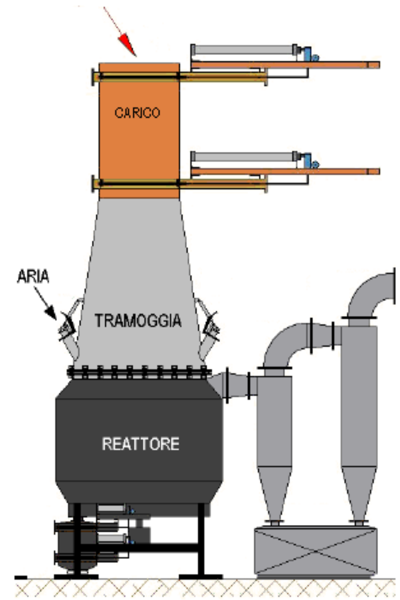
rendimento gassificazione	65.7 %

Prof. Ferruccio Pittaluga

Univ. degli Studi di Genova

Facoltà di Ingegneria

DIMSET-DIPTEM



Double stage

UNIVERSITÀ DEGLI STUDI FIRENZE

cirad

Biomass gasification process, and apparatus, and their applications
EP 1312662 A2 - 2003

Philippe Girard
Laurent Van de Steene
Thomas Koch
Gérard Antonini
Ammar Bensakhria

- PYR:Pyrolysis Chamber
- Char (CH) Reduction Chamber: CRC
- PG: Pyrolysis Gas
- CH: Char
- AS: Ashes
- GWC: Gas Washer Cooler
- WW: Waste Water
- ALK: Alkali Vapours
- PhS: Phase Separator

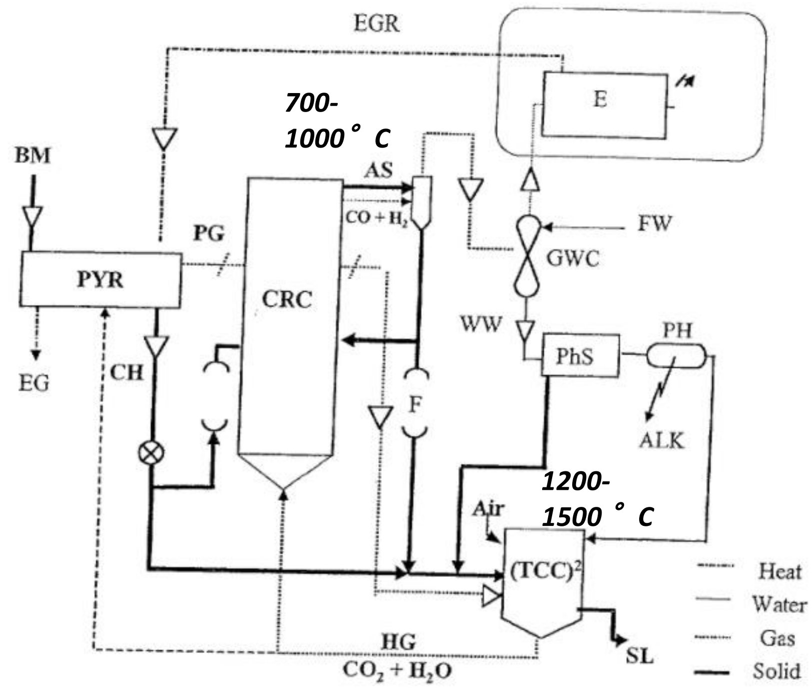


Figure 1 B

- Total Tar Combustion and Tar Cracking Chamber: $(TCC)^2$
- HG: Hot Gases
- EGR: Exhaust Gas Recirculation
- EG: Preheating gases
- SL: Liquid Slag

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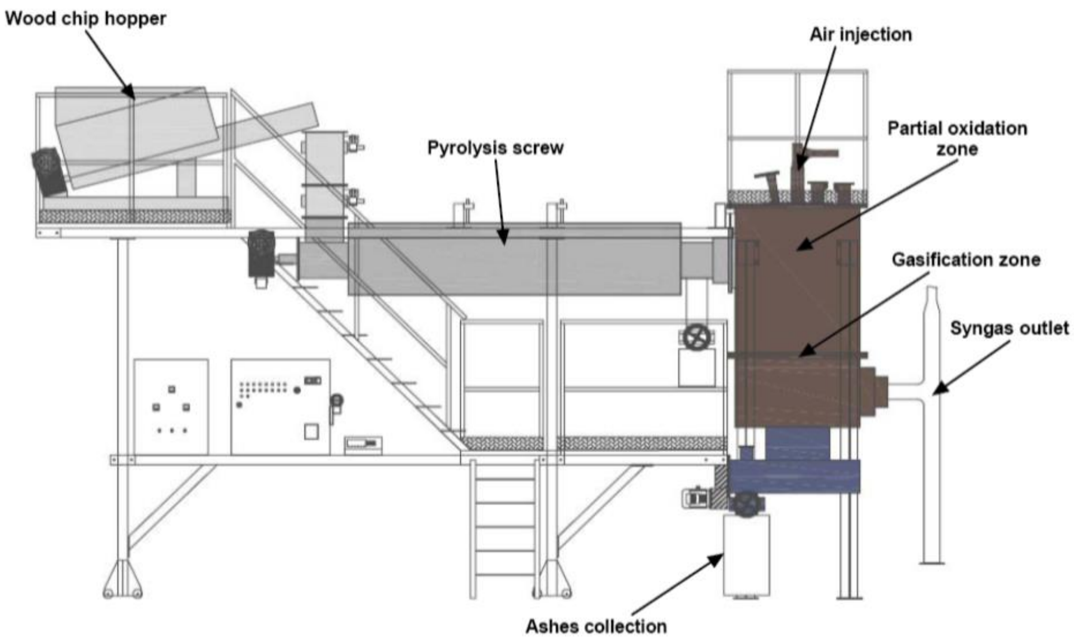
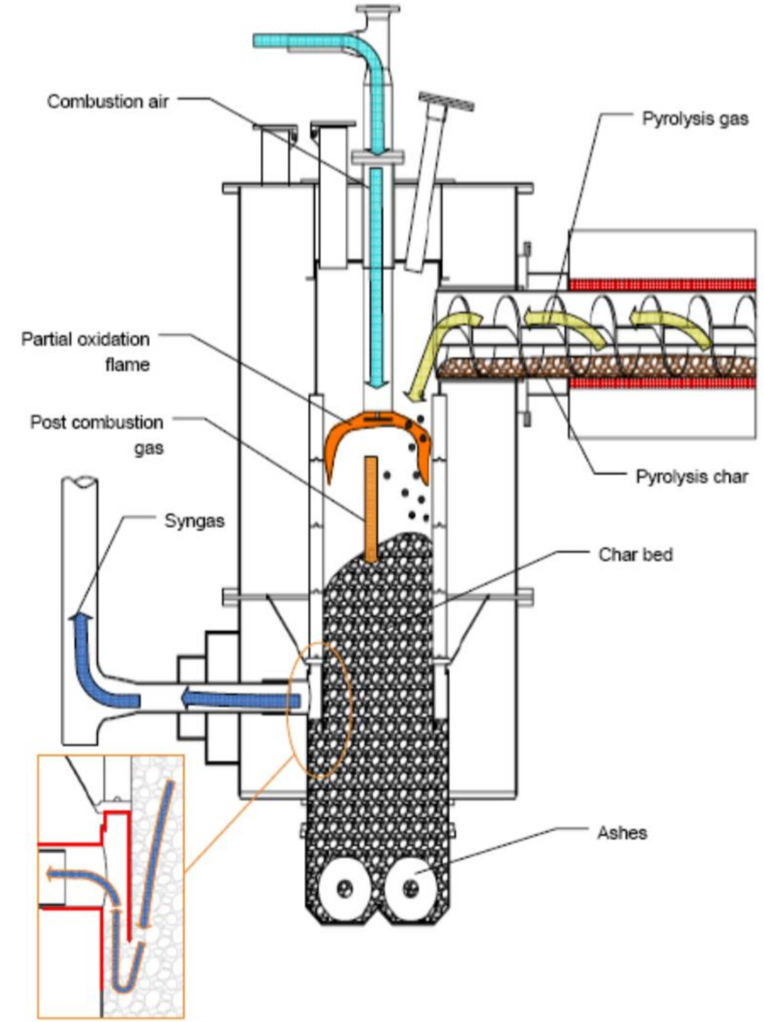
Double stage

cirad





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Duel stage: Operational experience

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Viking gasifier, DTU CHP application with 17 kWe power production

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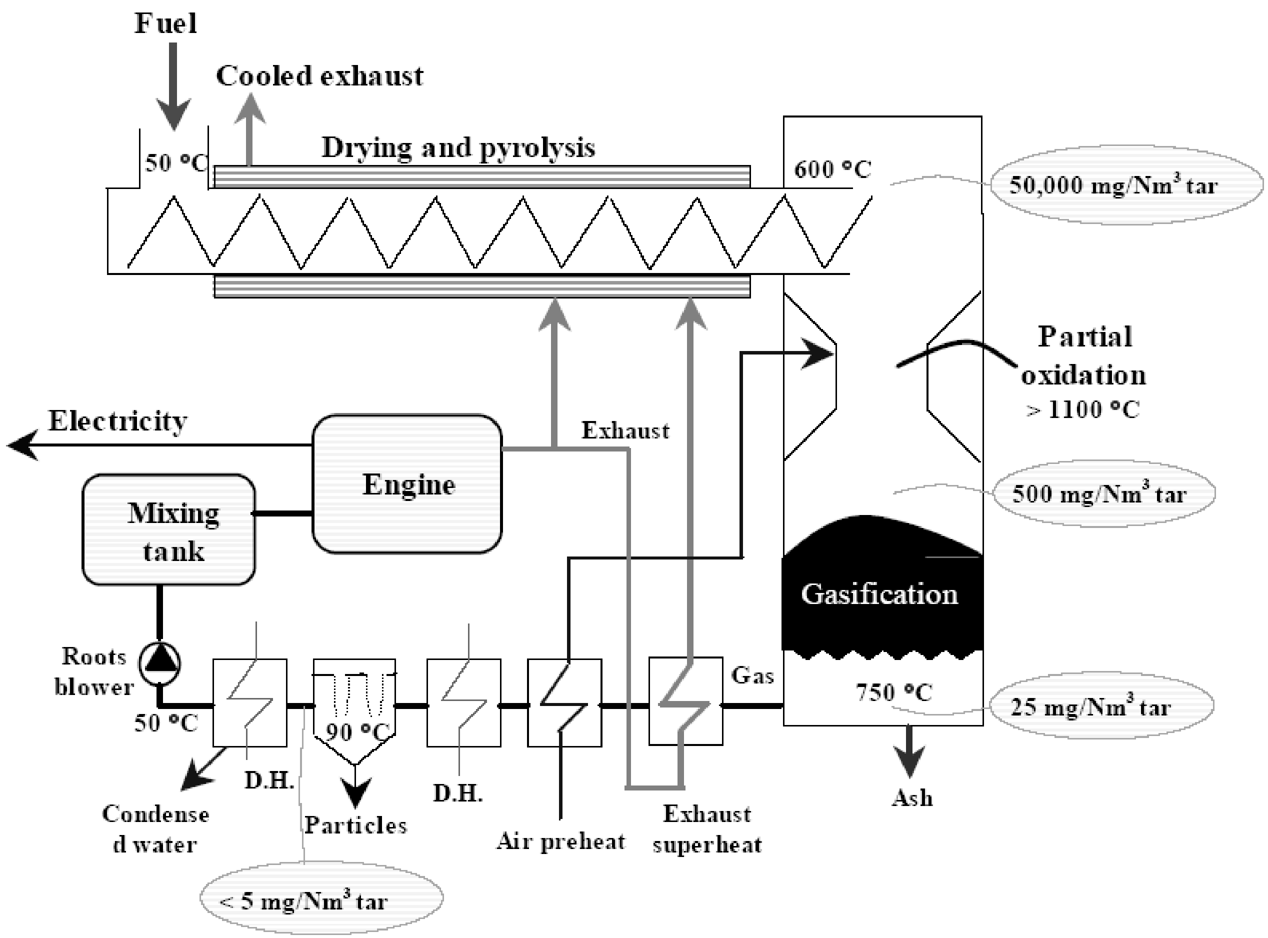
Viking - Denmark

UNIVERSITÀ DEGLI STUDI FIRENZE

- Two stage gasifiers: very effective tar reduction even at small scale



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Two-stage gasifiers – TK Energy

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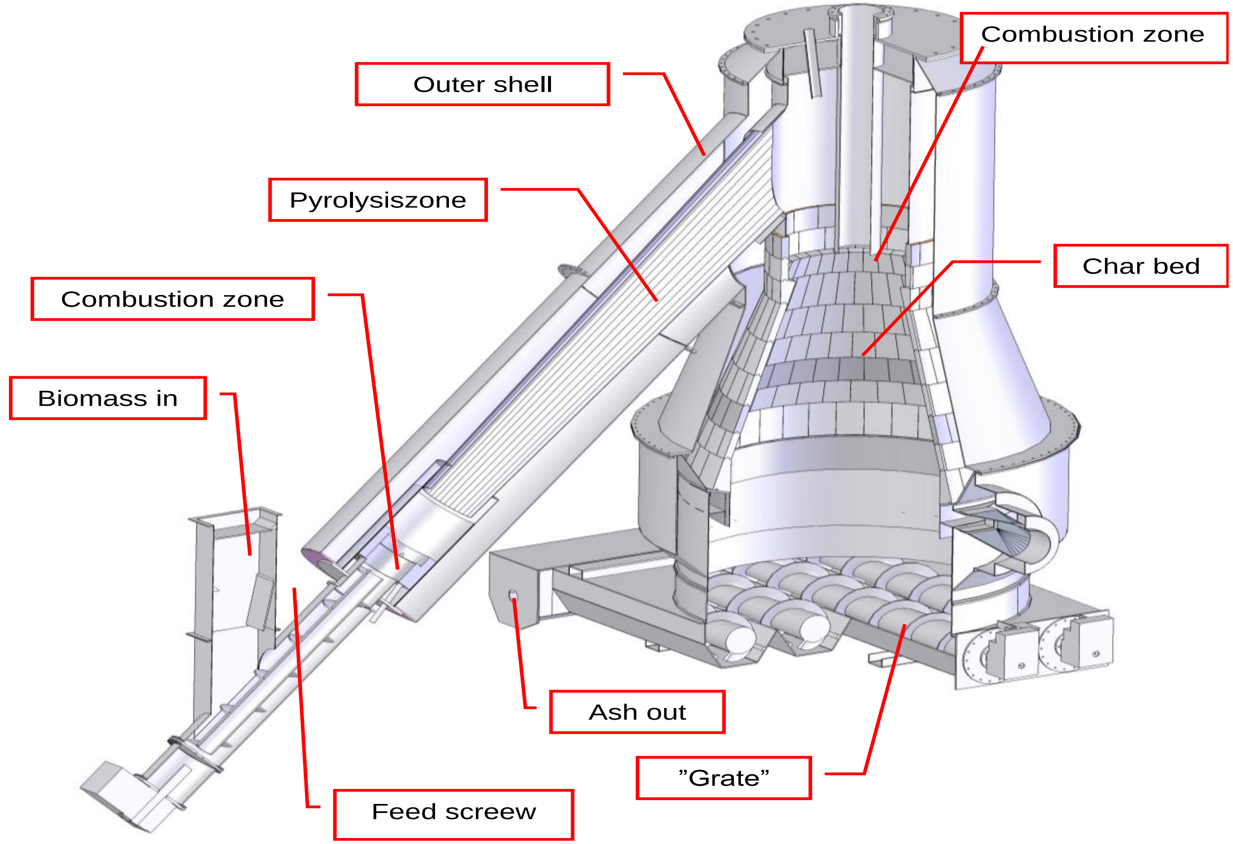
TK Energi AS



Source: Thomas Kock, 2005

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Two-stage gasifiers – TK Energy
Health & Safety

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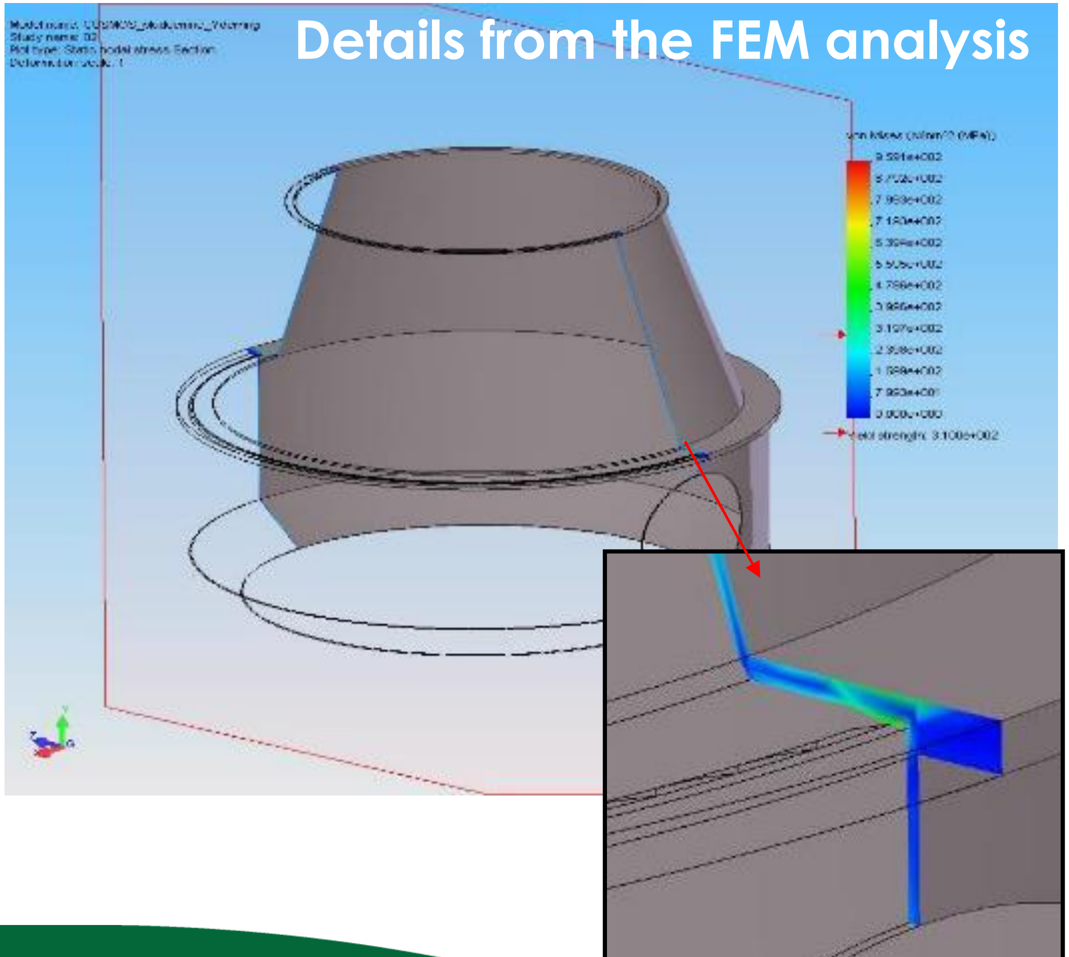
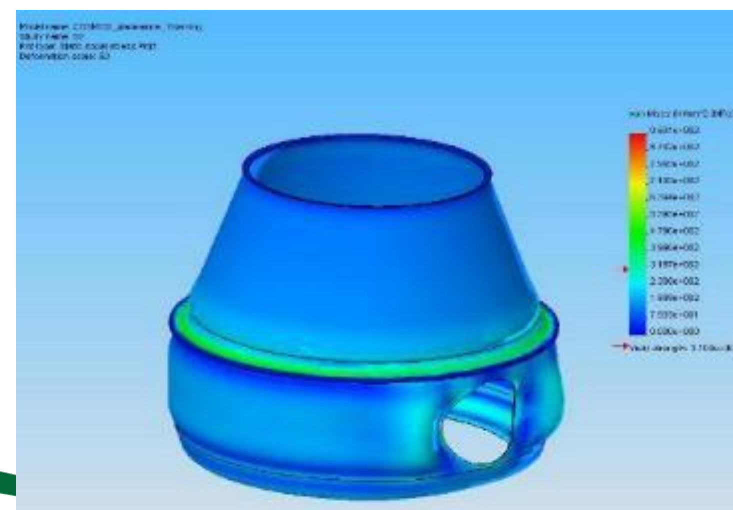


Source: Thomas Kock, 2005

TK Energi AS

- Cold pressure barriere calculated to with stand maximum explosion pressure
- Insulation materials will not reduce and reduce strength of outer shell
- No moving parts that can cause blockages



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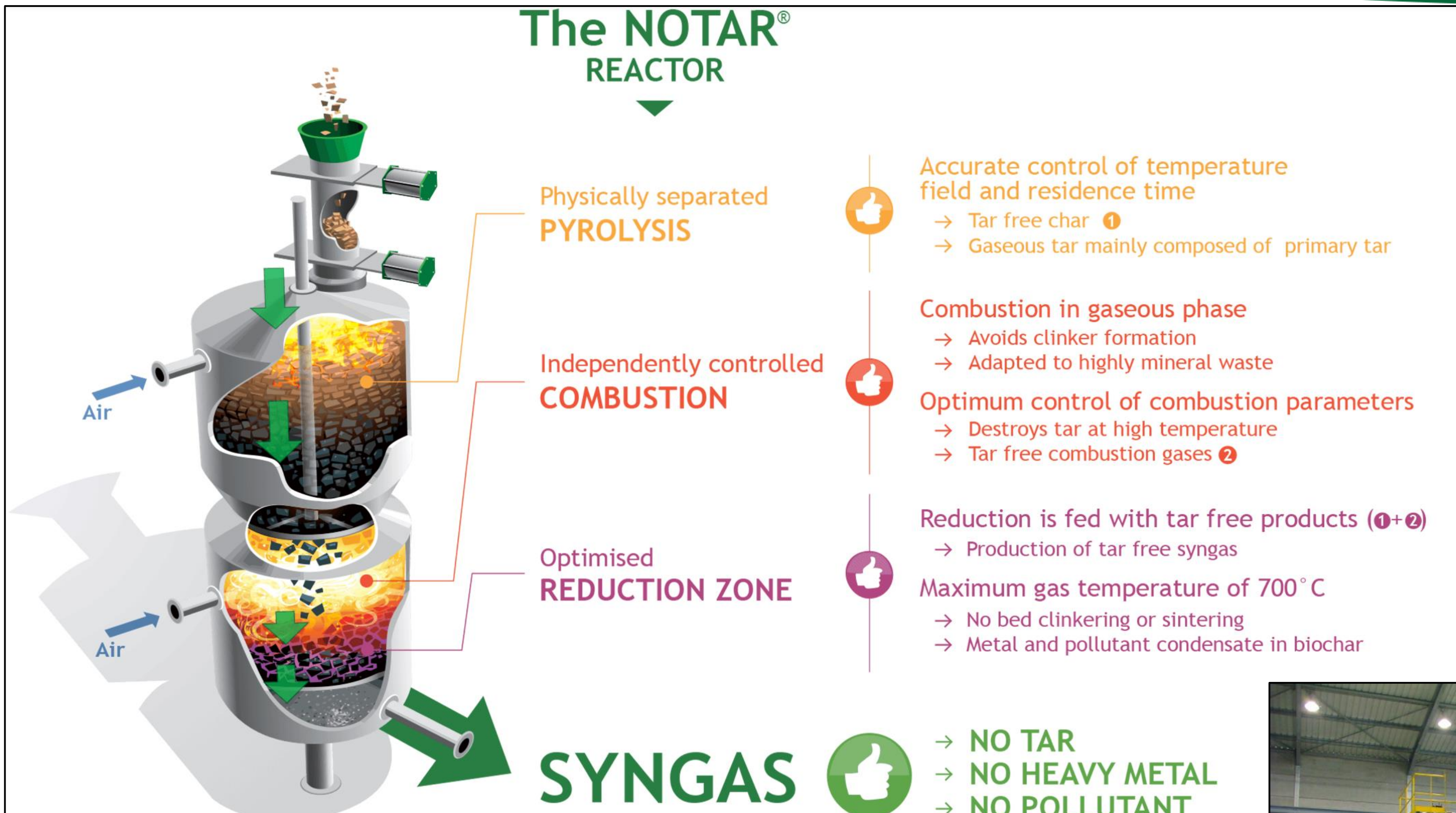
Xylowatt



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Three stage

THREE-STAGE GASIFIER, FIXED BED, WHICH HAS BUFFER ZONE OF GASEOUS FLOW BETWEEN PYROLYSIS ZONE AND COMBUSTION ZONE

Lampros Elefsiniotis , 2008

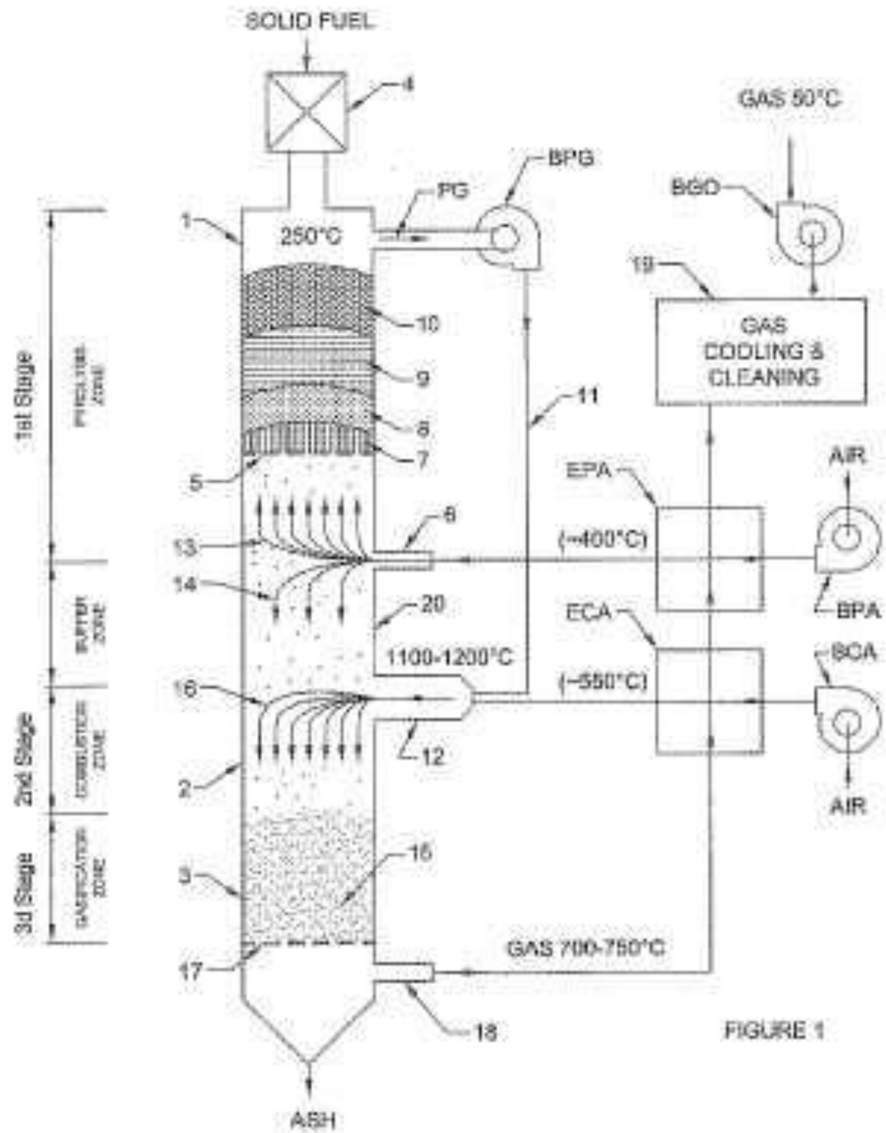
Bibliographic data: EP2126008 (A2) — 2009-12-02

Pyrolysis
(countercurrent)

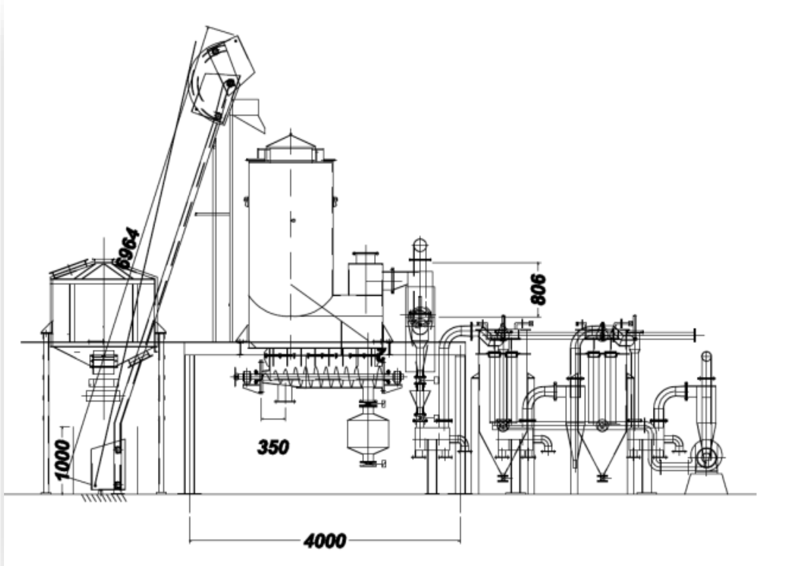
Buffer zone

Combustion

Gasification
(cocurrent)



IIS Open-Top Twin-Fire



- Large High Temperature reaction zone combined with Extensive Gas Cleaning
- Mix of dry and wet gas cleaning steps

Updraft configurations

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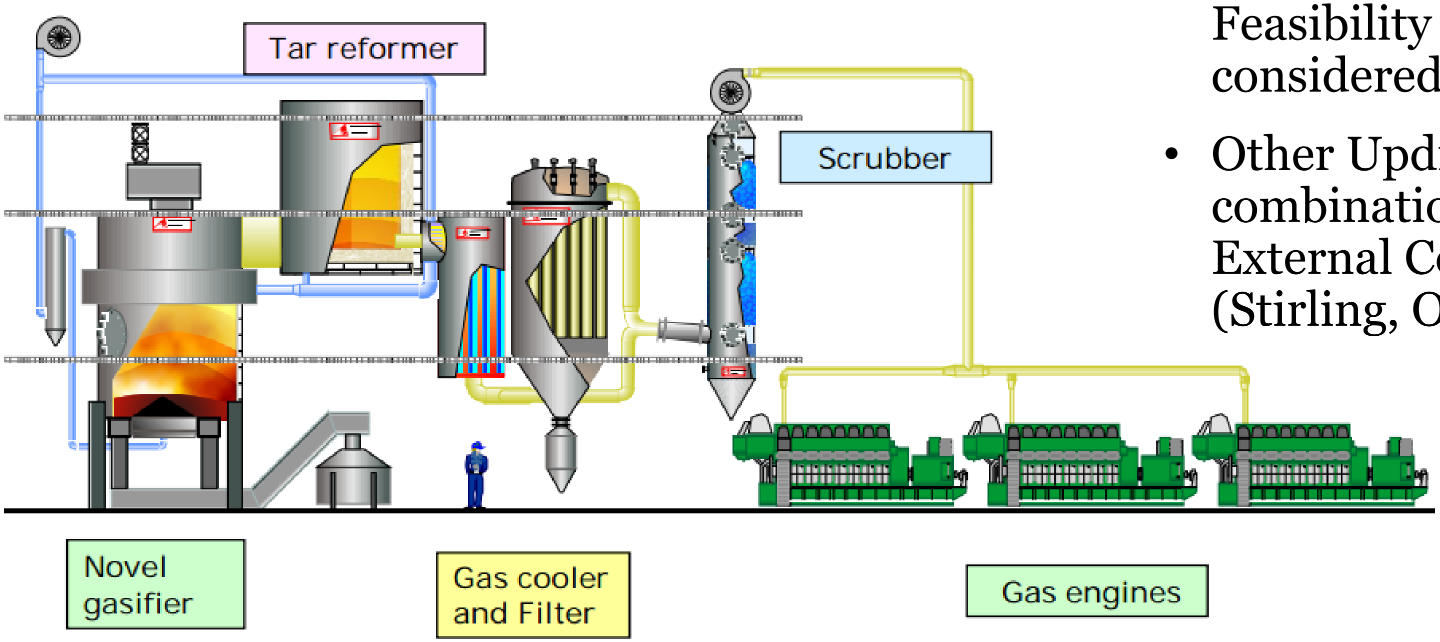
Novel power plant: 1.8 MWe + 3.3 MW heat

- Supplier: Condens Oy
- Kokemäki, Finland



- Few other cases of Updraft Gasifiers proposed in CHP.
- Extensive cleaning needed. Feasibility to be carefully considered.
- Other Updrafts proposed in combination with with External Combustion Systems (Stirling, ORCs)

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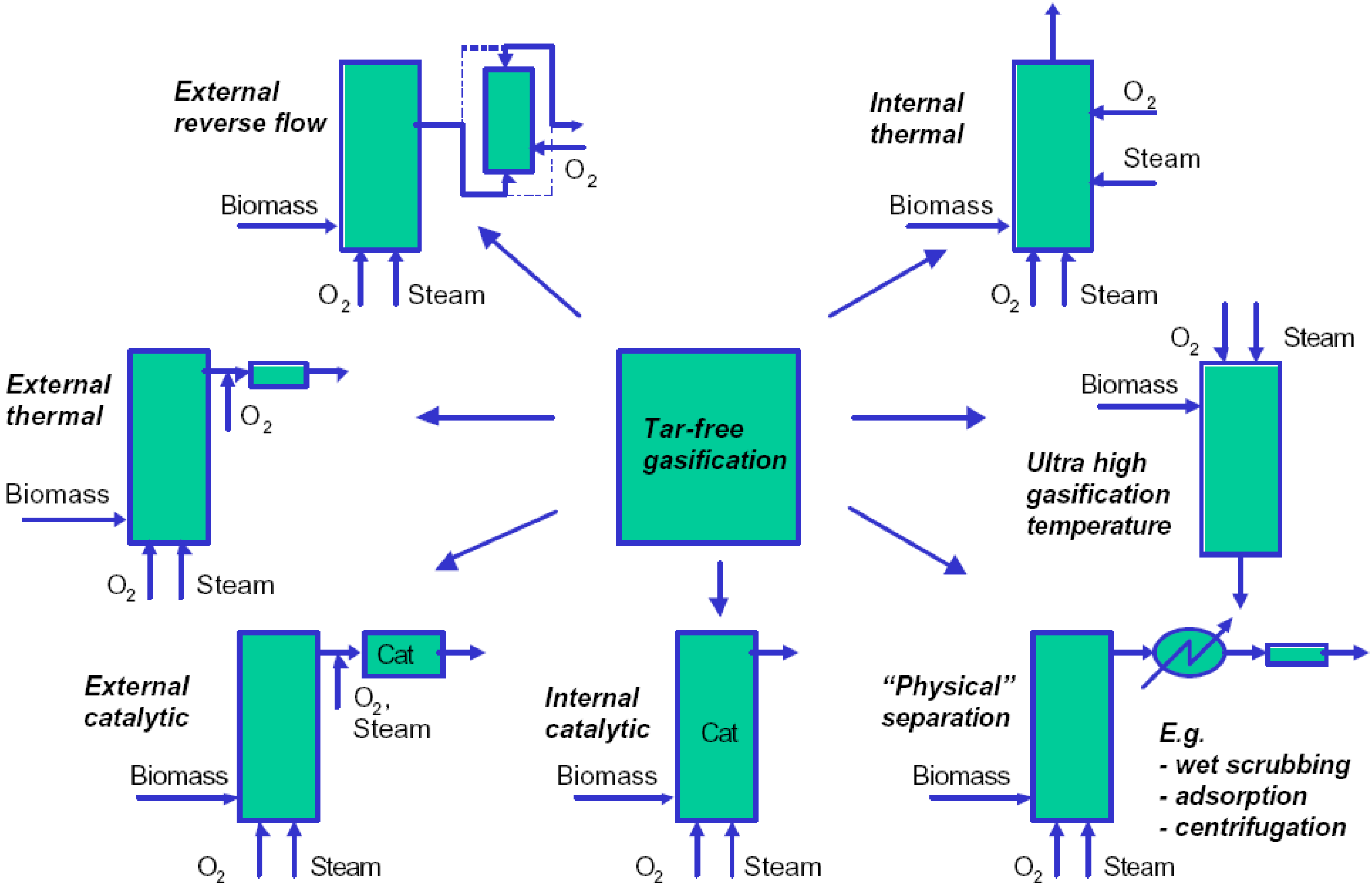
Systems for tar removal or conversion – Gas Cleaning



Source: Stassen, Prins, Van Swaaji, 2002

Tar reduction potential for different systems

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- Different systems with variable performances.
- Need to select the most appropriate and cost-effective solutions for the specific plant scale and operator skills.

Table 4: Residual tar matter contamination after treatment in [mg/m³ st.c. dry producer gas] [3,4,6,7,14], with 500 mg m³/st.c.dry at the inlet

Technology	Contamination at the outlet
In situ catalyis	50-200
Part. combustion	10-100
Post catalyis	50-250
Wash tower	300-400
Spray tower	400-500
Sieve colum	100-200
Packed colum	100-200
Packed colum, solv.	10-100
Venturi scrubber, drop.	40-200
Adsorption	50-200
Co adsorption on filtercake	200-500
Electric precipitator cooled	5-50

Kleinhappl, 2002

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Gas Cleaning requirements

- Tars, particulate matters, NH_3, H_2S, HCl and SO_2
- Tar the most relevant
- Tar tolerance (CHP) limit :
  - ✓ ~*500 mg/Nm³: compressors*
  - ✓ ~*100 mg/Nm³: IC engines*
  - ✓ ~*5 mg/Nm³: industrial GTs*
- IC & μGT → small scale CHP
- Tar & NH_3 formation → f (air-fuel ratio & process T)
- ↑ T & A/F ratio ↓ Tar/NH_3 but
  - Costly materials
  - Less chemical energy in the producer gas

Renewable and Sustainable Energy Reviews 40 (2014) 118–132
Contents lists available at ScienceDirect
Renewable and Sustainable Energy Reviews
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Biomass gasification gas cleaning for downstream applications: A comparative critical review

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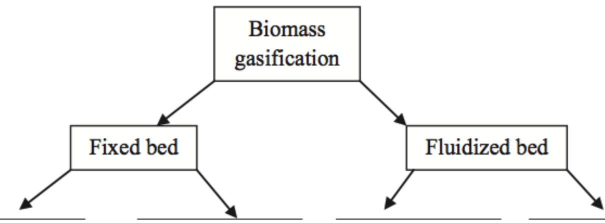

Gas quality	Co-current [65-68]	Counter current [65-68]	Bubbling fluidized bed [88-92]	Circulating fluidized bed [67, 69, 70]
Tar, mg/Nm³	10-6000	10000-150000	1500-9000	9000-10000
PM, mg/Nm³	100-8000	100-3000	12000-16000	7000-12000
LHV, MJ/Nm³	4.0-5.6	3.7-5.1	3.5-5.0	3.6-5.9
H_2, vol%	15-21	10-14	10-15	15-17
CO, vol%	10-22	15-20	13-20	15-18
CO_2, vol%	11-13	8-10	17-22	16-18
CH_4, vol%	1-5	2-3	1-4	4-6
C_nH_m, vol%	0.5-2	nd	nd	1.0-1.5
N_2, vol%	rest	rest	rest	rest

Gas quality requirement

Gas quality	IC engine [20, 72, 93, 94]	Gas turbine [20, 73, 95, 96]	F-T synthesis [97-99]
Tar, mg/Nm³	< 100	< 5 (all in vapor phase)	< 1[a]
PM, mg/Nm³	< 50	< 20	0
Particle size, μm	< 10	< 0.1	
Minimum LHV, MJ/Nm³	-	4-6	-
Minimum H_2 content, vol%	-	10-20	-
Max alkali concentration, ppb	-	20-1000	< 10
S component (H_2S, SO_2, CS_2, ppm	-	< 1	< 1
N component (NH_3 + HCN), ppb	-	-	< 20
HCl, ppm	-	< 0.5	< 0.1
Alkali metals, ppb		< 50	< 10

[a]Unit in ppmV

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Main gas cleaning methods

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General classification	**Cold** gas cleaning		**Hot** has cleaning	
Specific Classification	**Dry** cleaning	**Wet** cleaning	**Thermal** treatment	**Catalytic** treatment
Main critical issues	Disposal of tars	Disposal of tars	Slow reaction rates (inertness of poly-aromatic HC). High T and Activat.Energy to start reactions.	Slow reaction rates (inertness of poly-aromatic HCs). High T and Activation Energy to start reactions. Adsorption of impurities (HCl, H_2S, SOx) on cat.active sites. Tar conversion to cocke on cat.surface/active sites. Cat.resistant to hot gas clean-up. Cat.selectivity to gas and not coke pathway
Type of equipments	Cyclone, rotating particle separators (RPS), electrostatic precipitators (ESP), bag filters, baffle filters, ceramic filters, fabric/tube filters, sand bed filters, absorbers, etc.	Spray towers, packed column scrubber (wash tower), impingement scrubbers, venture scrubbers, wet electrostatic precipitators, wet cyclones, etc.	High-temperature devices such as ceramic filter/candle filter	Primary bed in the gasifier or in the secondary reformer

Source: Asadullah, 2016

Cold gas cleaning

- Engines need gas at T_{amb}.
- Cooling before or after cleaning.
- Dry vs wet
  - Dry: mainly physical removal without using water → no water cleaning system needed.
  - Wet: cools the gas & collect particles and impurities. H3, HCl, H2S and SO2 highly soluble in water. Very effective. Necessary to reach sufficient residence time (difficult at large scale). Some tars are however non polar and do not dissolve in water and constitute a separate condensate. Some impurities can escape the scrubber. Water cleaning system to be installed.
- Wet scrubbing is normally combined with physical treatments, e.g. cyclones and filters.

Cold gas cleaning

Details of cold gas cleaning including gasifier and feedstock types, equipment involved in cleaning and gas composition and quality.

Gasifier type	Feedstock type with feeding rate (kg/h)	Gas cleaning equipment	Gas composition (vol%)					Tar (mg/ Nm^3)	PM (mg/ Nm^3)	LHV (MJ/ Nm^3)	Cold gas eff., (%)	Electrical eff., (%)	Ref.
			H_2	CO	CH_4	CO_2	N_2						
Fixed bed gasifier													
Fixed bed downdraft	Wood chip, 250	Cyclone, spray tower, packed column scrubber, condenser, a purification tower, two wire mesh mist eliminators	16.1	16.6	2.3	13.8	51.2			4.7	53.0	16	[118]
Double air stage downdraft gasifier	Eucalyptus wood, 10–12	Cyclone, heat exchangers, and a bag house filter	16.8	19.0	0.9	13.6	50.6	< 35	< 10	4.6	67.0		[119]
Downdraft gasifier	Sawdust and sunflower seed pellet, 54	Cyclone, venture scrubber, chiller condenser, two saw dust filter and a bag filter	17.2	21.2	2.5	12.2	67.7			5.6	67.7		[120]
Fixed-bed twin fired	Wood chip, 25	A cyclone and a RME (rapemethylester)/H_2O quench system followed by a wet electrostatic precipitator (ESP)	18.3	20.4	2.5	14.7	45.5	180–240	0.7	5.8	63.5		[121]
Two stage downdraft	Corncob, 45–50	Heat exchanger, bag filter, limestone+activated carbon+desulfurization sorbent packed in a absorber	25–38	25–38	< 2	16–25	8.0–10.0	20	20				[122]
Two stage downdraft	Wood chip	Heat exchanger, bag house filter, paper cartridge filter, demister	32.5	15.0	2.1	19.5	30.0	15		6.0		25	[123]
Downdraft gasifier	Olive kernel, 100–110	Cyclone, venture scrubber, heat exchanger, chiller, mist eliminator, fine filter	24.1	10.7	4.2	4.6	75.0	10	10	4.46	75.0	16	[124]
Dual fired downdraft gasifier	Wood, 98	Heat exchanger, bag house filter and paper cartridge filter	21.3	20.5	1.1	10.7	89.7	35	3	5.3	89.7	21	[125]
Downdraft gasifier	Rice husk, 85	Cyclone, wet scrubber, bag filter	6.9	17.2	4.1	19.4				5.6			[126]
Downdraft	Wood chips, 50	Physical filter	9.34	29.4	0.2	9.71	73.0			5.1	73.0	10	[126]
Downdraft gasifier	Wood chips and rice husk, 80 and 120	Cyclone, water scrubber, chiller scrubber								5.52		18	[126]
Fixed bed down draft gasifier	Wood chip	Cold gas cleaning								4.6	70.0–75.0		[126]
Fluidized bed gasifier													
Dual fluidized bed steam gasification	Poplar chips, 57–92	Pilot gas cleaning using CaO absorber, cyclone and cold gas filter	33.1	25.1	10.4	19.3	70.0		2.1	12.7	70.0		[127]
Dual fluidized bed		Heat exchanger, filter and scrubber	50.6	16.5	12.9	12.3	10.0	1000					[128]
Bubbling fluidized bed	Pine, maple-oak wood, seed corn, 86–170	Cyclone, bag house filter, iso-propyl alcohol impinger	16–17	19–21	6–7	19–20				8.26			[129]
Fluidized bed	Sewage sludge, 570	Cyclone, gas cooler, granular bed filter, Ceramic filter, water absorber, packed column for NH_3 and H_2S	13.8	13.3	4.2	13	54.7			4.7	70		[130]

Source: Asadullah, 2016

Hot gas cleaning

- Threee main routes for hot gas cleaning
  - ✓ Filtration
  - ✓ Tar removal by thermal cracking
  - ✓ Tar removal by catalytic cracking

- Hot gas filtration
  - ✓ Mostly cyclones and ceramic candles to remove particulate & tars
  - ✓ Critical issues: Pressure build-up (→ Coupled Pressure Pulse CPP cleaning)
  - ✓ Ceramic candles: good perf.with particulates, poor with tars (which remaines in the gs phase and can pass through the candle filter)

Hot gas cleaning

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- Thermal Tar Cracking
  - ✓ At high temperature (order of 1000-1300 ° C) large organic molecules cracked to smaller and non-condensable ones
  - ✓ Higher Air-Fuel ratio normally necessary to achieve the necessary high T → reduced heating value of the gas

Details of hot gas cleaning data derived from different gasifiers.

Gasifier and feedstock type	Scale (kg/h)	Temperature (°C)	Gas composition (vol%)					LHV (MJ/Nm^3)	Cold gas efficiency (%)	Ref.
			H_2	CO	CH_4	CO_2	Tar (mg/Nm^3)			
Downdraft	Pilot, 12	1000	14.0	24.0	2.0	14.0	< 50	5.8	60-78	[30]
Downdraft	Large-scale demonstration, 5000	1000	13.0–15.0	20.0–23.0	-	10.0–11.0	–	4.2–4.3	76	[114]
Downdraft	Pilot, 18.7	900	8.7–13.2	20.8–23.6	3.6–5.2	9.3–14.5	4800	6.1	67	[141]
Updraft and Downdraft	Pilot, 30	950	10.4	15.1	0.3	12.8	450	3.2	–	[13]
Regenerative downdraft	Pilot, 5	1000	14.1–16.3	14.2–21.6	5.2–2.5	15.2–10.3	44–107	5.2–5.4	–	[142]
Down draft	Pilot	954	11.1–20.9	14.3–20.2	2.9–2.8	–	45	4.2–6.0	60-7	[143]
Downdraft	Pilot 5.4	1000–1200	11.1	18.6	2.2	11.2	3000	4.7	–	[115]
Down draft	Pilot 3–4	1050	11.11	18.56	2.0	13.12	5	3.8–4.0	63-6	[116]
Continuous Fixed bed	Pilot 4	1050	15.9	9.8	0.2	10.8	–	3.4	–	[144]
Downdraft	Pilot 2.–3.5	900–1200	17–23.3	9.9–13.5	1.5–2.8	9.9–14.5	–	4.1–5.4	63	[117]
Downdraft	Pilot 15	1100	10–12	18–22	< 1	5–20	–	4.2	–	[145]

Source: Asadullah, 2016

Hot gas cleaning

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- Catalytic Tar Cracking
  - ✓ Tar are reformed on a catalyst bed. Four main groups: (1) mineral, (2) nickel based, (3) noble metal catalysts and (4) iron based catalysts
    - ✓ Magnesite ($MgCO_3$), olivine (magnesium iron silicate $(MgFe)_2SiO_4$), dolomite, nickel-based catalysts (as commercial Ni–$MgAl_2O_4$).
  - ✓ Barrier: poisoning of catalysts (e.g. S for nickel-based catalysts)
  - ✓ Investigation by Corella et al showed that Ni-based catalysts in secondary bed can survive only when tar conc.at gasifier exit is < 2 g/Nm^3, while normally it is 2.25-42 g/Nm^3 → primary bed with dolomite to reduce tar to 2 g/Nm^3.
  - ✓ Recent work by Asadullah et al on novel metal catalyst (Rh) at rather low T (650-700 ° C), and on char-supported iron catalysts

Details of catalytic hot gas cleaning data derived from different gasifiers.

Gasifier and feedstock type	Scale (kg/h)	Catalyst type/non-catalytic	Gas composition (vol%)						LHV (MJ/Nm^3)	Ref.
			H_2	CO	CH_4	CO_2	N_2	Tar (mg/Nm^3)		
Fluidized bed for wood	20	Sand Primary bed	21.9	31.7	8.6	30.7	31.5	10.1	–	[152]
Fluidized bed for wood	20	Olivine $(MgFe)_2SiO_4$ Primary bed	19.4	30.1	8.9	36.0	53.1	12.8	–	[150]
Fluidized bed for wood	20	Magnesite ($MgCO_3$) Primary bed	35.9	12.7	5.5	42.6	49.0	2.2	–	[152]
Circulating fluidized bed, Wood Miscanthus	20	Ni–$MgAl_2O_4$ Secondary bed	45	17	1.8	–	–	–	–	[154]
Fluidized for Pinewood chip	Pilot 10	Calcined dolomite in bed	43	27	4.8	20	–	2000–3000	12.3	[156]
Bubbling fluidized bed for Pinewood chip	10	Secondary bed dolomite	38	36.9	7.2	33.0	–	1720	15.0	[157]
Bubbling fluidized bed for Pinewood chip	5–20	Commercial Ni catalyst	51–59	24–32	0.2–1.6	9–23		5–20	10–12	[161–163]

Source: Asadullah, 2016

Conclusions on gas cleaning

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Gas composition	Tar content	Particle Content	Gas Heating Value & Cold Gas Efficiency
High T (>1000 °C) promotes CO & H production Lower Air-to-Biom ratio favor CO, H_2, CH_4 and higher HCs formation Catalysts favor the yield of combustible gas	Tars can be either removed by filtration or inhibited from forming (but the high T needed are problematic). (1) mineral, (2) nickel based, (3) noble metal catalysts and (4) iron based catalysts New iron-based catalysts on activated charcoal, cheap and resistant towards deactivation.	Several methods developed. Dry and wet methods, and combinations of these two. Cold and Hot methods as well. Water scrubbing also cools the gas.	Addition of steam increases H_2 content (WGS reaction), but overall HHV is unchanged. Catalytic tar reforming also contributes to increase gas HHV (as it also helps to reduce the ER in the gasification reactor). Higher input of gasifying agent means reduced CGE. Catalytic tar reforming, working at lower T, contributes to higher CGE
Expensive materials to withstand high T Low A/B ratio favor Tar formation (handling & disposal of tars)	Catalysts requires < 2 g/Nm^3 tar content in the gas at inlet (double bed necessary). Catalysts can be deactivated by poisoning substances)	Downstream technologies normally requires particulate levels < 50 mg/Nm^3.	Commercial catalysts can be deactivated on long-runs. New catalysts (such as iron-based char-supported ones)

Source: Asadullah, 2016

Mixed oxygenates —400 °C→ Phenolic ethers —500 °C→ Alkyl phenolics —600 °C→ Heterocyclic ethers —700 °C→ PAH —800 °C→ Larger PAH (900 °C)

Source: Elliot, 1988

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Final remarks on Small Scale CHP

- The stable and reliable operation of small scale CHP gasification system is essential towards economic and environmental sustainability of Business Plans
- An often underestimated issue in planning phase
  - ✓Offers from Technology providers are sometimes unclear/incomplete and difficult to compare on this respect
  - ✓Customers are committed to operate the plant properly and feed appropriate fuel
- Regulating & controlling these issues at the beginning as well as during the whole plant life is essential

Third-party Assessment of Performances (short & long-term)

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- Third-party verification is a guarantee for
  - ✓ The Customer
  - ✓ The financing Institution
  - ✓ Technology providers
- As well as a market opportunity for the technology developers
- CTI 13 –> E0209E590 –>

  UNI 11603: 2015

DATI DI COPERTINA E PREMESSA DEL PROGETTO E0209E590

Impianti per la produzione e l'utilizzo di gas da gassificazione di biomassa combustibile

Classificazione, requisiti, regole per l'offerta, l'ordinazione, la costruzione e il collaudo

Plants for the production and the use of gas based on biomass gasification

Classification, requirements, guidelines for construction, trade offer, final order, acceptance tests of the plants

ORGANO COMPETENTE: CTI - Comitato Termotecnico Italiano

CO-AUTORE

[...]lità di classificazione, i requisiti essenziali, le regole per l'offerta, [...]e il collaudo degli impianti per la produzione e l'utilizzo di gas da [...]combustibile destinati alla produzione in sito di energia elettrica e/o

CTI EnergiA AmbientE

UNI ENTE ITALIANO DI NORMAZIONE

codice progetto: E0209E590

Performance Test Protocol for Small Scale Gasifier

White Paper elaborated 2015 under IEA Bioenergy, Task 33 Thermal Gasification of Biomass

Martin Rüegsegger, ETECA GmbH, Fahrni, Switzerland

November 2015

Abstract

This White Paper "Performance Test Protocol for Small Scale Gasifier" [PTP] was elaborated by the IEA Bioenergy under Task 33 (Thermal Gasification). For the last years appeared more commercial available gasifier units on the market. As a guideline during a project for a Gasifier CHP unit this white paper can help to improve the project quality and the successful proof of performance after commissioning. The handover of a gasifier CHP unit from supplier to the client will be easy and successful, if there is accurate PTP existing.

IEA Bioenergy

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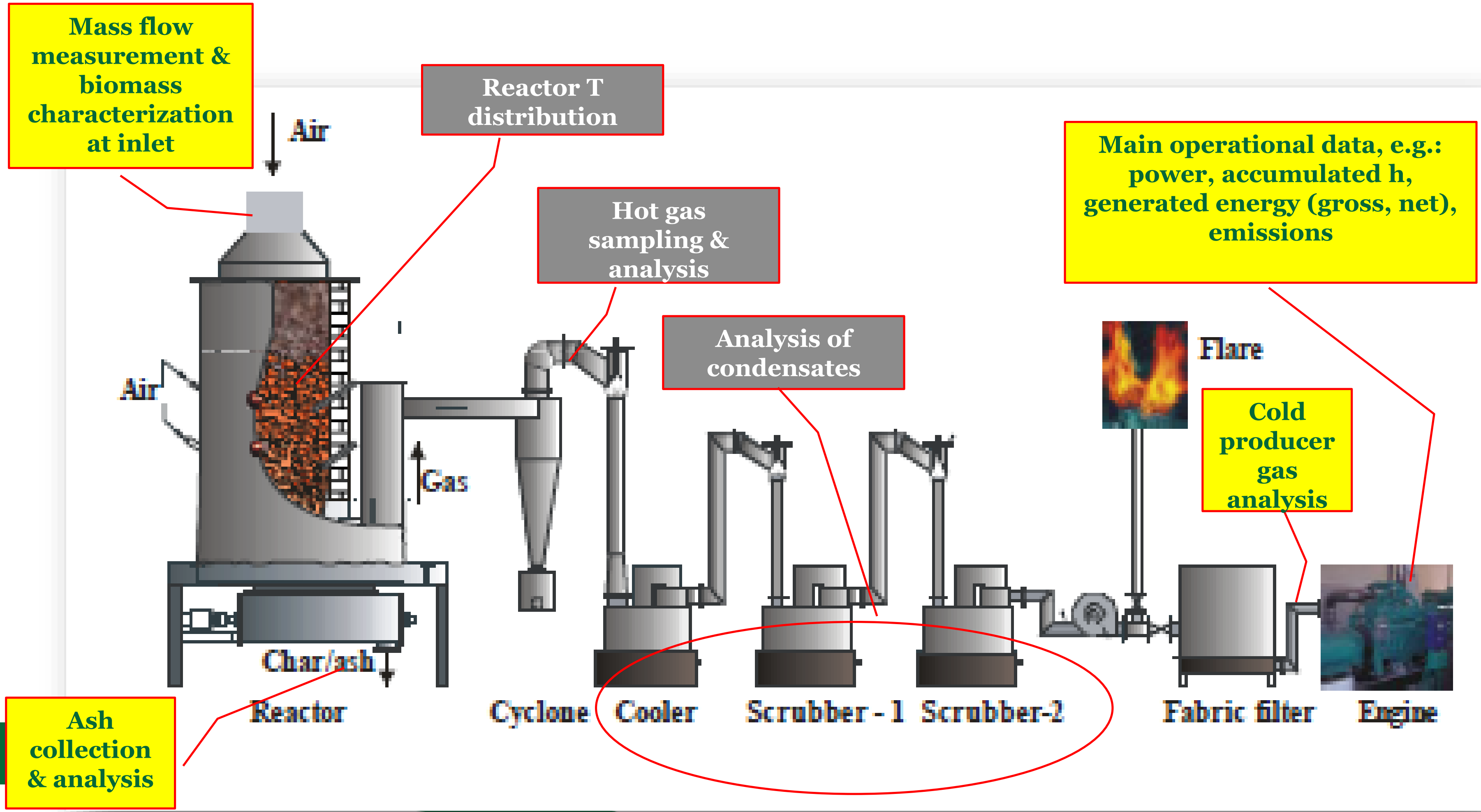
Measuring performances of small scale gasifiers..



→ Mass & Energy Balance

Equipments & skills are needed for performance assessment

Sampling

Tars Condensation

GC-NDIR

GAST Project

Experiences in biomass GAsification in South-Tyrol: energy and environmental assessment

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- **Scope**
  - *Preliminary screening of small scale biomass-gasification-based cogeneration plants located in South Tyrol*
  - *Two or three representative plants selected for the monitoring campaign*
  - *Characterisation/Monitoring*
- Coordinator & Partners
  - **Libera Università di Bolzano (prof Marco Baratieri)**
  - **Eco Research SrL**
  - Subcontractors: **RE-CORD**, **TIS Innovation Park**

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Carbonisation + Heat … A small biorefining approach

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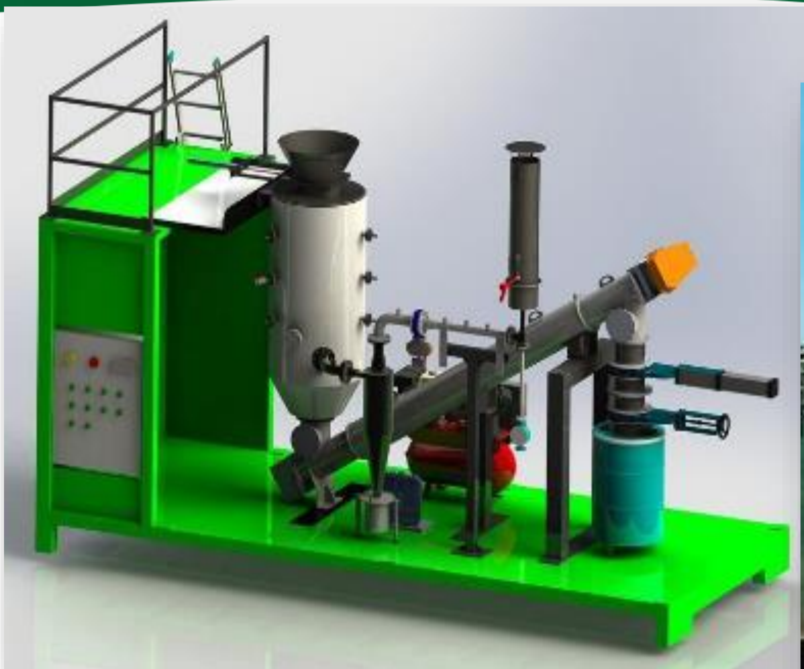

Key issues

- ✓ Slow Oxidative Pyrolysis
- ✓ Open top, cooled screw (discharge)
- ✓ Products: char + High T Heat

- ✓ **50** kg/h_in, **12** kg/h_out, **60-70** kWth
- ✓ **250** kg/h_in, **50** kg/h_out, **350-400** kWth

- *R&D: Condensing PO + CHP ?*
- *Grid parity theoretically possible…*

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Conclusiong on Small Scale biomass gasification CHP systems

- CHP Gasification is a very dynamic sector, but dependent on Incentives (while PV has almost achieved Grid Parity) and Heat use.
- Decades of R&D work behind us. No need to re-invent the wheel: past experiences should drive technology evaluation and selection.
- Reliability still an issue: BPs based on running hours per year! Guarantees?
- Mix of large industries and small/very small companies on the market. Company financial dimension vs guarantee a key issue.
- Feeding adequately pretreated biomass is key for continuous operation.
- Fight on CAPEX (to make investment attractive) does not help the sector and generated lack of credibility!
- Claimed performances are sometimes overestimated. Third Party Assessment would be a useful support for Financing Institutions, Suppliers and Customers in order to develop sound BP and commercial projects.

Thanks for your Attention!

UNIVERSITÀ DEGLI STUDI FIRENZE

www.re-cord.org

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