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2018 EEC/WTERT Bi-Annual Conference
Sustainable Waste Management: The Forefront of Innovation

The City College of New York - October 4th & 5th, 2018

A case study of gasification CHP in northern Italy in the European context and comparison to traditional combustion systems

Marco Baratieri

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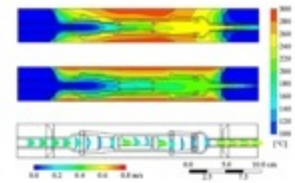
Thermochemical conversion (pyro-gasification)

+ Analytics
  . Feedstock characterization
  . Advanced thermal analysis
  . Catalyts analysis
+ Process analysis

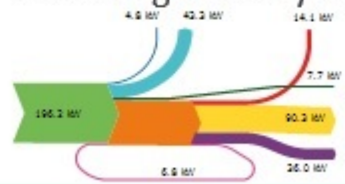
+ kinetic modelling
+ thermo fluidynamic modelling

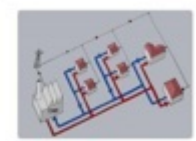


CHP systems

+ Pilot/bench scale plant design and development
+ Monitoring of real scale plants

+ Modelling of energy systems
+ Modelling of DH systems

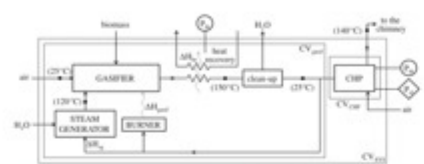




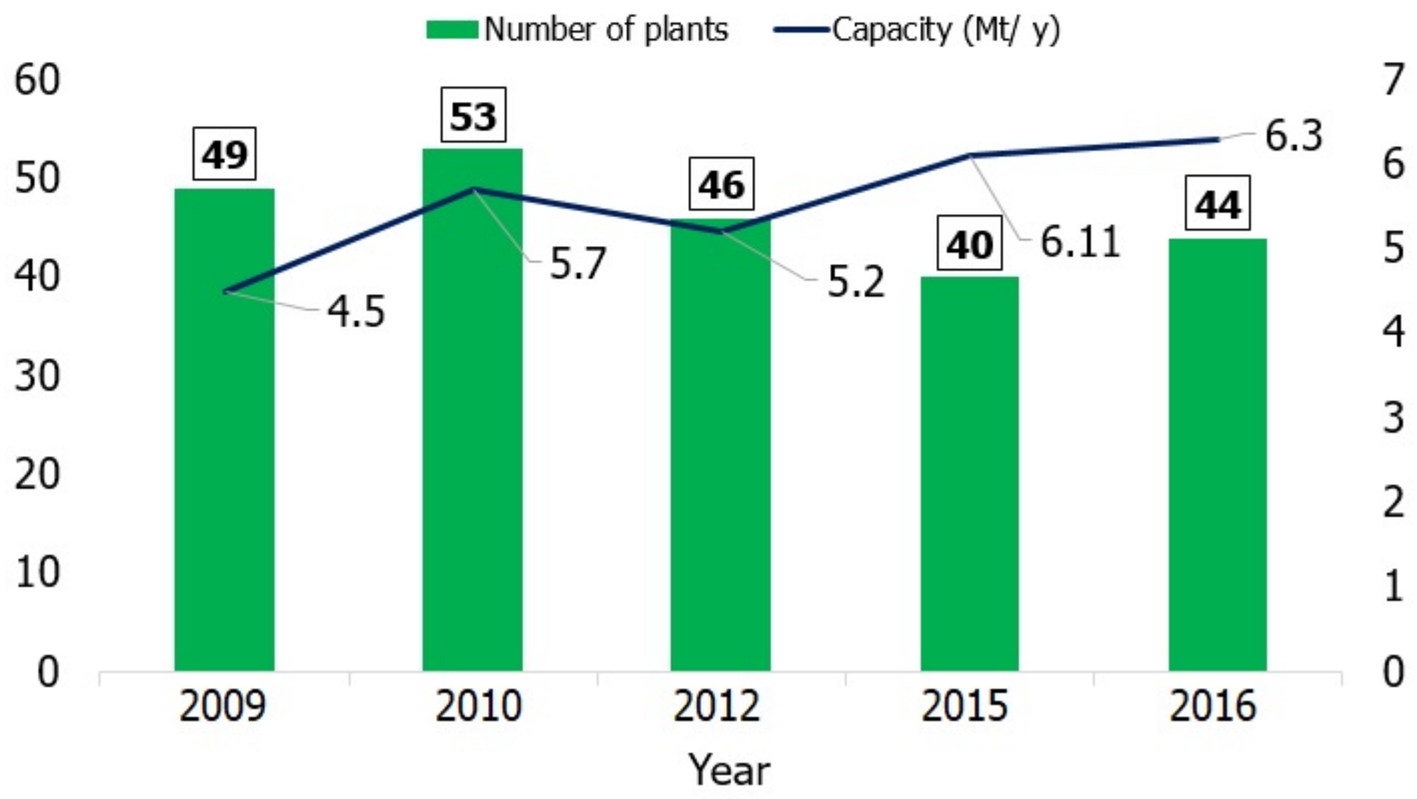
By- products management - Polygeneration

+ Char valorisation pathways
  . Activated carbon production
  . FT synthesis
  . Biodiesel production
+ Tar analysis / reduction

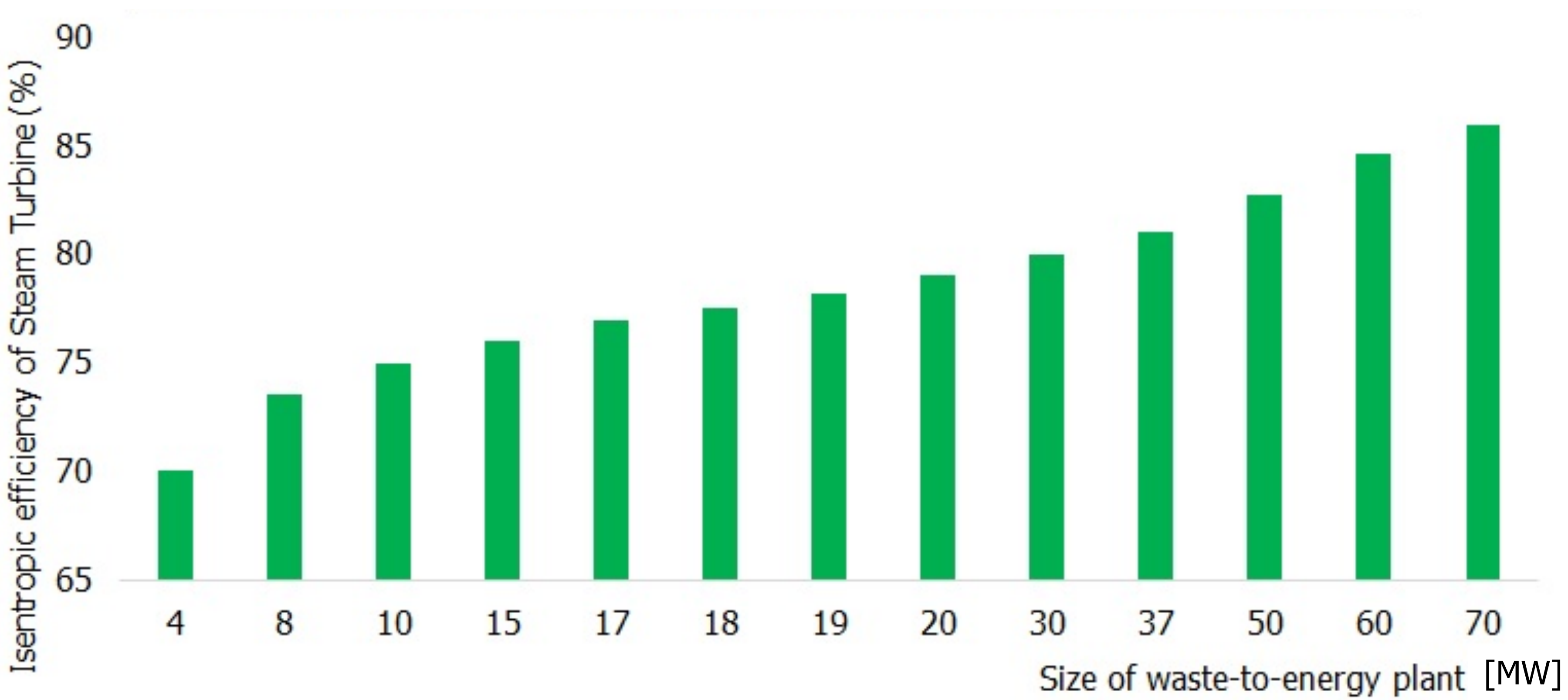
+ Analysis of scenarios
  . Optimization strategies
  . B.O.P.



Waste - to - energy plants in Italy



Size of W2E plants and efficiency of steam turbines



Source: adapted by Consonni, 2014

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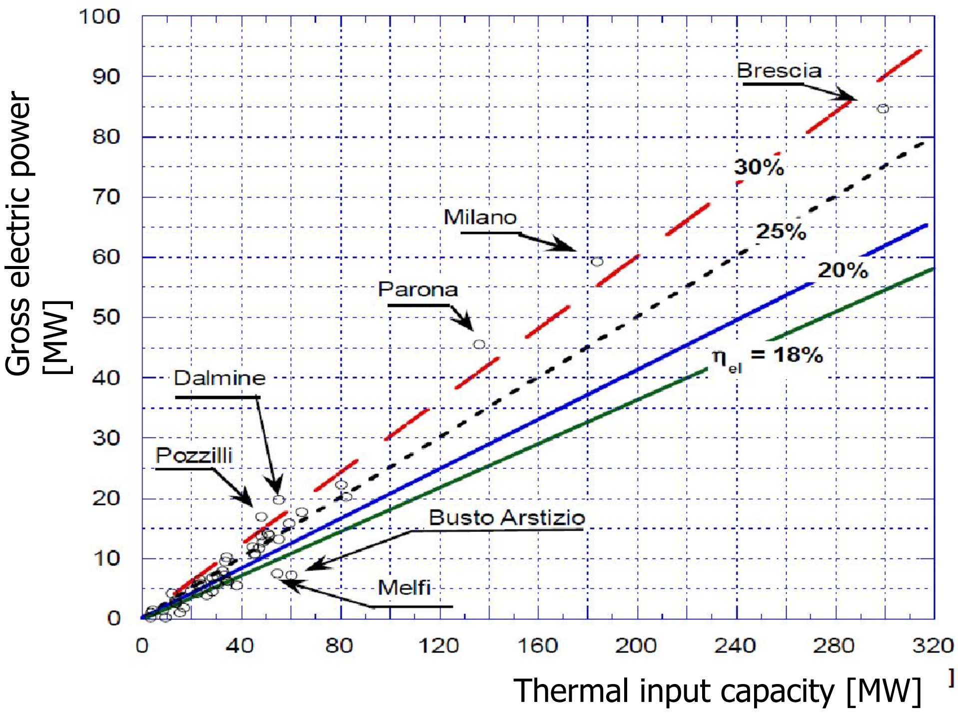
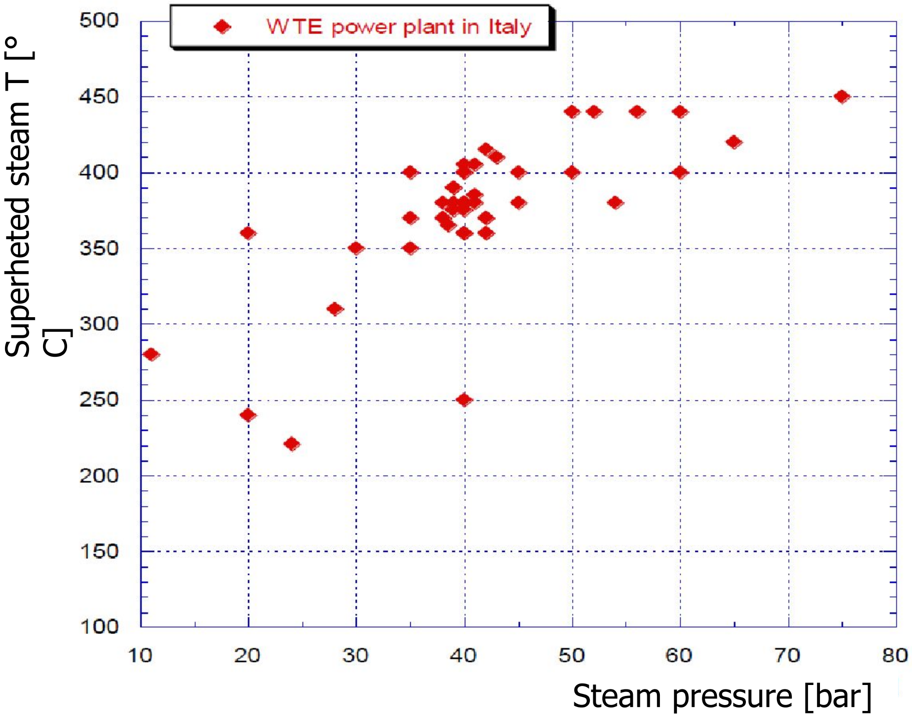
Operational parameters of Italian waste-to-energy plants





Source: Branchini, 2012

Waste-to-energy plant in Brescia

- ✓ 3 lines: 2 MSW and 1 biomass
- ✓ In 2008, the facility burned ~ 801 kt/y
- ✓ The electrical efficiency exceeds 27 %
- ✓ The facility covers approx. 75% of the city's heat demand
- ✓ In 2006 it was accredited by Global Waste To Energy Research and Technology Council (WTERT) as the best WtE plant in the world

Sources: Chaliki et al., 2014
Bogale & Viganò,2014

Waste management crisis in Naples

- ✓ The Naples waste management crisis is a series of events surrounding the lack of waste collection in Campania region that took place from 1994 to 2012
- ✓ Since the mid-1990s, Naples and the Campania region have suffered from the dumping of municipal solid waste into overfilled landfills.
- ✓ Beginning on 21 December 2007, the municipal workers refused to pick up any further material; as a result, the waste had begun to appear as regular fixtures on the streets of Naples, posing grave health risks to the metropolitan population.
- ✓ Heavy metals, industrial waste, and chemicals and household waste were dumped near roads and burned to avoid detection, leading to severe soil and air pollution.
- ✓ In 2008, the (at the time) new waste commissioner, Guido Bertolaso accelerated the recovery plan by approving the development of new landfill sites and an incinerator.

The Acerra waste-to-energy plant

- ✓ Since September 2009, the plant has been capable of functioning at full power.
- ✓ Working full power, the plant can transform quantities of refuse equal to 1,950 tons per day into energy, for a total of 600,000 tons per year.
- ✓ 120 MWe, 340 MWth and 380 tonnes of steam produced per hour
- ✓ The annual consumption of 200,000 households can be met by the production of electricity by the plant when working at full capacity

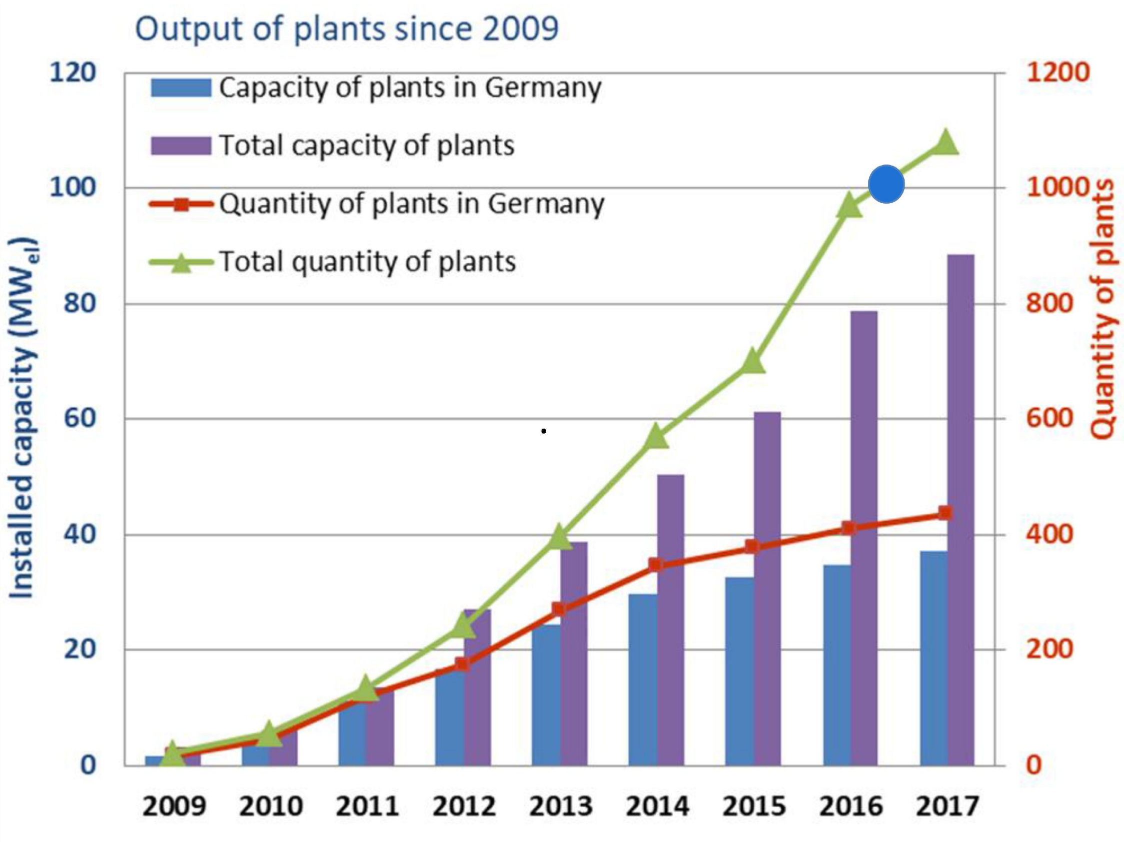
For the Acerra plant, the best technology available has been adopted to ensure minimum environmental impact in relational to emissions into the atmosphere, liquid discharges, solid residues, noise and traffic.

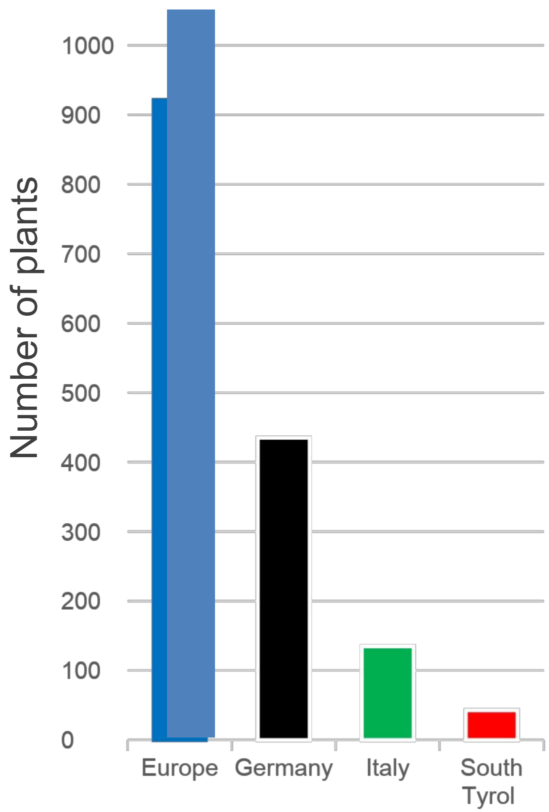
Some remarks & status quo

- ✓ The totality of waste-to-energy plants in Italy and the vast majority of waste-to-energy plants worldwide are (for the moment) **incineration** facilities.
- ✓ Incineration of MSW has several advantages but also a few obvious limitations.
  - The size vs electrical efficiency, the management of ash remains a challenge, for the years 2004 – 2007 the CHP facilities were equal to electricity plants
- ✓ For the case of biomass, Italy and other Central-European countries have installed several **gasification** facilities.
- ✓ Gasification can be an interesting solution to be investigated due to the increased electrical efficiencies and due to the high quality of the produced solid by-product, i.e. char.
  - The example of South Tyrol can be used as a case study

Small scale gasification: facts & figures

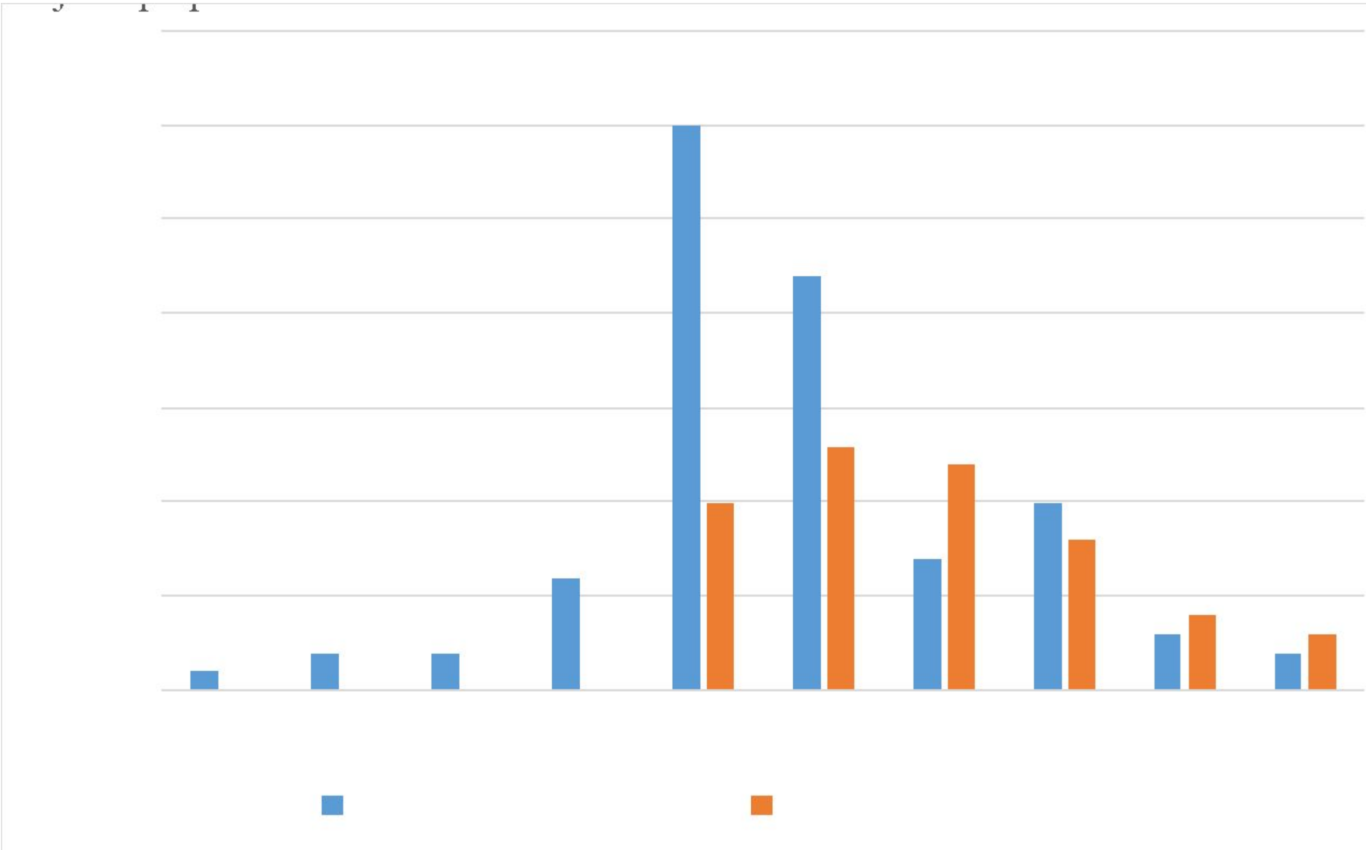
Europe ~ 1040; Germany ~ 435*, Italy ~ 120-150; South Tyrol ~ 46





[D. Bräkow, 9. „Internationale Anwenderkonferenz Biomassevergasung", 5. Dezember 2017 / Innsbruck]

Gasification technology development



Relevant projects on gasification

Project partners

Funding bodies

GAST (2013-16): "Experiences in biomass **Ga**sification in **S**outh **T**yrol: energy and environmental assessment"

NEXT GENERATION (2016-17): "**N**ovel **EXT**ension of biomass poly-**GENERATION** to small scale gasification systems in South-Tyrol

Project partners: eco research, RE-CORD, IDM Südtirol Alto Adige, TIS innovation park
Funding bodies: Autonome Provinz Bozen Südtirol / Provincia Autonoma di Bolzano Alto Adige

WOOD-UP (2016-2019): "Optimization of **WOOD** gasification chain in South Tyrol to prod**U**ce bio-energy and other high-value green **P**roducts to enhance soil fertility and mitigate climate change"

Project partners: Laimburg, IDM Südtirol Alto Adige
Funding bodies: efre · fesr Südtirol · Alto Adige (Europäischer Fonds für regionale Entwicklung / Fondo europeo di sviluppo regionale), European Union

FlexiFuelGasControl (2017-2020): "Increased **FUEL FLEXI**bility and modulation capability of fixed-bed biomass **GAS**ifiers by means of model based **CONTROL**"

Project partners: bioenergy2020+, TU Graz (Graz University of Technology), URBAS energietechnik
Funding bodies: FFG

Relevant projects on gasification

Project partners

Funding bodies

GAST (2013-16)

Plant monitoring

NEXT GENERATION (2016-17)

Char industrial valorization

Partners: eco research; RE-CORD; IDM Südtirol Alto Adige; TIS innovation park

Funding: Autonome Provinz Bozen Südtirol / Provincia Autonoma di Bolzano Alto Adige

WOOD-UP (2016-2019)

Char in agriculture

Partners: Laimburg; IDM Südtirol Alto Adige

Funding: efre · fesr Südtirol · Alto Adige – Europäischer Fonds für regionale Entwicklung / Fondo europeo di sviluppo regionale; European Union

FlexiFuelGasControl (2017-2020)

Fuel flexibility and predictive control

Partners: bioenergy2020+; TU Graz – Graz University of Technology; URBAS energietechnik

Funding: FFG

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The NEXT GENERATION project (2016-17)

"**N**ovel **EXT**ension of biomass poly-**GENERATION** to small scale gasification systems in South-Tyrol"

Project partners

eco research

RE·CORD

IDM SÜDTIROL ALTO ADIGE

Funded by:
Autonomous Province of Bolzano

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Abteilung 40. Bildungsförderung, Universität und Forschung

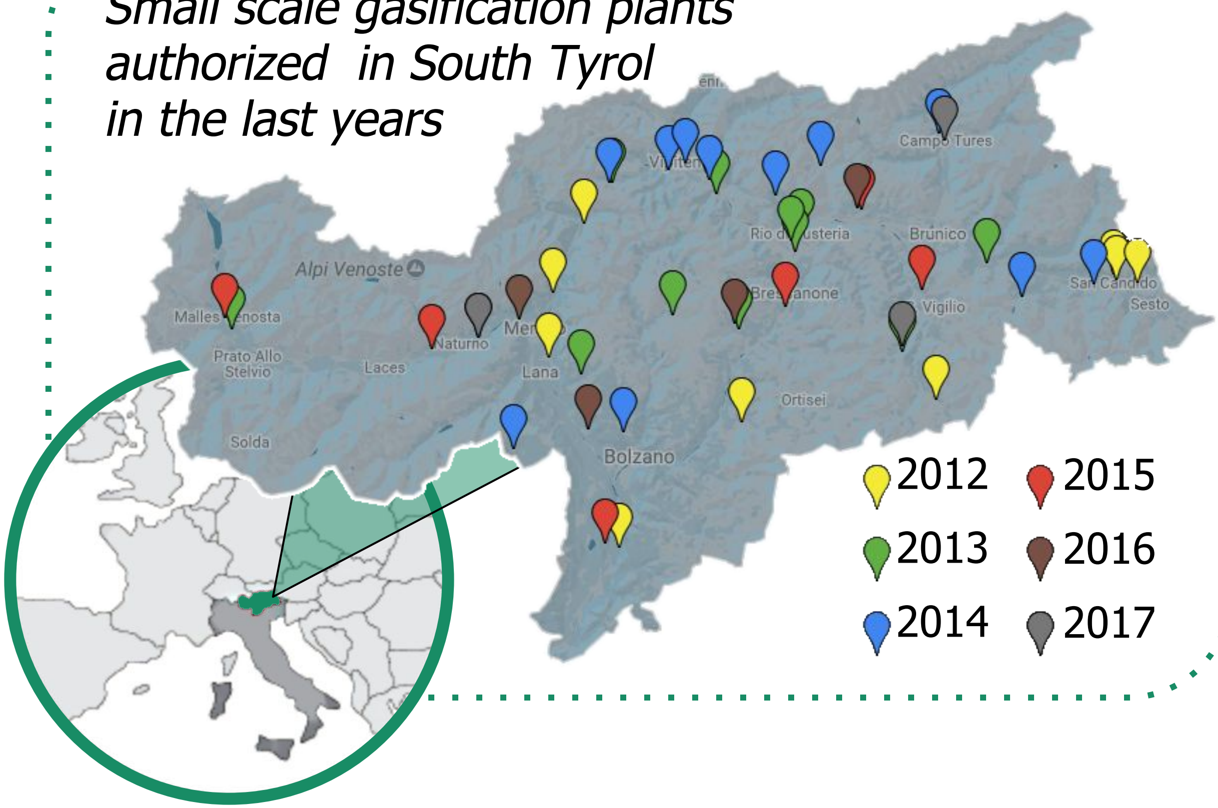
PROVINCIA AUTONOMA DI BOLZANO - ALTO ADIGE
Ripartizione 40. Diritto allo Studio, Università e Ricerca scientifica

Aims of the project

1. Complete the dataset of **small-scale gasification technologies** in S-T
2. Evaluate the **main products** and **by-products fluxes** and **characteristics**
3. Assessment of **valorization pathways** of gasification by-products (char)
    a. adsorbent
    b. catalyst support (FT-synthesis, DRM)
    c. tar cracking application (ongoing)
    d. energy production (co-firing)

Distribution of gasification plants in South-Tyrol

Small scale gasification plants authorized in South Tyrol in the last years



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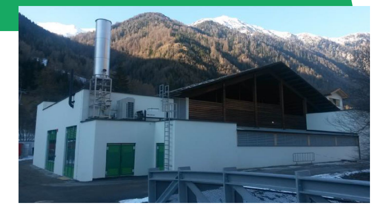


Installed technolgies



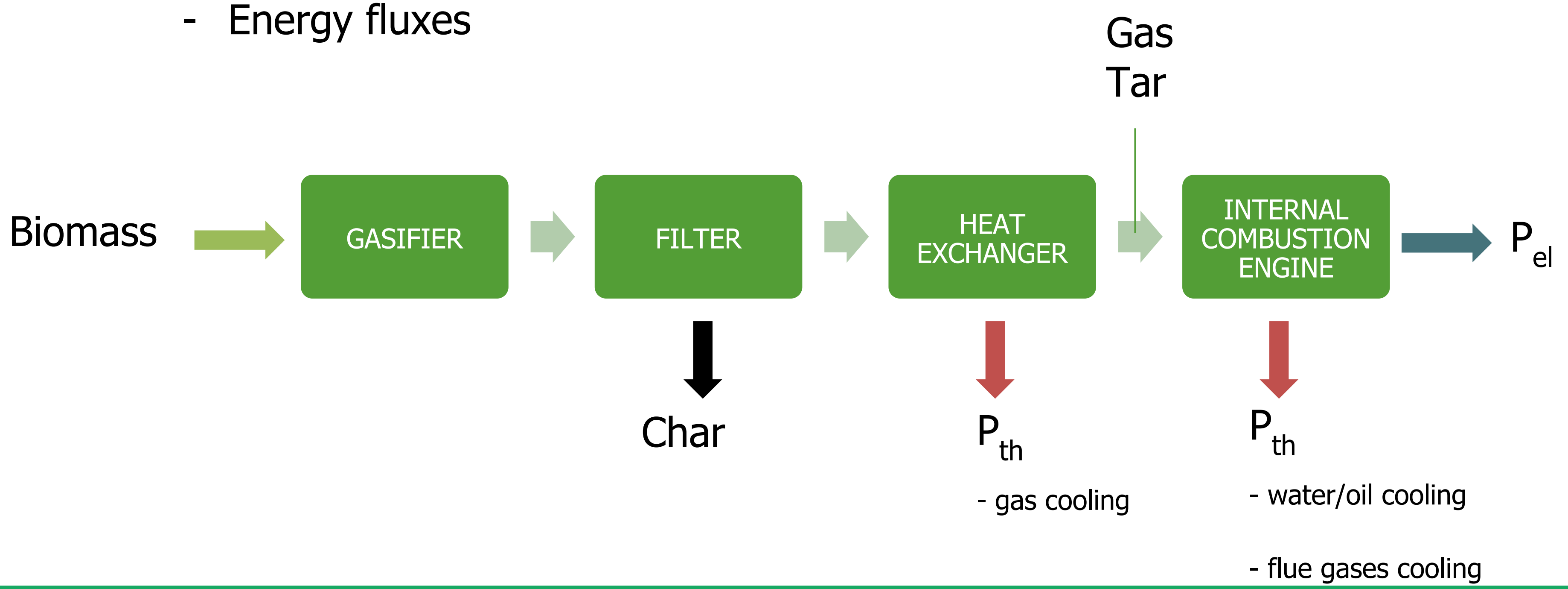

Technology	Reactor	Biomass	Electric power [kW]	Thermal power [kW]
Burkhardt GmbH	Rising co-current	Pellet	180	270
Entrade Energiesysteme GmbH	Downdraft Fixed bed	Pellet A1	25	60
Future Green Srl (Wubi)	Downdraft Fixed bed	Woody chips	100	200
Hans Gräbner	Downdraft Fixed bed	Woody chips	30	60
Holzenergie Wegscheid GmbH	Downdraft Fixed bed	Woody chips and brickets	140	270
Kuntschar Energieerzeugung GmbH	Downdraft Fixed bed	Woody chips	150	260
Spanner Re^2 GmbH	Downdraft Fixed bed	Woody chips	45	105
Stadtwärke Rosenheim	Double stage Fixed bed	Woody chips	50	110
Syncraft Engineering GmbH	Double stage Fixed bed	Woody chips	250	990
Urbas Maschinenfabrik GmbH	Downdraft Fixed bed	Woody chips	296	550
Xylogas & EAF	Downdraft Fixed bed	Woody chips	440	880




Monitoring activities

Analyzed parameters

- Feedstock and gasification products (gas, char e tar) characteristics
- Mass fluxes
- Energy fluxes



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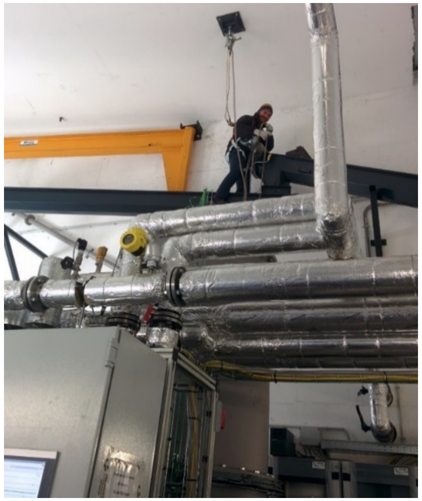
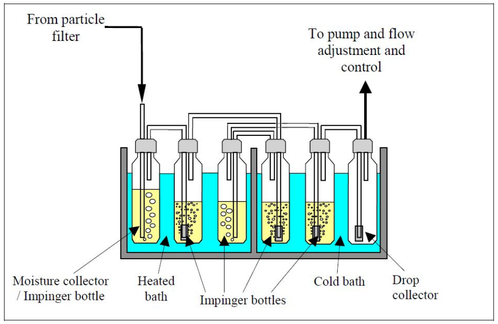
On site monitoring activities



Mass fluxes
- Woody biomass flow rate
- Gasifying agent (air) flow rate
- Producer gas flow rate
- Char flow rate

Energy fluxes
- Input fuel
- Producer gas
- Power and heat

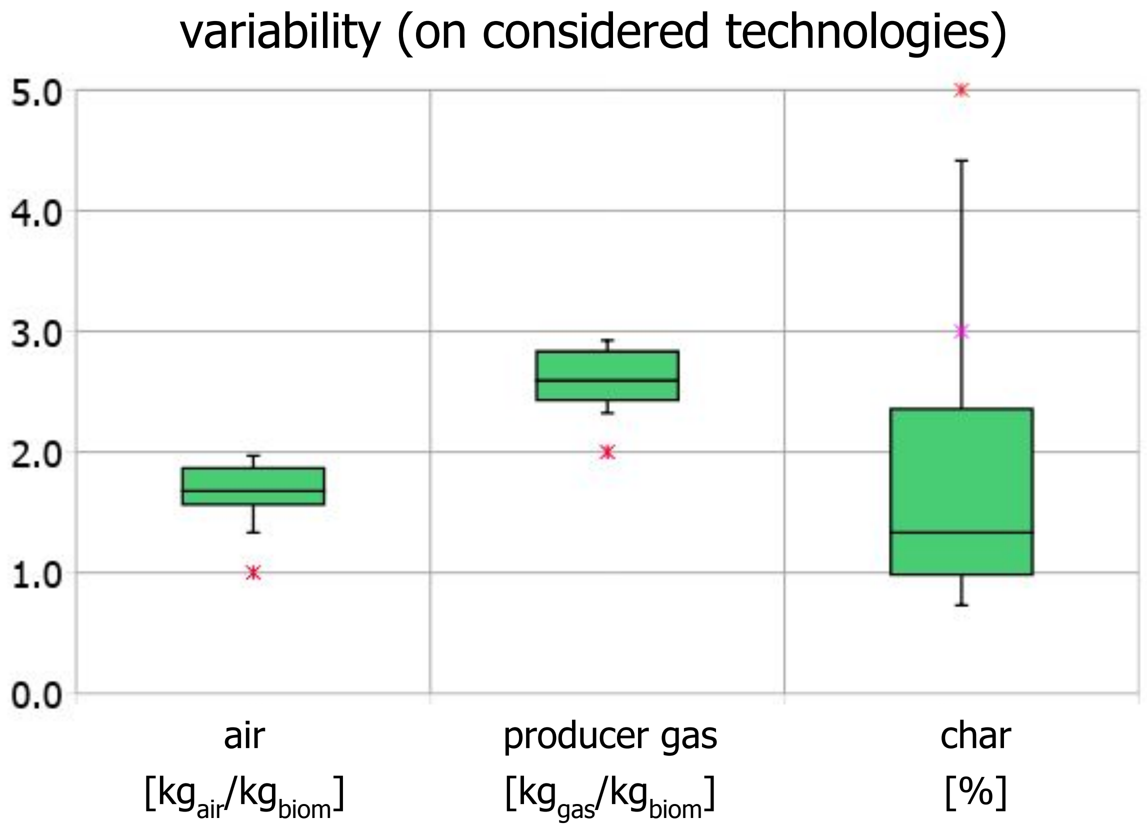
By-products characterization
- Liquid: tar
- Solid: char



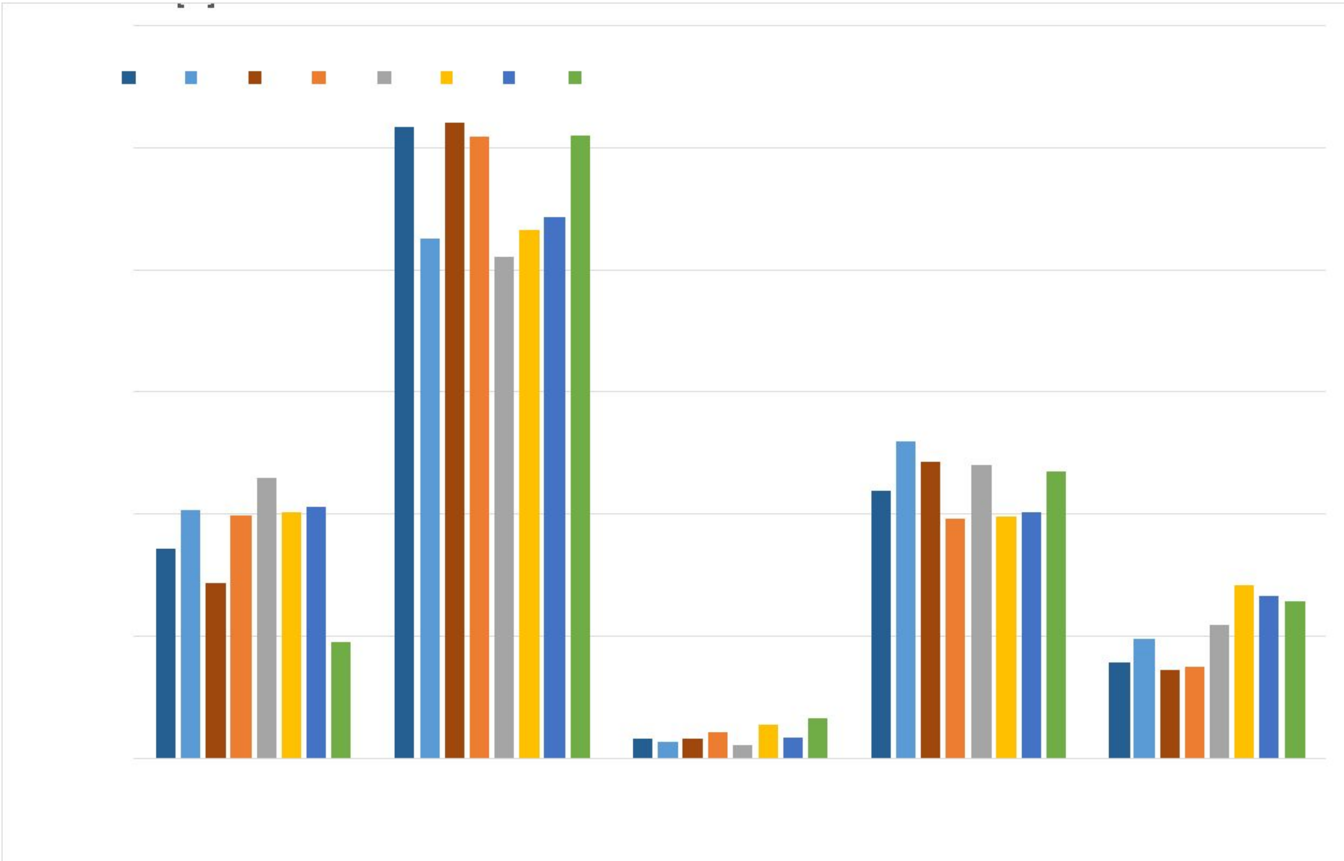
Mass balances of selected technologies

Technology	Dry biomass [kg/h]	Air [kg/h]	Producer gas [kg/h]	Char [kg/h]	Mass balance closure [%]
A	39.6	68.7	107.6	0.7	-
B	127.3	205.8	313.9	1.3	-5.4
C	116.9	155.6	271.4	1.1	-
D	123.8	185.0	297.6	5.1	-2.0
E	42.6	78.2	121.3	0.7	1.0
F	229.0	363.3	558.8	22.8	-1.8
G	338.4	663.0	990.4	3.6	-0.7
H	150.8	296.9	426.5	1.1	-4.5

Mass balance

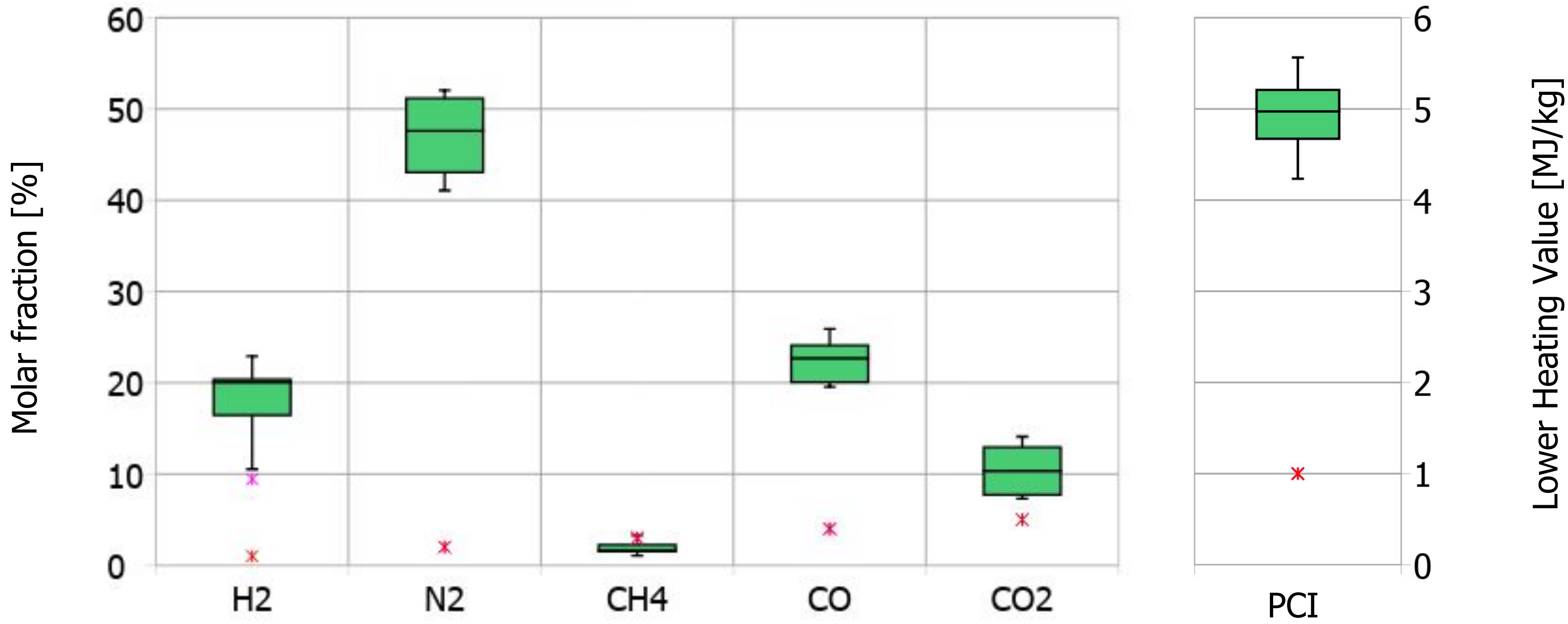


Producer gas composition

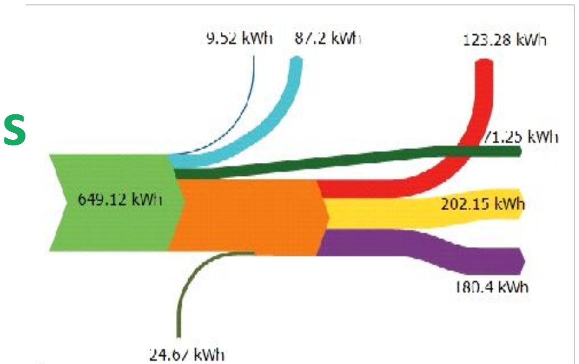


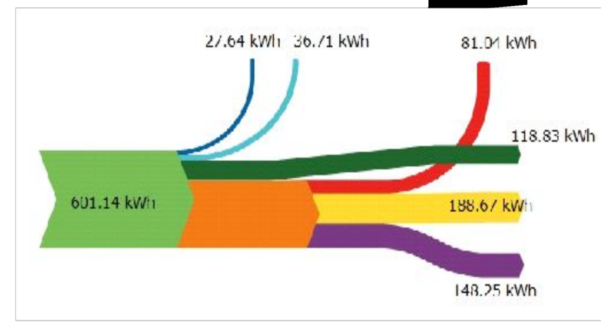
Producer gas composition

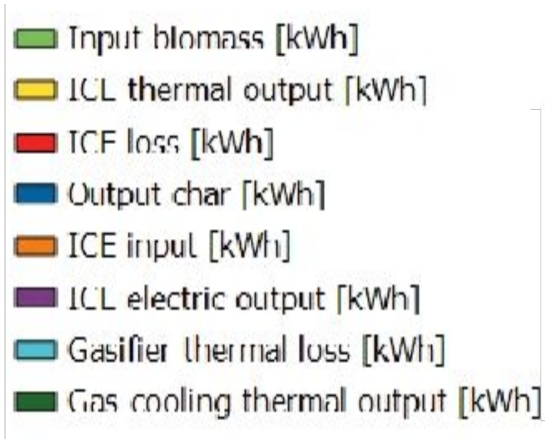
variability (on considered technologies)

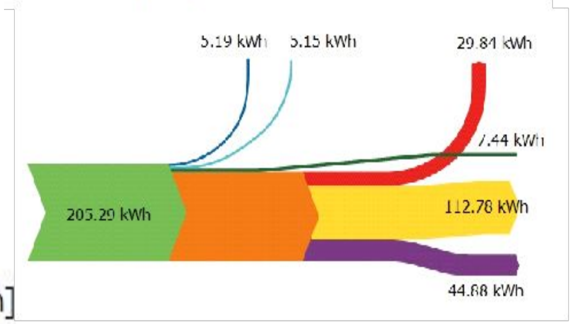


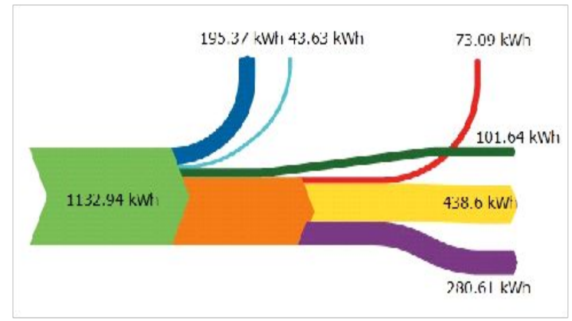
Energy balance of selected technologies

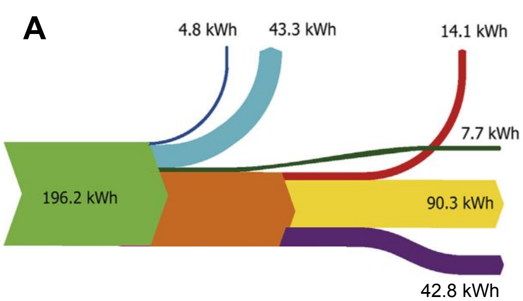


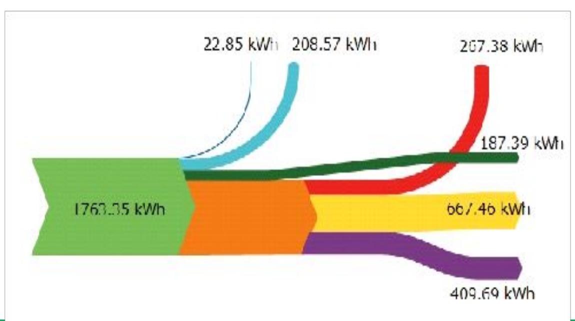


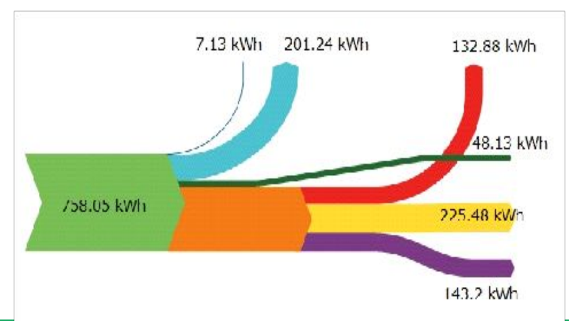










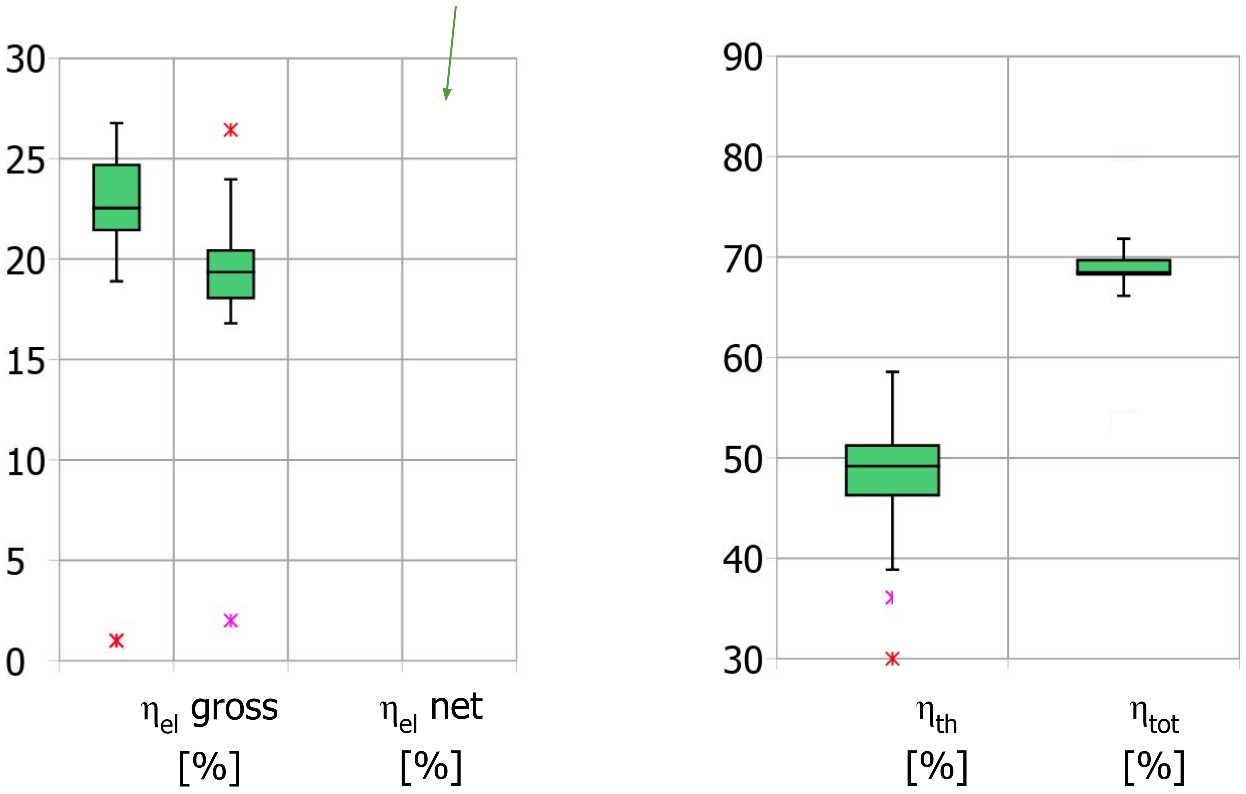


Gasification performance parameters

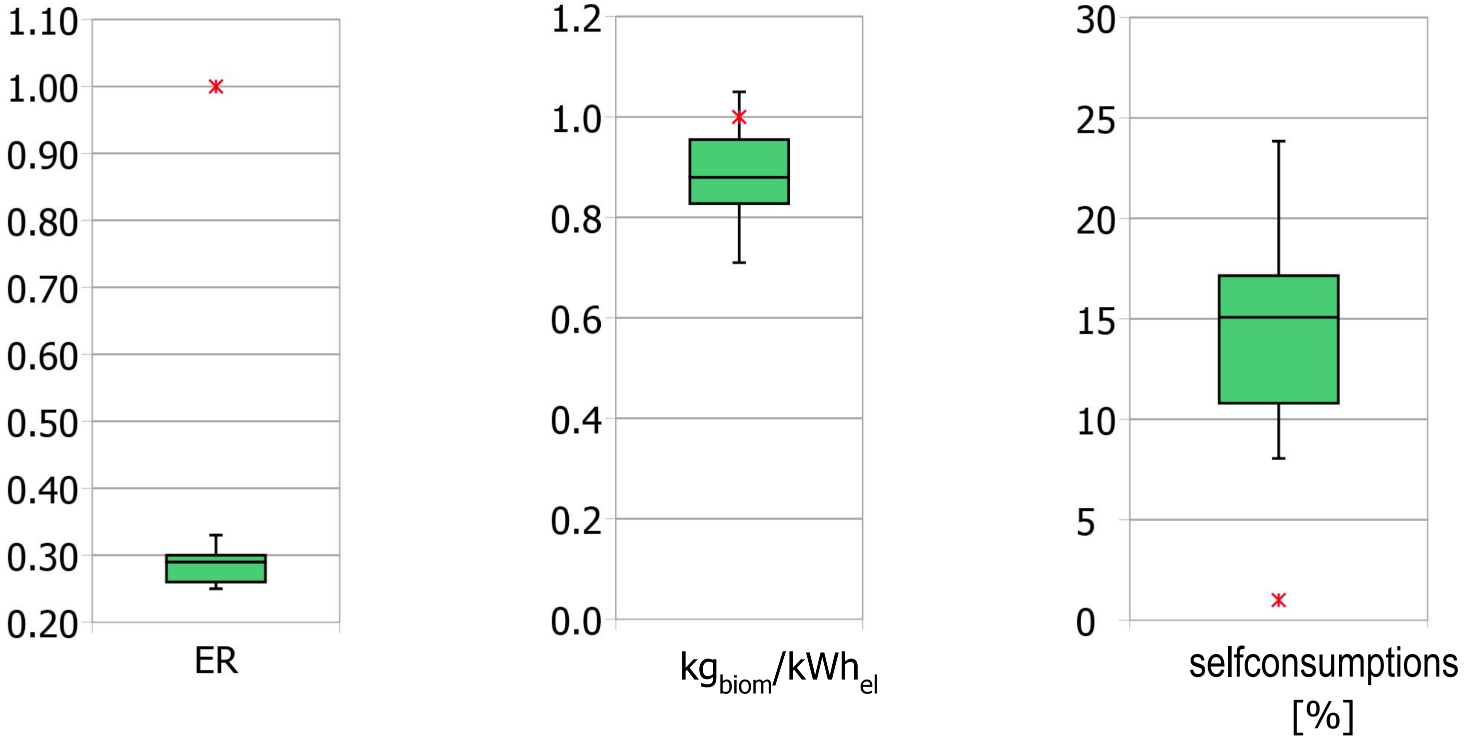
Technology	A	B	C	D	E	F	G	H
ER	0.30	0.26	0.29	0.25	0.29	0.26	0.33	0.30
η_{EL}	18.3%	26.4%	16.8%	18.8%	19.9%	21.9%	19.9%	17.4%
η_{TH}	49.9%	42.1%	52.5%	51.2%	58.6%	47.7%	48.5%	36.1%
η_{TOT}	68.2%	68.6%	68.3%	69.9%	78.5%	69.6%	68.4%	53.5%
kg_{BIOM}/kWh_{EL}	0.93	0.71	0.97	0.83	0.95	0.82	0.83	1.05

Performance

Dual fuel engine (3 l/h of vegetable oil)



Characteristic parameters



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Combustion Vs Gasification: performance in real operation

	Boiler-ORC		Gasifier-ICE
Power load (%)	79	94	95
Electrical power (kWe)	790	940	43
Thermal power (kWt)	4160	4710	98
Input power (kWt)	6290	7140	196
Biomass consumption (kg h^{-1})	1454	1703	40
Biomass water content on wet basis (%)	14.4	15.6	6.6
Biomass LHV on “as receive” basis (MJ kg^{-1})	15.6	15.1	17.8
Ash/char production (kg h^{-1})	11.2	11.5	0.75

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Combustion Vs Gasification: performance in real operation

	Boiler-ORC		Gasifier-ICE
Power load (%)	79	94	95
Gross electric efficiency (%)	12.6	13.2	21.8
Thermal efficiency (%)	66.0	66.2	49.9
Power-to-heat ratio (-)	0.19	0.20	0.44

Higher electric efficiency for gasifier-ICE @ small scale

Flexible operation of boiler-ORC (partial load)

Char characterization

Technology	A	B	C	D	E	F	G	H
Ash [%]	27.84	16.08	49.52	31.50	13.34	6.49	29.17	25.64
C [%]	68.63	80.23	48.03	66.96	78.97	91.59	69.46	69.49
H [%]	0.33	0.49	0.89	0.18	0.68	0.52	0.11	0.20
N [%]	0.83	0.23	0.25	0.16	0.20	0.25	0.12	0.46
O [%]	2.37	2.69	1.31	0.57	6.50	0.60	0.87	3.88
LHV [MJ/kg]	23.04	26.64	14.33	19.65	25.38	30.81	22.84	24.12
PAH [mg/kg]	4881.4	2625.6	2.76	315.6	1223.5	85.6	31.43	441.2
PCB [mg/kg]	339.5	10.7	0.03	0.56	1.83	0.40	0.20	107.8
BET [m2/g]	352	128	78	281	587	272	320	306

Co-firing of wood/char mixtures

Preparation of saw dust and char blends pellets

Fuel	Pure saw dust pellets	Saw dust with 10% char	Saw dust with 20% char
Denomination	0% char	10% char	20% char

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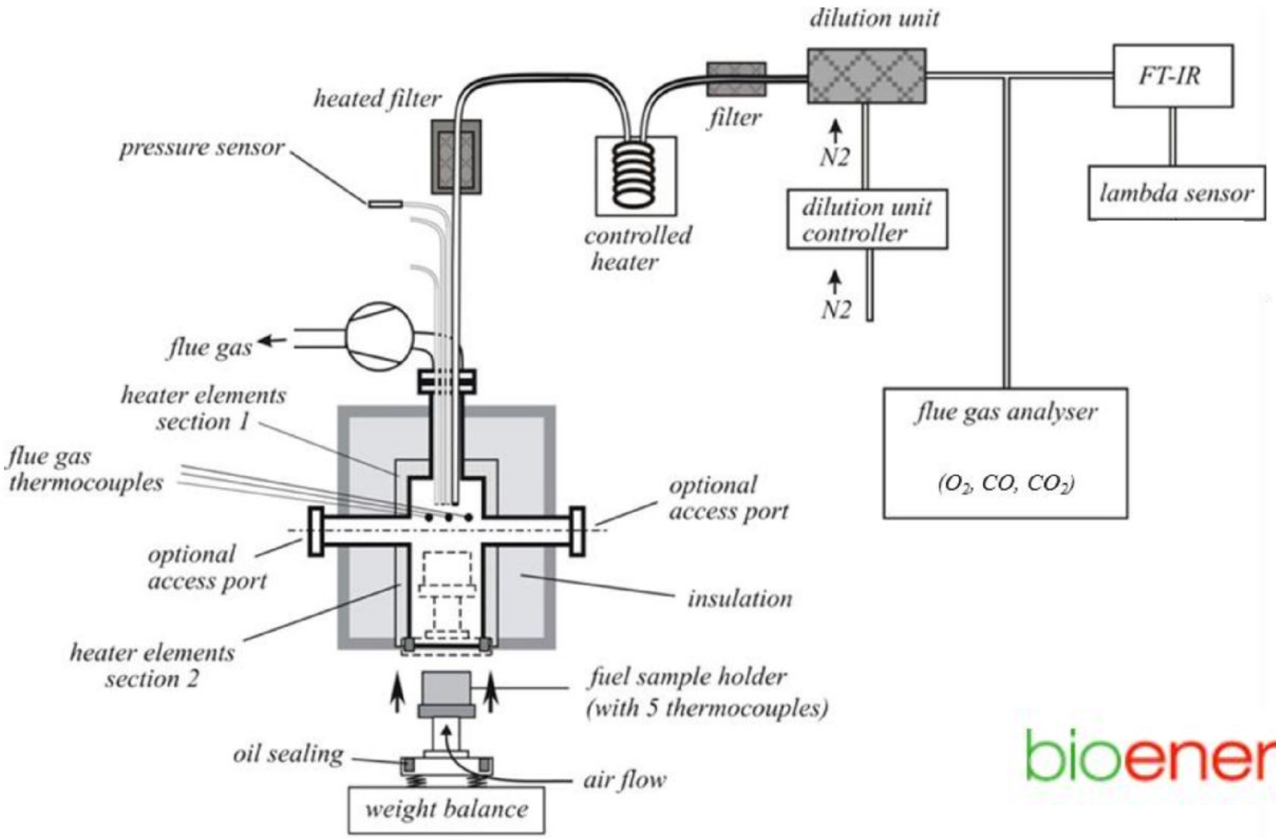
Lab combustion chamber



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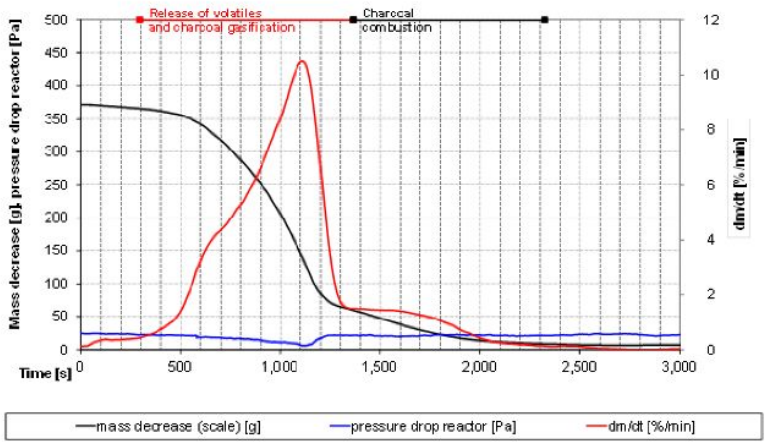
Chemical analyses of fuels

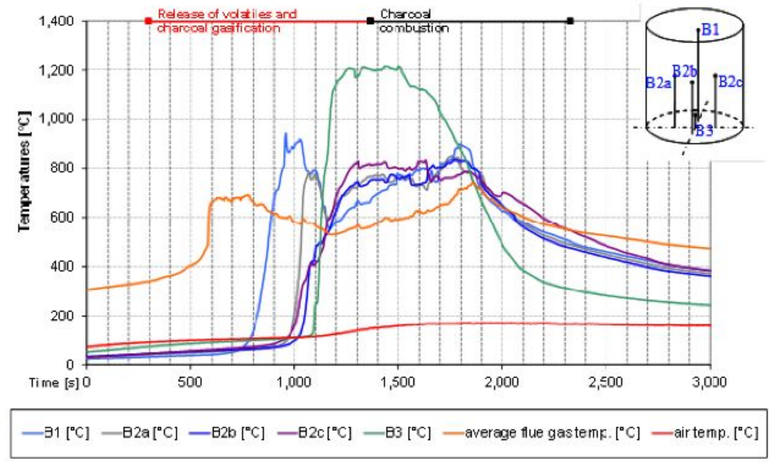
		0% char	10% char	20% char	
Mechanical durability	%	95.9	98.0	96.8	≥ 97.5 % (ISO 17225-2)
Moisture content	%wt fb	7.4	9.2	8.8	
Ash content	%wt db	1.26	1.87	2.2	no ash melting
CO_2-free ash content	%wt db	0.99	1.42	1.62	
C	%wt db	51.3	51.4	51.8	small increase
H	%wt db	5.5	5.4	5.2	
N	%wt db	0.21	0.23	0.19	
S	mg/kg db	190	204	221	increase
Cl	mg/kg db	115	108	117	

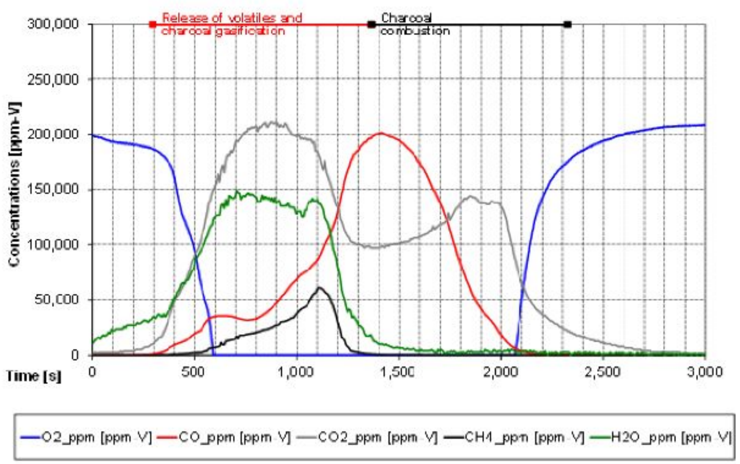
Chemical analyses of fuels

		0% char	10% char	20% char
Si	mg/kg db	658	778	668
Ca	mg/kg db	3170	4540	5680
Mg	mg/kg db	354	467	551
Al	mg/kg db	286	307	262
Fe	mg/kg db	241	289	263
Mn	mg/kg db	101	117	127
P	mg/kg db	244	262	279
K	mg/kg db	1330	2210	2820
Na	mg/kg db	19.5	36.8	45.5
Zn	mg/kg db	27.8	29.9	40.8
Pb	mg/kg db	3.0	3.0	3.0
TIC	mg/kg db	57000	65500	73000
Si/K	mol/mol	0.69	0.49	0.33

Combustion performances

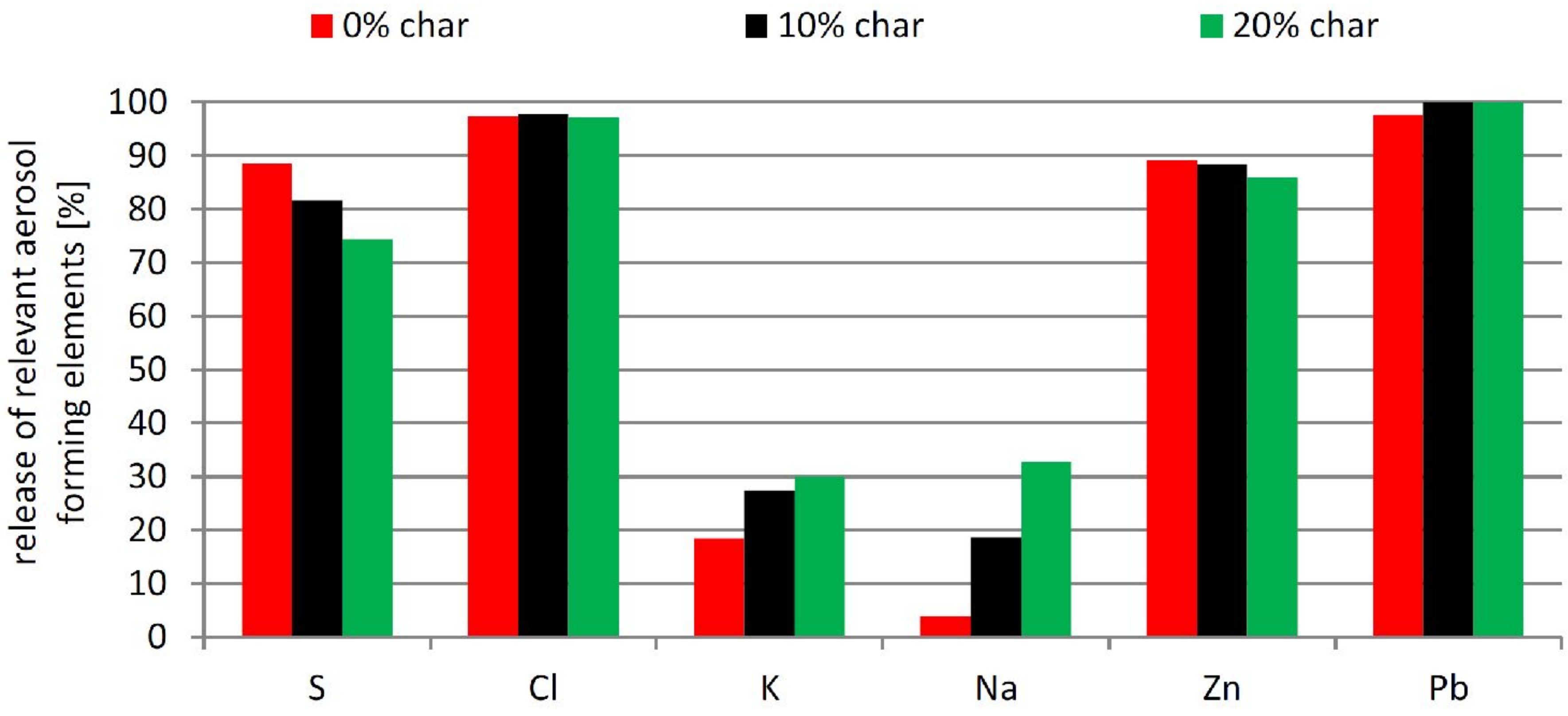






Fuel mass loss and pressure drop in the reactor (left up), temperatures (fuel bed, average flue gas and air) (right), concentrations of the most important flue gas components (bottom) for **20% char**.

Release ratios of S, Cl, K, Na, Zn and Pb for the fuel tested



Estimated aerosol emissions of all fuels tested

ASSESSMENT OF INNOVATIVE PATHWAYS FOR CHAR VALORIZATION

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Valorization of biomass gasification char

Characterization:

- Ultimate and proximate analysis
- Constant volume calorimetry
- Thermogravimetric analysis
- Physisorption analysis
- Small-angle X-ray scattering
- Wide-angle X-ray scattering
- Scanning electron microscopy

Results:

- High carbon content (up to 90%)
- Very large specific surface area (up to 600 m^2/g)
- Micro-porous structure
- High surface reactivity

↓

Similarities between char and activated carbon

↓

Possible utilization of char as substitute for activated carbon both in **adsorption** and in catalytic **applications**

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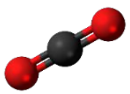
Char as adsorbent for CO_2 uptake

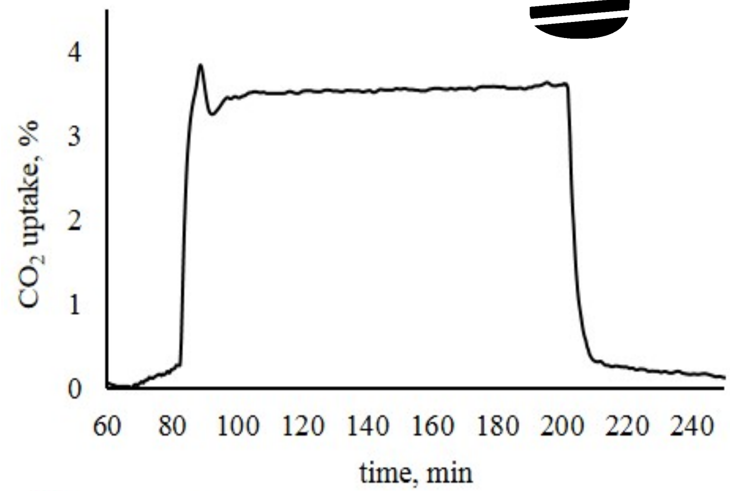


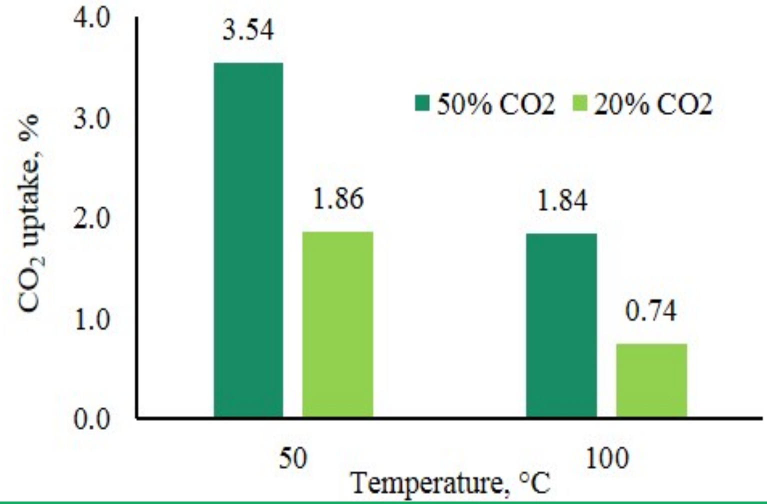
Adsorptive: CO_2

Adsorbent: gasification char

- T_{ads} = 50 – 100 °C
- $CO_2:N_2$ = 1:1 – 0.2:0.8

Thermo-gravimetric tests run in a Jupiter STA449-F3 (NETZSCH)

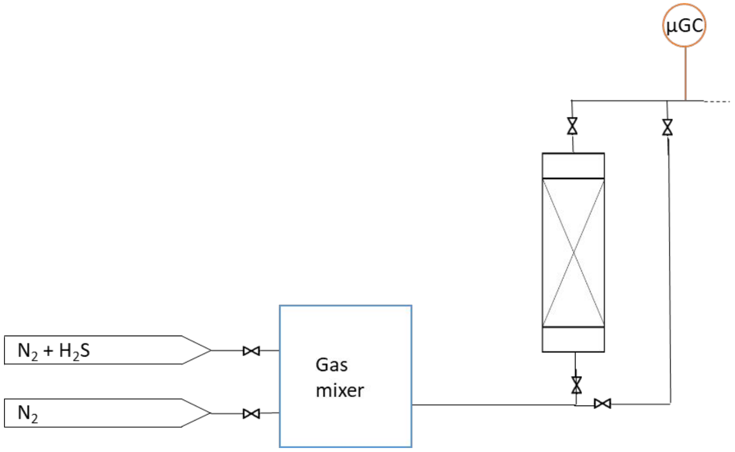




Char as adsorbent for H_2S uptake

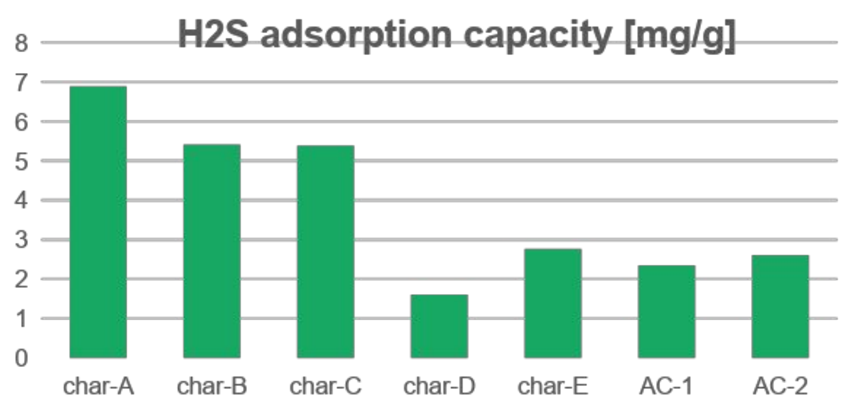
Adsorption tests performed in a lab-scale fixed-bed quartz reactor

- Inlet gas: 250 ppmv of H_2S in N_2
- Total gas flow: 100 Nml/min
- Char-bed height: 2.5 cm (150-200 mg)
- $T = T_{amb}$



Adsorption capacity [mg_{H2S}/g_{char}]:

$$m_{ads} = \frac{M \cdot P \cdot Q}{R \cdot T \cdot m_{char}} \int_{o}^{t_{fin}} (c_{in} - c_{out}) dt$$



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Char as catalyst support for FTS

Catalysts

Precursors:

$Co(NO_3)_2 \cdot 6H_2O$

$Fe(NO_3)_3 \cdot 9H_2O$

Supports:

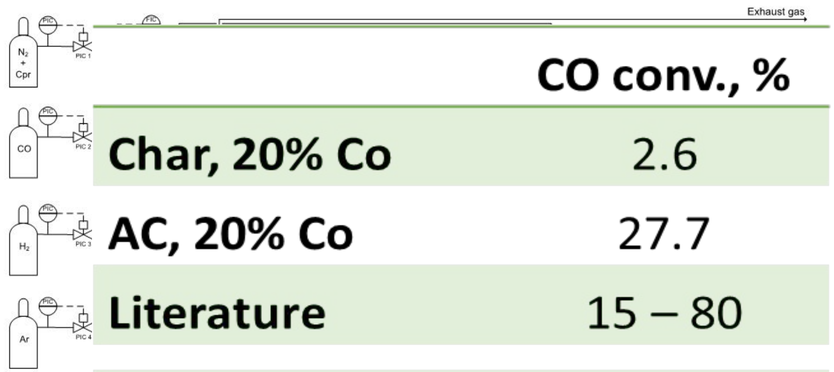
Char

HNO_3 treated char

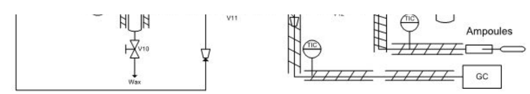
CO_2 activated, HNO_3 treated char

Commercial activated carbon

Method: Incipient wetness impregnation

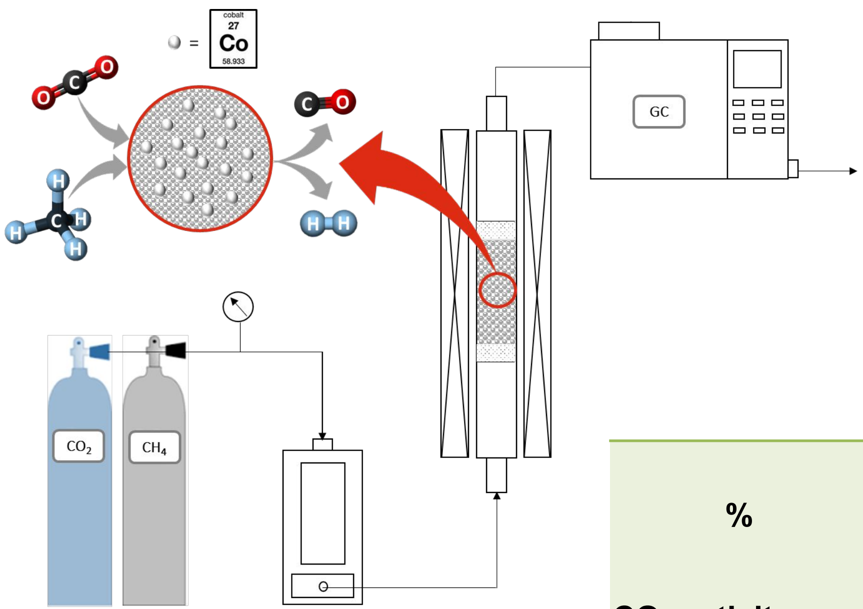


	CO conv., %
Char, 20% Co	2.6
AC, 20% Co	27.7
Literature	15 – 80
Char, Fe	26



- Fixed-bed reactor
- $H_2 : CO = 2 : 1$
- $T = 240°C$
- $P = 16$ bar
- $WHSV = 3600\ ml\ g^{-1}\ h^{-1}$
- $t = 24 – 72$ h

Char as catalyst support for DRM



$$CO_2 + CH_4 \rightarrow 2CO + 2H_2$$

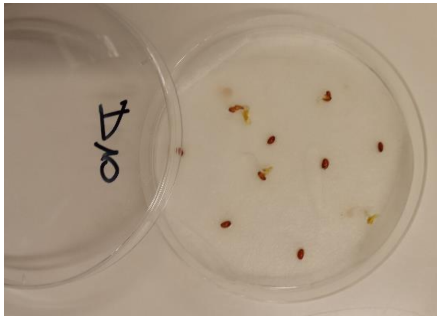
- CH_4:CO_2 = 1:1
- T = 850 °C
- P = 1 atm
- WHSV= 6500 ml g^{-1} h^{-1}
- t = 4 – 5 hours

%	Pure char	Char-based catalysts			
		10% Co	15% Co	20% Co	HNO_3, 10% Co
CO_2 activity	17.73	22.52	12.06	11.72	29.04
CH_4 activity	12.41	17.14	7.56	5.76	18.97
H_2 yield	1.74	1.33	0.76	0.63	2.87
CO yield	10.95	14.44	7.84	7.12	17.54

Char characterization - toxicity

1. Germination index (cress seeds)
2. Germination tests (corn plants)
3. High content screening (human cellular models)

1



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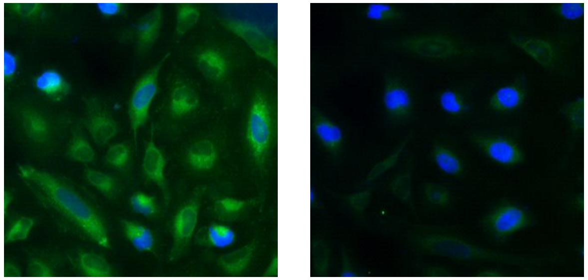

2

Remarks

Quite **reliable operation** of commercial small scale CHPs (< 200 kW_{el})

- the plants ensure 7000 h/year of operation
- similar overall efficiencies for the compared technologies (≈ 70%)
- high electrical efficiency (20-30 %)
- Interesting char valorization possibilities

but…

- high quality feedstock (agricultural waste are a challenge)
- **tar** content higher than the limit suggested in the scientific literature (frequent engine **maintenance** required)
- **char** (for the moment) has to be disposed off and this is a **cost**

Remarks

- **co-firing of char** and biomass should be possible in real-scale grate combustion systems (technical aspects such as grate design, fuel gas recirculation and aerosol emission limits should be considered)
- char from commercial small-scale gasifiers shows interesting features that would allows its industrial utilization in **adsorption and catalytic application**
- market is finding its own solutions: **post-combustion** stage
- **co-gasification** can also be an interesting solution to be investigated

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The authors want to thank the Autonomous Province of Bolzano, Provincia Autonoma di Bolzano – Alto Adige, Ripartizione Diritto allo studio, Università e ricerca scientifica for the financial support to the NEXT GENERATION project:
"Novel EXTension of biomass poly-GENERATION to small scale gasification systems in South-Tyrol"
CUP B56J16000780003, contract: 20/34 03/11/2016.

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2018 EEC/WTERT Bi-Annual Conference
Sustainable Waste Management: The Forefront of Innovation

The City College of New York - October 4th & 5th, 2018

A case study of gasification CHP in northern Italy in the European context and comparison to traditional combustion systems

Thank you very much for your attention!

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