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GAS ANALYSIS WORKSHOP 2018

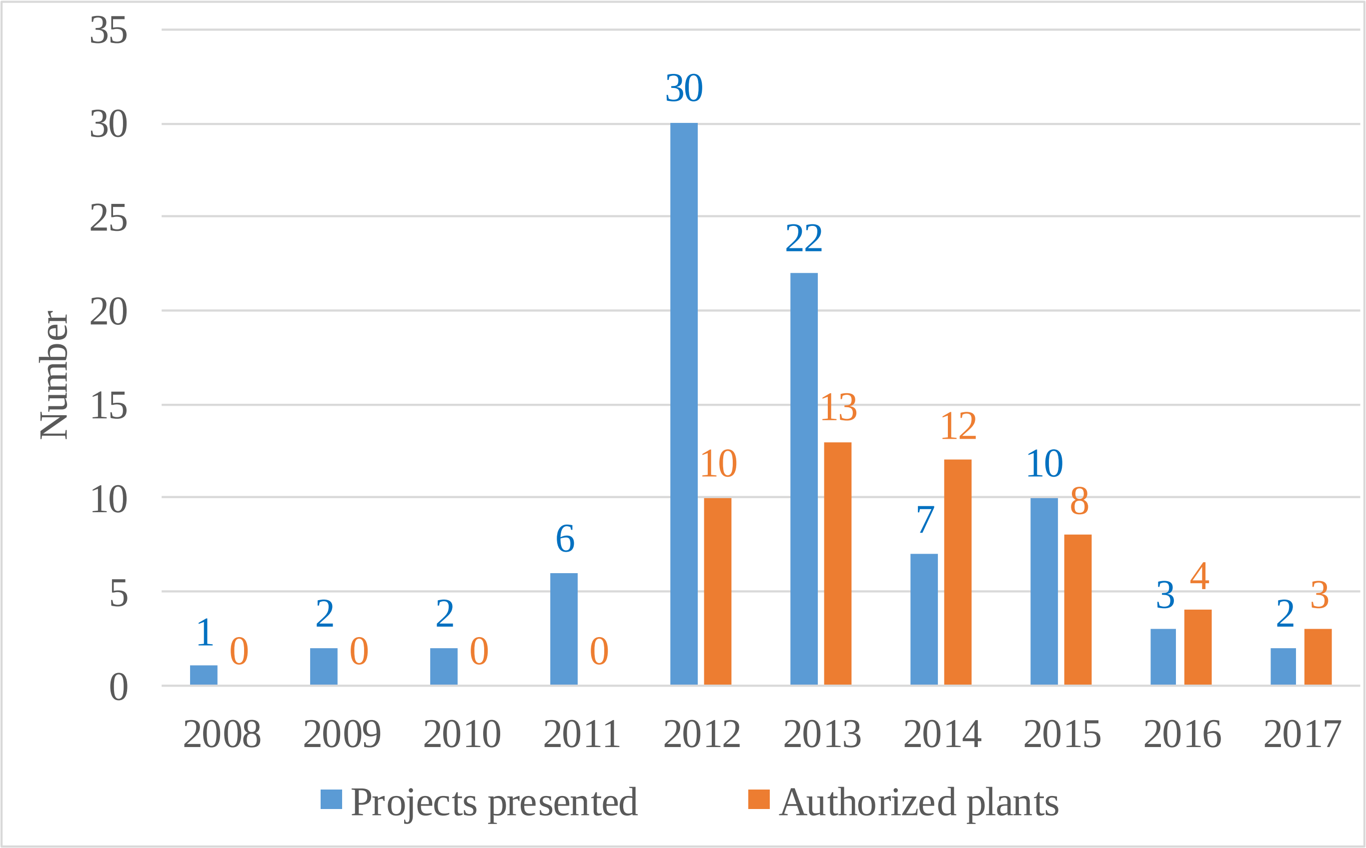
DTU - Copenhagen, 18 May 2018

Extensive monitoring of small-scale biomass gasification systems in South-Tyrol (Italy): experiences and lessons learned in the last 5 years

J. Ahmad, S.S. Ail, D. Antolini, D. Basso, V. Benedetti, E. Cordioli, F. Patuzzi, M. Pecchi, S. Piazzi, S. Vakalis, M. Baratieri

BACKGROUND

Gasification technology development



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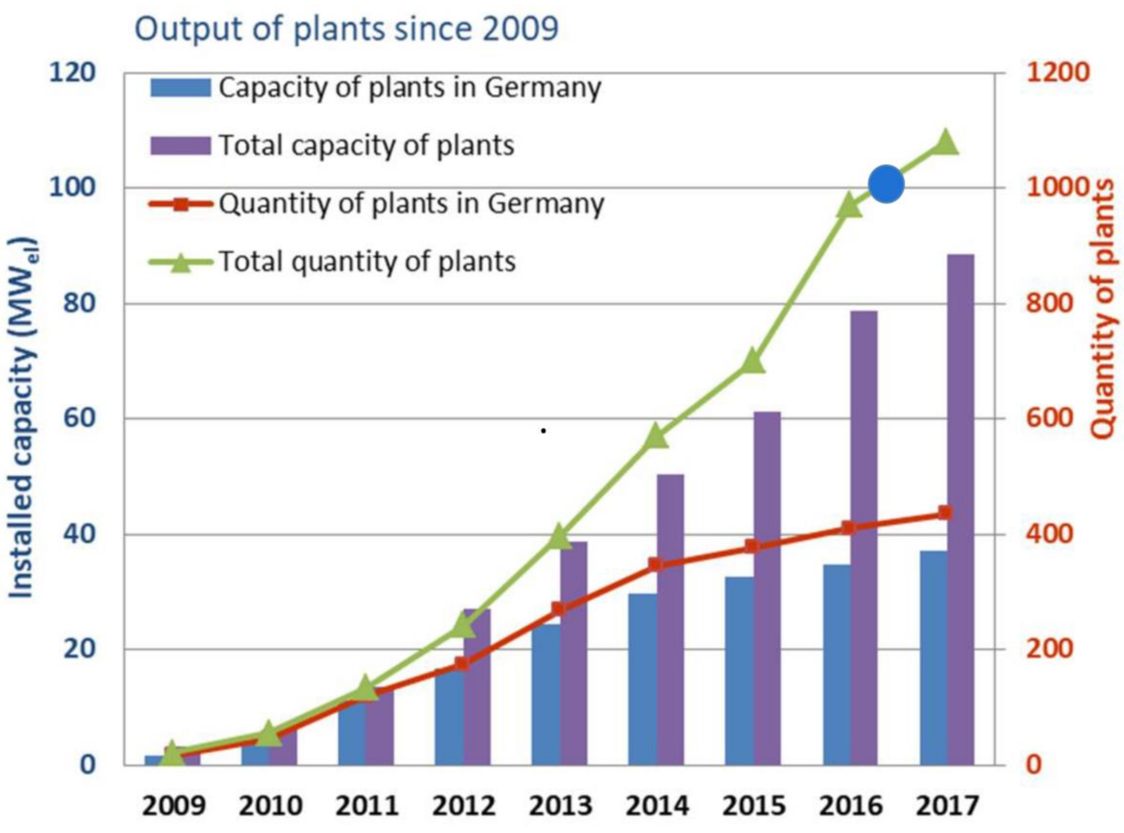
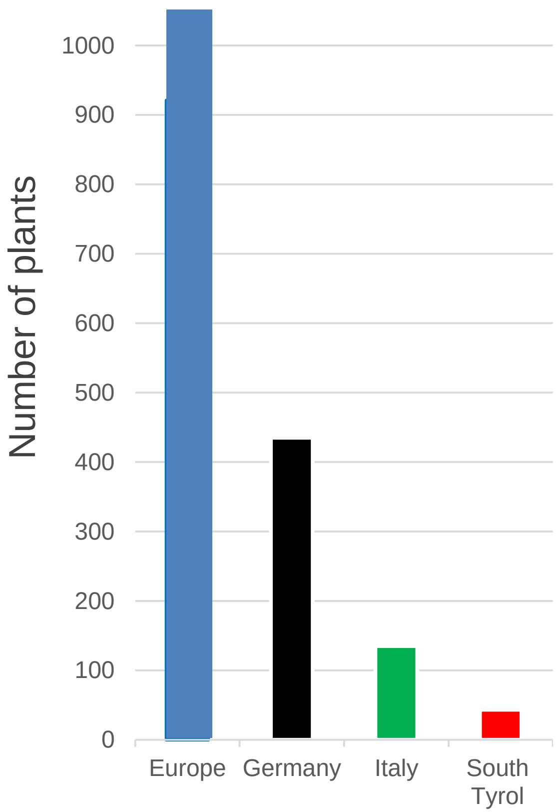
Small scale gasification: facts & figures

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





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

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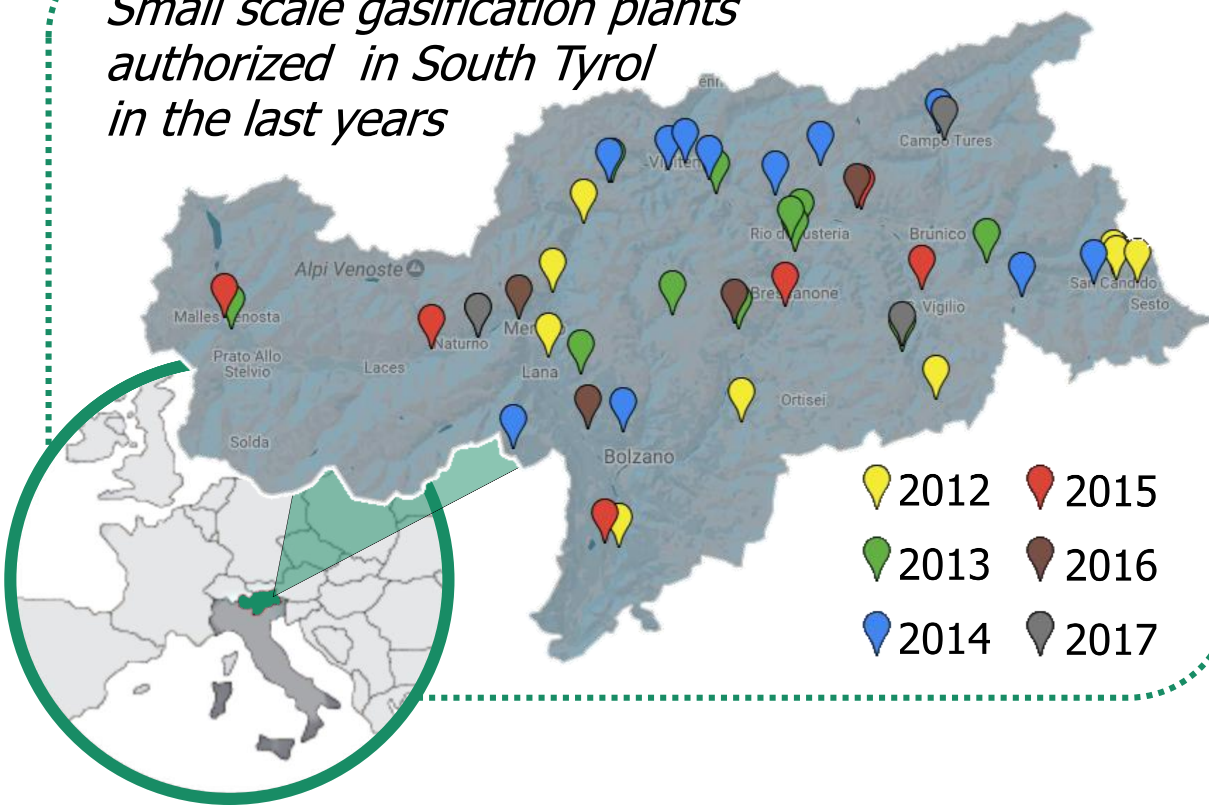
Distribution of gasification plants in South-Tyrol

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



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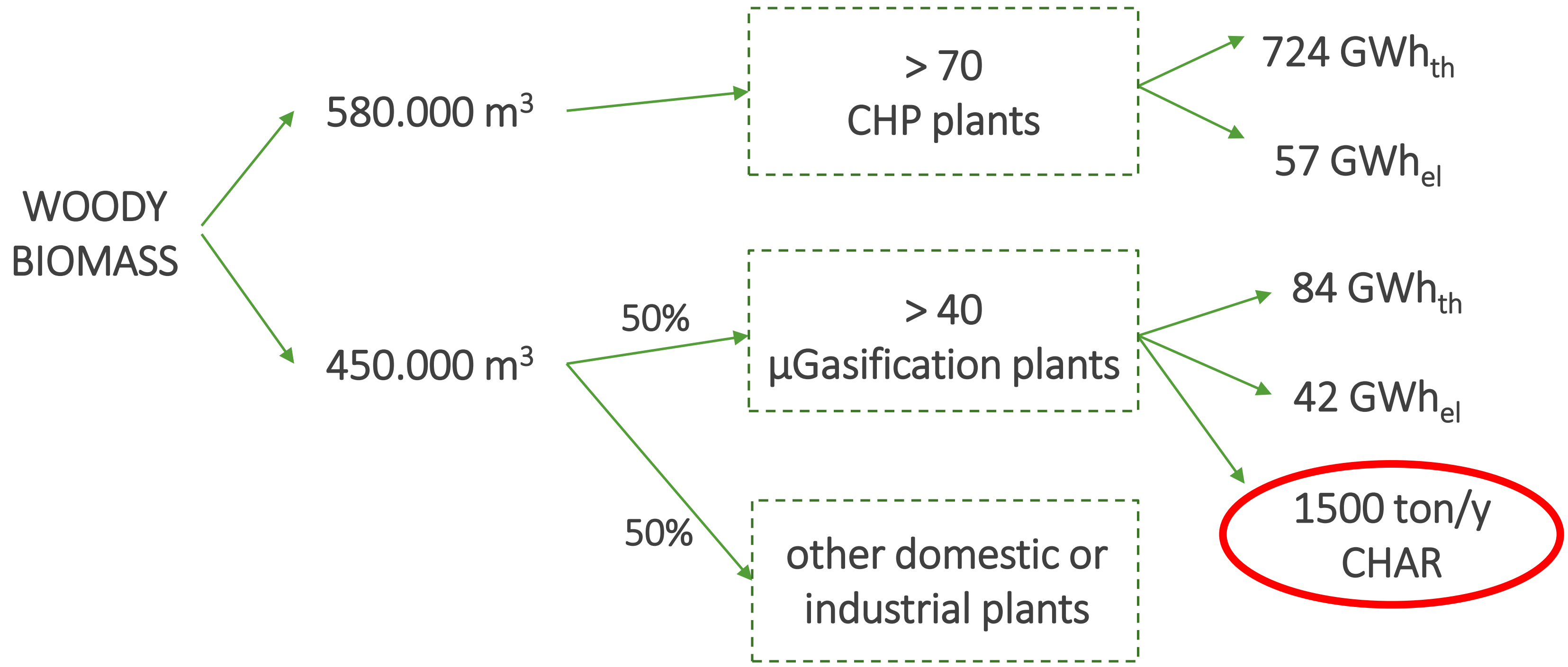
Gasification in South-Tyrol



FACTS & FIGURES

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 Re² 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

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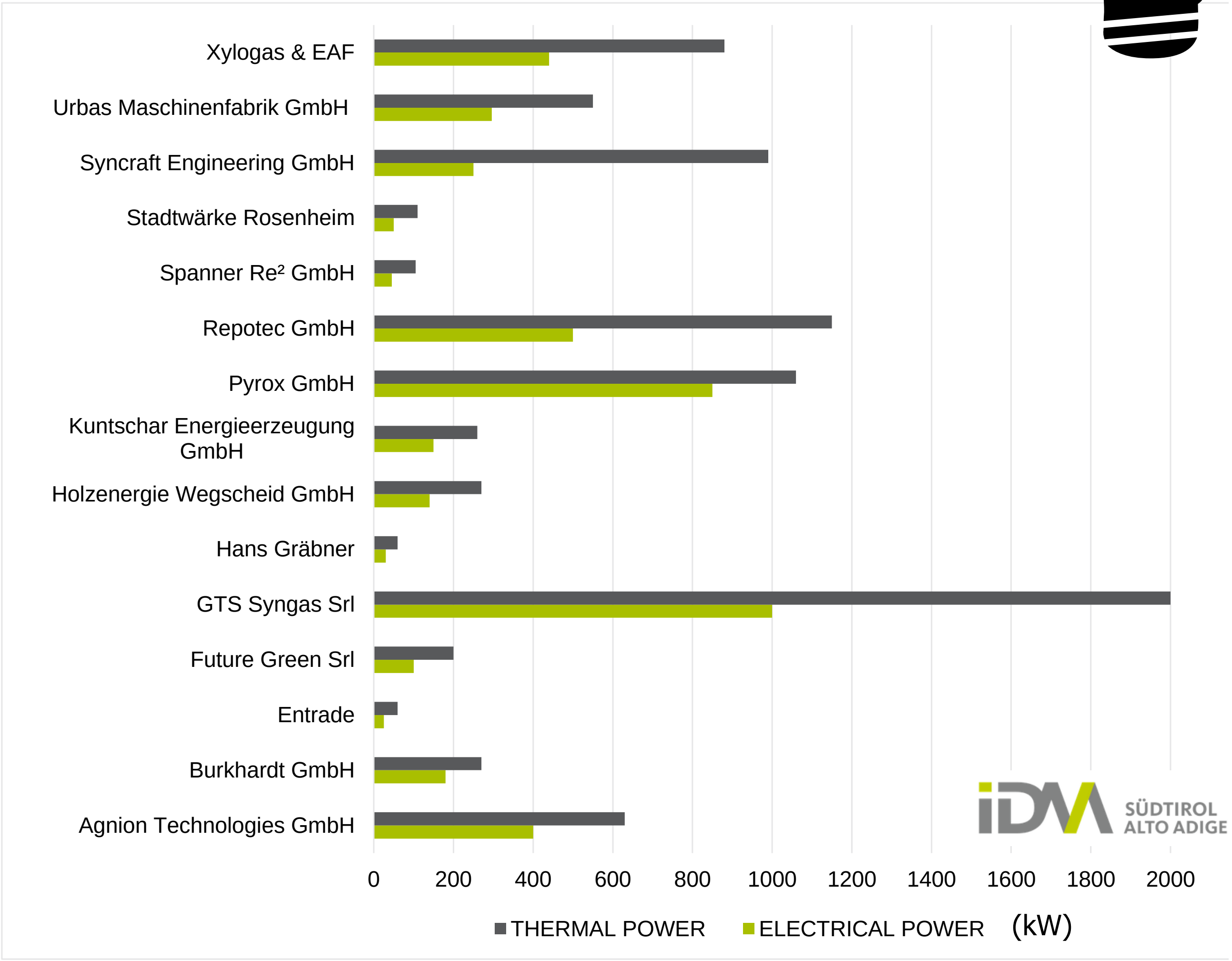
FACTS & FIGURES

Technology	Place
Agnion Technologies GmbH	Ora
Burkhardt GmbH	Ora
Burkhardt GmbH	Sinigo
Burkhardt GmbH	Campo di Trens
Burkhardt GmbH	Campo di Trens
Burkhardt GmbH	S. Genesio
Entrade	Terlano
Future Green Srl	Lagundo
Hans Gräbner	Campo Tures
Holzenergie Wegscheid GmbH	Rio di Pusteria
Kuntschar Energieerzeugung GmbH	Braies
Kuntschar Energieerzeugung GmbH	Senale San Felice
Kuntschar Energieerzeugung GmbH	Rio Pusteria
Pyrox GmbH	Lasa
Repotec GmbH	Malles
Spanner Re² GmbH	Badia (S. Cassiano)
Spanner Re² GmbH	Castelrotto (Siusi)
Spanner Re² GmbH	Riffiano
Spanner Re² GmbH	S. Candido
Spanner Re² GmbH	S. Candido
Spanner Re² GmbH	S. Candido
Spanner Re² GmbH	S. Leonardo i.P.
Spanner Re² GmbH	Campo di Trens
Spanner Re² GmbH	Chiusa (Latzfons)
Spanner Re² GmbH	Glorenza
Spanner Re² GmbH	Naz Sciaves
Spanner Re² GmbH	Naz Sciaves
Spanner Re² GmbH	Racines
Spanner Re² GmbH	Rio Pusteria (Spinga)
Spanner Re² GmbH	S. Martino i.B.
Spanner Re² GmbH	Sarentino
Spanner Re² GmbH	Valdaora
Spanner Re² GmbH	Verano
Spanner Re² GmbH	Dobbiaco
Spanner Re² GmbH	Malles
Spanner Re² GmbH	Racines
Spanner Re² GmbH	Vandoies
Spanner Re² GmbH	Lagundo (Aschbach)
Spanner Re² GmbH	Laimburg
Spanner Re² GmbH	n.p.
Stadtwärke Rosenheim	Bressanone
Syncraft Engineering GmbH	Versciaco
Urbas Maschinenfabrik GmbH	Valles
Urbas Maschinenfabrik GmbH	Castelbello
Urbas Maschinenfabrik GmbH	Malles
Xylogas & EAF	Val di Vizze

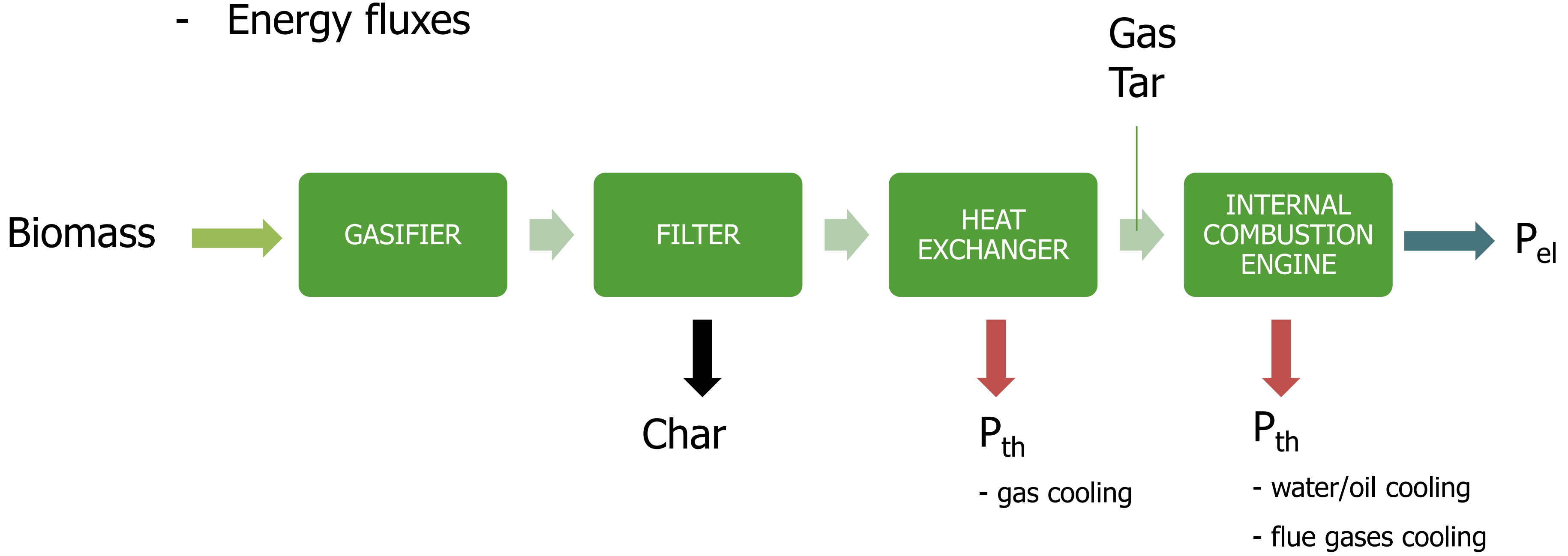


IDM SÜDTIROL ALTO ADIGE

The GAST project

Analyzed parameters

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



Applied methodologies

Mass fluxes

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

Input biomass weighted and **manually fed** to the reactor…

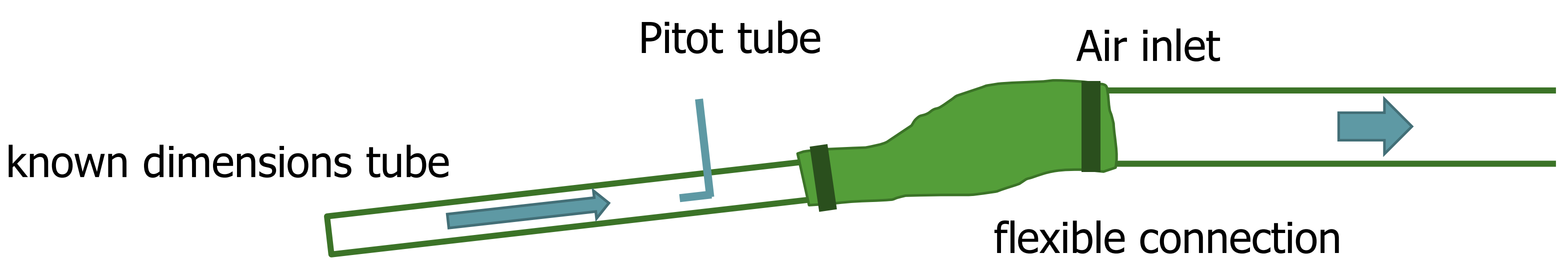
… or **inverse strategies** applied (e.g. maximum level of the storage used as reference)

Applied methodologies

Mass fluxes

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

Determined by means of the **velocity in a known dimensions tube** connected to the air inlet. Velocity measured by means of a **Pitot tube**.



Applied methodologies

Mass fluxes

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

Determined once measured the **gas composition** and the input **air flow rate**, assuming negligible the nitrogen content in the fuel.

$$\dot{V}_{gas} = \frac{x_{N_2}}{0.21} \dot{V}_{air}$$

Applied methodologies

Mass fluxes

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

Determined collecting the char during the whole monitoring period.

All the parameters have been monitored for a continuous steady operation period of at least 5-6 hours.

Applied methodologies

Energy fluxes

- Energy related to the input fuel
- Energy related to the producer gas
- Produced electrical and thermal energy

Determined on the basis of the **biomass flow rate** and of its **Lower Heating Value (LHV)**, measured by means of calorimetric bomb.

$$P_{comb} = \dot{m}_{comb} \cdot LHV_{comb}$$

Applied methodologies

Energy fluxes

- Energy related to the input fuel
- Energy related to the producer gas
- Produced electrical and thermal energy

Producer gas LHV calculated on the basis of its **composition**, measured by means of a **portable gas chromatography system.**

$$P_{gas} = \dot{m}_{gas} \cdot LHV_{gas}$$

Applied methodologies

Energy fluxes

- Energy related to the input fuel
- Energy related to the producer gas
- Produced electrical and thermal energy

Electrical power measured by means of power analyser and/or integrated meter of the plant.

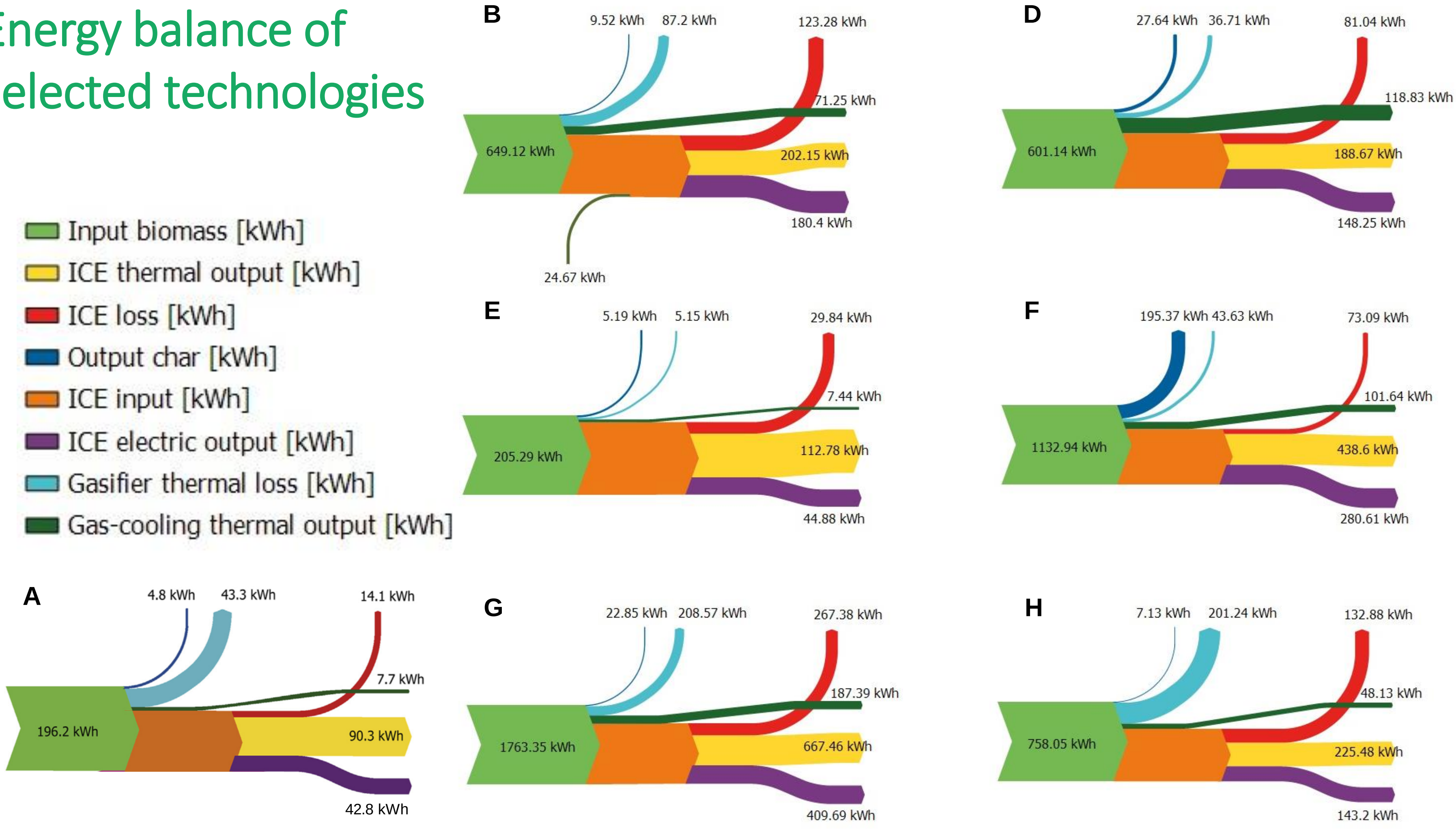
Thermal power estimated from:

- Medium flow rate (ultrasonic meter)
- Supply and return temperature (thermocouples type k)

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

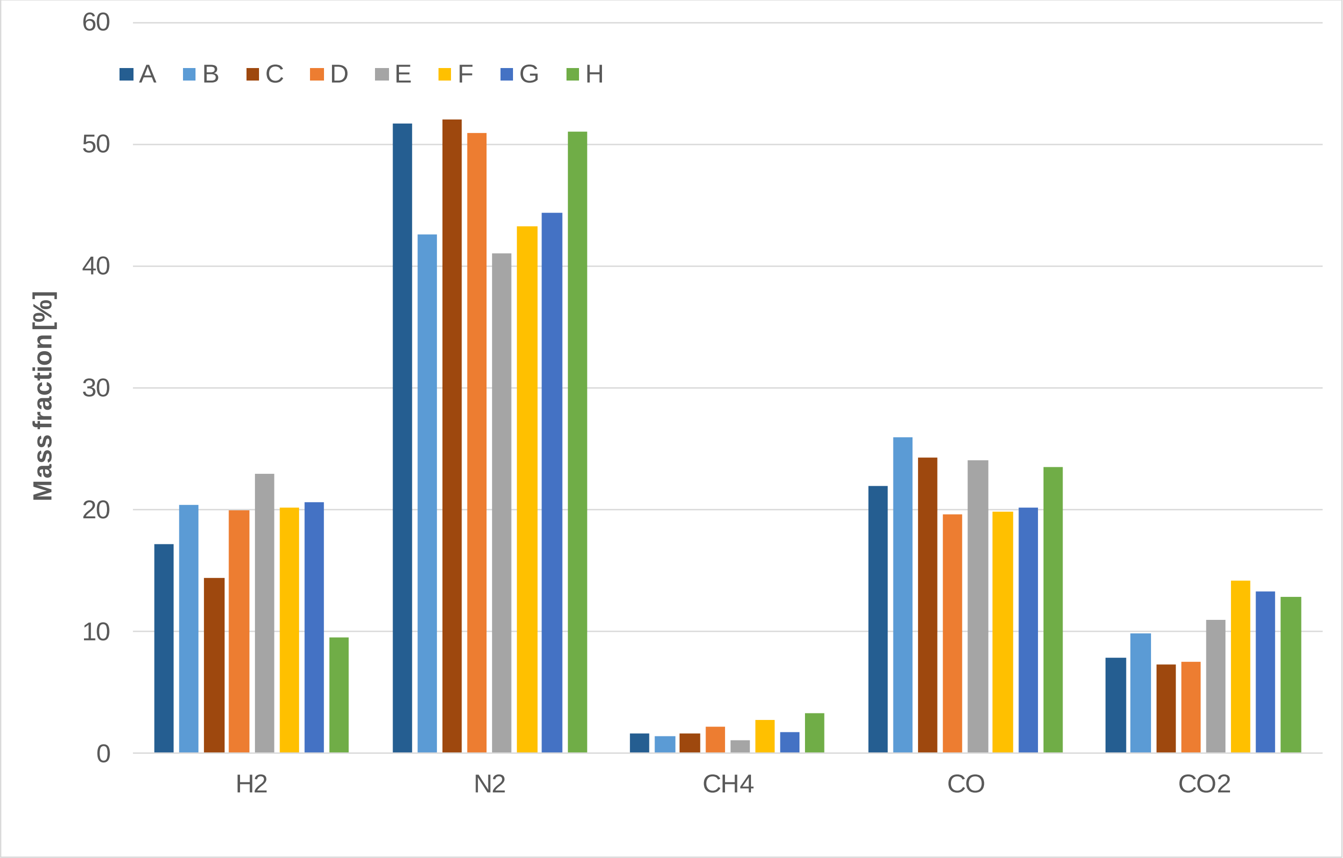
Energy balance of selected technologies



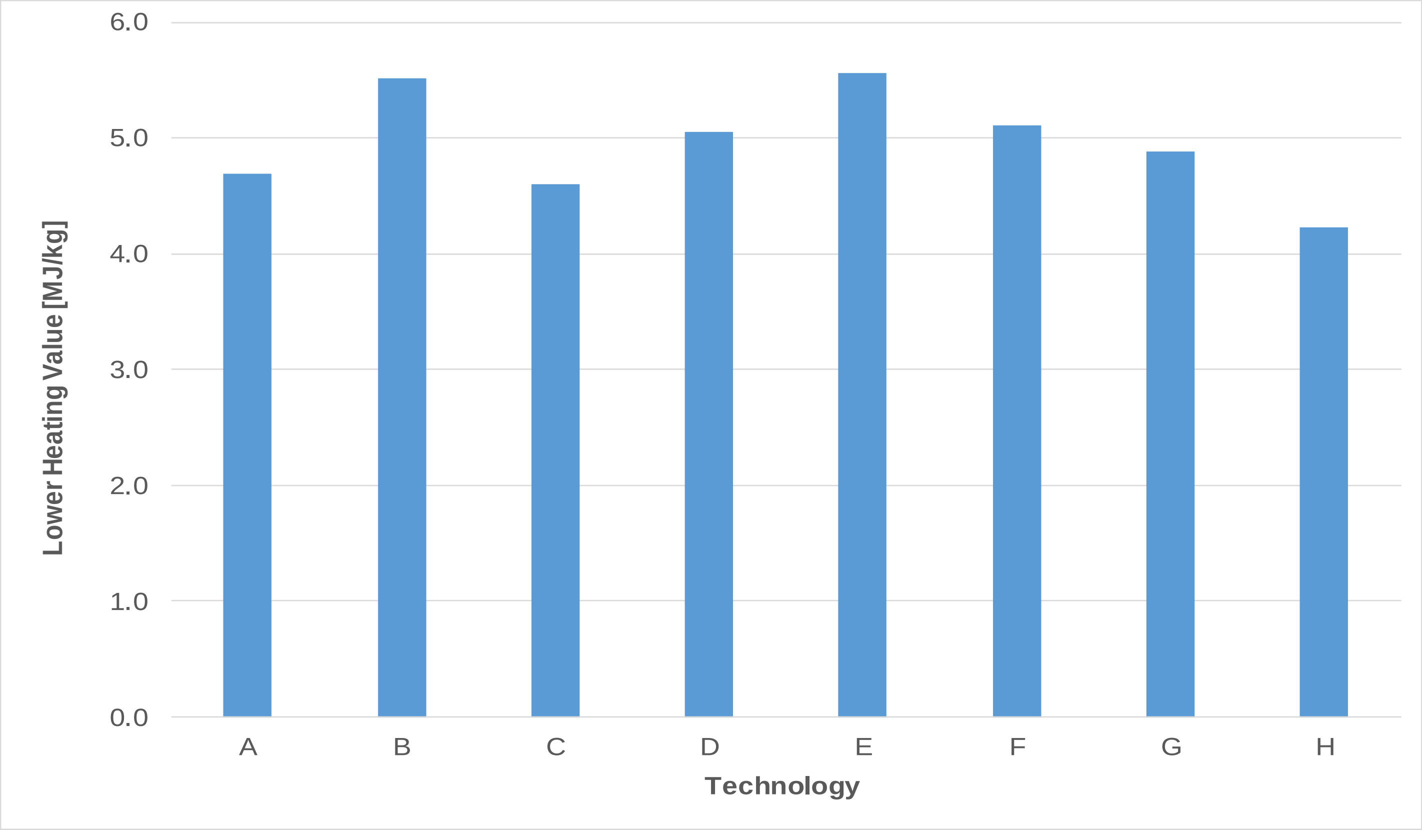
Gasification performance parameters

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

Producer gas composition



Producer gas LHV



Different μGC calibration methods:

01: two-points, at the installation of the microGC, in the lab

02: single-point, in the lab

03: multi-points, linear regression on the pure mixture + 9 dilution points

04: multi-points, linear regression only on the 9 dilution points

05: multi-points, quadratic regression only on the 9 dilution points

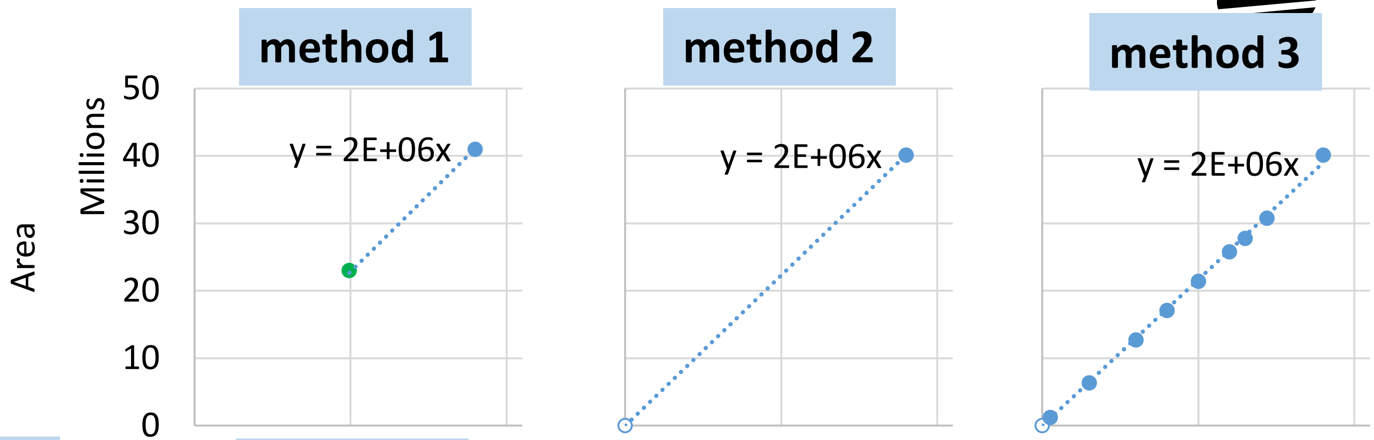
06: single-point, directly on the sampling line at the plant

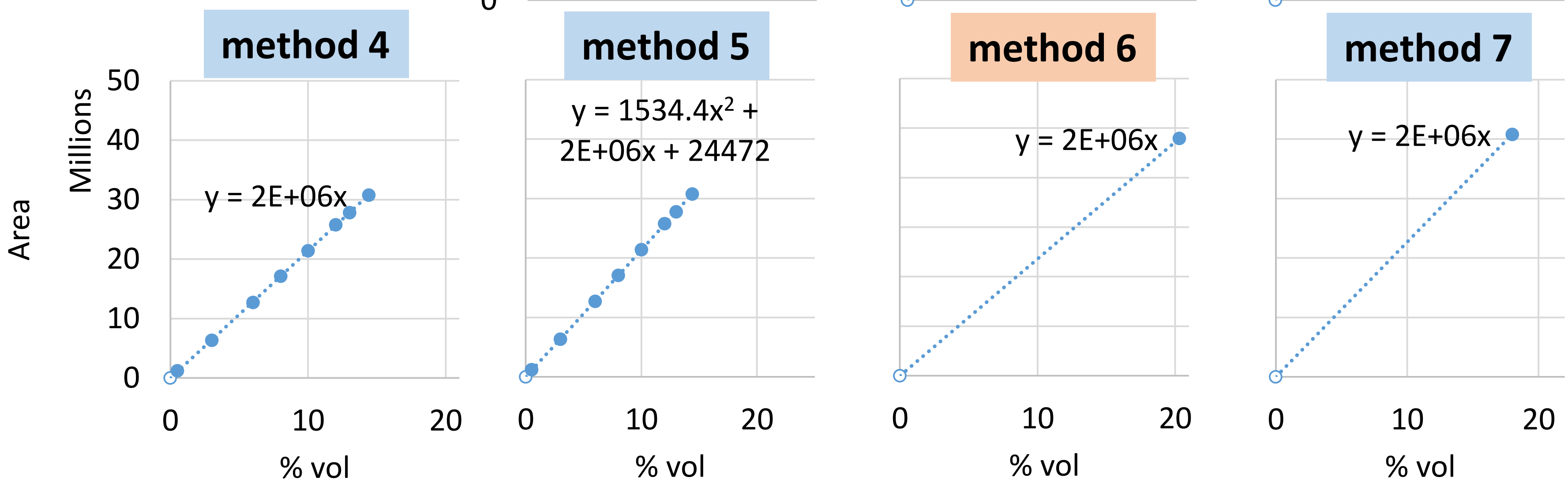
07: single-point, in the lab

µGC calibration

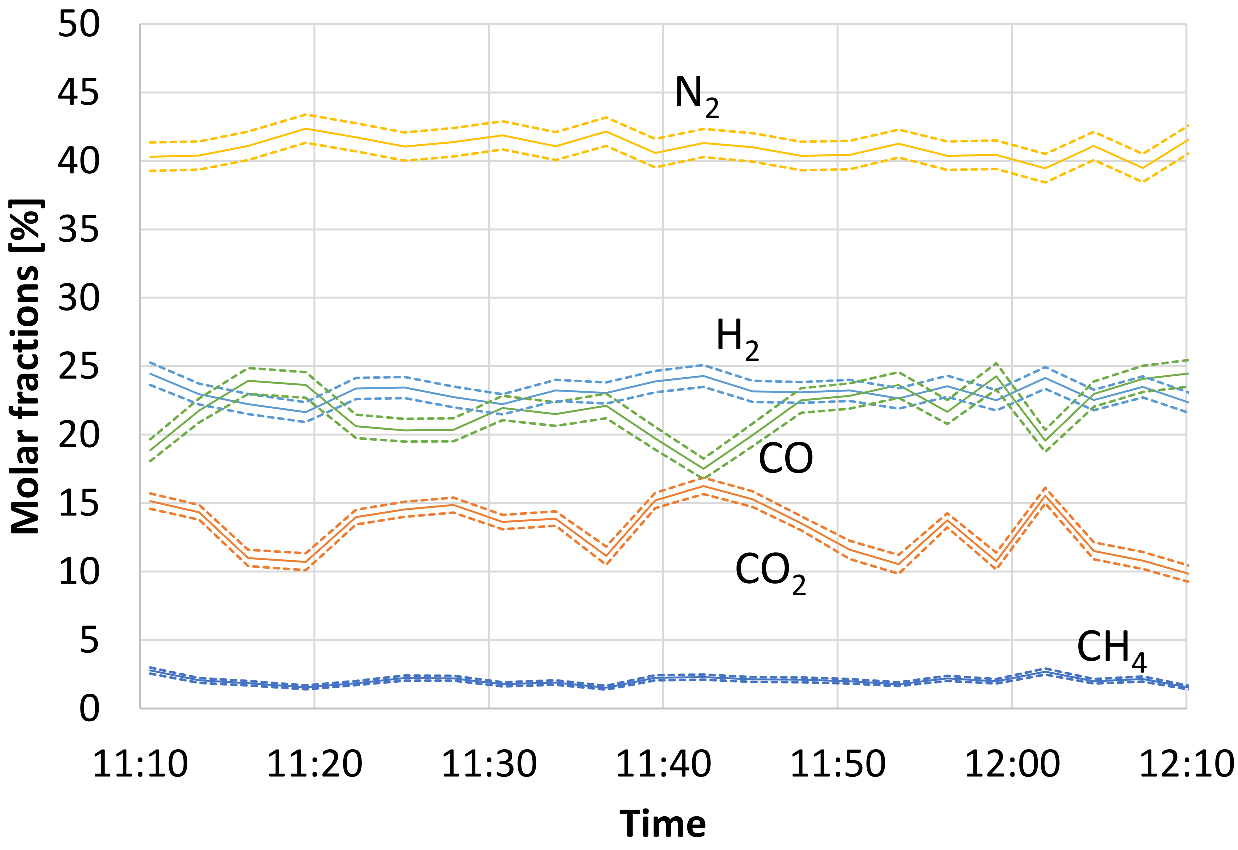
e.g. for H_2

	tank 1	tank 2
CH4	2.5	2.0
CO2	15.0	14.7
H2	18.0	20.3
CO	25.0	19.4
N2	39.5	43.6
C2H6	0.2	-

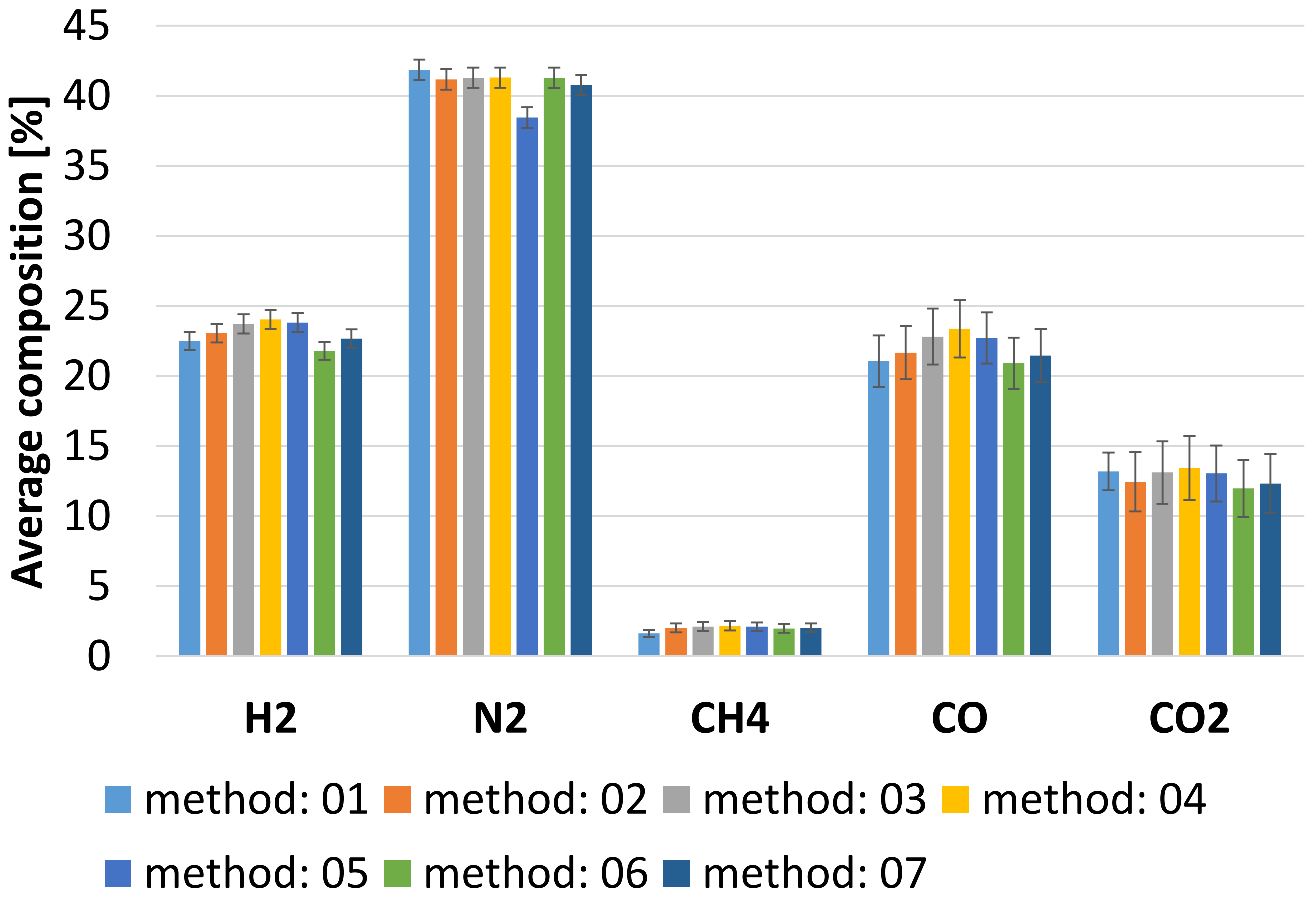




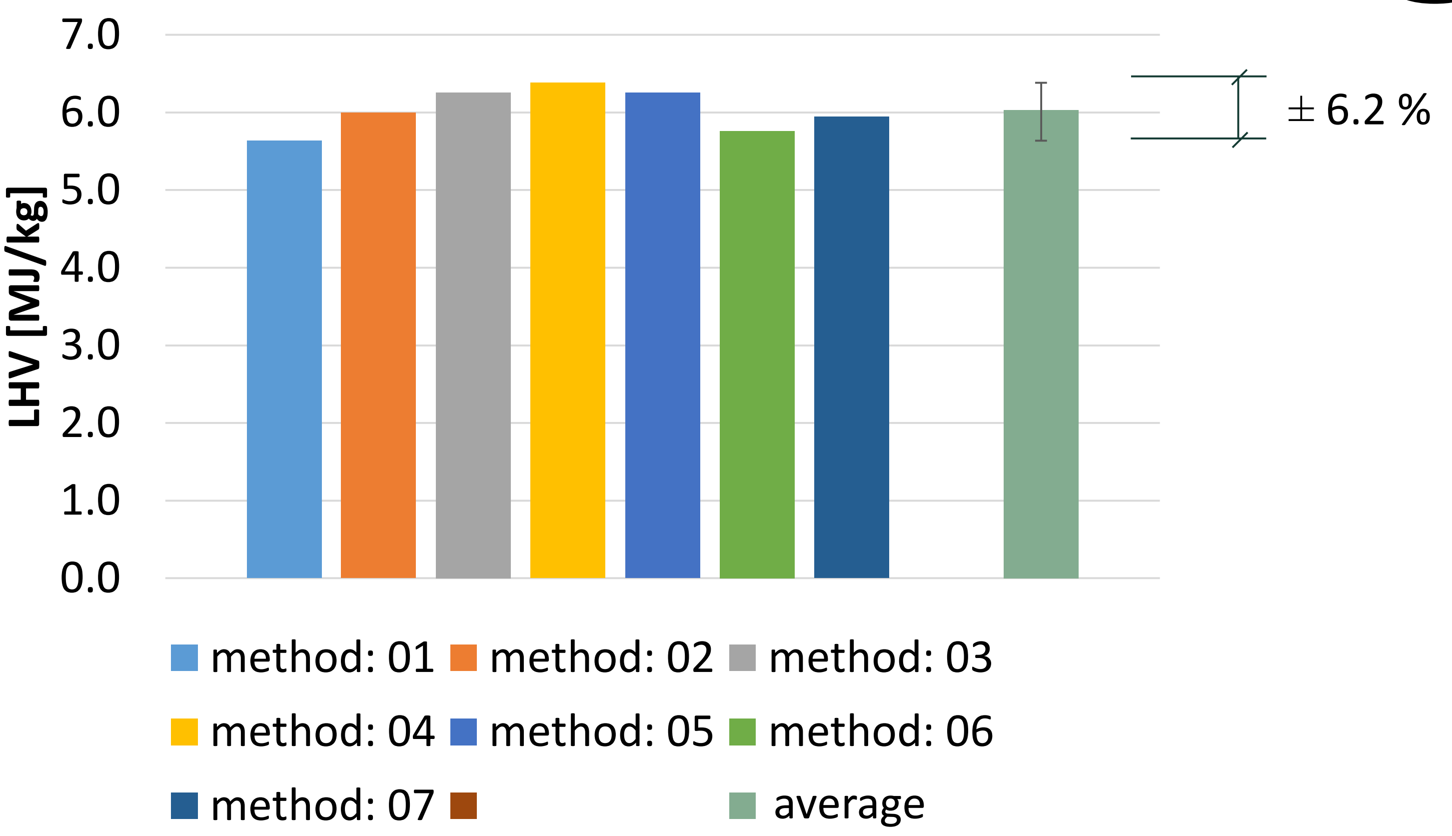
μGC calibration



μGC calibration

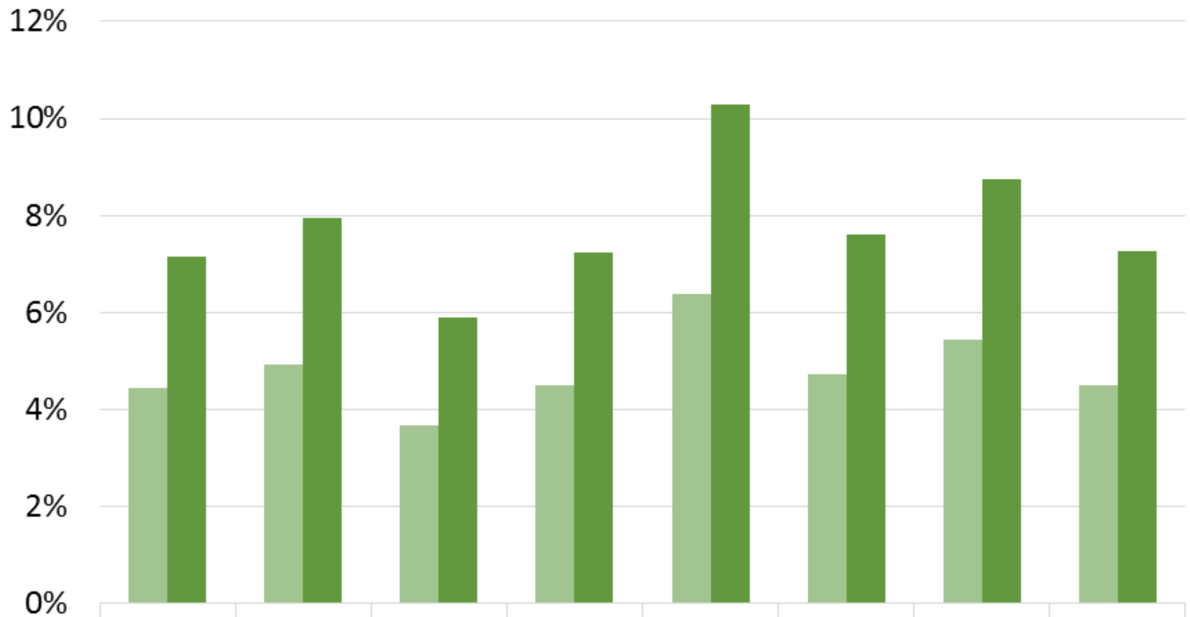


μGC calibration



μGC calibration

CGE - error



	A	B	C	D	E	F	G	H
LHV - error (6 %)	4%	5%	4%	4%	6%	5%	5%	4%
LHV - error (10%)	7%	8%	6%	7%	10%	8%	9%	7%

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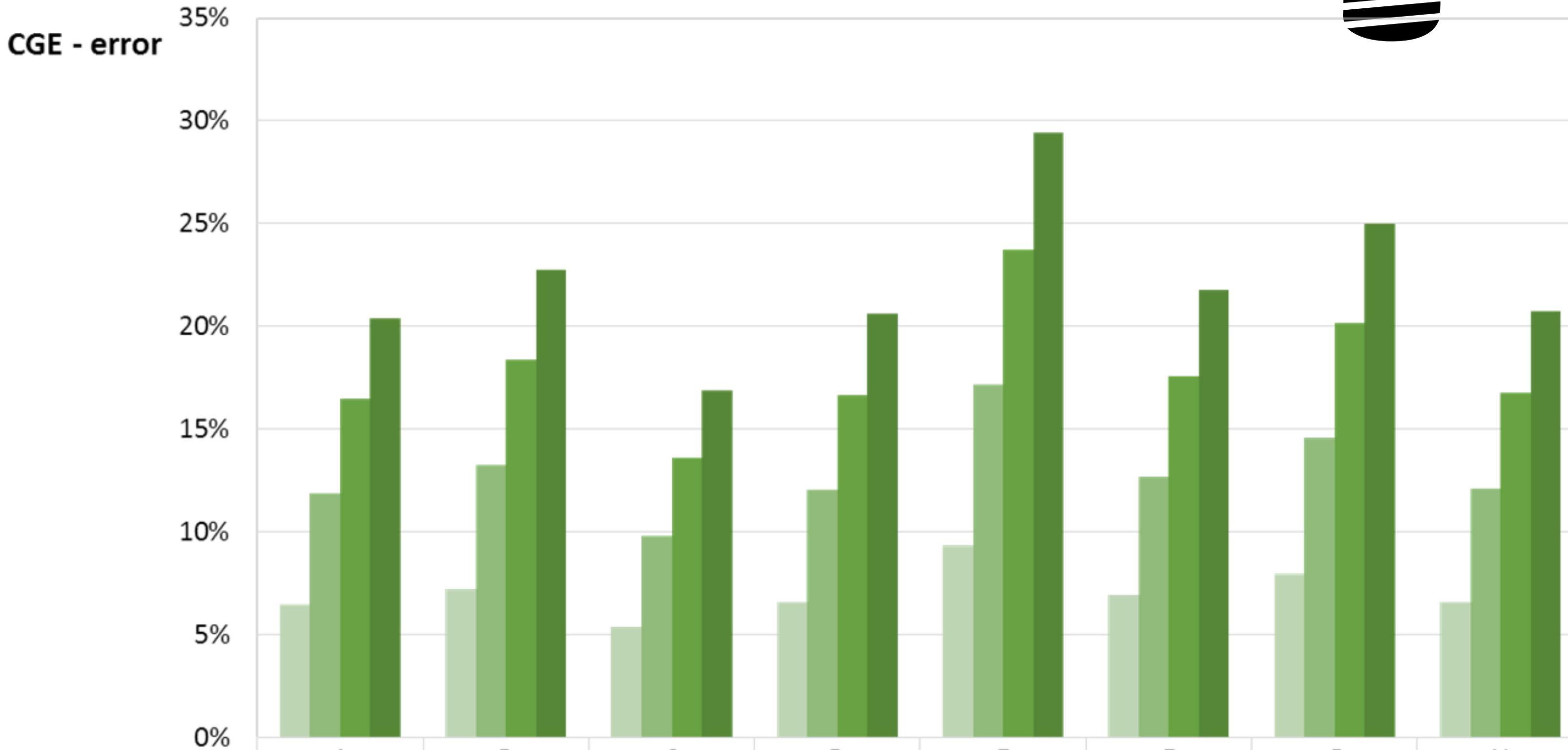
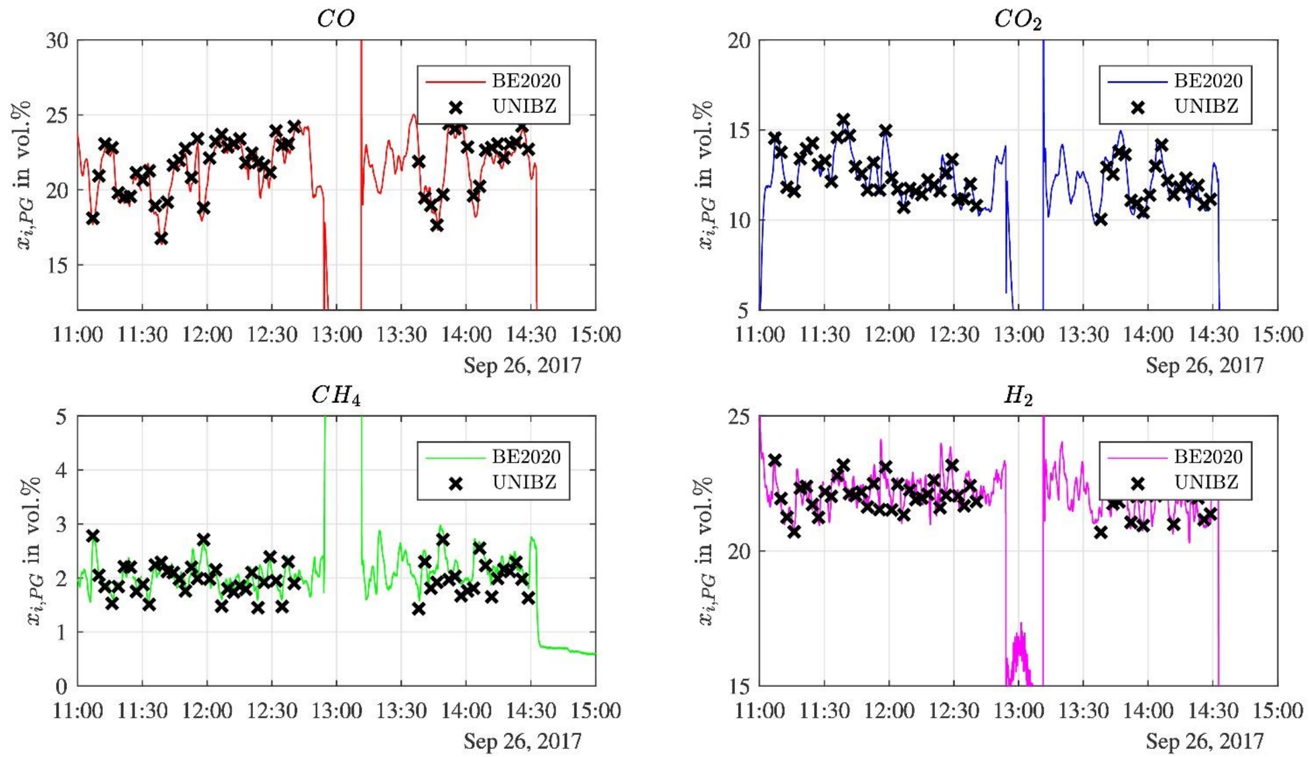
Biomass feeding rate



	A	B	C	D	E	F	G	H
Biomass feeding rate - rel. error (10 %)	6%	7%	5%	7%	9%	7%	8%	7%
Biomass feeding rate - rel. error (20 %)	12%	13%	10%	12%	17%	13%	15%	12%
Biomass feeding rate - rel. error (30 %)	16%	18%	14%	17%	24%	18%	20%	17%
Biomass feeding rate - rel. error (40 %)	20%	23%	17%	21%	29%	22%	25%	21%

An example of round robin measurements - gas analysis

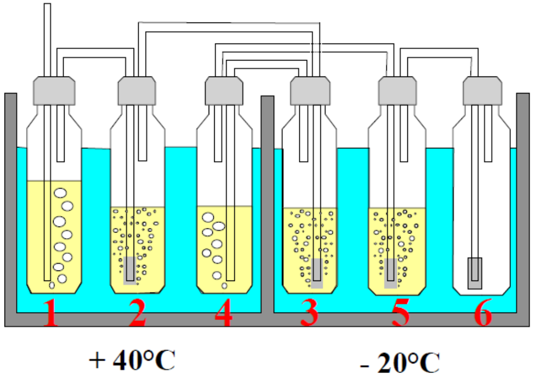


Applied methodologies

By-products characterization

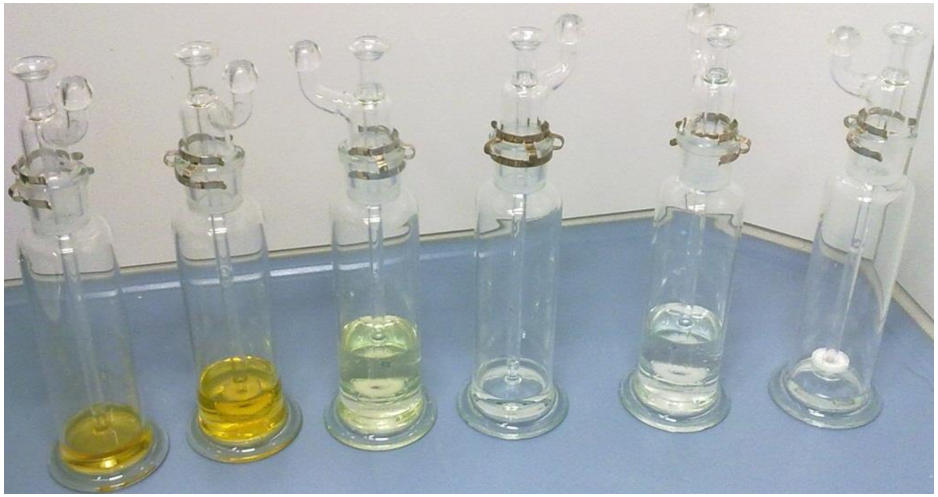
- Liquid: tar
- Solid: char

Tar in the producer gas sampled and analyzed according to **UNI CEN TS 15439** (bubbling in **isopropanol**)



Tar in the producer gas

Technology	A	B	C	(D)
Gravimetric tar (mg/Nm³)	650-750	200-300	150-250	150-250



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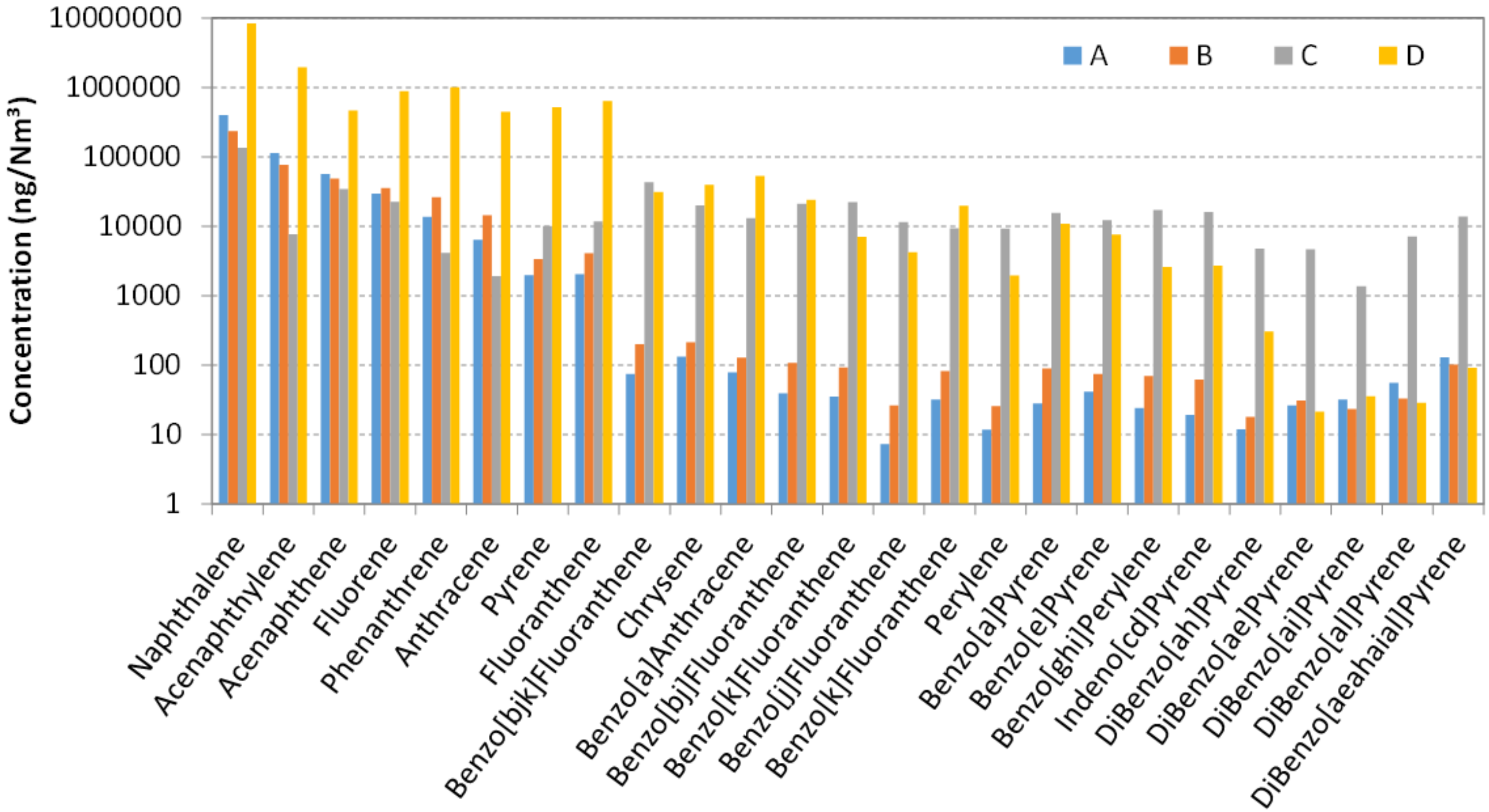
Tar in the producer gas



use of solvent

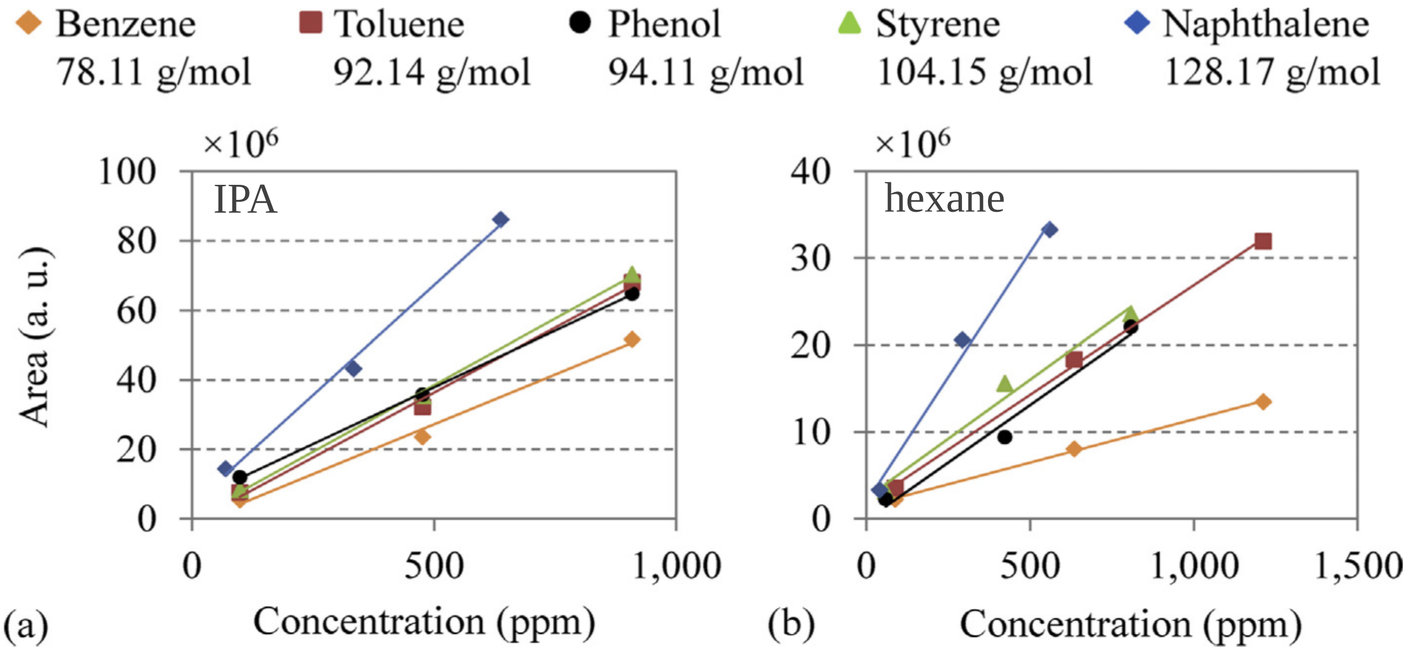


Fig. 3. Calibration curves; IPA as solvent (a), hexane as solvent (b).

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use of solvent

Quantification of tar compounds (mg N m^{-3}) in the raw gas when the gasifier is operated with Casuarina woodchip.

Sample #	IPA (solvent)				Hexane (solvent)			
	1_ipa	2_ipa	3_ipa	Avg. ipa	1_hex	2_hex	3_hex	Avg. hex
Benzene	160 ± 37	102 ± 18	108 ± 14	**123 ± 66**	–	93 ± 14	116 ± 21	**104 ± 34**
Toluene	86 ± 12	68 ± 9	64 ± 5	**73 ± 26**	–	117 ± 17	98 ± 13	**108 ± 30**
Styrene	38 ± 2	0	7 ± 1	**15 ± 3**	–	35 ± 4	22 ± 3	**28 ± 7**
Phenol	0	25 ± 3	0	**8 ± 1**	–	10 ± 3	16 ± 4	**13 ± 7**
Naphthalene	4 ± 2	33 ± 4	0	**12 ± 7**	–	2 ± 1	1 ± 1	**2 ± 3**
Furans[a]	0	0	0	**0**	–	5	4	**4**
Cycloheptatriene[a]	0	0	0	**0**	–	2	0	**1**
Furfurals[a]	0	3	0	**1**	–	8	4	**6**
Dimethyl heptene[a]	0	0	0	**0**	–	0	0	**0**
Ethylbenzene[a]	7	10	0	**6**	–	16	10	**13**
Xylenes[a]	10	13	0	**8**	–	20	13	**16**
Anisole[a]	0	4	0	**1**	–	5	2	**4**
Benzofurans[a]	12	17	0	**9**	–	13	7	**10**
Indenes[a]	8	19	0	**9**	–	9	6	**8**
Acetic acid[a]	0	0	19	**6**	–	0	8	**4**
Cresols[a]	0	0	0	**0**	–	1	0	**0**
Cyclohexane[a]	3	0	5	**3**	–	0	0	**0**
Total GC–MS	327	294	201	**274**	–	337	309	**323**
Total estimated[a] (%)	12	22	12	**15**	–	24	18	**21**
Gravimetric tar	73	41	30	**48**	72	45	60	**59**

[a] Concentration calculated by means of estimated calibration curves.

use of solvent

Quantification of tar compounds (mg N m^{-3}) in the raw gas when the gasifier is operated with coconut shell.

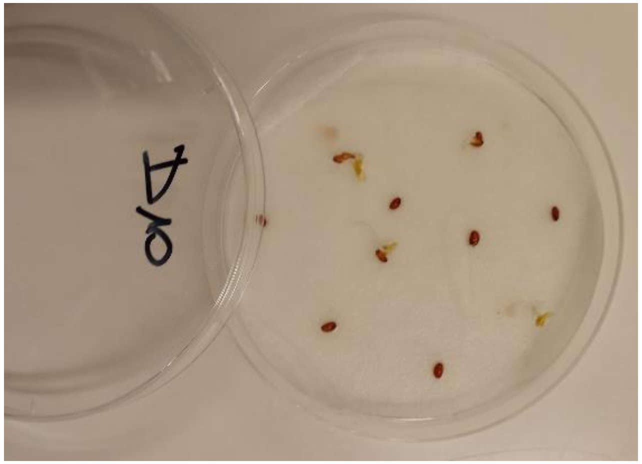
Sample #	IPA (solvent)				Hexane (solvent)			
	1_ipa	2_ipa	3_ipa	Avg. ipa	1_hex	2_hex	3_hex	Avg. hex
Benzene	292 ± 43	86 ± 9	268 ± 13	**215 ± 65**	–	141 ± 21	193 ± 29	**167 ± 50**
Toluene	156 ± 34	55 ± 9	225 ± 15	**146 ± 65**	–	109 ± 14	87 ± 22	**98 ± 37**
Styrene	59 ± 10	0	7 ± 2	**22 ± 4**	–	33 ± 15	26 ± 13	**29 ± 29**
Phenol	10 ± 3	44 ± 2	16 ± 4	**23 ± 13**	–	32 ± 16	46 ± 9	**39 ± 27**
Naphthalene	2 ± 2	32 ± 3	0	**11 ± 12**	–	1 ± 1	2 ± 2	**2 ± 4**
Furans [a]	0	0	0	**0**	–	4	0	**2**
Cycloheptatriene [a]	0	0	0	**0**	–	0	0	**0**
Furfurals [a]	12	9	0	**7**	–	10	3	**7**
Dimethyl heptene [a]	0	0	0	**0**	–	0	0	**0**
Ethylbenzene [a]	13	4	1	**6**	–	9	4	**7**
Xylenes [a]	20	10	0	**10**	–	16	9	**13**
Anisole [a]	0	3	0	**1**	–	2	7	**5**
Benzofurans [a]	29	20	0	**16**	–	18	17	**18**
Indenes [a]	22	21	0	**14**	–	11	14	**12**
Acetic acid [a]	16	24	0	**13**	–	4	8	**6**
Cresols [a]	0	0	0	**0**	–	1	0	**0**
Cyclohexane [a]	5	0	4	**3**	–	0	0	**0**
Total GC–MS	637	308	521	**489**	–	392	418	**405**
Total estimated [a] (%)	18	30	1	**16**	–	19	15	**17**
Gravimetric tar	50	44	63	**52**	138	54	46	**79**

[a] Concentration calculated by means of estimated calibration curves.

Applied methodologies

By-products characterization

- Liquid: tar
- Solid: char



Char toxicity assessed by means of **germination tests**

- cress seeds (*Lepidium sativum L.*), treated with **char extracts** and
- incubated for 24 hours at 25 °C (UNI 10780)

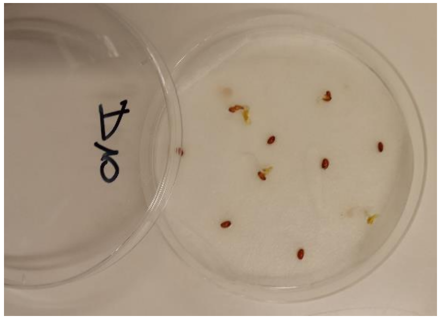
$$GI = NGS_{sample} \times MRL_{sample} / (NGS_{control} \times MRL_{control})$$

GI: germination index
NGS: number of germinated seeds
MRL: mean root length of seedlings mm

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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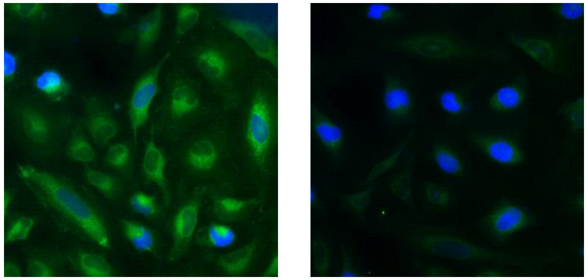

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