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Small-scale Biomass Gasification CHP Systems: Comparative Performance Assessment and Char Valorization

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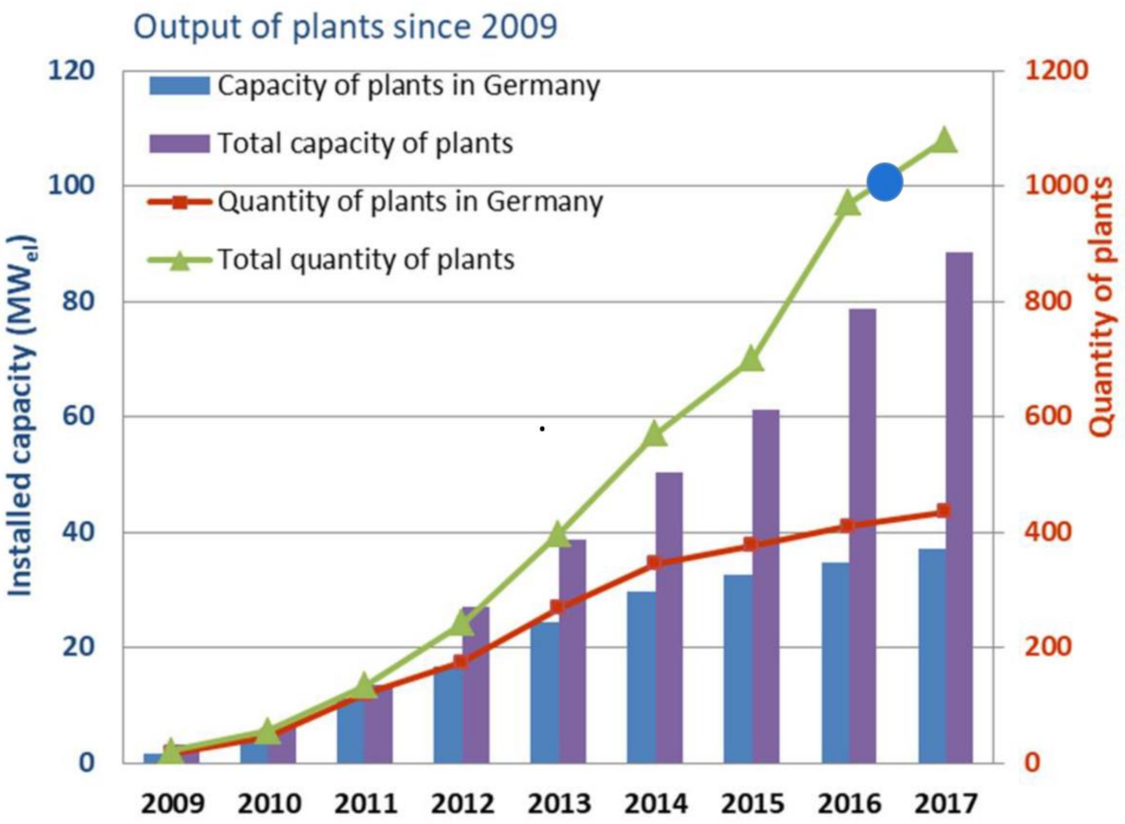
Small scale gasification: EU facts & figures



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

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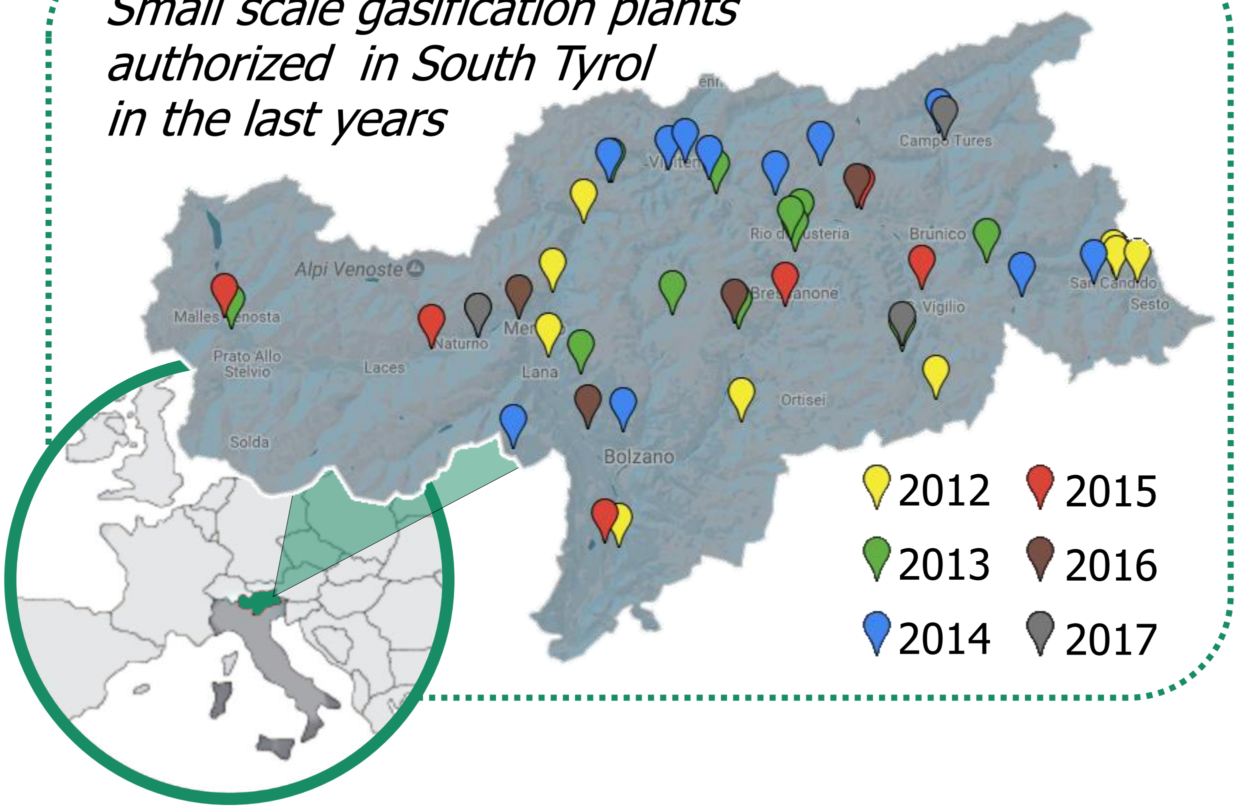
Distribution of gasification plants in South-Tyrol

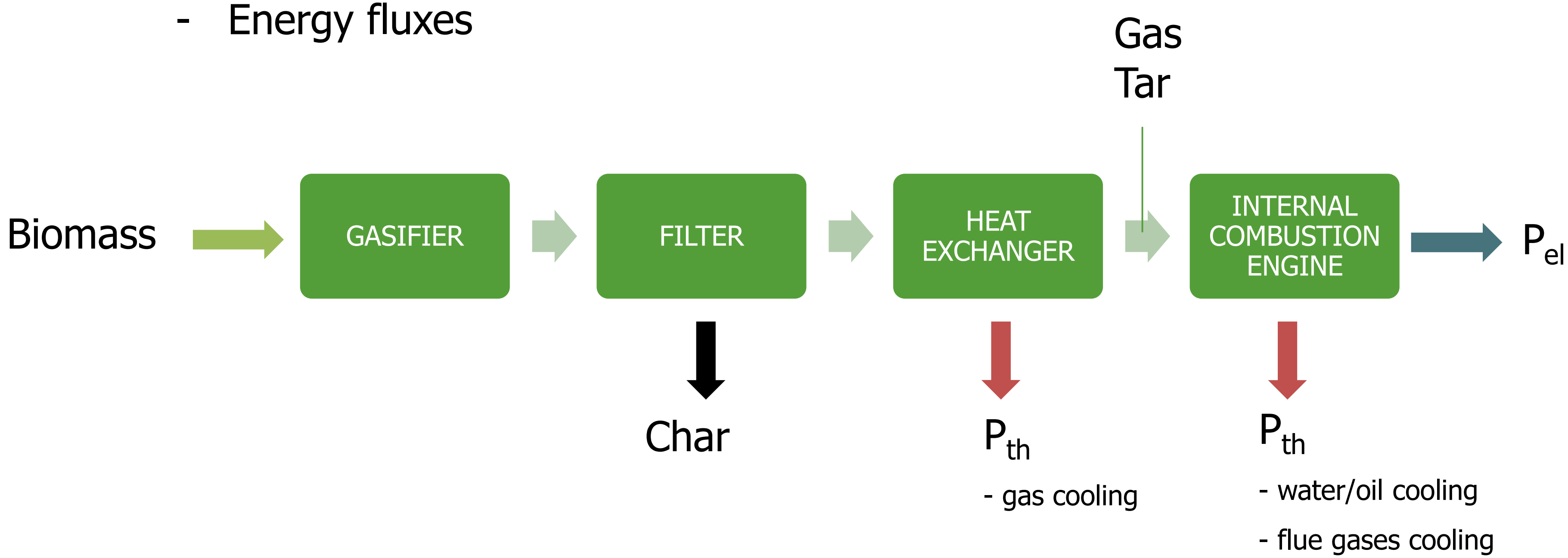
Small scale gasification plants authorized in South Tyrol in the last years



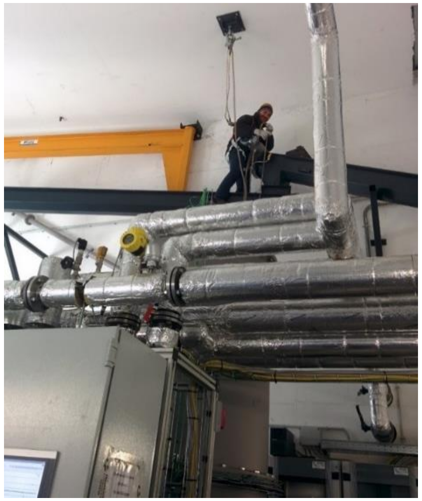
Outline of systems & monitoring activities

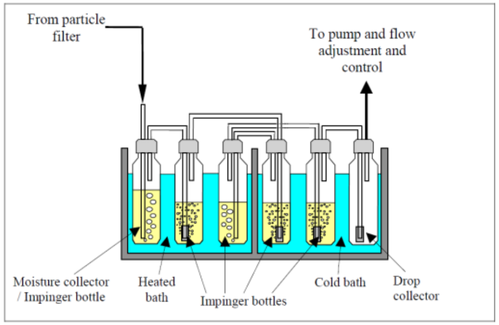
Analyzed parameters

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



On site monitoring activities





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

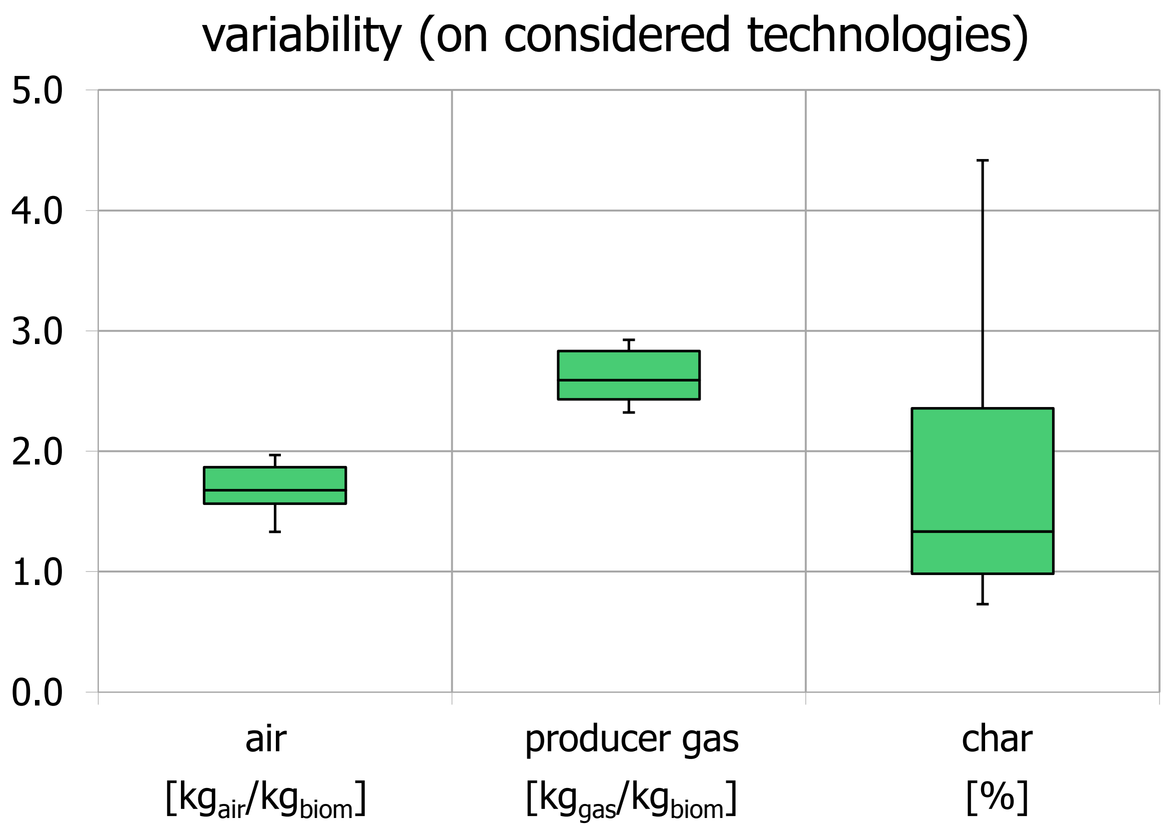
Energy fluxes
- Input fuel
- Producer gas
- Power and heat

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

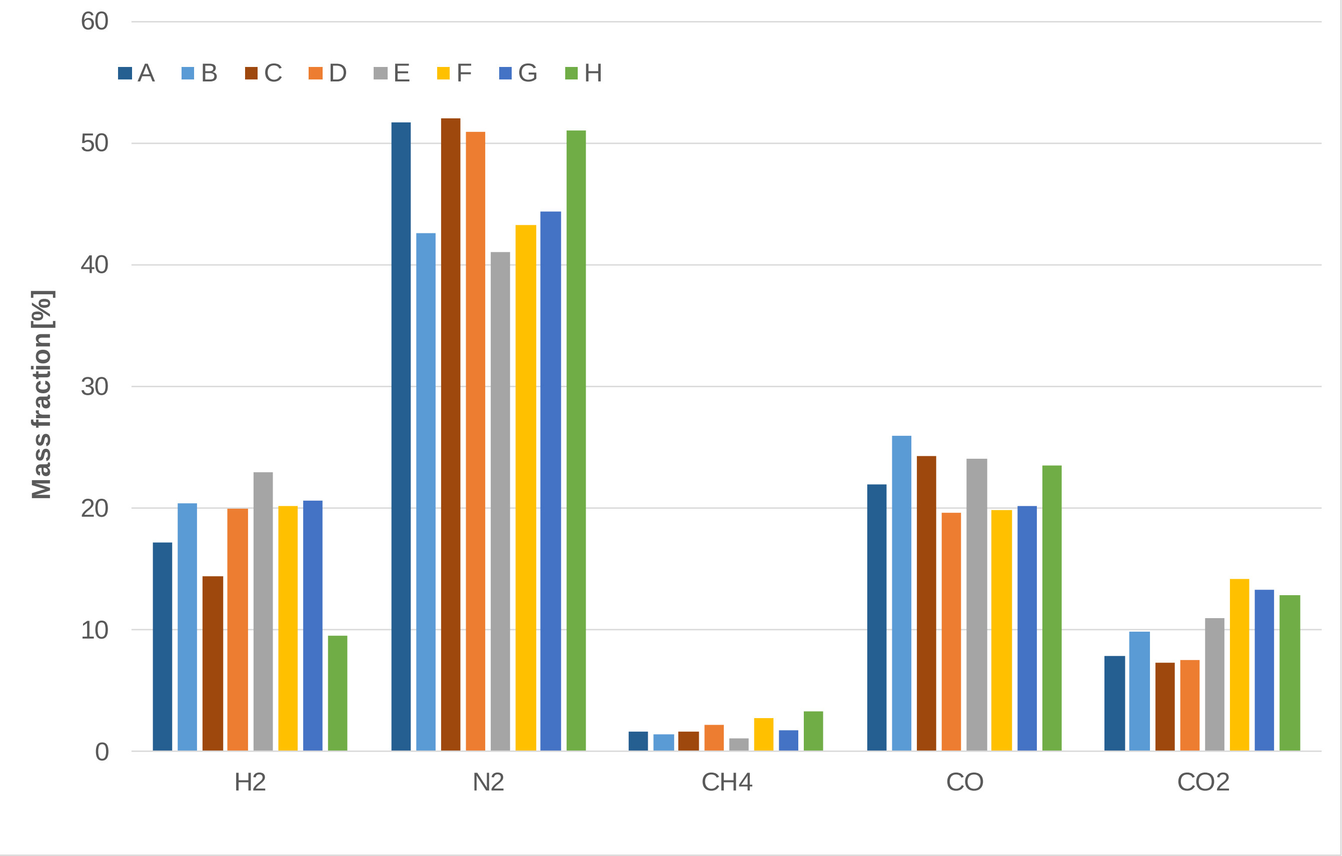
Mass balances of selected technologies

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



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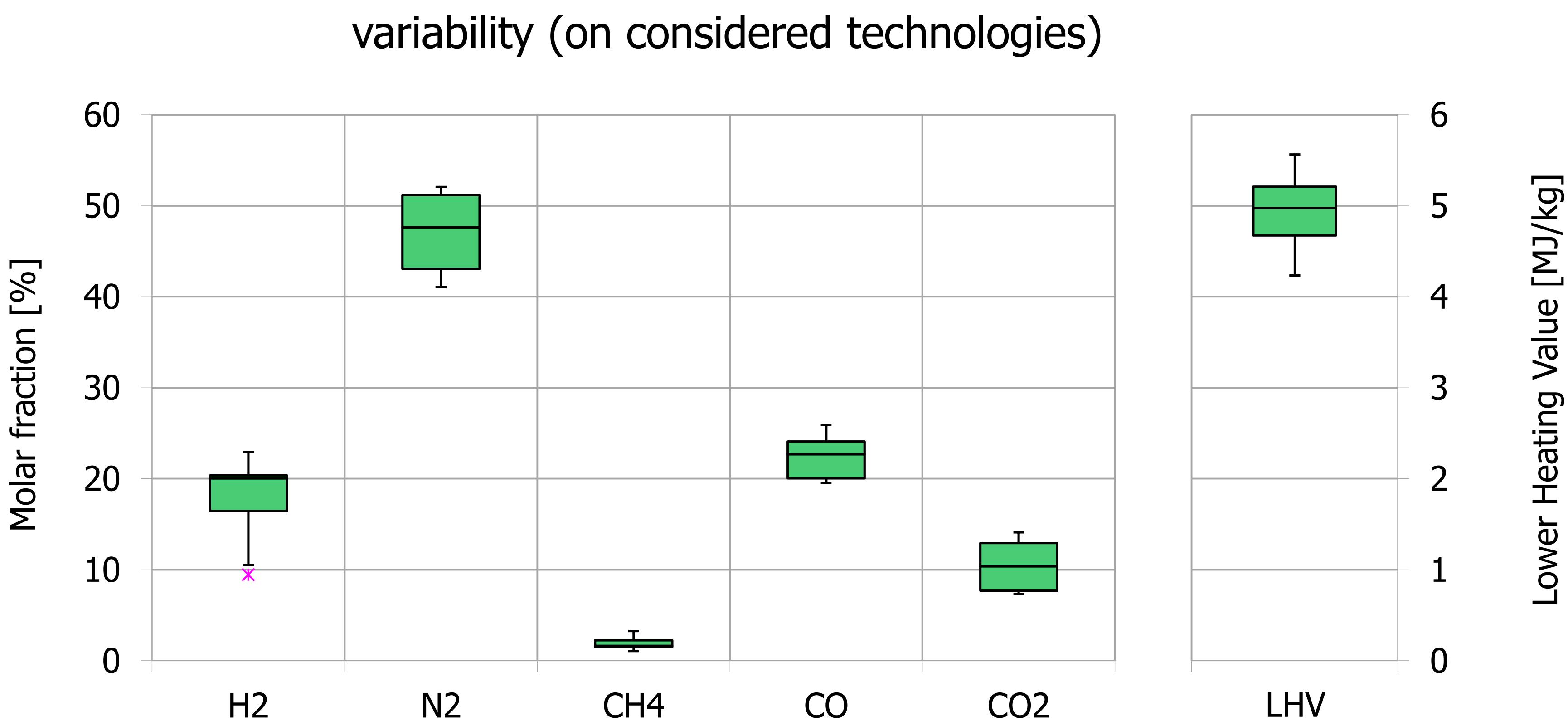
Producer gas composition



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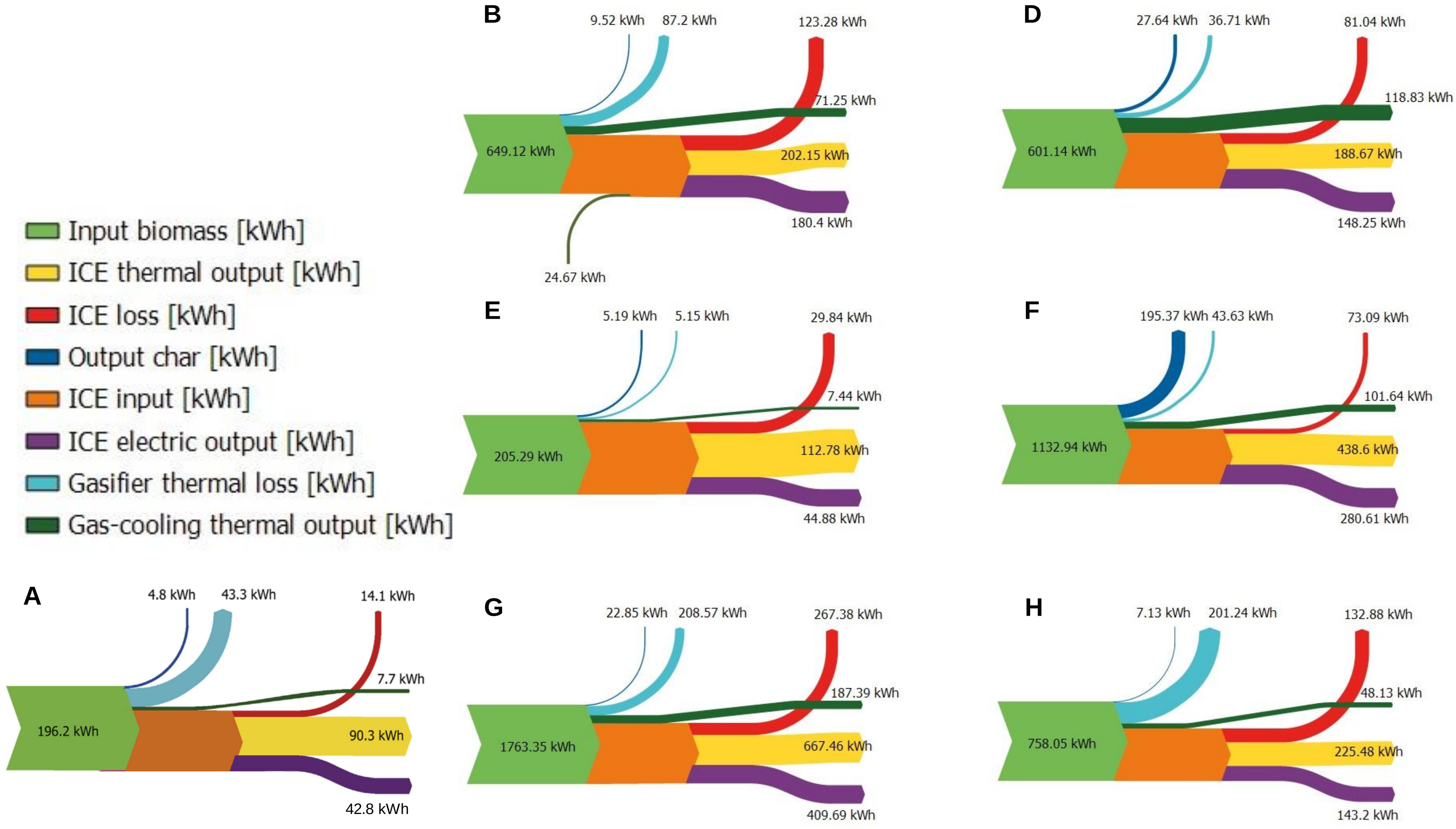
Bioenergy & Biofuels LAB

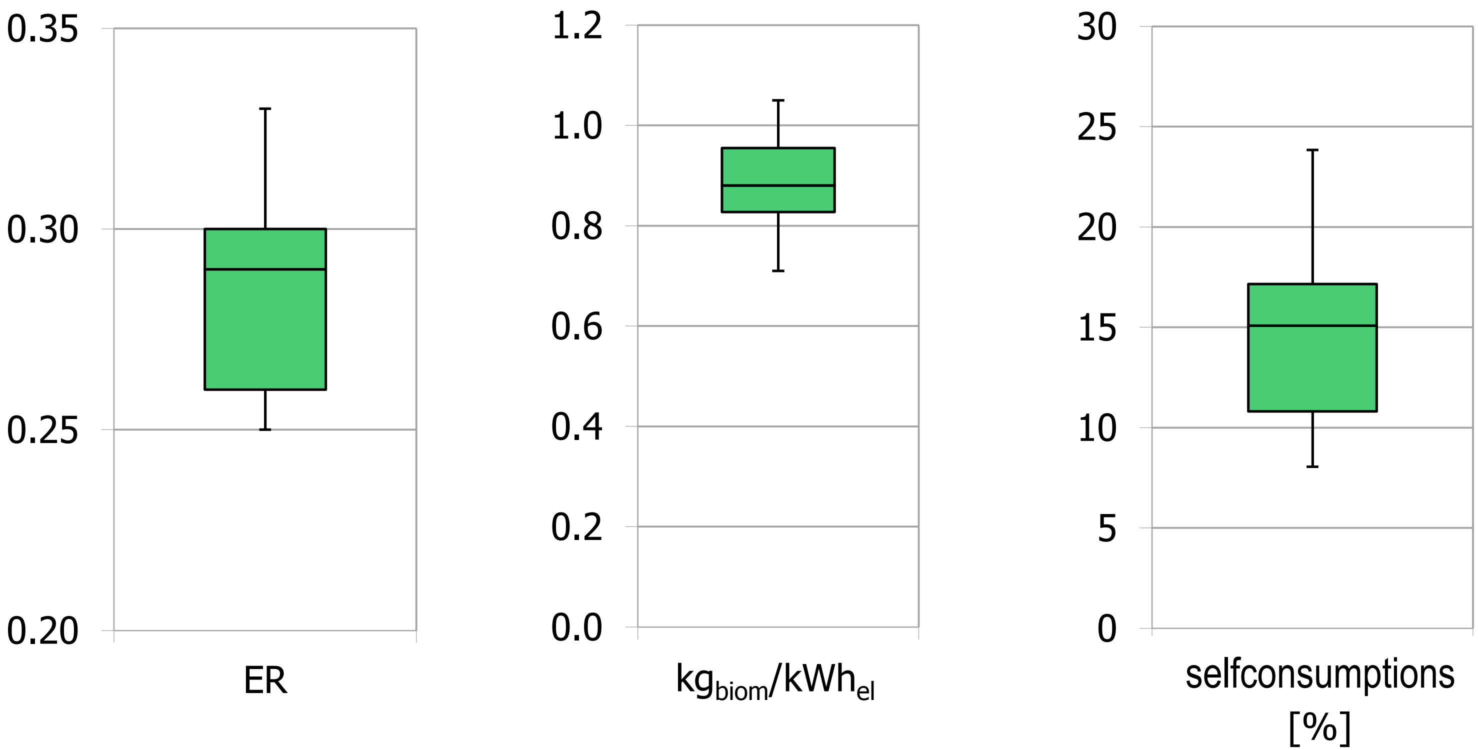
Small scale gasification: b.o.p.



Gasification performance parameters

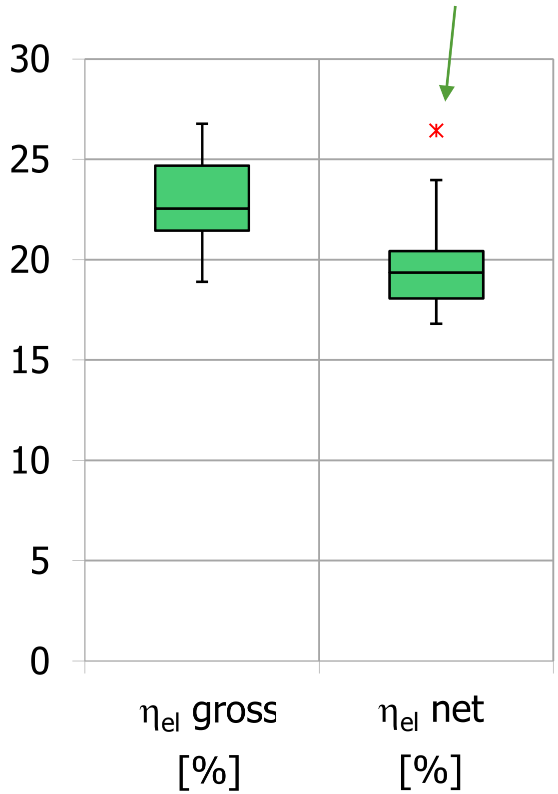
Technology	A	B	C	D	E	F	G	H
ER	0.30	0.26	0.29	0.25	0.29	0.26	0.33	0.30
η_{EL}	18.3%	26.4%	16.8%	18.8%	19.9%	21.9%	19.9%	17.4%
η_{TH}	49.9%	42.1%	52.5%	51.2%	58.6%	47.7%	48.5%	36.1%
η_{TOT}	68.2%	68.6%	68.3%	69.9%	78.5%	69.6%	68.4%	53.5%
kg_{BIOM}/kWh_{EL}	0.93	0.71	0.97	0.83	0.95	0.82	0.83	1.05

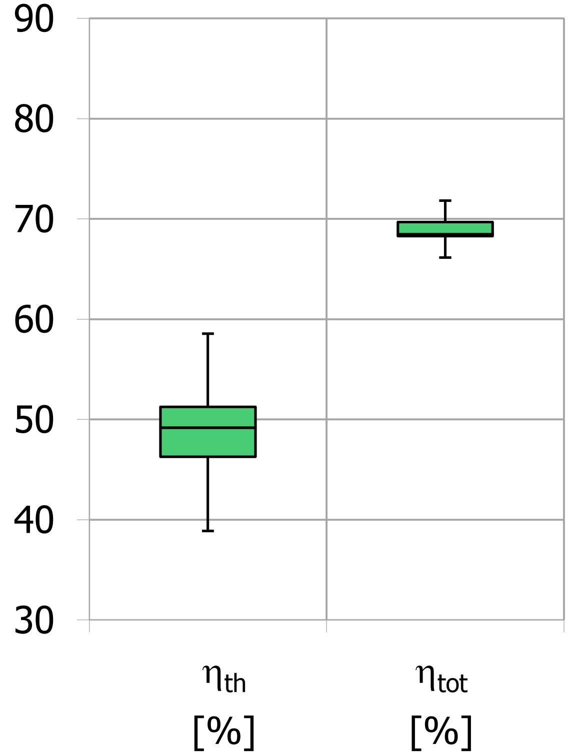
Characteristic parameters



Performance

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





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

Small scale gasification: feedstock (critical issues).

- ✓ Very low moisture content: < 10%
  - Vs direct combustion: 15-20%
  - need of a dryer
- ✓ Constant characteristics
  - homogeneous granulometry (e.g. chips, pellets)
  - constant typology (wood)
  - very few (no) finer presence
- ✓ Biomass higher cost: approx. 130 – 150 € / ton

  Vs direct combustion 70 – 80 € / ton

Small scale gasification: char (critical issues).

- ✓ Char management
  - char screw conveyors extract hot char from the gasifier, so they are subjected to deformation and breakage
  - char management and storage is often problematic because it is a very light material and easily transportable by air

- ✓ High disposal cost: approx. 200 – 400 € / ton

Small scale gasification: gas cleanup (critical issues).

Pollutant	Example	Problems	Method
Particulate	Ash, char	Erosion	Filtration, scrubbing
Alkali	Na, K compounds	Hot corrosion	Cooling, condensation, filtration, adsorption
Nitrogen	Mainly NH_3, HCN	NOx formation	Scrubbing, SCR
Tar	Aromatic compounds	Filters clogging, combustion problems, deposits, catalysts poisoning	Removal, condensation, thermal/catalytic cracking
Sulfur, Clorine	Mainly H_2S, HCl	Corrosion, gaseous emissions, catalysts poisoning	Scrubbing, with dolomite or lime, adsorption

Small scale gasification: others (critical issues).

- ✓ Autonomy and control of the system
  - low degree of automation, i.e. problems lead to complete shut down of the system; time to restore the operation
- ✓ Feeding system: (screw conveyors):
  - blockage/distortion for presence inhomogeneous or inert material or different woodchips geometry
- ✓ Reactor and air nozzles
  - high temperature can melt steel components
  - higher T values than expected ones
  - reactors must be periodically opened and cleaned to remove inert materials

Challenges for gasification

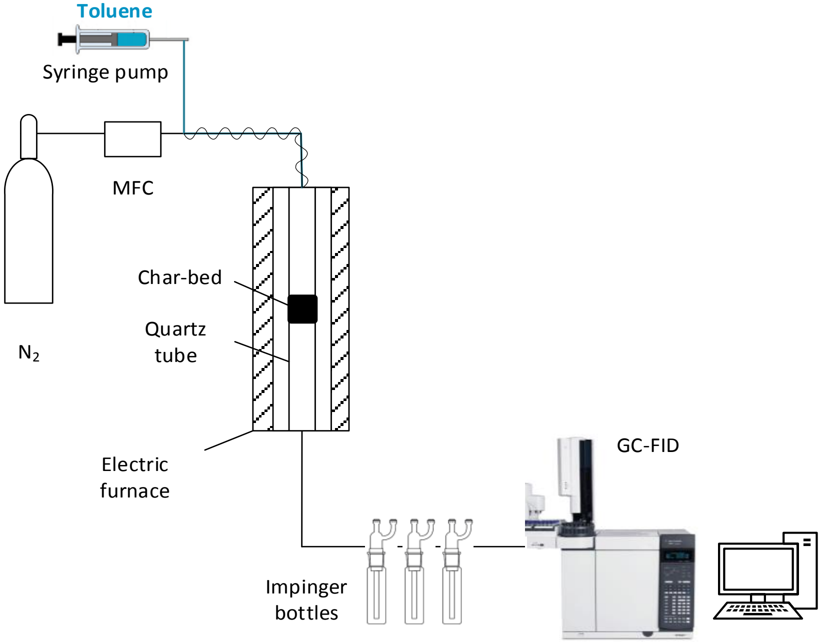
short term
CHP upgrade

- fuel flexibility
- partial load operation
- char utilization
  . filtering medium (ACS subs.)
  . catalyst

medium term
CHP → POLYGENERATION

- biofuels
- hydrogen
- SNG
  . PtG (Power2gas / CO_2 capture)
  . integration with other renewables

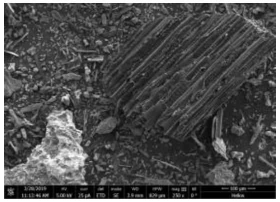
Use of char: tar cracking

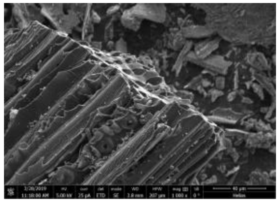


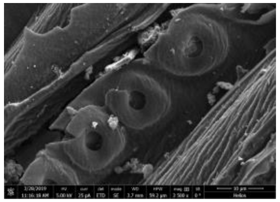
Cordioli et al., Energies (2019)

Plant type	Dual stage gasifier
Feedstock	Wood chips
Proximate and ultimate analysis [$wt\%_{dry}$]	
Ash	22.20
C	78.97
H	0.68
N	0.20
S	0.31
HHV_{dry} [MJ/kg]	25.53
S_{BET} [m^2/g]	587
Pore volume [cm^3/g]	0.30

Ash composition	**Mass fraction** [%]
Ca	17.47
Mg	2.18
Fe	1.12
P	0.84
Mn	0.56
Na	0.40
Al	0.38
S	0.37
Cr	0.30
Ba	0.22

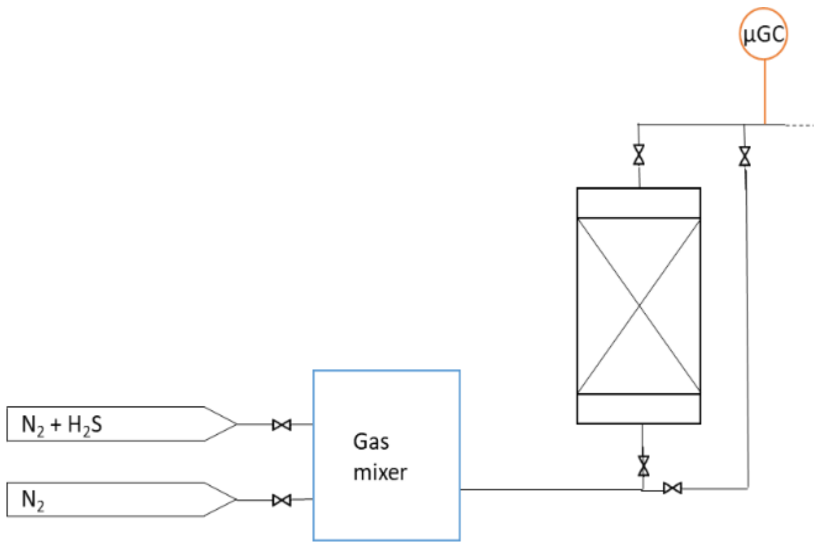


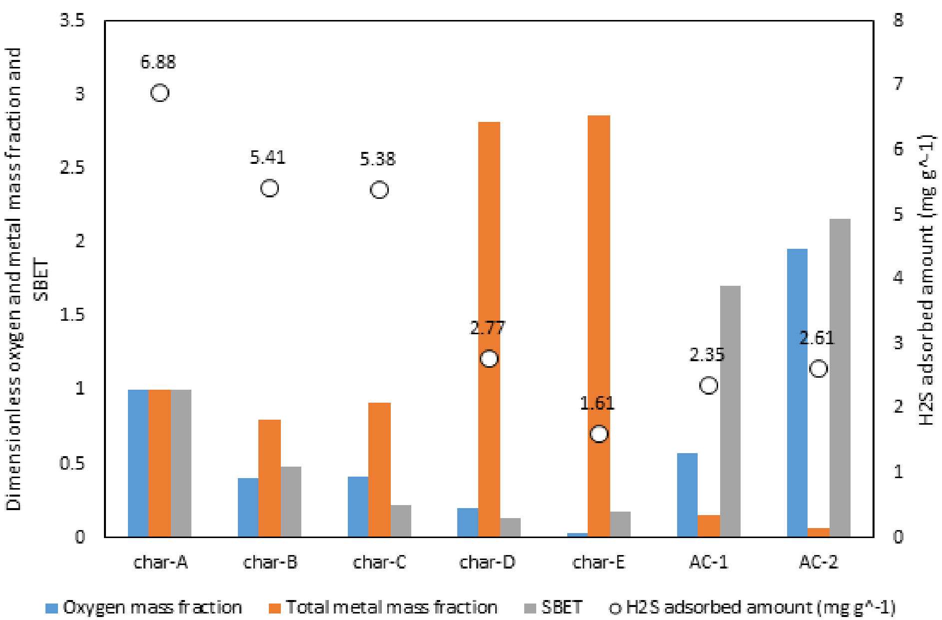




	Empty-reactor tests		**Tests with char-bed**	
	900 °C	**1000 °C**	**900 °C**	**1000 °C**
Toluene removal efficiency [%]	39.9	97.3	60.3	99.0

Use of char: adsorption





Marchelli et al. (2019)

Benedetti et al. (2019)

Use of char: catalyst support for FT synthesis

Catalysts

Precursors:

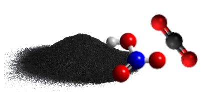

$Co(NO_3)_2 \cdot 6H_2O$


$Fe(NO_3)_3 \cdot 9H_2O$

Supports:

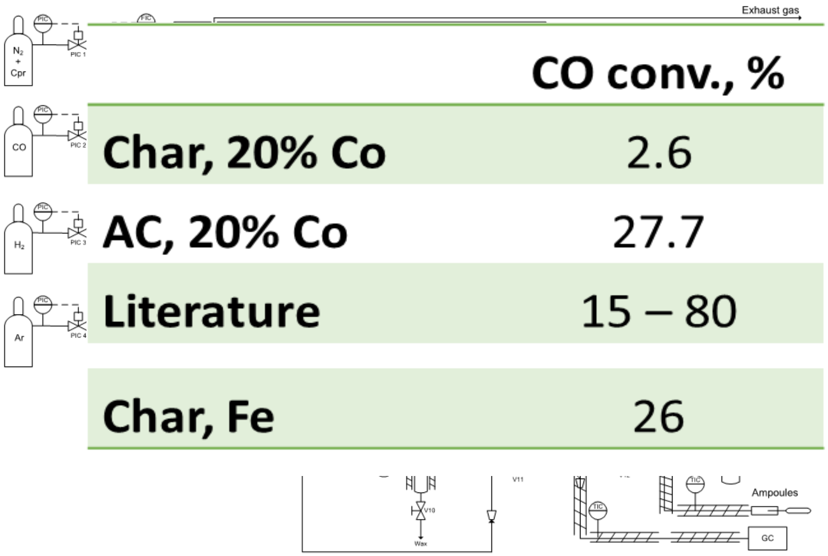

Char


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

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Towards advanced biofuels: polygeneration

Renewable Energy Directive II (RED II)

Renewable transport fuels target: 14% (3.5% advanced b.)

SET plan & Action 8 Implementation plan

Gasification is a key technology in 3 (of 7) value chains

required: efficiency improvement, 30%, GHG savings, 60%

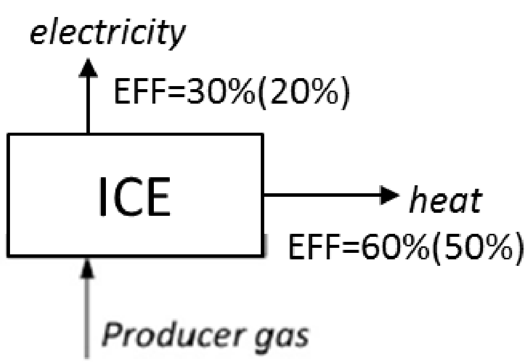
cost reduction, to 50 (2020) – 35 (2050) €/MWh

Strategic Research and Innovation Agenda (ETIp, EERA Bioenergy)

Major role for gasification value chains in agreement with SET pl.

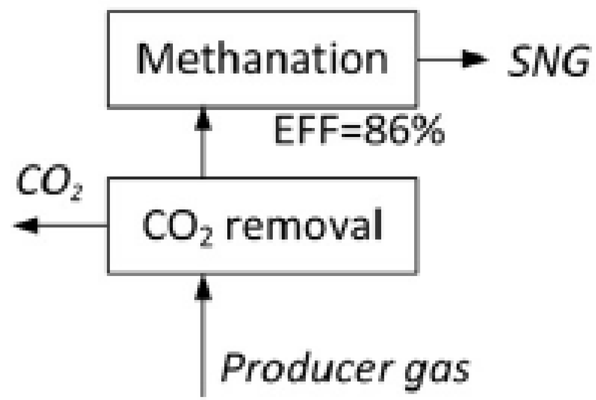
Polygeneration

Today (… almost yesterday)



Saric et al., Journal of CO_2 Utilization, 20 (2017) 81-90

Tomorrow (… almost today)

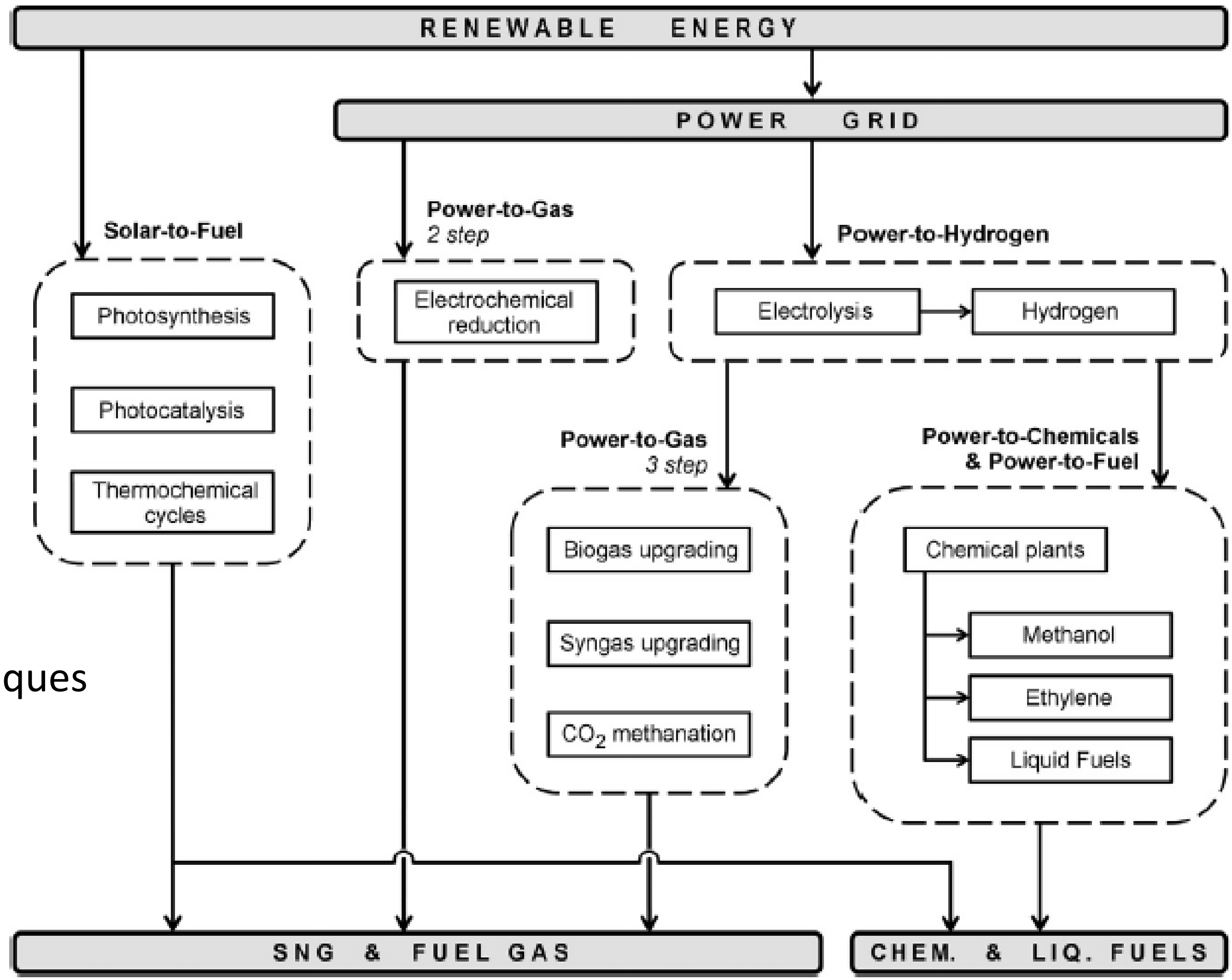


Sabatier reaction

$$CO_2 + 4H_2 \leftrightarrow CH_4 + 2H_2O$$

$$\Delta H = -164.9\ \mathrm{kJ/mol}$$

Power-to-gas (PtG)



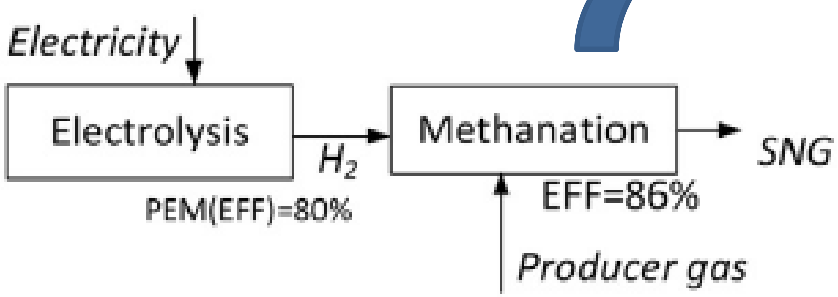
M. Bailera et al. Renewable and Sustainable Energy Reviews 69 (2017) 292–312

Renewable energy and
CO_2 hybrid storage techniques

Power-to-gas (PtG) and gasification

Tomorrow (PtG)

Tomorrow (biomethanation)



Syngas fermentation

Saric et al., Journal of CO_2 Utilization, 20 (2017) 81-90

Menin et al. (2019)

Remarks: main directions for gasification

- **Increase fuel flexibility** [use of low-cost feedstock]
- **Use char as co-product** [(!) legislative framework]
- **Co-production of fuels/chemicals/materials** [poly-generation]
- **Combining thermochemical and biochemical processes**
- **Optimization of resource efficiency** [wind, solar, hydro]

Thank you very much for your attention!

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