
Freie Universität Bozen
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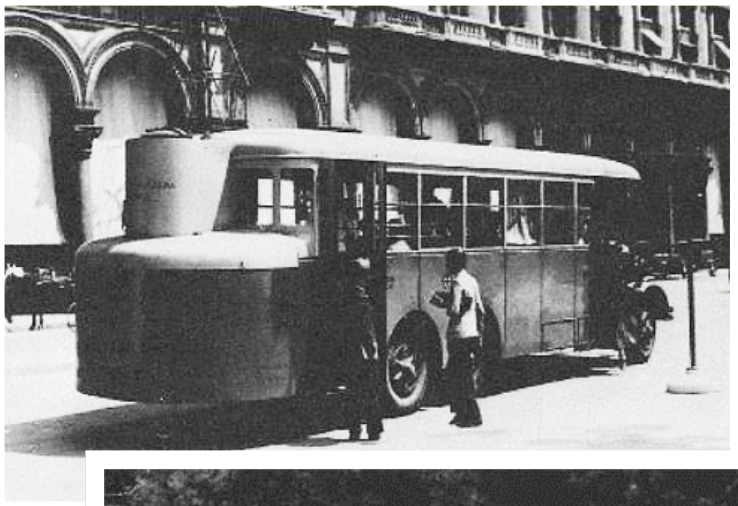
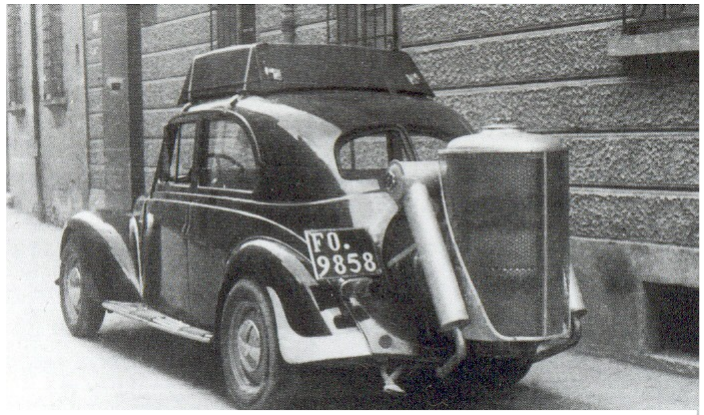
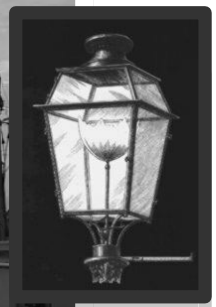
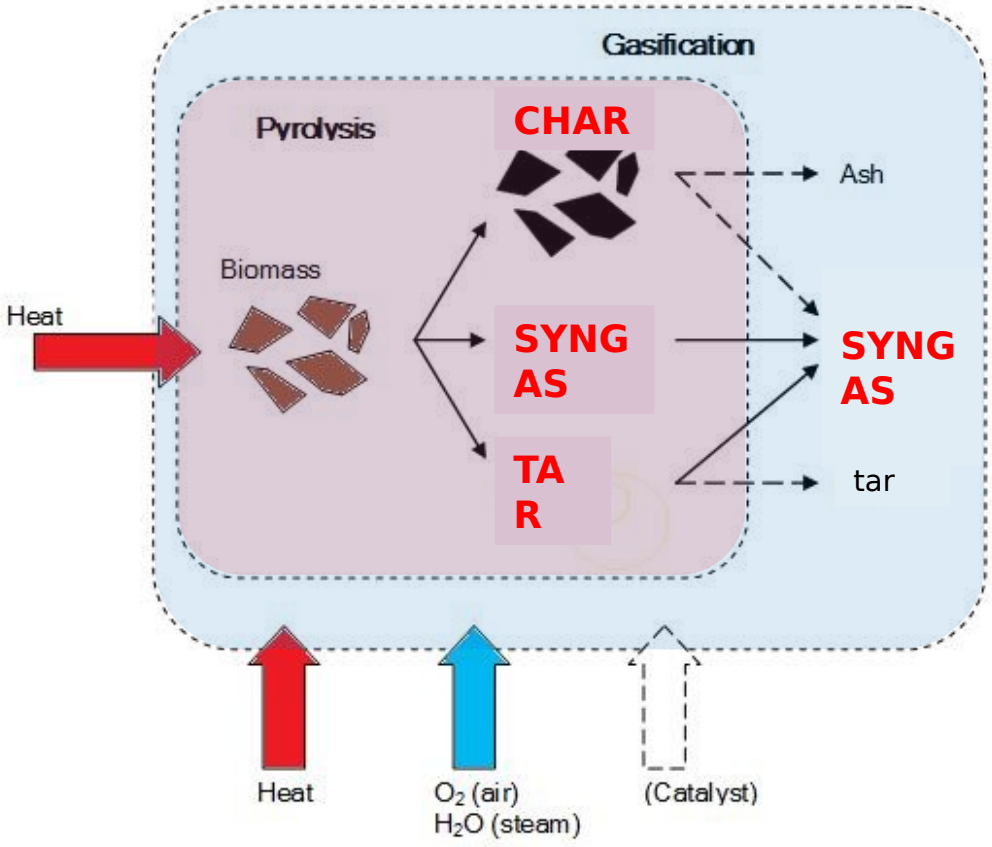
# Gasification





# Gasification for solid fuel upgrading




SYNG AS

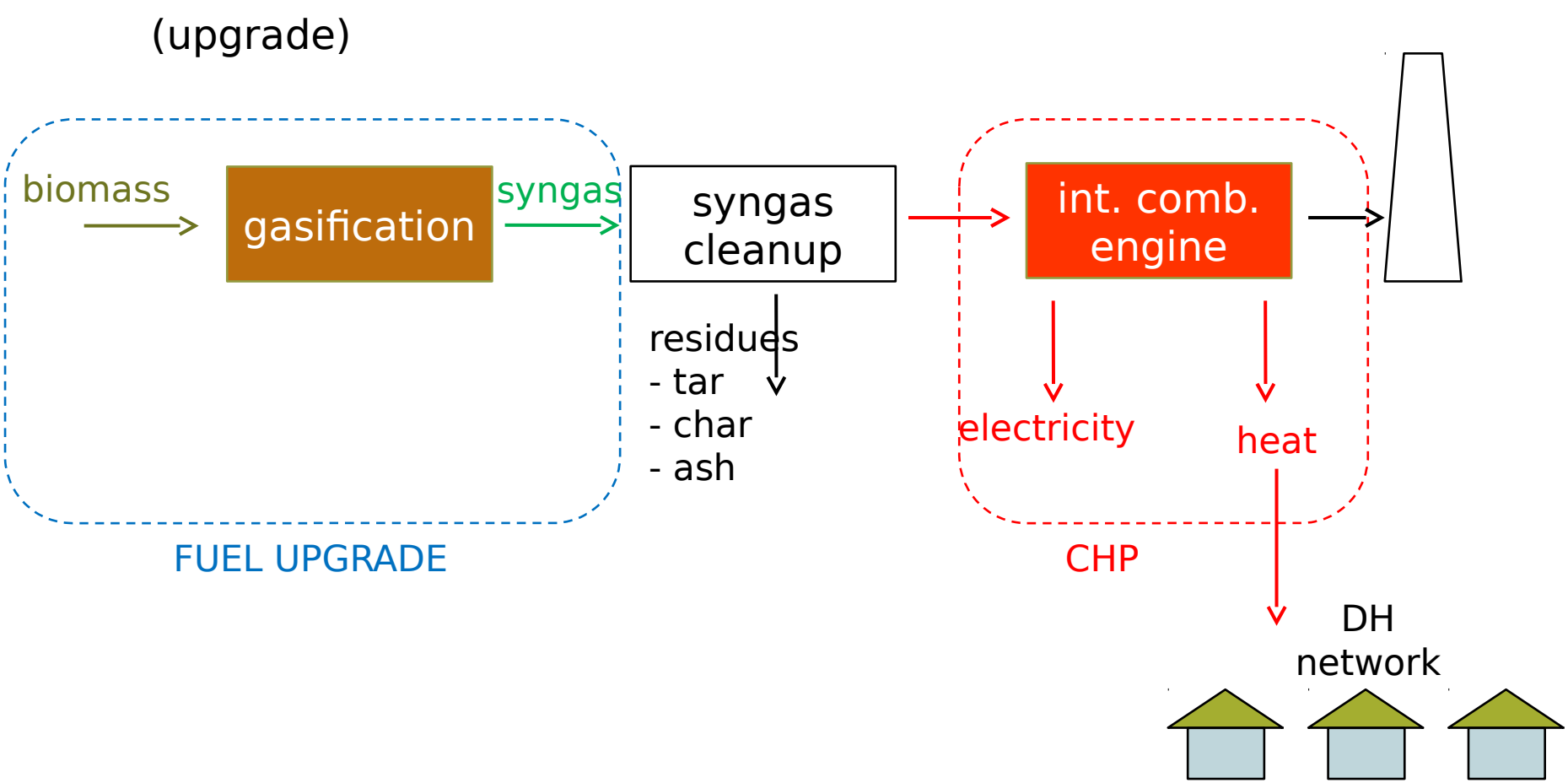
HEAT & POWER

SNG

FT liquid fuels

Hydrogen, chemicals

# Gasification for CHP

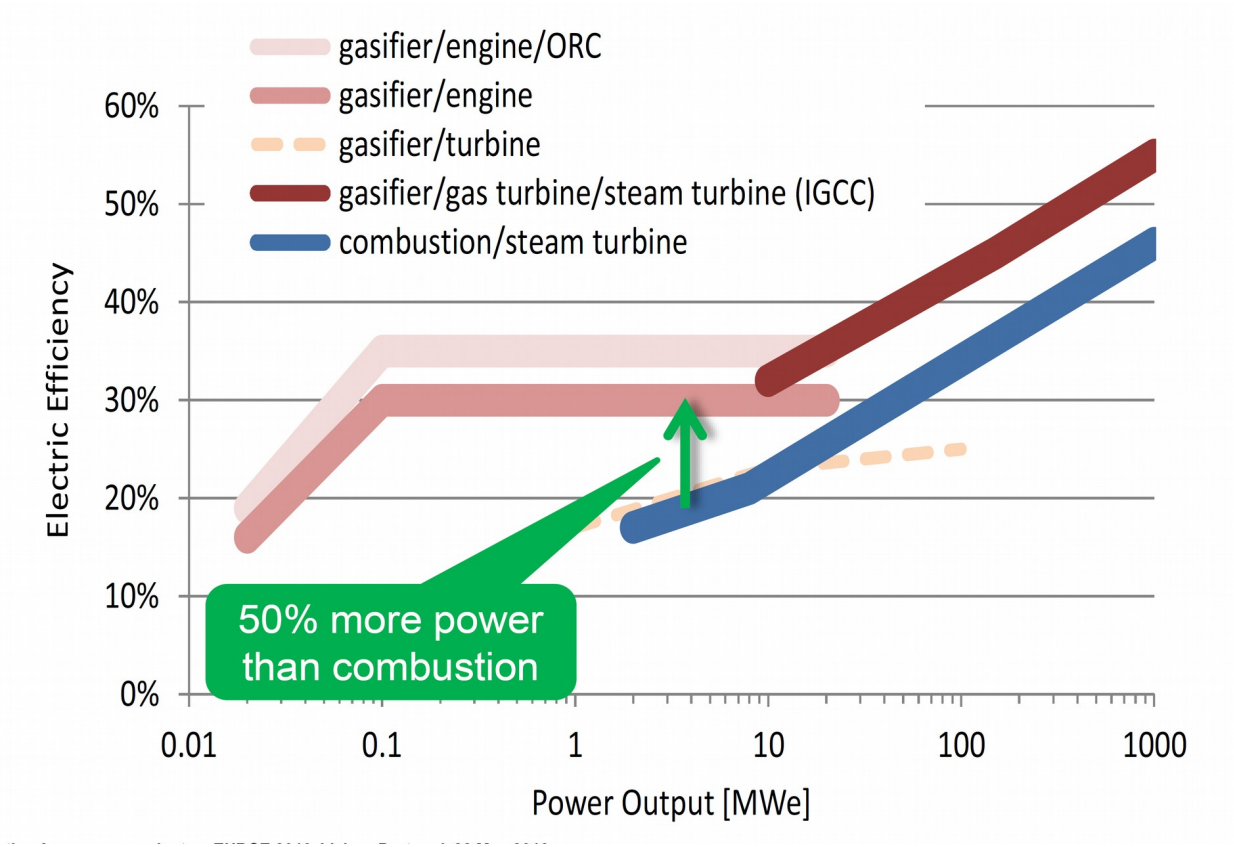



# Systems for CHP

(combustion Vs gasification based)

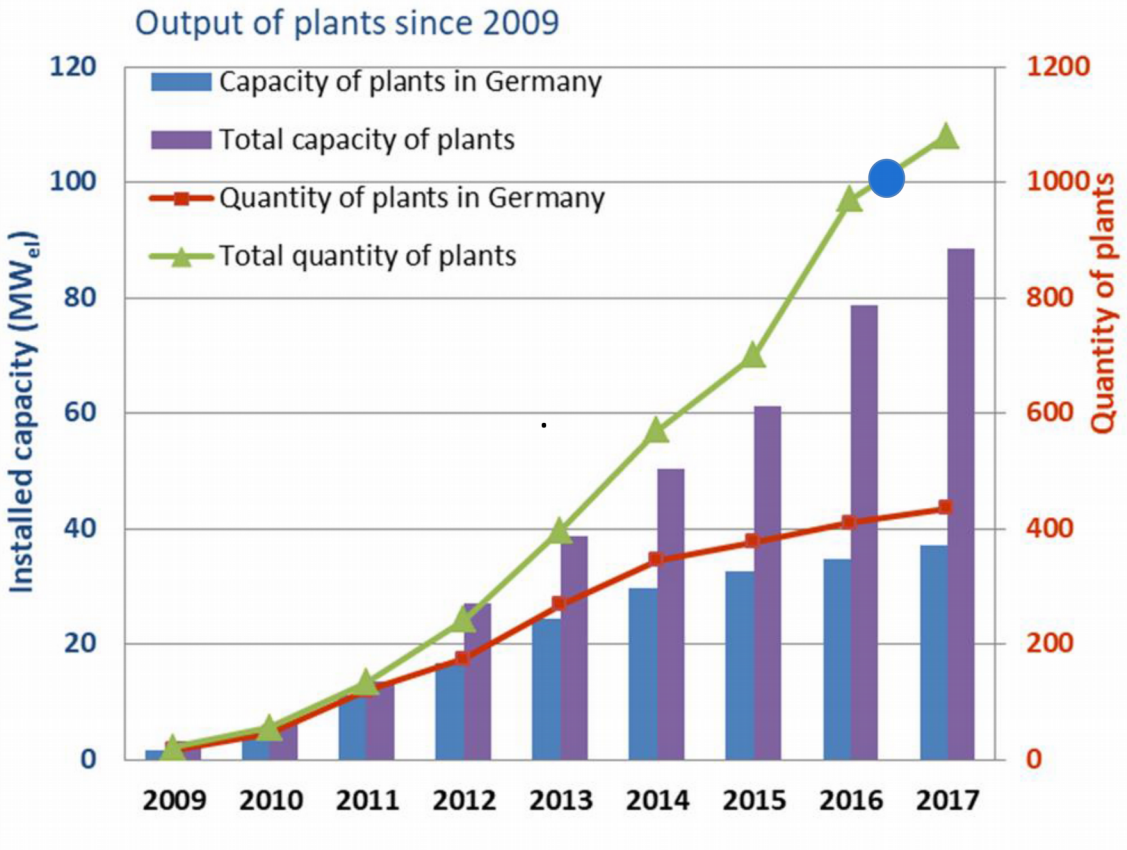
| | Combustion based CHP systems | | | Gasification based CHP systems | |
|---|---|---|---|---|---|
| | ST | ORC | Stirling | ICE | BIGCC |
| **Electrical Power** | 50 kW – 250 MW | 500 kW – 10 MW | < 200 kW | 10 kW – 10 MW | 50-100 MW |
| **CHP electrical efficiency** | 0.10-0.25 | 0.13-0.18 | 0.10-0.15 | 0.25-0.30 | 0.3-0.4 |
| **CHP overall efficiency** | 0.8-0.9 | 0.8-0.9 | 0.8-0.9 | 0.8-0.9 | 0.8-0.9 |
| **Power-to-heat ratio** | 0.10-0.35 | 0.20-0.25 | 0.15-0.20 | 0.4-0.5 | 0.7-0.9 |
| **Field experience** | extensive | extensive | limited | sufficient | very limited |

# Systems for CHP




[J. Keel, EUBCE 2019]

# Small scale gasification: EU facts & figures



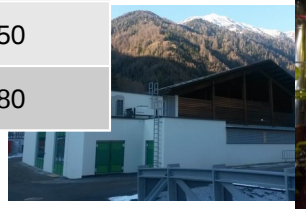

[D. Bräkow, 9. „Internationale Anwenderkonferenz Biomassevergasung“, 5. Dezember 2017 / Innsbruck]


# Small scale gasification: technologies

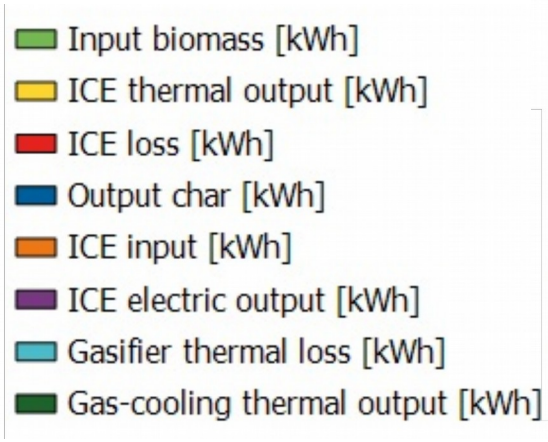
| Name | Country | Name | Country |
|---|---|---|---|
| **Agnion Technologies GmbH** | Germany | MEVA ENERGY AB | Sweden |
| **AHT Pyrogas Vertriebs GmbH** | Germany | Nexterra Systems Corp. | Canada |
| **Andritz AG** | Austria | Pyrox GmbH | Italy |
| **Ankur Scientific Energy Technologies Pvt. Ltd.** | India | Qalovis GmbH | Germany |
| **BIO&WATT Gasification s.r.l.** | Italy | Refgas Ltd | UK |
| **Burkhardt GmbH** | Germany | ReGaWatt GmbH | Germany |
| **Cortus Energy** | Sweden | Repotec GmbH | Austria |
| **Ronda Engineering Srl (Ecogasgenerator)** | Italy | Simam S.p.A. | Italy |
| **ENTRADE ENERGY SERVICES LTD.** | Germany | Spanner Re² GmbH | Germany |
| **EQTEC** | Spain | Stadtwärke Rosenheim GmbH | Germany |
| **ESPE Srl** | Italy | Stirling DK | Denamrk |
| **Froling srl** | Italy | Syncraft Engineering GmbH | Austria |
| **Future Green S.r.l.** | Italy | Terruzzi Fercalx Spa | Italy |
| **GLOCK Ökoenergie GmbH** | Austria | Urbas Maschinenfabrik GmbH | Austria |
| **GTS Syngas Srl / BR Energy Group AG** | Italy / Switzerland | Varat - Enea | Italy |
| **Hans Gräbner** | Germany | Volter Oy | Finland |
| **Hargassner GesmbH** | Austria | Weiss A/S | Denamrk |
| **Holzenergie Wegscheid GmbH** | Germany | Xyloenergy GmbH | Germany |
| **Kuntschar Energieerzeugung GmbH** | Germany | Xylogas & EAF / Christof industries | Austria |
| **KWS** | Germany | XyloPower AG | Switzerland |
| **Ligento green power GmbH** | Germany | Xylowatt S.A. | Belgium |
| **LiPRO Energy GmbH & Co. KG** | Germany | | |

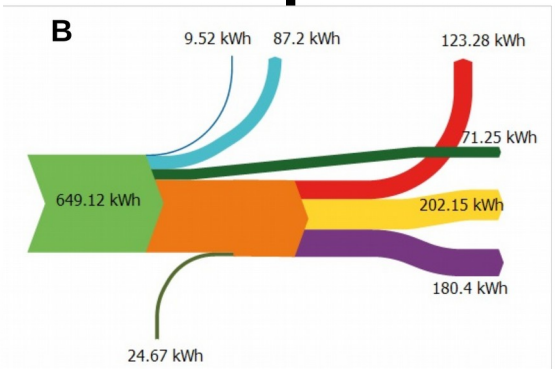
# Small scale gasification: technologies

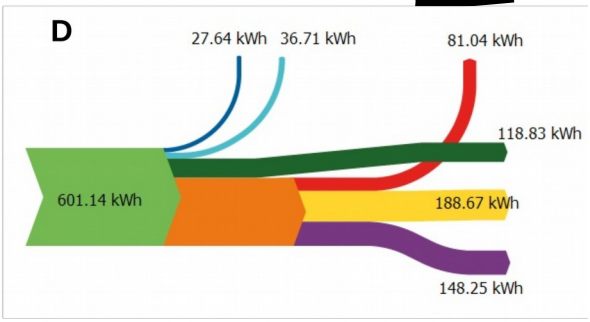
| Technology | Reactor | Biomass | Electric power [kW] | Thermal power [kW] |
|---|---|---|---|---|
| Burkhardt GmbH | Rising co-current | Pellet | 180 | 270 |
| Entrade Energiesysteme GmbH | Downdraft Fixed bed | Pellet A1 | 25 | 60 |
| Future Green Srl (Wubi) | Downdraft Fixed bed | Woody chips | 100 | 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 |

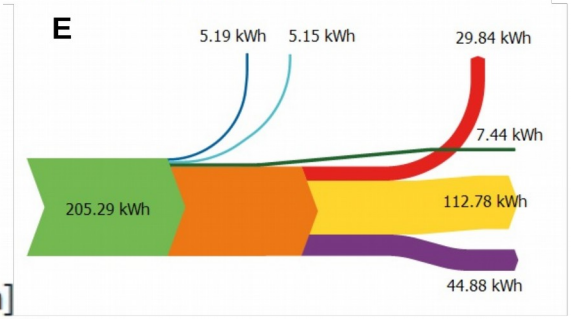


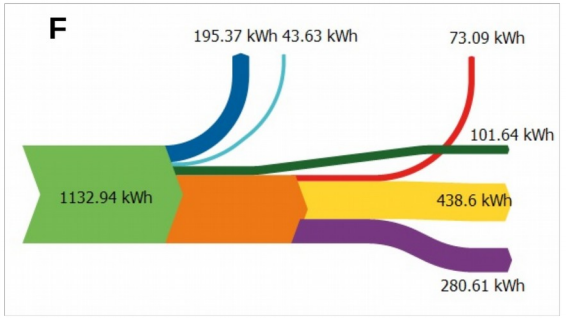
# Small scale gasification: b.o.p.

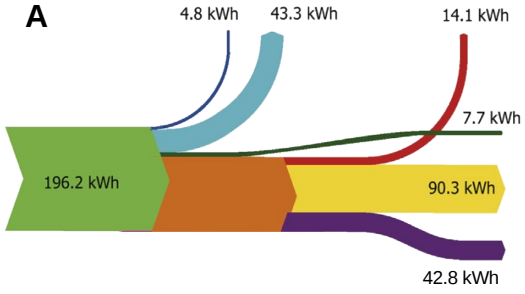


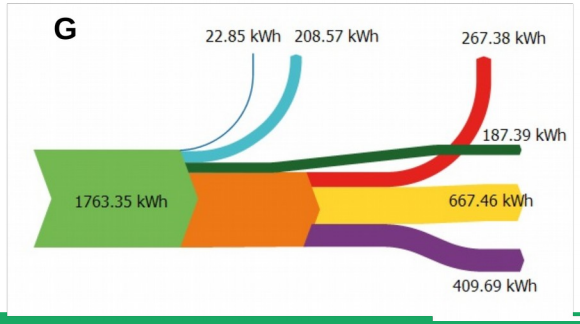



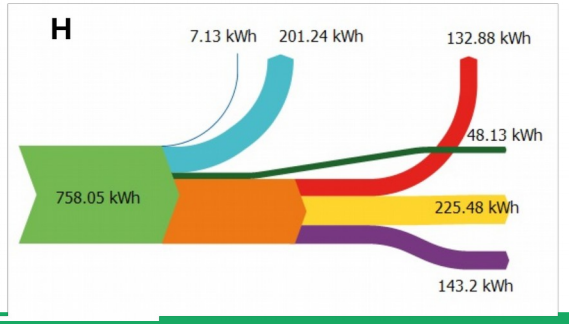



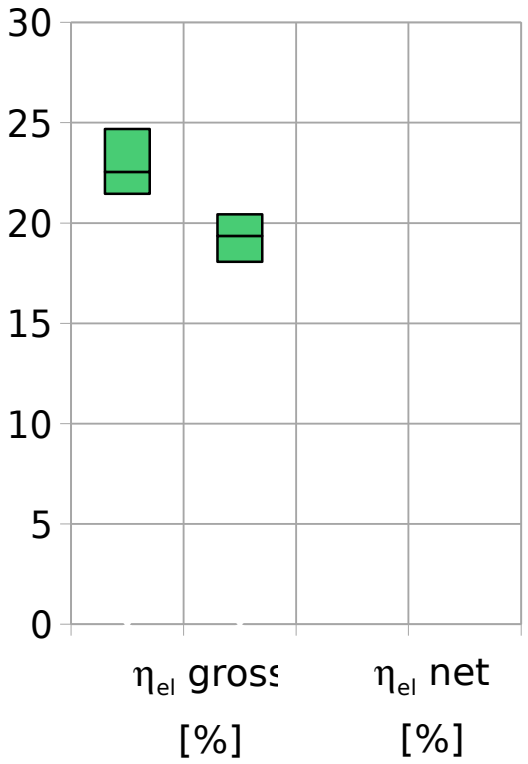



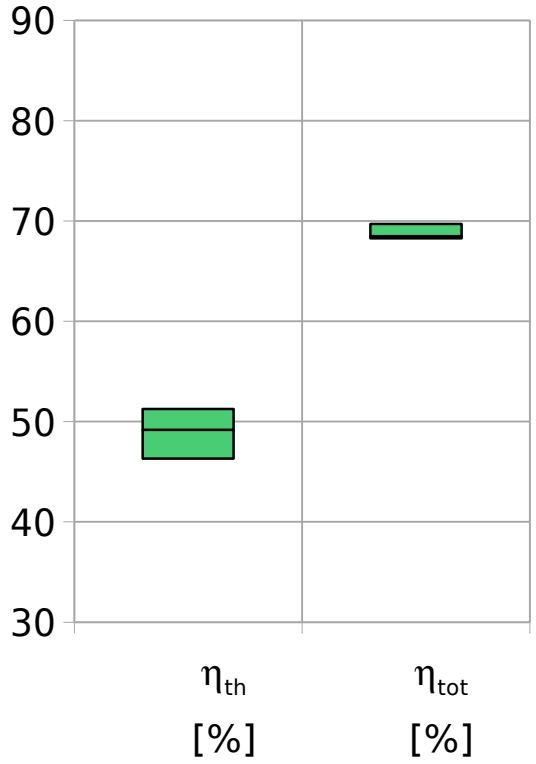



# Small scale gasification: performance



# Small scale gasification: feedstock (critical issues).

- ✓ <u>Very low moisture content:</u> < 10%
  - Vs direct combustion: 15-20%
  - need of a dryer
- ✓ <u>Constant characteristics</u>
  - homogeneous granulometry (e.g. chips, pellets)
  - constant typology (wood)
  - very few (no) finer presence

- ✓ <u>Biomass higher cost:</u> approx. 130 – 150 € / ton

  Vs direct combustion 70 – 80 € / ton


# Small scale gasification: others (critical issues).

- ✓ Feeding system: (screw conveyors):
  - blockage/distortion for presence inhomogeneous or inert material
  - problems with woodchips geometry
- ✓ Reactor and air nozzles
  - high temperature can melt steel components
  - gasifier can reach higher T values than expected ones, because of a drier or larger particles
  - reactors must be periodically opened and cleaned to remove inert materials (rocks, metal pieces or molten ashes)


# Small scale gasification: others (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
- ✓ Autonomy and control of the system
  - low degree of automation, i.e. the software detects a problem and shut down the entire system; to restore the operation, there must be an operator who manages the problem manually and restarts the system.


# 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 |

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# Challenges for gasification

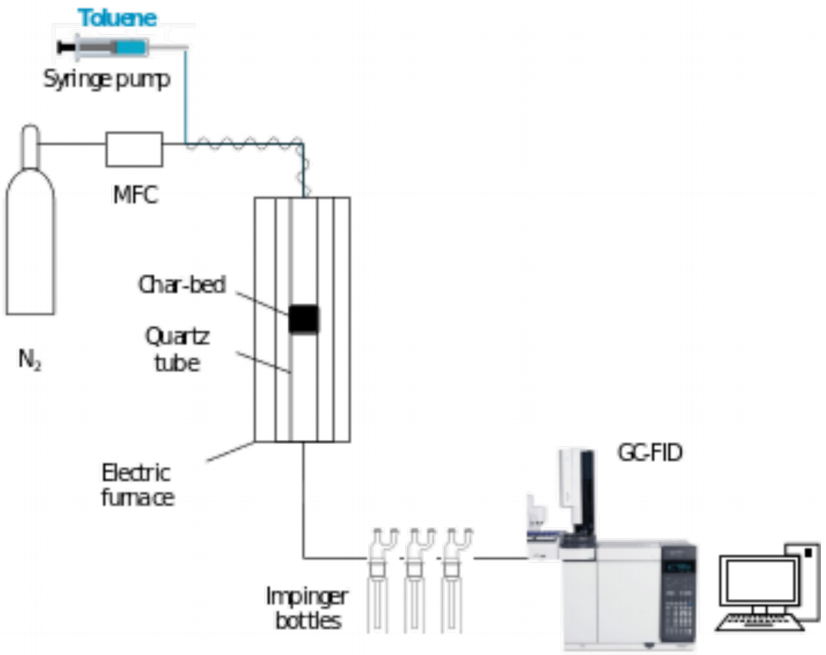
## short term
CHP upgrade

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

## medium term
CHP  POLYGENERATION

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

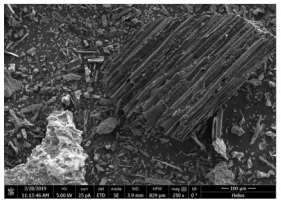
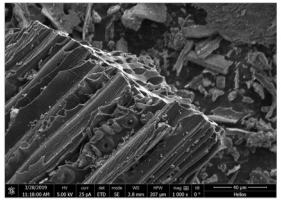
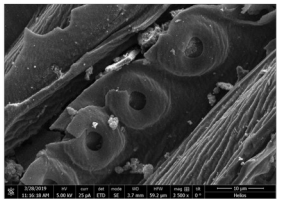
# CHP upgrade: use of char (tar cracking)




*Cordioli et al., EUBCE (2019)*

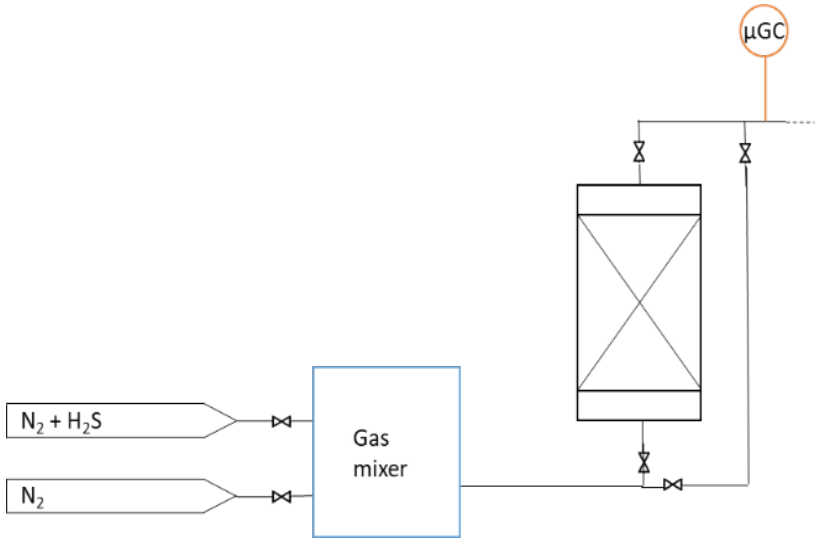
| **Plant type** | Dual stage gasifier |
|---|---|
| **Feedstock** | Wood chips |
| **Proximate and ultimate analysis** [$wt\%_{dry}$] | |
| Ash | 22.20 |
| C | 78.97 |
| H | 0.68 |
| N | 0.20 |
| S | 0.31 |
| $HHV_{dry}$ [MJ/kg] | 25.53 |
| $S_{BET}$ [$m^2/g$] | 587 |
| Pore volume [$cm^3/g$] | 0.30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

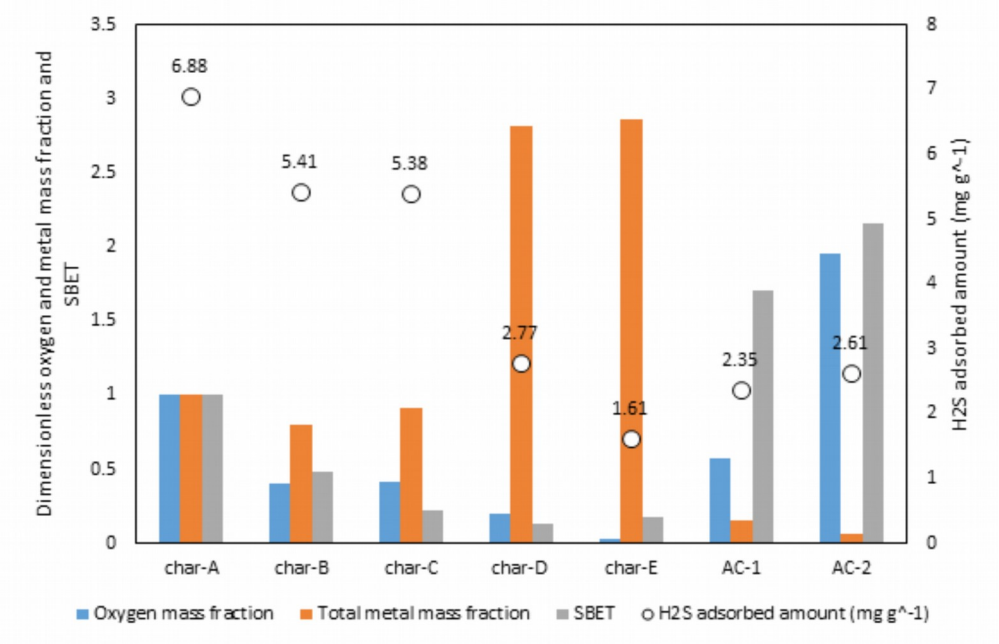
| **Ash composition** | |
|---|---|
| **Mass fraction** [%] | |
| Ca | 17.47 |
| Mg | 2.18 |
| Fe | 1.12 |
| P | 0.84 |
| Mn | 0.56 |
| Na | 0.40 |
| Al | 0.38 |
| S | 0.37 |
| Cr | 0.30 |
| Ba | 0.22 |

| | **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 |

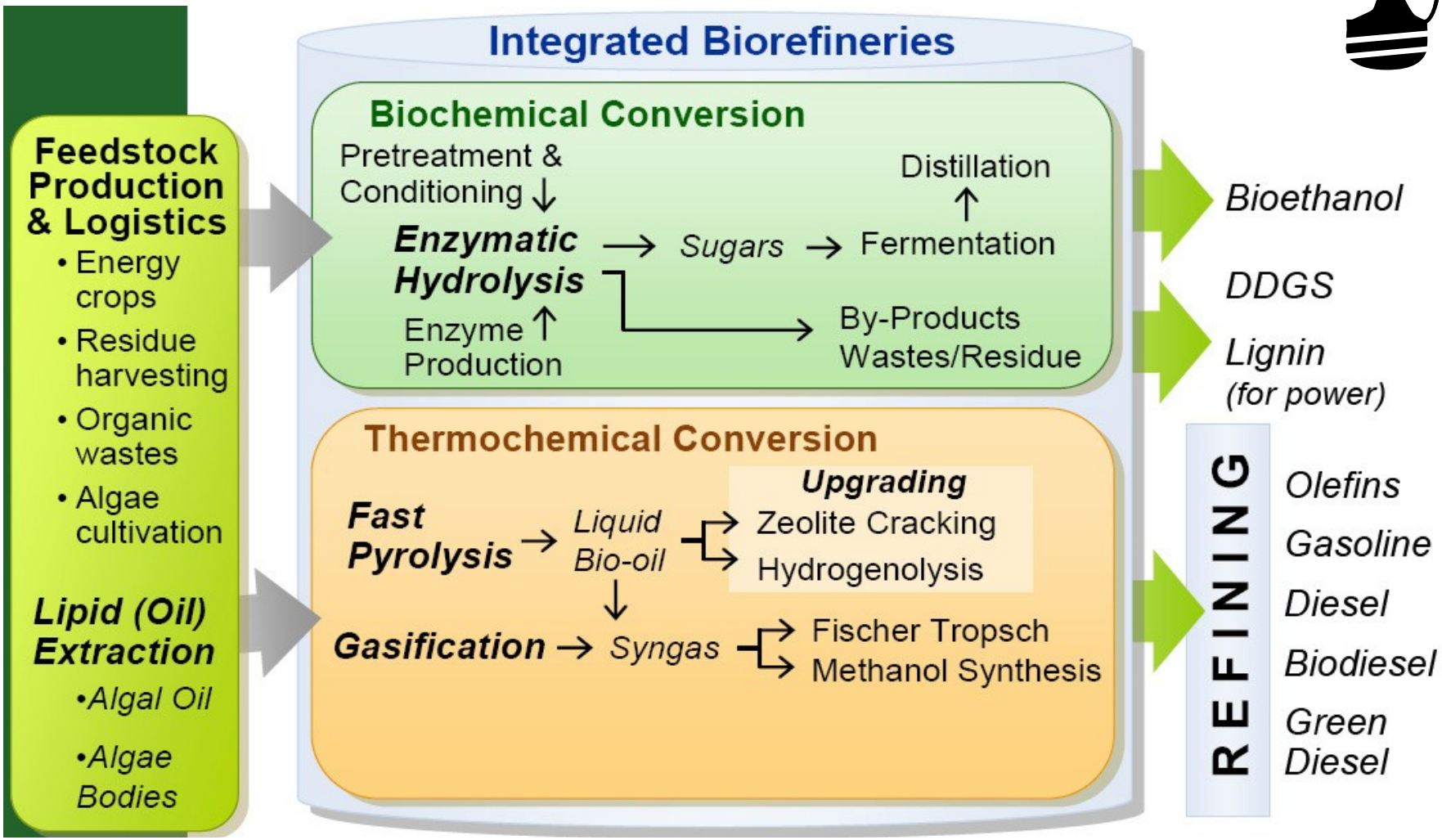
# CHP upgrade: use of char (adsorption)




*Marchelli et al. (2019)*

*Benedetti et al. (2019)*




[D. Chiaramonti, 2011]

# 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%

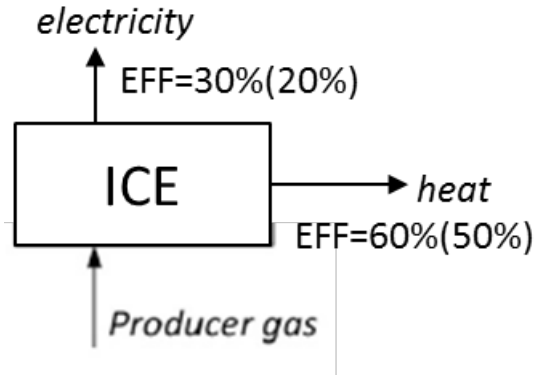
cost reduction, to 50 (2020) – 35 (2030) €/MWh

**Strategic Research and Innovation Agenda (ETIp, EERA Bioenergy)**

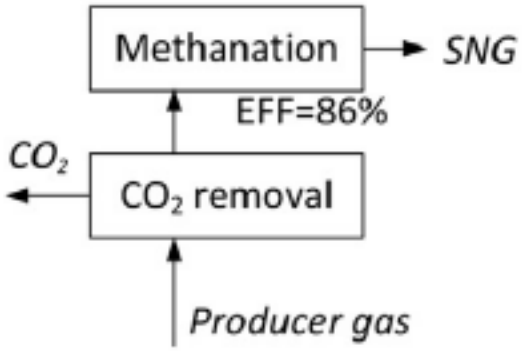
Major role for gasification value chains in agreement with SET pl.

# Polygeneration

## Today (almost yesterday)




## Tomorrow (almost today)



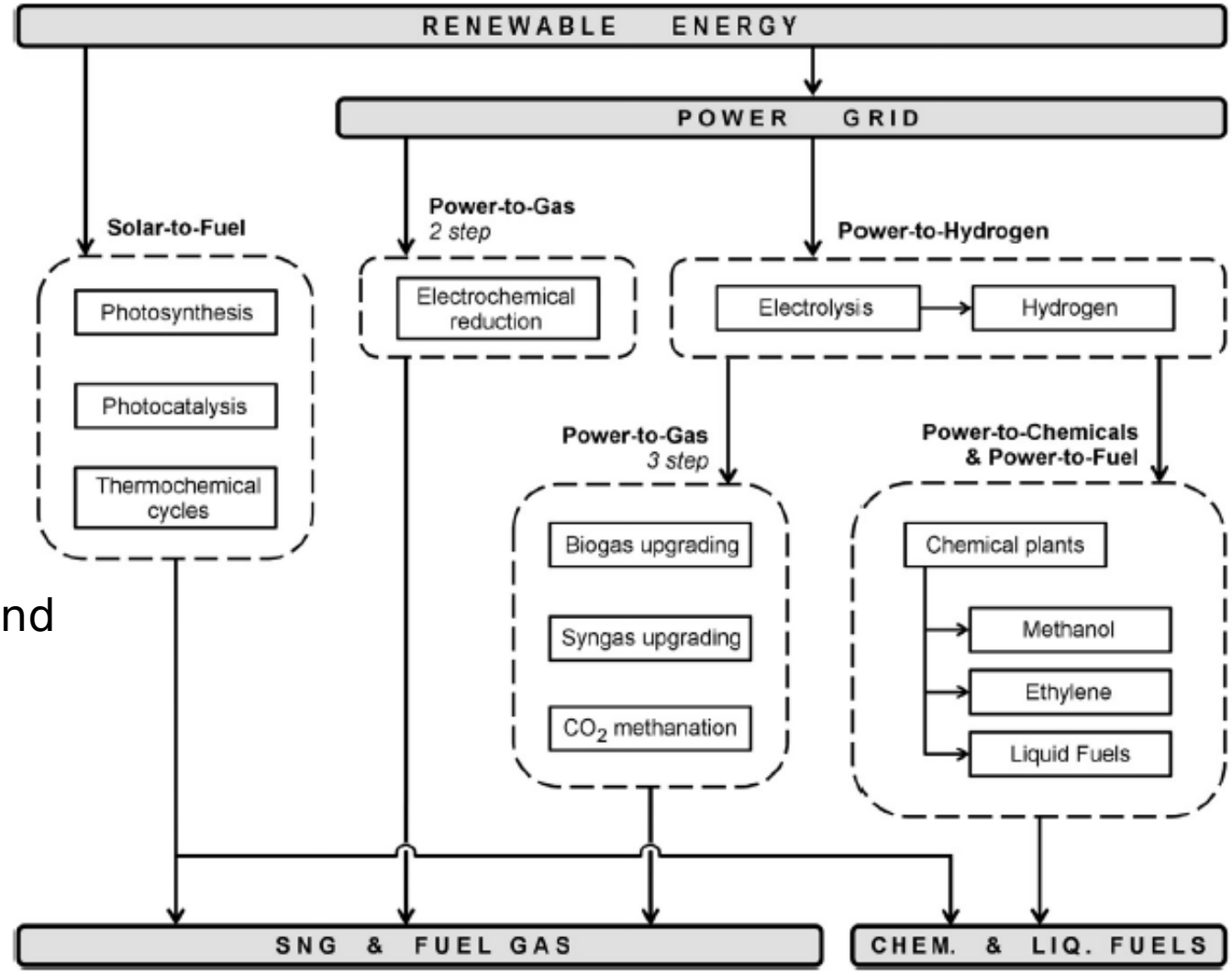

Sabatier reaction

$$CO_2 + 4H_2 \leftrightarrow CH_4 + 2H_2O \quad \Delta H = -164.9\ \text{kJ/mol}$$

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

# Power-to-gas (P

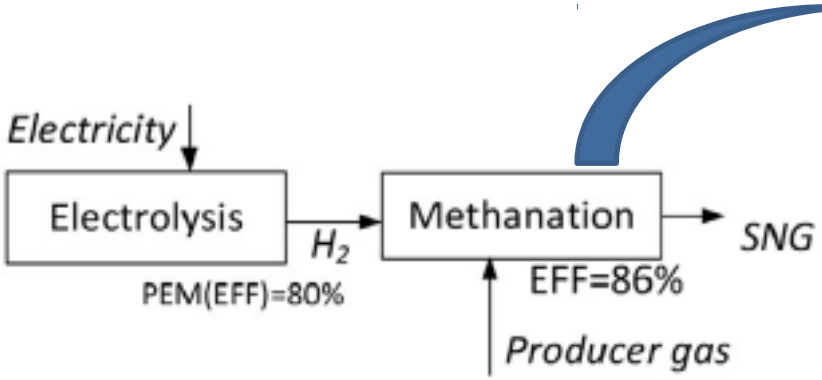
Renewable energy and $CO_2$ hybrid storage techniques




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

# Power-to-gas (PtG) and gasification

**Tomorrow (PtG)**




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

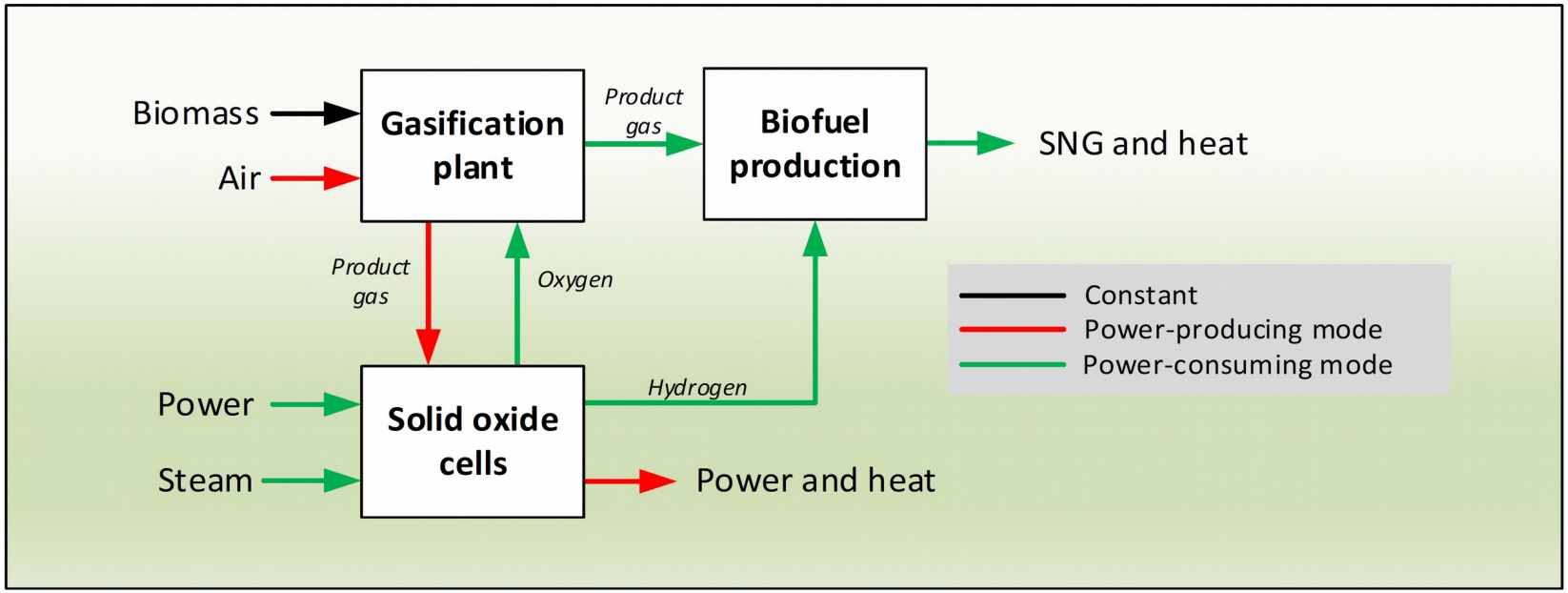
**Tomorrow (biomethanation**

**Syngas fermentation**

*Menin et al. (2019)*

# Power-to-gas (PtG) and gasification

**Tomorrow ("internal" PtG):** low/high electricity prices




*R.Ø. Gadsbøll et al., Energy 158 (2018) 495-503*
*Rasmus Ø. Gadsbøll, "Biomass Gasification Polygeneration", PhD Thesis, DTU*

# Ref: liquid biofues

| Plant | Type P/D/C | Start-up year | Feedstock capacity | Product | By-product | Hours in operation |
|---|---|---|---|---|---|---|
| Bioliq, Karlsruhe, Germany<br>Pyrolysis<br>Gasification Synthesis | P | 2010<br>2013<br>2014 | 0.5 tonnes/h<br>1 tonnes/h<br>700 $Nm^3/h$ | 0.45 tonnes/h<br>1,700 $Nm^3/h$<br>0.2 tonnes/h | -- | (December 2017)<br>630<br>900<br>160 |
| Chemrec gasifier, Piteå, Sweden | P | 2005 | 3 MW<br>(20 tonnes/d dry BL) | 1.8 MW | -- | >27,000 (- 2016) |
| Gasifier + BioDME, Piteå, Sweden | P | 2011 | | 4 tonnes/d DME | -- | ~11,000 (- 2016) |
| GTI/Carbona/HTAS, Chicago, USA | D | 2012 | 19.2 tonnes/d | 3 tonnes/d gasoline | -- | 3,000 (- 2014) |
| Enerkem, Westbury, Canada | D | 2009 | 48 tonnes/d (db) | 11 tonnes/d ethanol | -- | 12,800 |
| Enerkem, Edmonton, Canada | C | 2015 | 300 tonnes/d | 88 tonnes/d ethanol | -- | Accumulated over 5,000 hours<br>Presently in EtOH production ramp-up phase |
| Enerkem, Varennes, Canada | C | 2021 | 350 tonnes/d (dry) | 320 tonnes/d methanol | -- | Project in development |
| Sunshien Kaidi NEG, Wuhan, China | P | 2013 | -- | -- | -- | -- |
| Sunshine Kaidi NEG, Ajos, Kemi, Finland | D/C | 2019 | ~800 MW | 500 tonnes/d FT diesel<br>167 tonnes/d bionaphta | -- | Project in development |
| BioTfuel, Dunkerque, France | D | 2018 | 3 tonnes/h (15 MW) | A small FT unit for validation tests | Steam/power prod not installed | Commissioning and start-up completed |
| Fulcrum Sierra Biofuels, Tahoe, ND, USA | C | 2020 | 160,000 tonnes/y RDF | 40,000 $m^3$ FT crude | -- | -- |
| Red Rock Biofuels, Lakeview, OR, USA | C | 2020 | 127,000 tonnes/y (dry wood) | 58,000 $m^3$ FT fuel<br>Diesel 40%, Kerosene 40%, Naphta 20% | -- | -- |

*Adapted from: ART Fuels Forum study "Continuing the work of the sub group on advanced biofuels for the RED II market deployment of advanced biofuels", Eds. I. Landälvet al., 28*

# Ref: SNG



| Plant | Type P/D/C | Start-up year | Feedstock capacity | Product | By-product | Hours in operation |
|---|---|---|---|---|---|---|
| Güssing, Austria | C | 2002 | 8-10 MW | 2.0 $MW_e$ 4.5 $MW_{th}$ | -- | >80,000 |
| GoBiGas, Göteborg, Sweden | D | 2013 | 3 MW (20 tonnes dry BL per day) | 20 MW SNG | 6 MW district heat | Gasifier 12,000 h Methanation 70 GWh produced |
| Gogreengas, Swindon, UK | P | 2016 | 0.4 tonnes/d | -- | -- | n/a |
| Gogreengas, Swindon, UK | D | 2019-202? | 10,000 tonnes/y | 4 MW 22 GWh | -- | Plant in construction |
| GAYA, Saint-Fons, France | P | 2018 | -- | 400 kW SNG | -- | Commissioning completed, 2019 full test programme |
| SCW systems, Alkmaar, NL | D | 2018 | 2 MW | SNG | -- | Full operation scheduled for 2019 |
| Ambigo, Alkmaar, NL | D | 2019 | 4 MW demolition wood | 2.8 MW SNG | -- | Project in development |

*Adapted from: ART Fuels Forum study "Continuing the work of the sub group on advanced biofuels for the RED II market deployment of advanced biofuels", Eds. I. Landälvet al., 28 December 2018.*


# Remarks: main directions for gasification

- Process simplification and intensification
- Increasing fuel flexibility (use of low-cost feedstock)
- Co-production of fuels/chemicals/materials (polygeneration)
- Combining thermochemical and biochemical processing
- Optimization of resource efficiency (wind, solar, hydro)

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