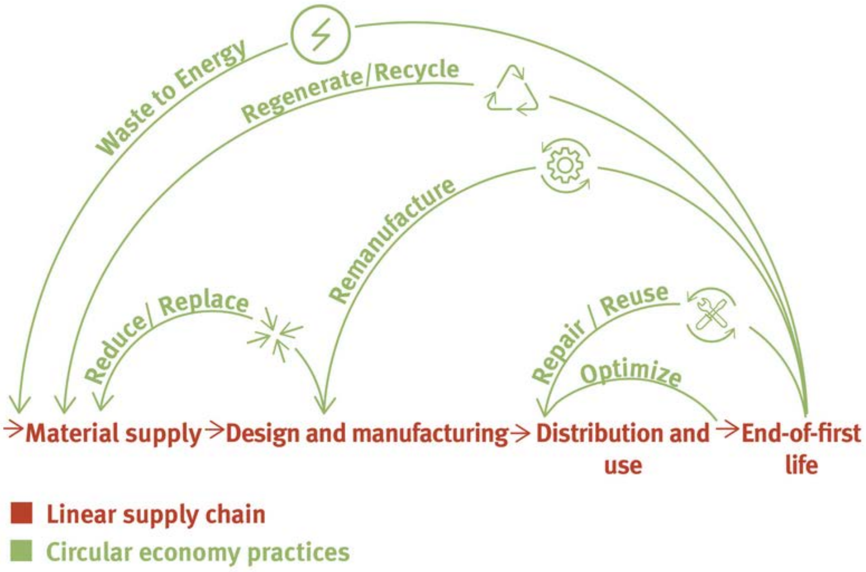
IEA Bioenergy
Technology Collaboration Programme

Gasification - a key technology in the energy transition and for the circular economy

Workshop report

IEA Bioenergy: Task 33

March 2022



Gasification - a key technology in the energy transition and for the circular economy

Workshop report

Jitka Hrbek, BOKU

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Figure 1st page - source: https://www.unido.org/

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Introduction

The impact of fossil fuel use on climate change are now universally recognized, as evidenced by the many recent global initiatives of peaceful demonstrations or political initiatives for more support on climate action, as by the G20, the international forum that brings together the world's major economies, and COP26 (26th UN Climate Change Conference of the Parties).

The acceptance of climate change has a severe impact on how our energy and materials system needs to change in order to sufficiently reduce global greenhouse gas emission. Fossil fuels play an important role in our daily lives and to reduce our dependence on this we need to deploy a multitude of technologies which each play a role in achieving our targets. Gasification in that aspect is a versatile technology that can be used for energy, fuels, chemicals, hydrogen and reach negative CO_2 emissions if applied correctly. Energy intensive sectors such as power production, transport, steel making and industry rely heavily on fossil fuels and have a large CO_2 foot print. To replace fossil fuels in these sectors, renewable energy sources (RES, i.e. the energy from naturally replenishing and virtually inexhaustible sources) can be a solution. RES are different and of these, biomass is probably the best known and oldest, since widely used before the advent of fossil fuels.

Biomass, meant as matter of plant origin, is by its inherent nature carbon-neutral and therefore its use rightly arises as a useful resource to achieve independence from fossil fuels and the targets of net zero CO_2 emissions. Although from a chemical point of view the characteristics of CO_2 do not depend on the original source, in environmental terms CO_2 from fossil sources and from biomass have very different impacts. CO_2 originated from residual biomass, and biogenic fractions, through the photosynthetic cycle of carbon dioxide, results in fact in almost net zero emissions into the atmosphere. Coupled with CO_2 capture systems, its use can even lead to a reduction of CO_2 in the atmosphere, i.e. negative emissions.

Through the conversion of biomass into gaseous stream rich in CO and H_2, it becomes possible to use it both as RES for direct application in conventional CHP systems and gas turbines, and for more advanced applications, as the use in solid oxide fuel cells (SOFC), for the production of hydrogen, as synthesis gas for the production of gaseous and liquid energy carriers (i.e. biofuels, e.g. SNG, diesel and gasoline, methanol, DME) as well as for the production of (green) chemicals. Properly integrated with discontinuous electricity production from solar and wind, gasification of RES combined with electrochemistry can be used to store surplus electricity in molecules. Via this approach it acts as a buffer in the stabilization of networks. Finally, considering solid waste, gasification can also be a useful tool for a circular use of materials that would otherwise be disposed in landfills or by combustion, with a higher environmental impact.

IEA Bioenergy Task 33 together with the Horizon 2020 GICO (Gasification Integrated with CO_2 capture and conversion) project organized a workshop that was dealing with all the above aspects. The versatility of gasification technology was presented and trough speakers from industry the listener was guided to what is relevant in this field.

The workshop presentations are available at the IEA Bioenergy Task 33 website. [1]

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[1] http://www.ieatask33.org/content/home/minutes_and_presentations/2021_Dec_WS

Workshop presentations

L. Benedetti, L. Mazzocchi: Status and perspective of bioenergy exploitation in Italy, incl. hydrogen production

F. Cotana: Italian Hydrogen Research Strategy - the role of gasification for the production of green and circular H2

L. Pelkmans: Role of sustainable biomass in global energy transition

M. Huber: Climate positive energy system via biomass gasification combined with biochar production

N. Davidsson: Meva Energy upcoming break-through projects and learnings

A. Pettinau: Power generation and hydrogen production from biomass and plastic waste gasification

B. Aydin: Highly efficient and fuel-flexible technology for combined heat and power from biomass via gasification coupled with SOFC

L. Wang: Waste-to-Energy for grid balancing services via gasification and RSOC

D. Cirillo: Lignocellulosic feedstock to green hydrogen

B. van der Drift: Short route to produce virgin plastic from plastic waste

D. Chafia: Waste gasification - A proven solution toward advanced biofuels

A.M. Rizzo: The BECOOL projects

R. Zweiler: Heat-to-fuel

H. Thunman: The role of gasification for production of polymers in a circular economy

P. Dieringer: CLARA - Chemical looping gasification for sustainable production of biofuels

M. C. Romano: The value of flexible power and biomass to X systems

A. Almena-Ruiz: Carbon balances of BECCS

E. Bocci: Gasification integrated with CO2 capture and conversion

S. Dasappa: Biomass to green hydrogen

Status and perspective of bioenergy exploitation in Italy, incl. hydrogen production

L. Benedetti, L. Mazzocchi

Present status of bioenergy in Italy was presented including current situation in the electricity, heating and transportation sectors.

ITALY ENERGY SYSTEM EVOLUTION - THE ROLE OF BIONERGY

Italy, as well as Europe and most of the world, is engaged in the fight against climate change. A fundamental path is to reduce fossil fuels use and substitute them with renewable sources:

- Renewable sources exploitation, starting from power generation, to be extended to heating/cooling and transport sectors
- Energy efficiency improvement

Italian National Energy and Climate Plan is addressing these objectives, taking into account energy costs for the users as well as security of supply.

Italian power system: scenario at 2030 - "PNIEC 2020" scenario (CO2 emissions – 43 % compared to 1990 level):

- Gas and hydro generation roughly unchanged
- Generation from coal and oil disappears
- Big PV and wind increase (triple compared to 2020 level)
- As today, CCGT operate at low load factor →some of them could be retired

New, more ambitious scenarios are being investigated (at European level, -55% at 2030, carbon neutrality at 2050), anyway, adequacy and flexibility are the critical issues.

According to Terna, the Italian TSO, the thermal capacity (LOLE = 3h), which will be needed in 2030 is about 55 GW, thus there is a wide room for programmable RES, in particular bioenergy (solid biomass CHP, biogas).

Italian Hydrogen Research Strategy - the role of gasification for the production of green and circular Hydrogen

F. Cotana

There are several pathways for hydrogen production:

- Nuclear energy (thermolysis of water)
- Renewable energy (photo-electrolysis, gasification)
- Production using fossil fuels (reforming)

European Research Strategy for Hydrogen

Roadmap in 3 steps:

- 2020-2024 → installation of 6 GW of electrolysers to produce H_2 with renewable energy, producing 1 Mt of green H_2 which replaces the one currently used in the chemical sector, also facilitating the introduction of the hydrogen vector in other industrial sectors and for sustainable mobility.

- 2025-2030 → installation of 40 GW of electrolysers and 10 Mt of green H2, to extend the application in the steel sector and heavy mobility (ships, trains, heavy transport).

- Beyond 2030 → the goal for renewable hydrogen is to reach maturity to be applied on a large scale. The planned investments up to 2030 are of the order of 24-42 billion euros for electrolysers, 220-340 billion euros to connect the production of renewable energy and another 160-200 billion euros for uses in the application sectors.

Focusing on hydrogen production from lignocellulosic biomass, two pathways were examined. In the following figure a comparison of gasification for hydrogen production and gasification for CHP and following electrolysis are compared.

Figure 1: Comparison of two different pathways for green hydrogen production

Role of sustainable biomass in global energy transition

L. Pelkmans

IEA Bioenergy and its goals were introduced as well as its activities.

Sustainable bioenergy plays and unique role, it is:

- **Available** now to phase out fossil fuels in existing energy infrastructure
- **Versatile**: role in different sectors – heat, power, transport fuels
- **Storable**: complements intermittent renewables in power systems
- Can **remove atmospheric CO_2** ("negative emissions") via deployment of Carbon Capture & Storage (CCS): BECCS / Bio-CCS

As can be seen in the following figure, there are several sources of biomass in form of organic residues and waste.

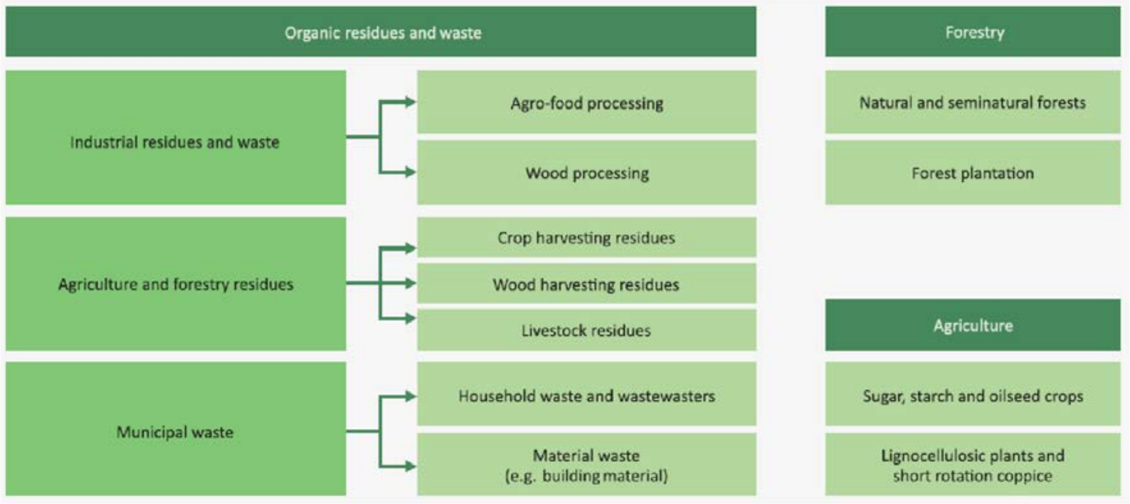


Figure 2: Multiple sources of biomass

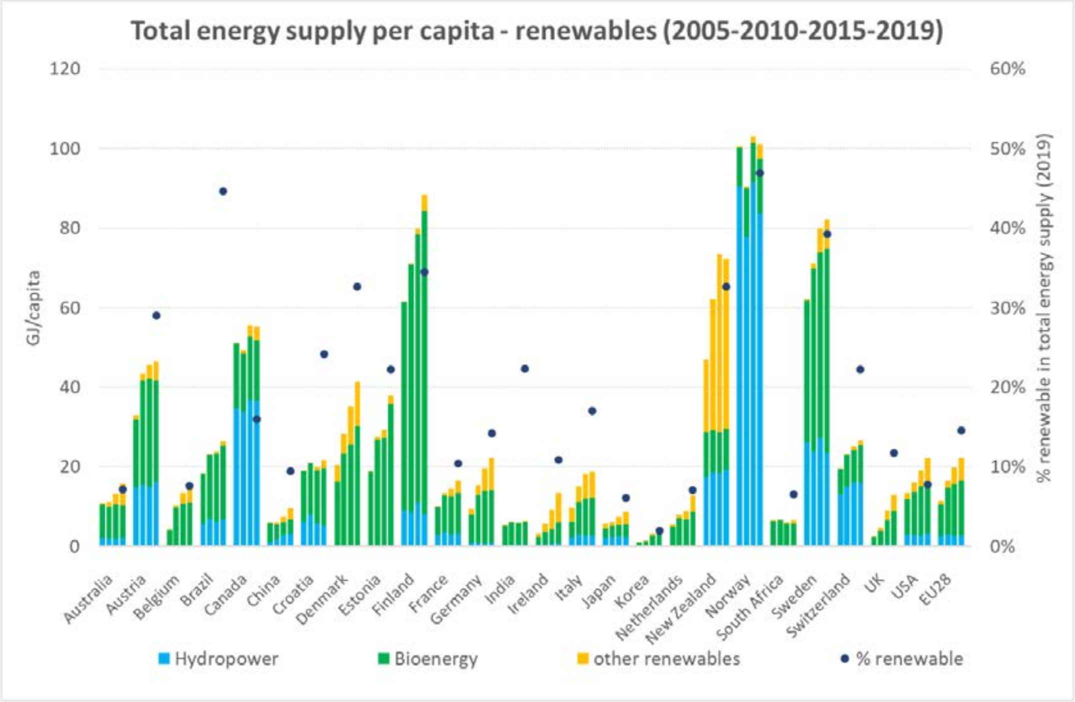
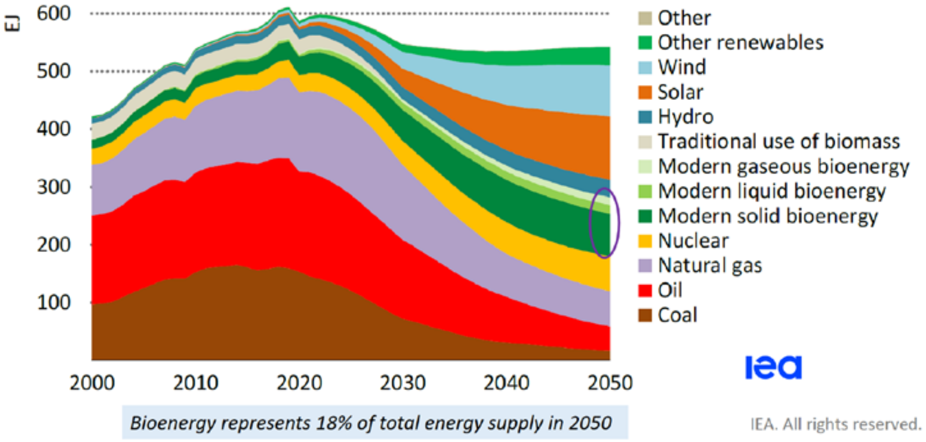


Figure 3: Total energy supply per capita – renewable in 2005, 2010, 2015 and 2019

Apart from countries with elevated levels of hydropower, bioenergy represents more than half of renewable energy supply in most countries.

IEA “Net Zero by 2050” roadmap[2] indicates the bioenergy´s role in future energy transition. In the following figure the evolution of total energy supply based on the roadmap is displayed. It is supposed, that bioenergy will represent about 18% of total energy supply in 2050.



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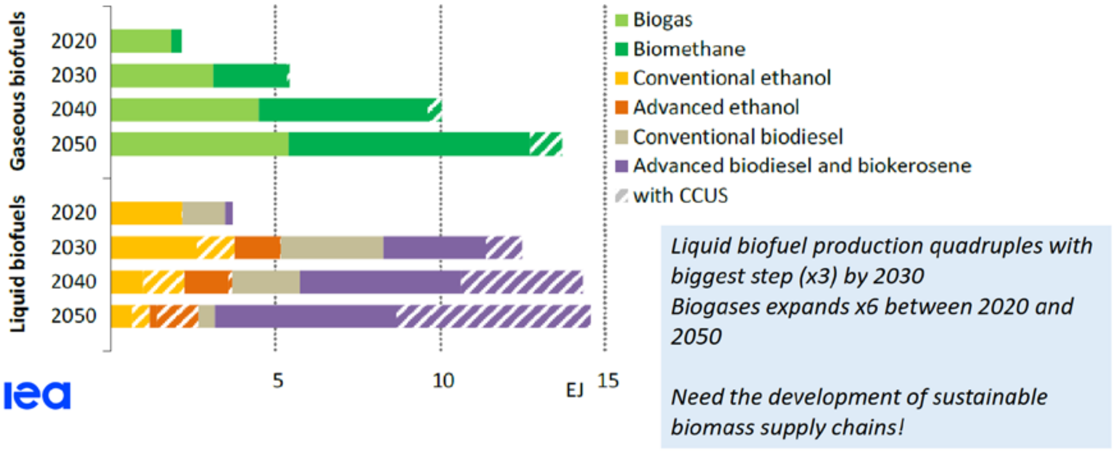
[2] https://www.iea.org/reports/net-zero-by-2050

Figure 4: Evolution of total energy supply in the IEA NZE roadmap

Here also the evolution of gaseous and liquid biofuels in the IEA NZE should be mentioned.



Liquid biofuel production quadruples with biggest step (x3) by 2030
Biogases expands x6 between 2020 and 2050

Need the development of sustainable biomass supply chains!

Figure 5: Evolution of gaseous and liquid biofuels in the IEA NZE

Sustainable bioenergy is an essential element in the portfolio of measures needed for a low carbon scenario. In the IEA NZE scenario bioenergy represents about 20% of total energy supply in 2050.

Biofuels can play a particularly important role in the transport sector (complementing energy efficiency measures and electrification, and with a special role in aviation, shipping and other long haul transport), but also grows in electricity and industry.

The combination with CCS can provide negative emissions (carbon extraction from atmosphere.

Progress in bioenergy is much slower than needed; need to

- Expand deployment of existing technologies
- Commercialise new technologies
- Develop sustainable supply chains and appropriate sustainability governance systems
- Build technical and regulatory capacity in a much wider range of countries and regions

Climate positive energy system via biomass gasification combined with biochar production

M. Huber

Austrian company SynCraft offers a unique floating fixed bed gasification units, which convert lignocellulosic biomass into gas and biochar. Details can be seen in the figure below.

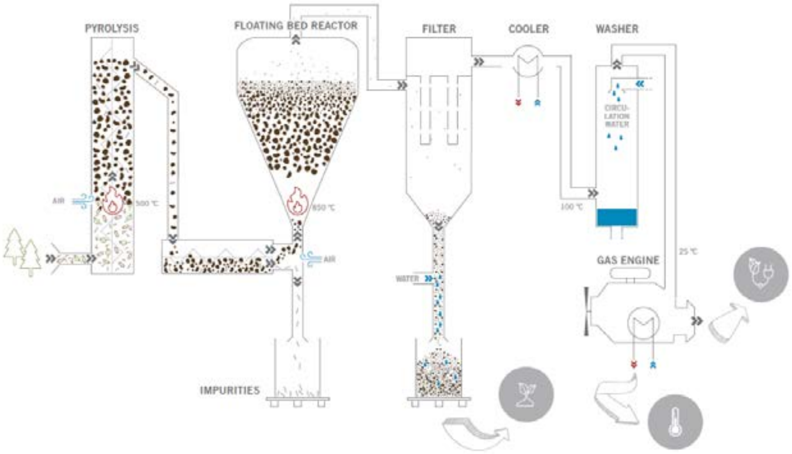


Figure 6: SynCraft – floating fixed bed gasification system

The gas can be used for production of power and heat or further processed. The following figure shows the concept of climate positive energy system.

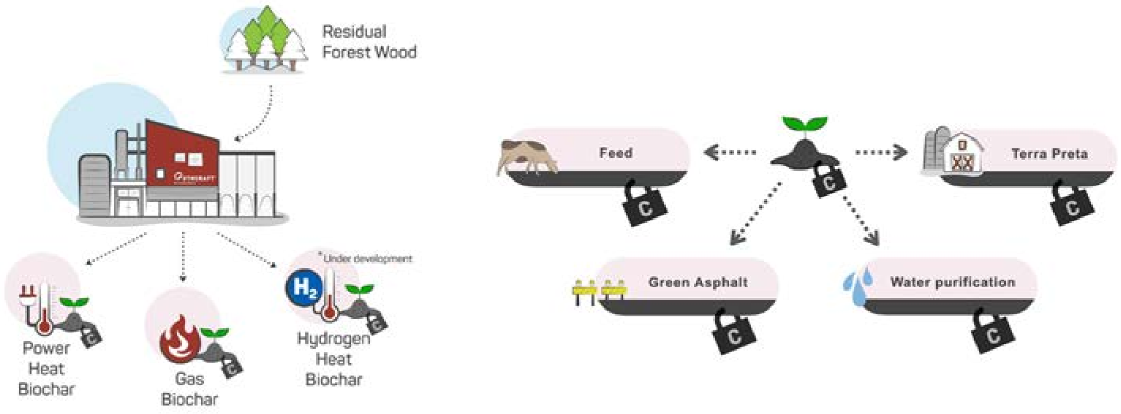


Figure 7: Utilization ways of SynCraft´s products

The biochar produced by SynCraft is of very high value and can be used in many different ways, some of them are displayed in the figure below. Carbon negative technology is one of the SynCraft´s mission. SynCraft obtained several certificates and credits for CO_2-sink technology. More information can be found on their website[3].

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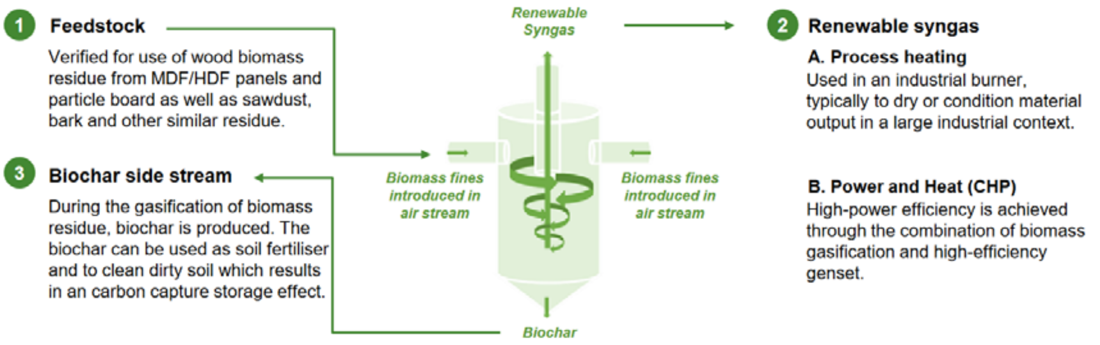
[3] www.syncraft.at

Meva Energy upcoming break-through projects and learnings

N. Davidsson

The Meva´s technology is based on cyclone gasification. The feedstock (very fine particles) is introduced into the reactor together with the air stream. The principle can be seen in the figure below.



① **Feedstock**

Verified for use of wood biomass residue from MDF/HDF panels and particle board as well as sawdust, bark and other similar residue.

③ **Biochar side stream**

During the gasification of biomass residue, biochar is produced. The biochar can be used as soil fertiliser and to clean dirty soil which results in an carbon capture storage effect.

② **Renewable syngas**

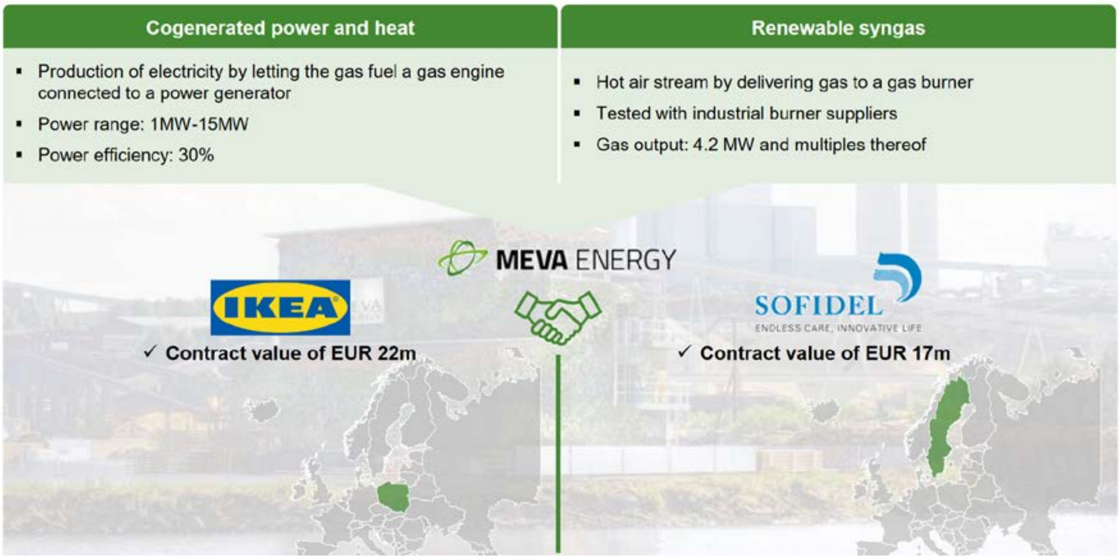
A. Process heating

Used in an industrial burner, typically to dry or condition material output in a large industrial context.

B. Power and Heat (CHP)

High-power efficiency is achieved through the combination of biomass gasification and high-efficiency genset.

Two Meva´s applications are proven and commercialised, one by IKEA in Poland and by SOFIDEL in Sweden.



Cogenerated power and heat

- Production of electricity by letting the gas fuel a gas engine connected to a power generator
- Power range: 1MW-15MW
- Power efficiency: 30%

Renewable syngas

- Hot air stream by delivering gas to a gas burner
- Tested with industrial burner suppliers
- Gas output: 4.2 MW and multiples thereof

✓ Contract value of EUR 22m

✓ Contract value of EUR 17m

Key commercial principles of Meva´s technology:

- Decentralised production
- Raw syngas (The gas is fed to either an adapted industrial gas burner or an adapted gas engine system)
- Low cost feedstock

Technology challenges:

- Tar handling and water treatment/separation
- Integration with gas engine/ gas burner/ paper machine
- Need for pre-projects with customers!

▪ Need to challenge established views ("You won't have flame stability with this low heating value", "It is impossible to burn NH_3 in our genset", "We need methane not raw syngas")
▪ Full-scale testing –> less risk but expensive
▪ Very important to have technology partners for lab and full-scale tests

Power generation and hydrogen production from biomass and plastic waste gasification

A. Pettinau

The company Sotacarbo, established in 1987 has two shareholders: Regional Government of Sardinia and ENEA. It is active in following fields:

- Biomass/waste gasification
- CO2 capture, utilization and storage
- Energy efficiency

Sotacarbo´s approach is experimental development from lab to demo-scale (moving bed, BFB) as well as CFD modelling.

Moving bed updraft (200 kW th)

- air-blown gasification
- atmospheric pressure
- process widely characterized at pilot and demo scale (in Italy and US)
- new experimental campaign
- plant optimization towards hydrogen production
- different fuel blends

Moving bed downdraft (40 kWth)

- 10 kg/h of primary fuel
- air-blown gasification
- atmospheric pressure

FABER - fluidized air blown experimental gasifier reactor

- feedstock capacity: 40-100 kg/h
- thermal input: up to 400 kW
- electric output: up to 120 kW
- reactor height: 4,700 mm
- inner diameter: 489 mm
- gasification agents: air, O_2, H_2O
- bed temperature: 700-950°C

Highly efficient and fuel-flexible technology for combined heat and power from biomass via gasification coupled with SOFC

B. Aydin

Tosto Group was introduced. Company markets are active in refining, chemical and petrochemical industry, gas processing and power generation. The group is involved in the EU project "BLAZE".

The technology is developed for a CHP capacity range from small (25-100 kWe) to medium (0.1-5 MWe) scale. Pilot plant is the integration of various innovative technologies:
- dual bubbling fluidised bed technology integrated with high temperature cleaning & conditioning system
- high temperature gas cleaning for HCl and H2S removal
- thermal and chemical integration of SOFC (efficient gas recirculation of the fuel cell anode exhaust to the gasification process)

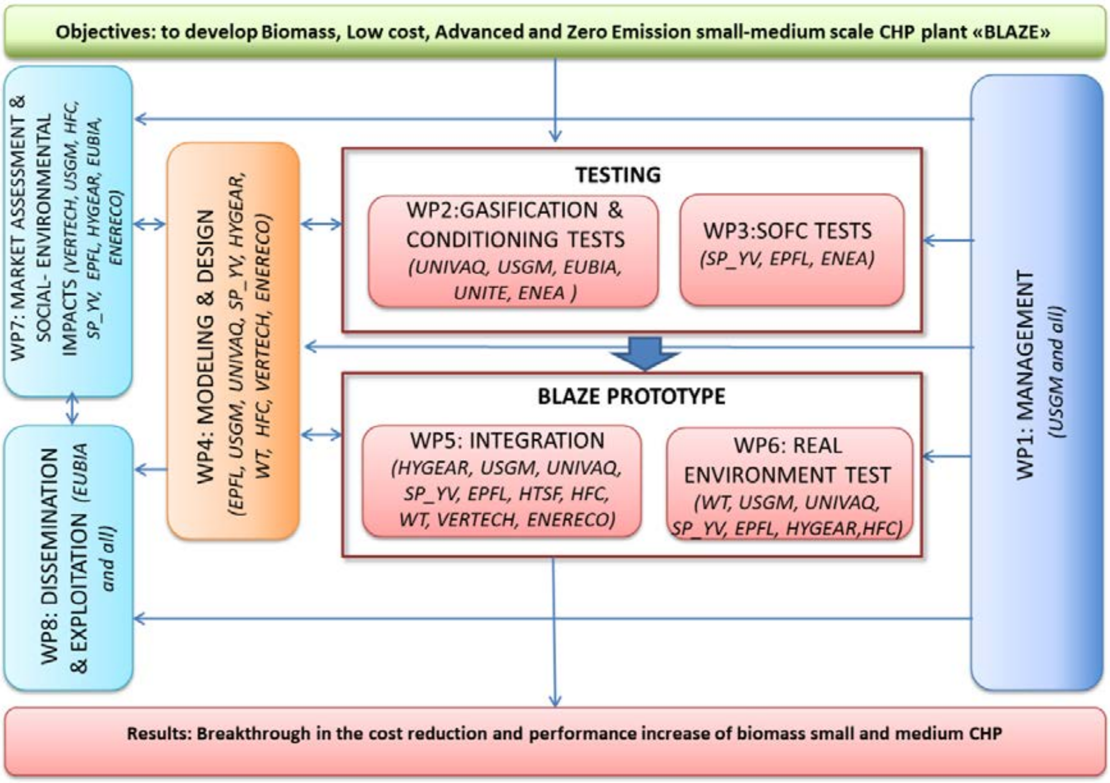


Figure 8: Work packages of the project BLAZE

The use of CHP technology will contribute to pursue energy savings targets intended within the energy efficiency policy measures

➢ Flexible CHP will boost wind and solar energy to ensure a continuous supply when availability is limited

➢ Biomass gasification is regarded as a promising option for the sustainable production of hydrogen rich gas used in fuel cells for power generation

➢ CHP via SOFC can be a solution for the locations with high spark spread (high electricity cost and low natural gas cost) or in the countries with lower grid reliability. It offers flexible operation with low emissions

➢ BLAZE plant will propose small-to-medium scale integrated gasifier-fuel cell combined heat and power plant for the decarbonisation of heat and power generation

Waste-to-Energy for grid balancing services via gasification and RSOC

L. Wang

Waste2GridS project info:
Converting WASTE to offer flexible GRID balancing Services with highly-integrated, efficient solid-oxide plants (theoretical investigation)

Biomass/biowaste can potentially participate grid balancing for high penetration of renewable energy sources (RES), given enhanced efficiency, reduced cost and increased utilization rate

One plant capable of switching between electricity and methane production can enable high annual utilization and cost reduction by sharing major components

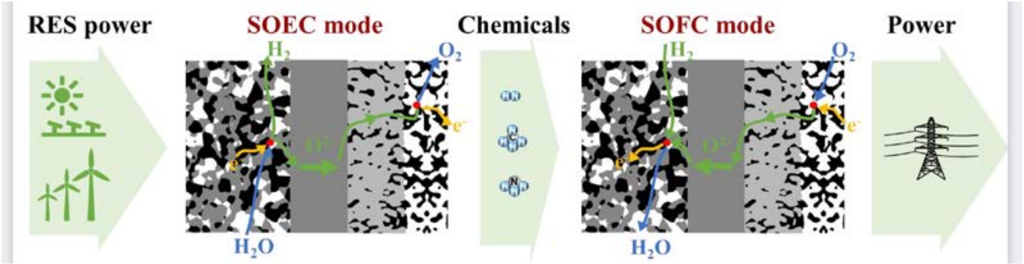


Figure 9: Syngas conversion technology for biomass utilization

Triple-mode grid-balancing plant by integrating biomass gasification & SOC

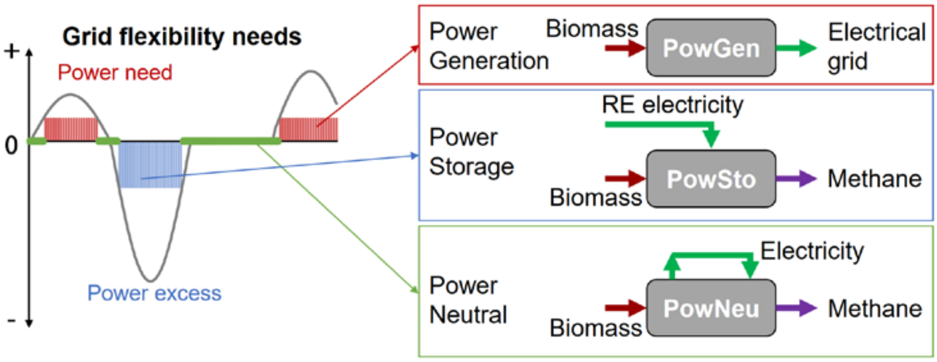


Figure 10: Possibilities to balance the grid

Key conclusions

- Large grid flexibility needs in DK and IT-SUD in 2030

- Local biomass sufficient to contribute significantly to grid balancing
- W2G concept enables highly-efficient grid-balancing service
- Given current grid-balancing prices, methane price and stack lifetime, economical feasible case studies exist with the conditions:
    - Single plant scale: biomass feed of up to a few hundreds of MWth, PowGen power up to 100 MWe, PowSto power up to a few hundreds of MWe
    - PowGen&PowSto hours: > 3500 hours
    - Stack costs: < 1600 €/kWe-SOFC

Lignocellulosic feedstock to green hydrogen

D. Cirillo

CMD company producing ECO20^x (gasification facilities) was introduced. The gasification facilities are able to process a wide range of feedstock for production of combustible gas, which could be used in many ways. One of them is production of renewable hydrogen.

ECO20x is IMMEDIATELY ready for RENEWABLE ENERGY PRODUCTION through BIOMASS valorisation. It can be integrated with other renewable resources as SOLAR power and EOLIC power. This GREEN POWER amount must be used to supply electrolyser to convert water into gas hydrogen.

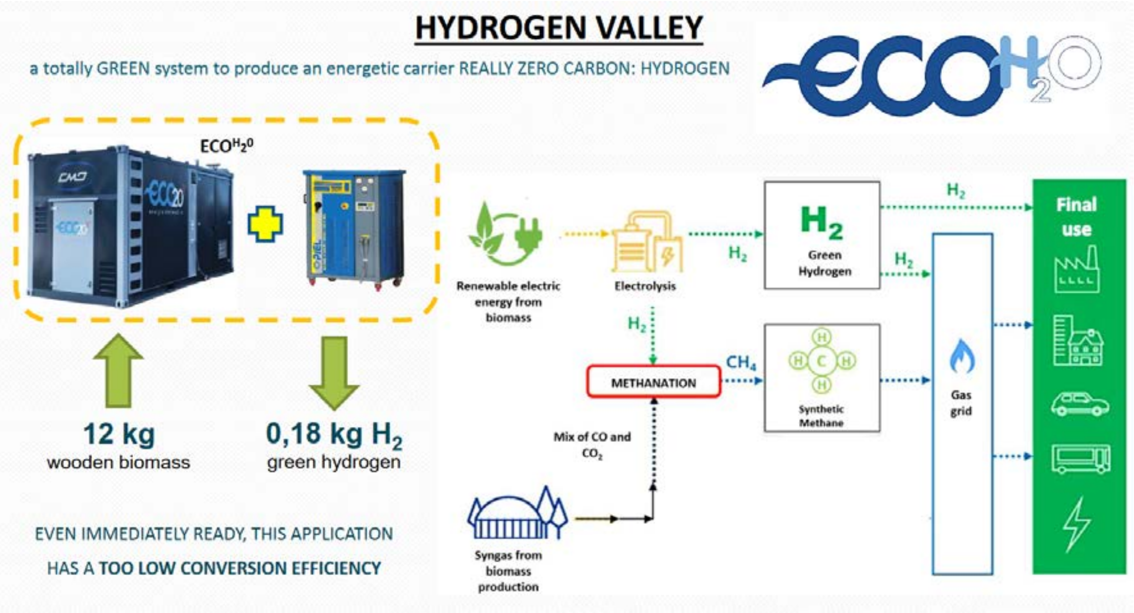


Figure 11: Hydrogen production from biomass

New challenge is an innovative reactor, able to produce hydrogen. Through the WGS reaction (Water Gas Reaction), improving process conversion efficiency.

Short route to produce virgin plastic from plastic waste

B. van der Drift

Synova – technology

MILENA CRACKER/GASIFICATION

- MILENA technology based on FCC technology coupled fluidized beds
- Heat transfer via circulating sand, no catalyst
- Operating at 700-800°C
- Coke and PAH's from downstream OLGA are burned to provide the energy for the cracking/gasification
- No external fuels required
- >7000h accumulated in Process Design Units (PDU's) and initial trial with ~1 tonne/h plant

OLGA GAS CLEANING

- OLGA technology based on Coke Oven Gas cleaning: gas/liquid contactors and Electrostatic Precipitator (ESP)
- Removes 99.9% of Poly Aromatic Hydrocarbons (tars) and particles
- >7000h accumulated in Process Design Units (PDU's) and initial trials with several ~1 tonne/h plants

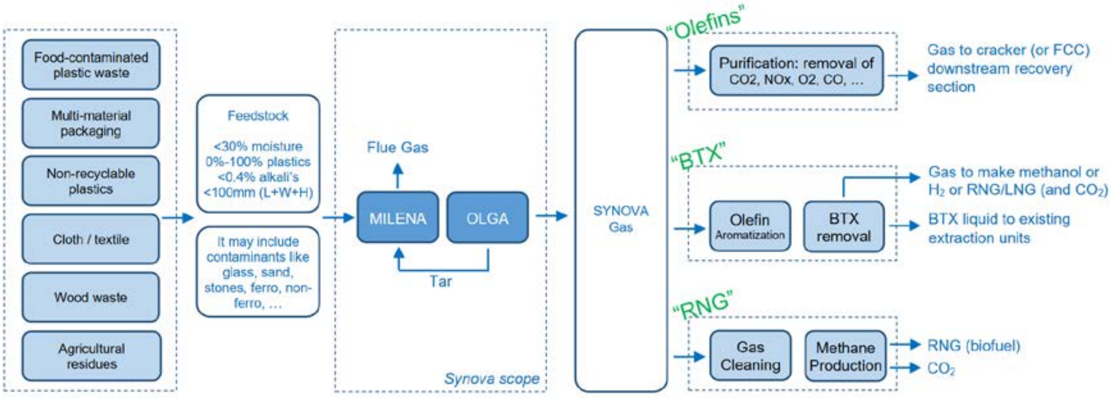


Figure 12: Synova´s unit in different processes

A wide range of feedstock can be used for production of value added products.

Name	Main Molecules	Main Market	Main Drivers
Olefins	Ethylene, Propylene, Butadiene, Benzene	Chemical industry, Refineries	Circularity, CO2
BTX	Benzene, Toluene, Xylenes	Chemical industry, Refineries	Circularity, CO2
RNG	Methane	Gas industry, Refineries	CO2

Synova offers affordable next generation plastic recycling with high circularity and high CO2 reduction. The temperature is high enough to break down to a few high-value molecules irrespective of the type of plastics and biomass content and low enough to keep the molecules in play.

Waste gasification - A proven solution toward advanced biofuels

D. Chafia

GIDARA ENERGY has acquired the proven and applied HTW® biomass/RDF gasification technology. It is building an advanced biofuels facility in Amsterdam “Advanced Methanol Amsterdam (AMA)” that converts refuse derived fuel (“RDF”) and waste wood into advanced bio-methanol. Advanced Methanol Amsterdam (AMA) is located in the Port of Amsterdam's Biopark, a development location for producers of renewable fuels. Once completed, AMA will be the flagship production site for GIDARA Energy.

AMA will produce an average of 87.500 tonnes of advanced methanol per year by converting non-recyclable waste equivalent to that of 290.000 households yearly, which otherwise would be landfilled or incinerated.

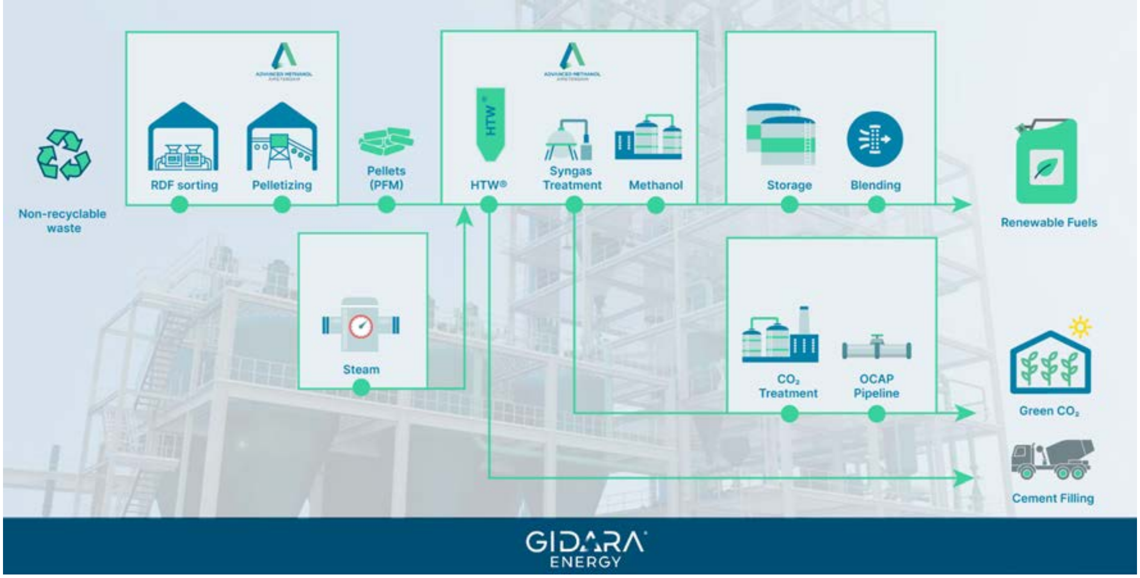


Figure 13: AMA – process flow

The advanced methanol will be used for fuel blending and therefore meet governmental objectives to achieve CO_2 emission reductions as defined in the RED II and translated in national legislations. The produced renewable fuel will replace fossil-based fuels, creating significant carbon savings.

The BECOOL projects

A.M. Rizzo

Development of advanced lignocellulosic biofuels from sustainable agricultural value chains.

In the BECOOL project, credible, cost-effective and sustainable value chains for several biomass types will be evaluated, taking into account feedstock production, supply logistics and conversion technologies.

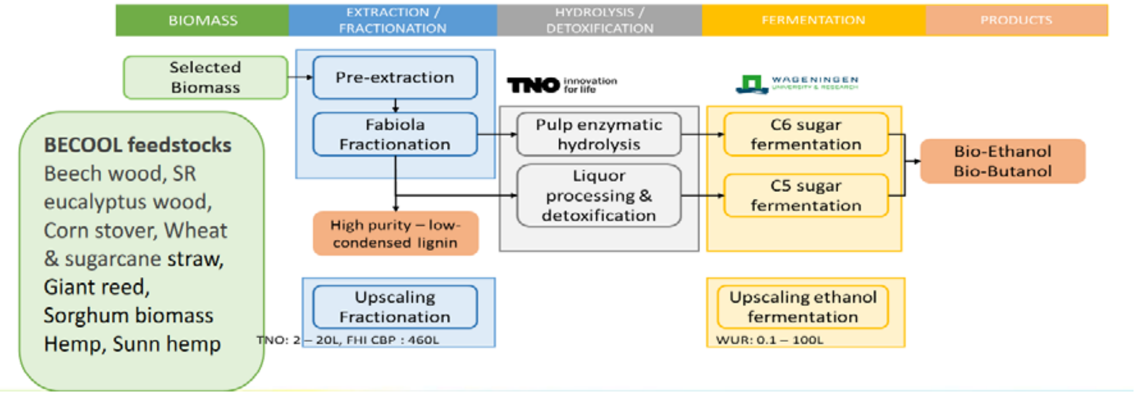


Figure 14: Process chain BECOOL project

Biochemical conversion

- Feedstocks screened throughout extraction+fractionation, hydrolysis and detoxification:
  Realistic sugar yields quantified via Acetone organosolv fractionation (Fabiola™).
- Ethanol fermentation of C5 and C6 sugars optimized for beech wood and fermentability assessed for selected agricultural residues and herbaceous biomass.
- Beech wood fractionation and C5/C6 sugar conditioning validated at pilot scale; product sugars to be fermented in 10L reactor to validate scalability

BECOOL – summary of achievements

• Leveraging innovative cropping systems, biomass for biofuel production can be obtained without negatively impacting on food production, soil quality, and customary land uses.

• Knowledge, know-how and models for conversion of several biomasses and intermediate energy carriers (FPBO e slurry) into syngas for liquid biofuel production, including aviation blendstock;

• Development of new fermentation technologies for advanced liquid biofuels and applied research to increase the energy efficiency of advanced biofuel processes.

• Holistic assessment of complete BECOOL value chains, including logistics, LCC/LCA/S-LCA & Market assessment

Heat-to-fuel

R. Zweiler

Heat-fo-fuel: Biofuels generated from any kind of waste (via DFB-FT and HTL-APR)

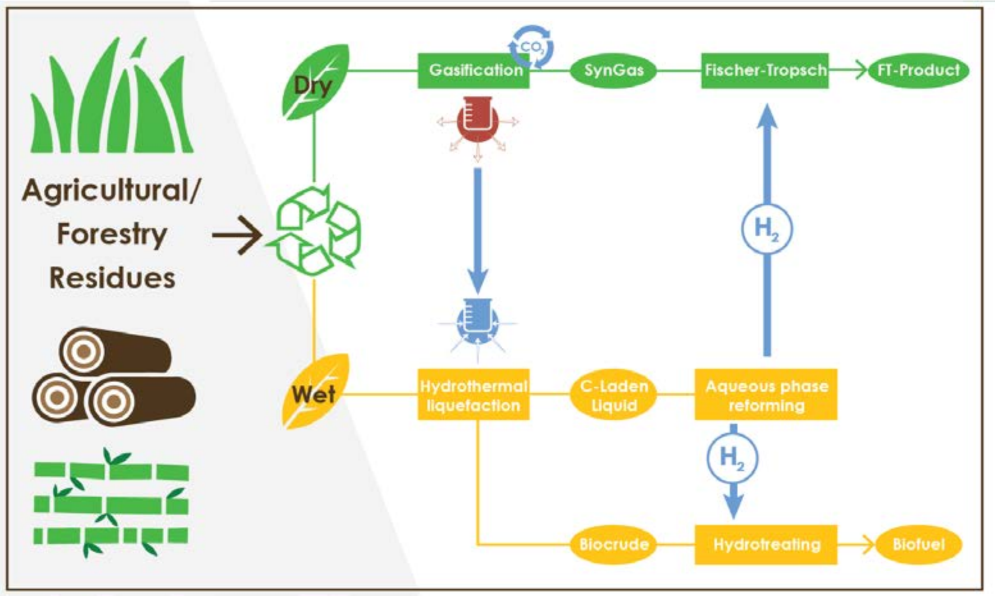


Figure 15: Heat-to-fuel concept

HTL - main achievements

\> 50 batch experiments
- Complete characterization of reaction products
- Influence of reaction parameters on yields and reaction mechanism
- Carbon balance
- Design, commissioning and operation of a continuous HTL unit
- 12 h time on stream
- 50 h operation
- Liquid-liquid extraction of HTL aqueous phase for APR
- Removal of aromatic compounds
- Evaluation of three extraction solvents
- Carbon balance

Demonstration FT+APR

Demonstration continuous APR unit within whole chain, demonstration (millistructured FT reactor) October 2021 – April 2022

Impact
- More than 10 peer-reviewed scientific articles
https://www.heattofuel.eu/publications/
- Videos are available at
https://www.heattofuel.eu/media/
- Recordings & presentations of e-fuel workshop:
https://www.heattofuel.eu/efuels-workshop/
- Recordings & presentations of HtF summer school:
https://www.heattofuel.eu/heat-to-fuel-summer-school/
- Social media: Join „Heat to Fuel“ at Twitter and LinkedIn

The role of gasification for production of polymers in a circular economy

H. Thunman

There are several routes for thermal recycling: via CO_2 and H_2, via gasification and H_2, via pyrolysis and H_2.

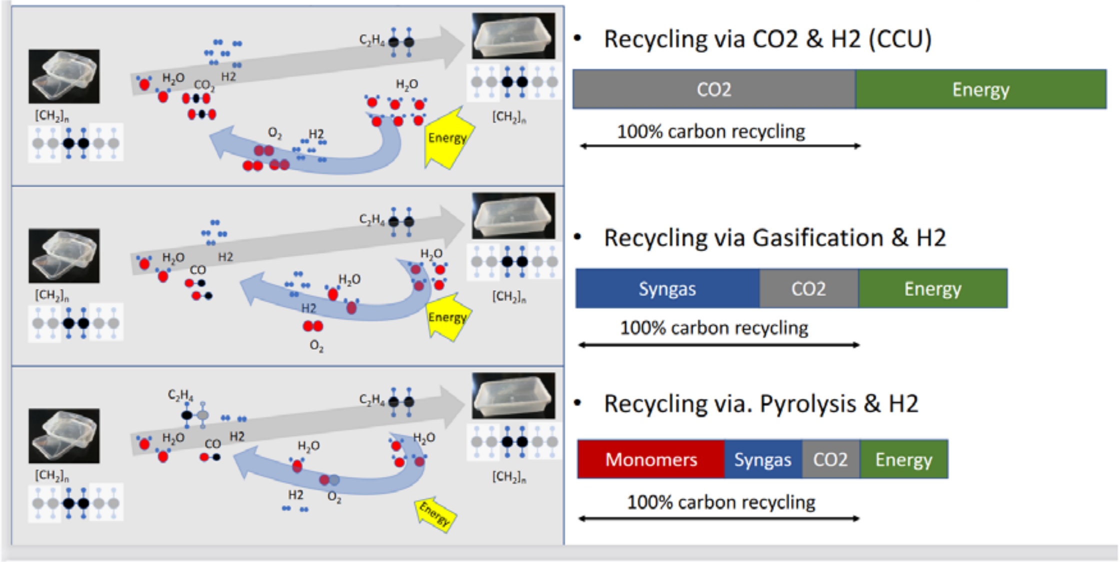


Figure 16: Thermal recycling methods

Production of hydrocarbons via gasification and hydrogen can be seen in the following figure.

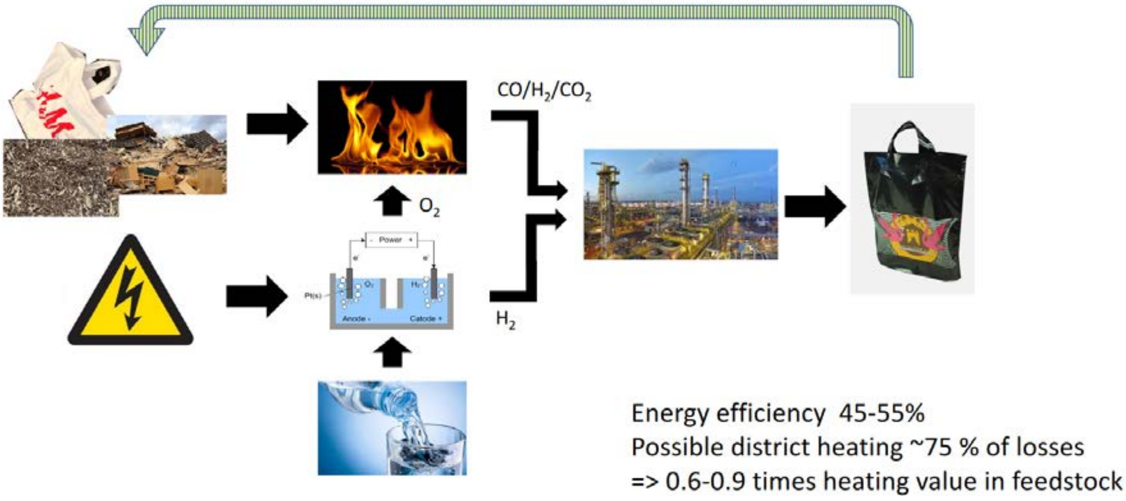


Figure 17: Production of hydrocarbons via gasification and hydrogen

Gasification technologies are the key to go from energy recovery of plastic waste to true recycling. The carbon collected in the waste system is enough to provide the carbon for the need of carbon based materials. To provide enough feedstock to the petrochemical production the technologies that is developed to be part of a circular economy need to handle the biogenic part of the waste.

CLARA - Chemical looping gasification for sustainable production of biofuels

P. Dieringer

The aim of the project is to development of concept for production of 2nd generation biofuels based on chemical looping gasification of biogenic residues and scale up of all associated technologies to 200 MW_{th}.

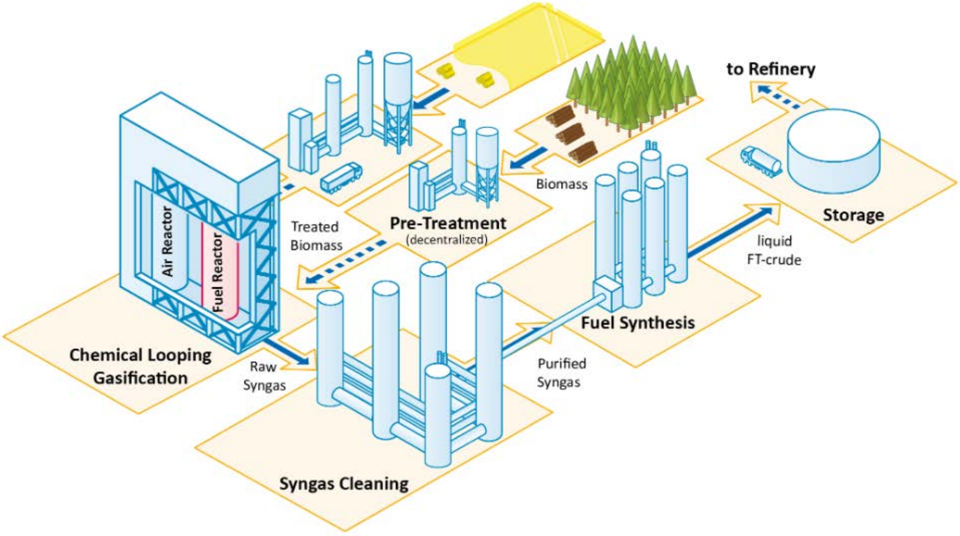


Figure 18: CLARA – technology flow

- Feedstock gasification with H_2O/CO_2 assisted by solid phase oxygen
- Circulation of Me_xO_y for oxygen & heat transport between reactors
    - No air separation required à cost-efficient
    - CO_2 concentrated in syngas à facilitation of net negative CO_2 emissions
    - Tar cracking/conversion on Me_xO_y surface
- Oxygen carriers: Fe_2O_3/Fe_3O_4, $Fe_2TiO_5/FeTiO_3$
- Low λ (0.3 - 0.5) to achieve partial biomass oxidation à formation of synthesis gas

Project progress 1 MW Full-Chain Tests:

- Investigation of full process in 1 MW th pilot scale at TUDA
- Industry-like conditions for pre-treatment, gasification & gas cleaning concepts

Novel Biomass-to-Liquid (BtL) process chain based on chemical looping gasification:

- Individual technologies have been analyzed in lab & pilot scale
- First 1 MW th full-chain test pending (Q1 2022)
- Upscaling of all relevant technologies by Q4 2022
- Techno-economic assessment of entire BtL chain by Q1 2023
- Techno-socio-economic risk evaluation of all technologies by Q1 2023

The value of flexible power and biomass to X systems

M. C. Romano

The FLEDGED project has delivered two technologies validated in industrially relevant environment (TRL5) for the production of Bio-Dimethyl Ether (DME) from biomass gasification, what means process intensification and flexibility.

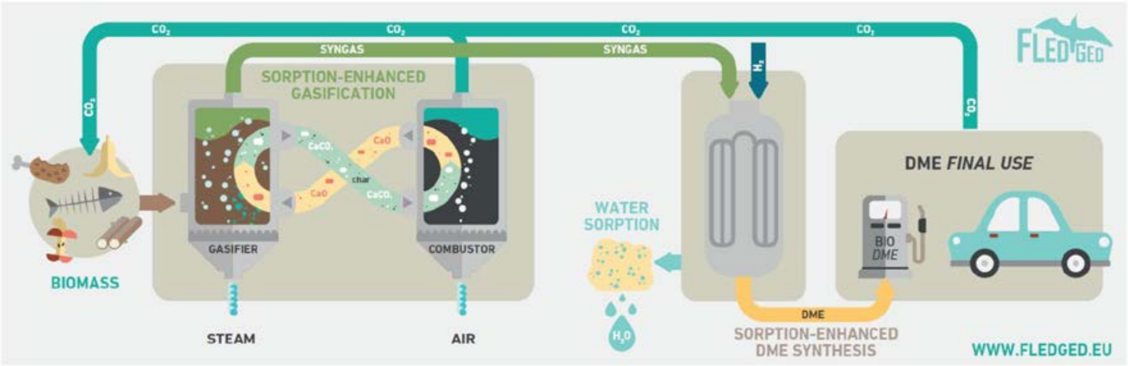


Figure 19: FLEDGED project flow

In Sorption-Enhanced Gasifier, CaO-rich sorbent circulates between a gasifier-carbonator and a combustor-calciner to produce:

- N_2 -free syngas with no need of air separation unit (indirect gasification)
- syngas with tailored module “M” thanks to in-situ CO_2 separation by reaction: $CaO + CO_2 \rightarrow CaCO_3$

Sorption-Enhanced DME Synthesis is a direct DME synthesis process using sorbent for in-situ water sorption:

- high per-pass DME yield, thanks to the reduced thermodynamic limitation of methanol dehydration reaction
- insensitivity on the CO/CO2 ratio in the feed (if module $M \approx 2$)

Due to the high cost of hydrogen from electrolysis in comparison with the cost of oversizing the MeOH synthesis unit, enhanced reactor design is to be preferred.

Competitive cost of the produced e-MeOH can only be achieved with high electrolyser capacity factors, it means to change of common paradigm that e-fuel plants should not operate during high electricity price periods. A prerequisite to make PBtM plants economically competitive is that the bio-MeOH/e-MeOH selling price must be sufficiently high to determine high “willingness to pay” price for the electric energy.
Different gasification technologies need different design and different operating strategies to manage operational flexibility.

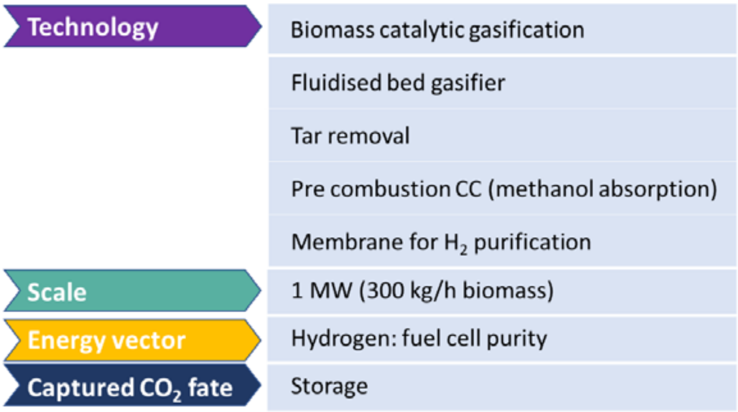
In future carbon-constrained world, the best bioenergy conversion pathway (electricity, H_2, MeOH, etc...) with/without CCS will depend on the relative value/price of the products and of CO_2, that vary over time with different time scales.

Carbon balances of BECCS

A. Almena-Ruiz

Most of the scenarios modelled by the IPCC limiting global warming to 1.5°C consider BECCS. UK Energy White Paper: BECCS is expected to contribute to reach net-zero by 2050.

Case study: hydrogen production via gasification with pre-combustion CO_2 capture using waste wood, e.g. white wood pellets from sawmill residues.



Technology	Biomass catalytic gasification
	Fluidised bed gasifier
	Tar removal
	Pre combustion CC (methanol absorption)
	Membrane for H_2 purification
Scale	1 MW (300 kg/h biomass)
Energy vector	Hydrogen: fuel cell purity
Captured CO_2 fate	Storage

Figure 20: Description of the case study

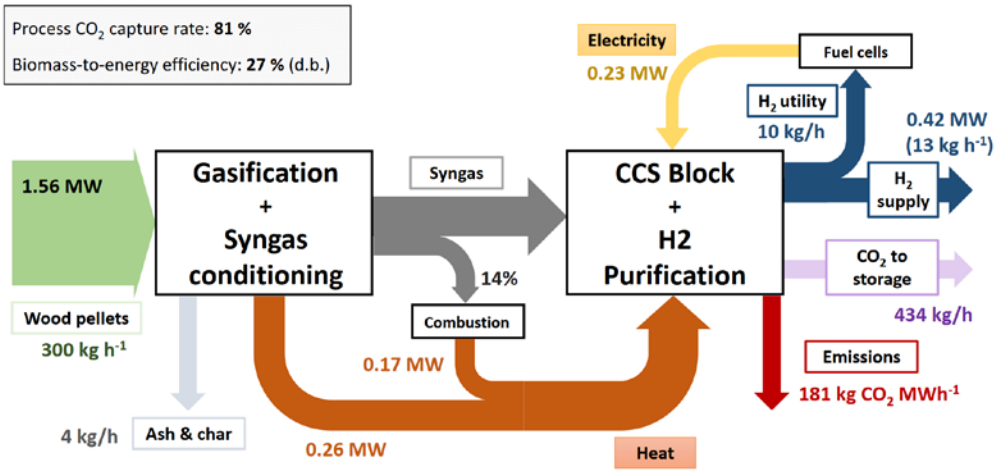


Figure 21: Process modelling (ASPEN)

BECCS can deliver net-negative emissions and supply low-carbon hydrogen simultaneously.

▪ There is currently in the UK biomass available to start delivering net-negative emissions while contributing to energy supply. Yet no BECCS facilities are built.

▪ Using all the UK wood production to supply BECCS is not enough to meet CDR and low carbon hydrogen supply annual targets.

▪ Decentralised BECCS deployment could represent a quicker solution for net-negative emissions providing flexibility on the use of technology, enabling regional biomass supply and local energy provision, involving low risk for investors and generating commercial experience on BECCS performance to help developing a supplementary large scale deployment.

- Different operation strategies for the same process, result in different CDR performance. Policy frameworks could enhance the operator to run the process aiming at the highest CDR potential.

- Since sustainable biomass resources are not unlimited, trade-offs between energy production and CDR score must be accounted when promoting those policies. Consider the mass-specific metric when biomass is involved.

Gasification integrated with CO_2 capture and conversion - GICO project

E. Bocci

Steam Gasification (SG), Carbon Capture Storage and Use (CCSU) and renewable Power-To-Gas (P2G) integration can be the basis of the RES next generation.

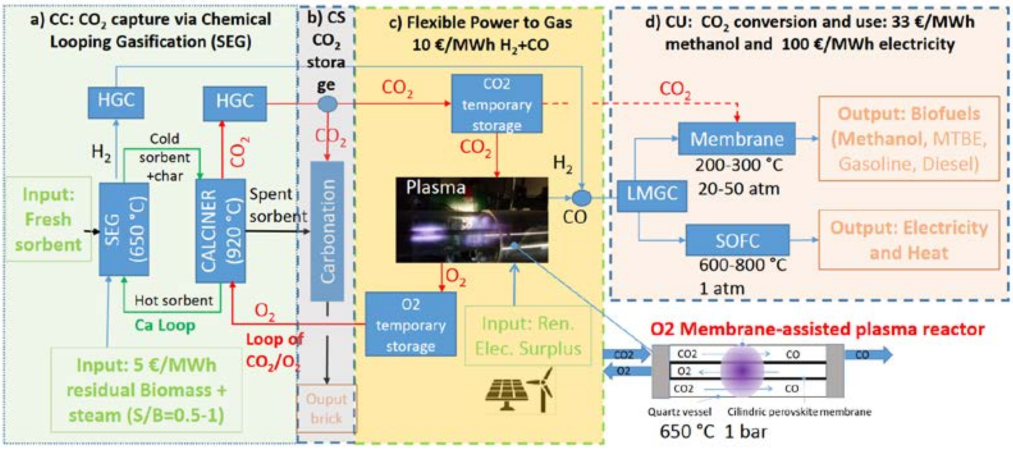


Figure 22: GICO - Project concept

GICO develops new materials (CO_2 capture sorbents; high temperature inorganic removal sorbents; catalytic filter candles; membranes for oxygen separation and methanol production) and technologies (Hydro Thermal Carbonisation; Sorption Enhanced Gasification; Hot Gas Conditioning; Carbon Capture, Storage and Use; Power To Gas via Plasma conversion) to:

1. **produce** intermediate solid (5 vs 15 €/MWh) and gaseous (10 vs 30 €/MWh with zero particulate and ppb contaminants level) **bioenergy carriers**;
2. **capture CO_2** (40 €/t vs 90 €/t) receiving waste high alkali content and producing bricks;
3. **convert CO_2** to CO and O2 (90 vs 10% efficiency) storing renewable electricity excess;
4. **produce methanol** (35 vs 75 €/MWh) **and electricity** (100 vs 200 €/MWh).

Aim: to develop small to medium scale residual biomass plants (i.e. 2-20 t/day and 500-5,000 kWe, compatible with the standard residual biomass availability of few thousand tons per year) connected to communities.

More information regarding the GICO project: https://www.gicoproject.eu/

Biomass to green hydrogen

S. Dasappa

For the first time a fixed bed system is used for oxy-steam gasification to generate hydrogen rich syngas in an allothermal mode.
A novel design of the open-top downdraft gasifier was developed in Indian Institute of Science (IISc) delivers product gas with tar less than 2 mg/Nm^3 in cold gas.

The principle, which is used in the design of the reactor increases the residence time of gas inside the reactor, by establishing a high temperature environment in the char bed, thus improving the conversion efficiency and reducing the higher molecular weight compounds.

The capacity of open top downdraft gasifier is about 100 kg/h; it has been adopted for the oxy-steam gasification with few modifications.

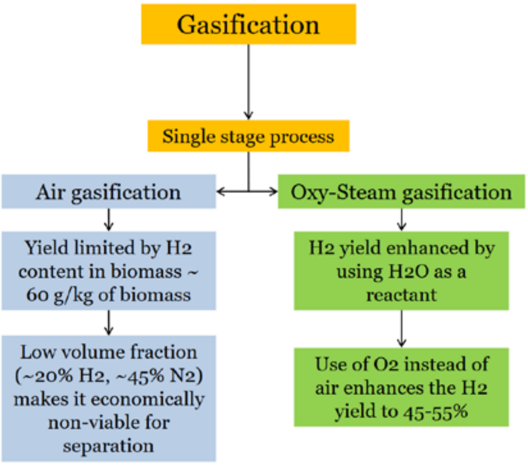


Figure 23: Air and oxy-steam gasification – comparison

Challenges:

- Establishing the syngas quality and process conditions for PEM fuel cell quality
- Fine tuning the gas composition as per the process requirements
- Ensuring overall energy balance to ensure minimizing in-house power consumption

Outlook:

- PEM single and stack level testing in progress
- Range of biomass to be tested
- Major initiative by IOCL to setup a 10 kg/hr hydrogen generation is being setup at their Faridabad plant for generation and utilization in the bus
    - The complete package from biomass gasification to separation and purification is planned for implementation
- Opportunities decarbonizing – Steel, fertilizers, etc
- High potential for MSW as a fuel for hydrogen production – Focused development required

Conclusions

The thermochemical gasification of biomass and waste can be seen as a versatile technology with a great potential and several benefits for the environment. This was also indicated in the workshop, which took place on the 2nd December 2021 in Trisaia, Italy.

The technology enables application of a broad feedstock variety: forest and agricultural biomass as well as waste materials, such as SRF, RDF, mixed waste, sludge etc.
After the conversion process a renewable combustible gas is produced and biochar as a by-product.

The gas can be used in several ways, for generation of renewable power and heat (also high temperature heat for industry) and/or production of green hydrogen, biofuels (diesel, kerosene, DME, gasoline or SNG) and biochemicals.

The gasification technology will play a significant role in energy transition, where no place for fossil fuels will be left over. It is and will be a part of circular economy and will be able to balance the power grid. The technology should be seen as carbon neutral or even carbon negative one if biochar as a carbon storage medium is employed.

This Workshop report is just a short summary of the presentations, which could be found on the IEA Bioenergy Task 33 website.[4]

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[4] www.task33.ieabioenergy.com,
http://www.ieatask33.org/content/home/minutes_and_presentations/2021_Dec_WS

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