Valuable (by-)products of gasification

Workshop report

IEA Bioenergy: Task 33

November 2022

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Jitka Hrbek, BOKU

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Introduction

The main product of biomass gasification process is a producer gas, which could be after cleaning and conditioning converted into synthesis gas. The syngas contains mainly CO and H_2; this mixture is beneficial for further processing, e.g. for production of biofuels and/or biochemicals.

In the figure below, the syngas utilization pathways can be seen. Starting with dry solid biomass, which is through gasification process and following cleaning and conditioning steps converted into syngas. Depending on the demands of the cleaning process, the syngas could be used for combined heat and power production, co-firing or production of high temperature heat.
For the synthesis of biofuels and/or biochemicals, more precise cleaning process is necessary. In this way gaseous bio-products such as synthetic natural gas (SNG), hydrogen or ammonia can be produced. Moreover, the liquids biofuels and biochemicals, such as Fischer-Tropsch (FT) liquids (e.g. biodiesel, biokerosene, biopetrol), mixed alcohols or methanol/DME can be produced.

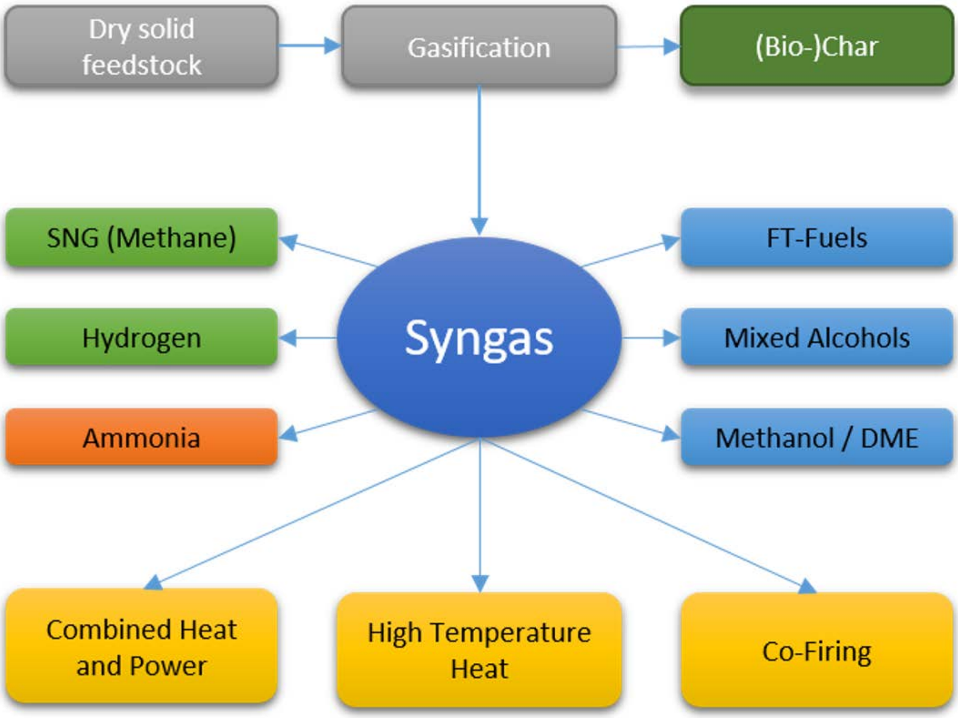


Figure 1: Syngas utilization pathways

As can be seen on the top of the figure, the valuable by-product of gasification is biochar, which could be utilized in many ways, e.g. for soil improvement, as an additive to animal feed, in industrial processes such as filtration medium, etc. In order to greenhouse gases balance (GHG), it could be employed as a storage of carbon.

On the left side of the figure bottom, combined heat and power production can be seen. Combined heat and power (CHP) production through biomass gasification is already matured technology and this fact is confirmed by more than 1 700 operational units in Europe.
To save the fossil fuels and for better GHG balance, biomass gasification is employed also in

industrial processes. The produced gas is co-fired in the boilers and the heat is used within the industrial process.

In the last years, development of units for SNG or FT liquids, as well as methanol of mixed alcohols can be observed. In this way it is clear that the gasification technology will play an important role in fossil-free future.

The actual developments in the field of gasification (by-)products was presented in the workshop.

All workshop presentations can be found on the IEA Bioenergy Task 33 website in the section “Workshops and events” or here.

WORKSHOP PRESENTATIONS

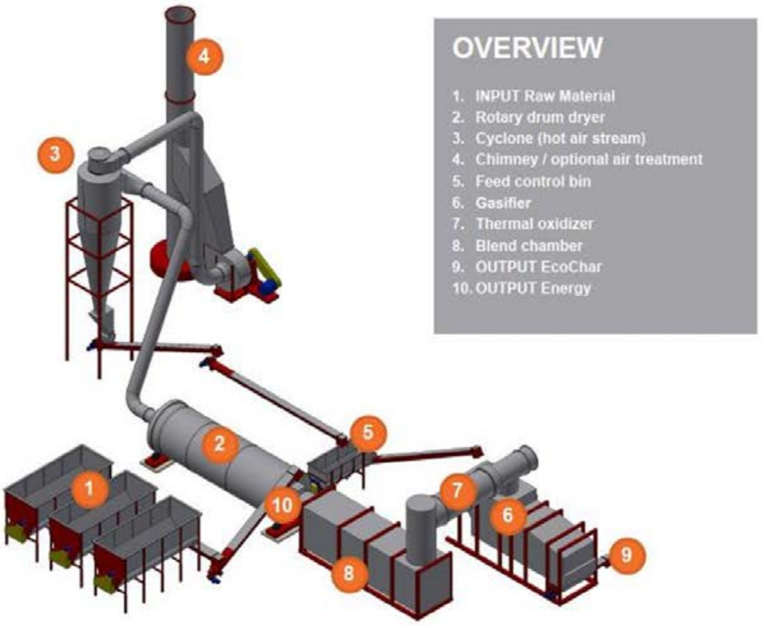
Keynote 1: “Actual trends in gasification technology”	Berend Vreugdenhil, TNO
Session 1: **CHP/Co-firing/High temp. heat**	
“The benefits of manure gasification”	C. Spaans, Mavitec
“Experimental study on the impacts of steam injection and air enrichment on two-stage downdraft wood gasification”	Arnaud Rouanet, UC Louvan
Session 2: **Negative emissions through gasification**	
Keynote 2: “Negative emissions”	Tobias Pröll, BOKU
“Negative Emissions through staged gasification from SynCraft – an evaluation”	Marcel Huber, SynCraft
„Added value through carbon sequestration in agriculture“	Nina Schaaf, MCI
“Negative CO_2 emissions by gasification of torrefied biomass into syngas, biochar and liquid CO_2”	R.P. van der Burg, Torrgas
Session 3: **Synthesis**	
Keynote 3: “Conversion of Renewable Synthesis Gas”	Reinhard Rauch, KIT
“Waste-2-Value”	Matthias Kuba, BEST
“Overview on research activities at TU Wien for the production of sustainable fuel-based energy carriers”	F. Benedikt, TU Wien
“Development of gasification solutions towards production of materials, based on the experiences from the GoBiGas demonstration”	Henrik Thunman, Chalmers/Joakim Lundgren, SFC
“Gidara gasification technology”	E. M. Moghaddam, Gidara
“Development of gasification projects in France”	Ch. Nait Saidi, ATEE
“Waste to chemicals”	NextChem
“New gasification with bio-thermo-chemical coupling technology”	Guanyi Chen, Tianjin University

The benefits of manure gasification
/ C. Spaans, Mavitec

Mavitec offers solutions for businesses with large quantities of animal by-products, biomass and other fuel sources and it is specialized in high quality recycling processes. The references table as well as the scheme of Mavitec gasifier can be seen below.

Table 1: Mavitec - references

Location	Owner	Operating since/ completion date	Processing	Capacity (20% moisture)
Wardensville, West Virginia	Frye Poultry	2011	Turkey and poultry manure	1.5 ton/hr
South Charleston,Ohio	Sexing Technologies	2012	Cow manure	2.3 ton/hr
Orleans, Indiana	Riverview Farms	May 2017	Poutry manure,turkey litter, swine manure, turkey and swine mortalities	2.3 ton/hr
Mead, Nebraska	Greencycle Solutions	March 2018	Wet distillery grain	2.3 ton/hr
Cordele, Georgia	Synergy Solutions	August 2018	Food waste,agricultural waste products	2.3 ton/hr
America, The Netherlands	Willems Agro BV	2018	Pig manure	2.3 ton/hr
St. Petersburg, Russia	Roskar	2019	Layer manure	2.3 ton/hr
Krasnobor, Russia	Krasnobor	2019	Turkey based on woodchips	2.3 ton/hr
Riyadh, Saudi Arabia	Almarai Company	2020	Poultry Litter	4 x 23 ton/hr



MAVITEC Environmental

Figure 2: Mavitec gasification technology

The gasification process can be seen in detail in the following figure. The process facility is divided into 3 chambers. The dry fuel is fed into the 1. one from the top, then using a screw feeder comes into the gasification part and the 3. chamber is used to cool down the char, which is remaining together with ash after the gasification process. The facility can process up to 50 tonnes of manure per single unit per day and generates 5.0-5.5 MWth @ 1000°C as hot air flow depending on caloric value input material. The facility produces 350-600 kg/hr high quality EcoChar as end product with the possibility of electricity generation (up to 1 MW) or high capacity steam generation (7 tonnes steam @ 10 bar).

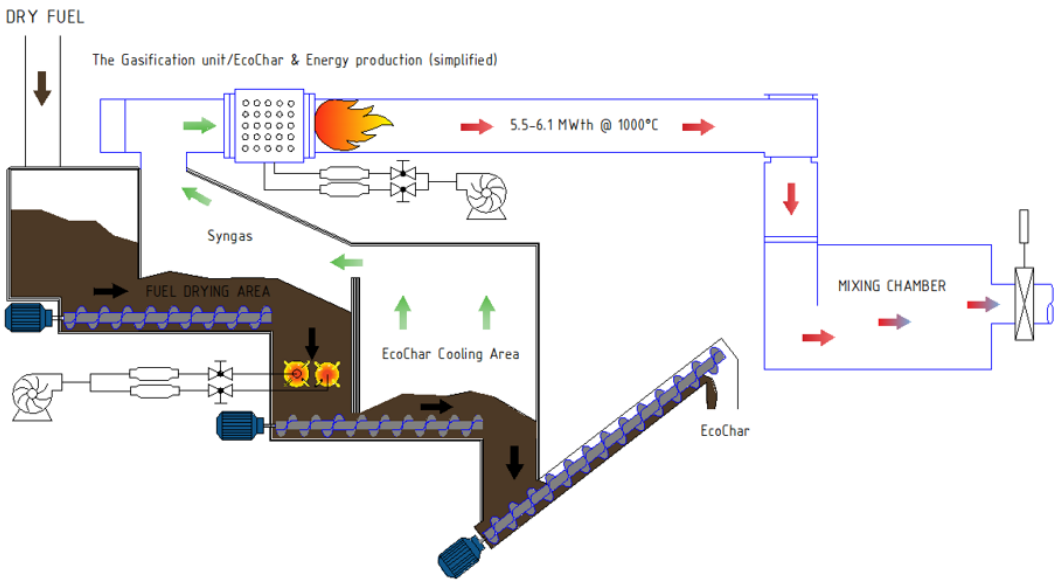


Figure 3: Gasification unit Mavitec

As a fuel, different organic waste with moisture up to 20 % can be used:

- Poultry litter/manure
- Cattle manure
- Porcine manure
- Sludge or digestate
- Biosolids

In the following figure the possible output pathways as well as utilization of ecochar could be seen.

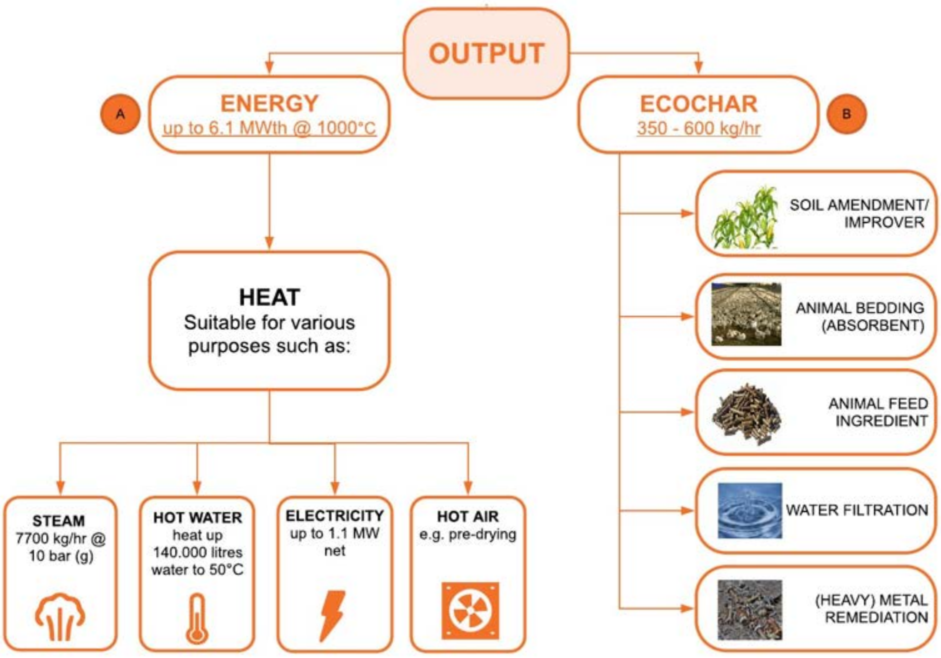


Figure 4: Mavitec – output pathways and utilization of ecochar

Experimental study on the impacts of steam injection and air enrichment on two-stage downdraft wood gasification

/ A. Rouanet, UC Louvain

For the study a two-stage downdraft fixed bed gasifier was employed. The figure of NOTAR gasifier can be seen below. The feedstock coming from the top into the gasification unit comes into pyrolysis zone, combustion and reduction zones. As a feedstock wood pellets were used.

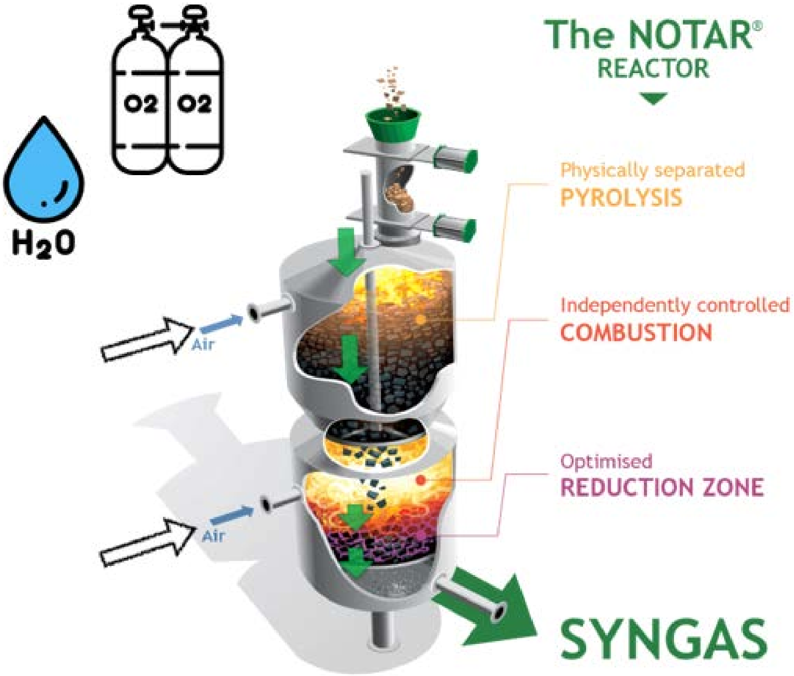


Figure 5: The NOTAR gasifier

The gasification tests were provided under air-steam or air-oxygen and oxygen-steam conditions.

Air-steam gasification

As can be seen in the figure bellow, steam shifts composition from CO to H_2.

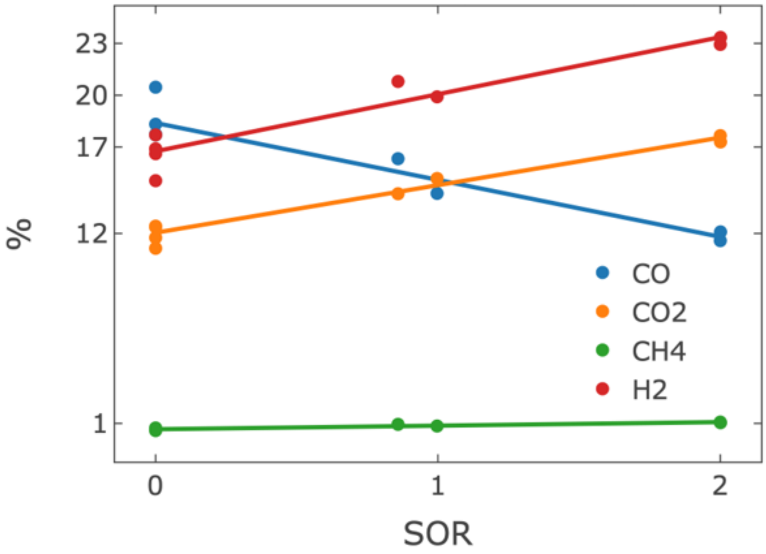


Figure 6: Gas composition by air-steam gasification

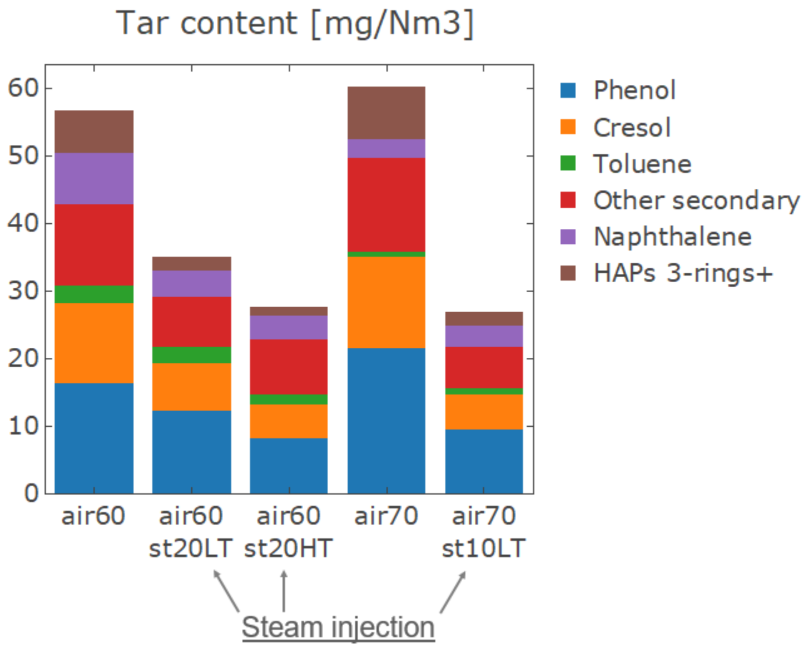


Figure 7: Tar composition by steam injection

Air-oxygen and oxygen-steam gasification

Gas composition by air-oxygen gasification can be seen in the figure. Removal of nitrogen boosts the syngas LHV.

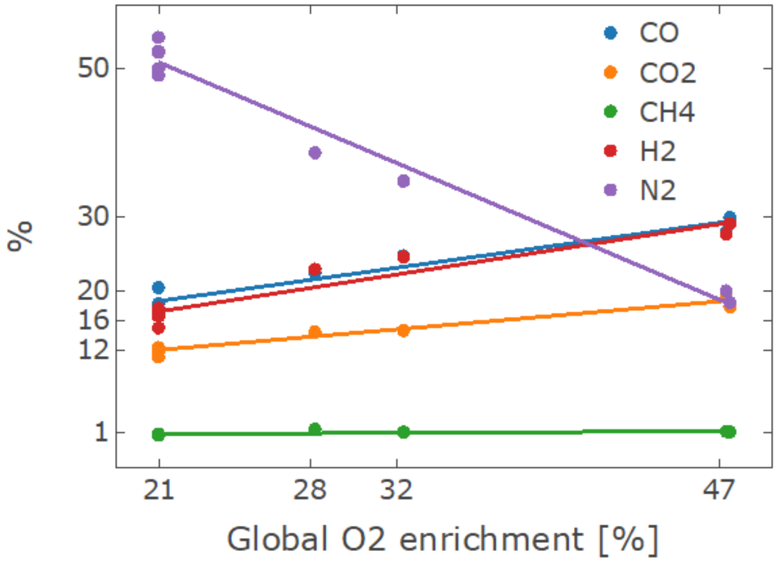


Figure 8: Gas composition air-O2

Oxygen-steam gasification

As can be seen in the figure, steam still shifts composition from CO to H_2.

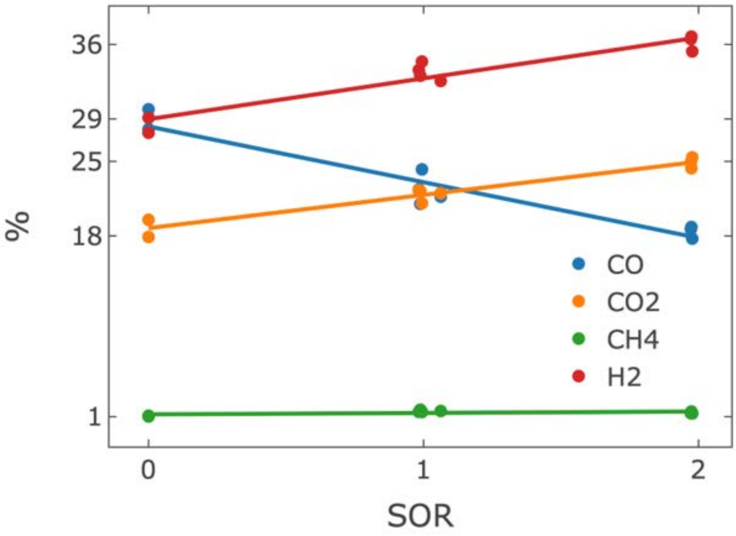


Figure 9: Oxygen-steam gasification

Conclusions:

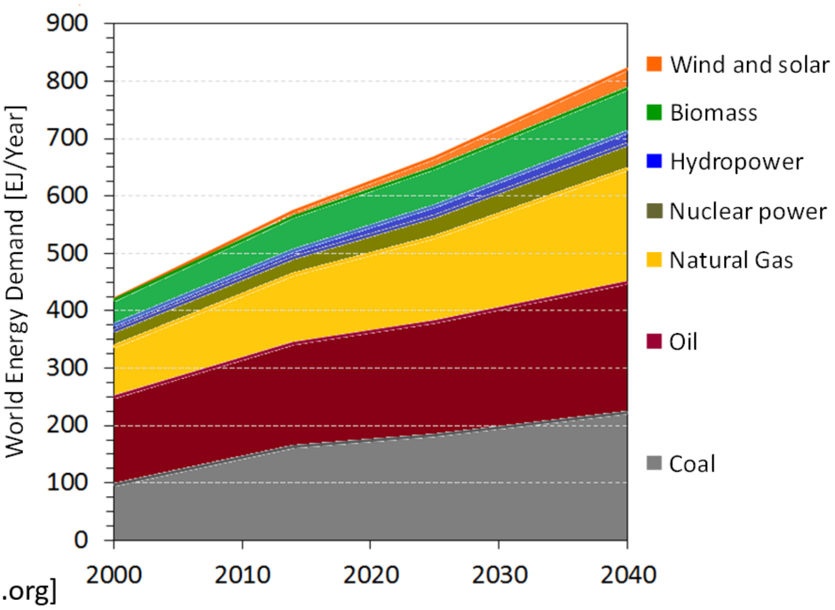
- Steam "shifts" syngas composition from CO to H_2, boosting the **H_2/CO ratio**
- Oxygen use at the secondary stage yields a +60% increase of the syngas **LHV**
- Steam efficiently acts as a "**thermal damper**" in combination with O_2, at the cost of a small reduction of the syngas LHV

- Steam favors a complete **carbon conversion**, for a higher gasification efficiency. **CGE** is maximized by the combined use of steam and oxygen

- Steam supports the reforming of **secondary** and **tertiary tar** into benzene

Negative emissions
/ T. Proell, BOKU

In the figure below, the actual status and expectations regarding energy demand can be seen. It is well known, that to reach the +1.5°C target, negative emissions from 2050 will be needed. Anyway, the longer we wait with deep emission reduction, the greater the problem will get.



[IEA World Energy Outlook 2016 – iea.org]

Figure 10: Actual status and expectations regarding energy demand

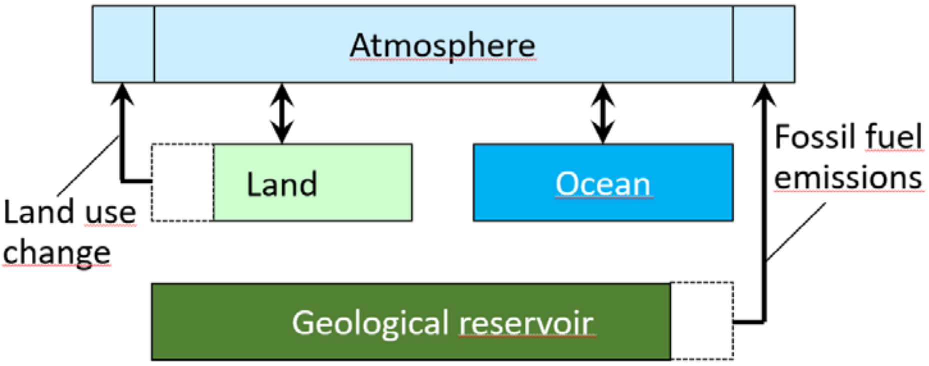


Figure 11: Scheme of current land use and fossil fuels utilization

How to get negative emissions:

- Agriculture, forestry and other land use change (AFOLU)
    - Afforestation and reforestation, Land restoration
    - Soil carbon sequestration
- Biochar addition to soil
- Bioenergy with carbon capture and storage (BECCS)
- Direct air capture and storage (DACS)
- Enhanced weathering
- Ocean alkalinisation

Biomass-based NETs - comparison

Biochar

- Simple process, no CO_2 transport and storage infrastructure
- Lower energy output (about 50% of bioenergy w/o CCS)
- No ash melting – nutrients available for recycle
- Suitable for biomass residues with low ash melting point

BECCS

- Higher energy output (about 80% of bioenergy w/o CCS)
- High temperature conversion, ash melting risk
- Suitable for wood as fuel (no ash melting issues)
- CO_2 transport and storage infrastructure required

Therefore

Biochar in sub-tropical and tropical regions where bioenergy is not competitive to solar power and soils are depleted

BECCS in cold climate where wood is sustainably available

Further possibilities regarding negative emissions were presented. Details you can find in the presentation.

Summary

- Large potential in AFOLU measures (at reasonable cost)
- Biomass-based NETs need to obtain biomass from sustainably managed land in accordance with AFOLU
- Biochar suitable for residual agricultural biomass
- BECCS requires higher quality biomass (wood) without ash melting issues
- Efficient BECCS could be reached using Chemical Looping Combustion
- DACS can be used in future scenarios with high CO2 prices in locations far from any chimney with renewable energy or highly effective CCS and access to suitable storage sites
- Large uncertainties for enhanced weathering and ocean alkalinisation

Negative emissions through staged gasification from SynCraft -an evaluation

/ M. Huber, SynCraft

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.

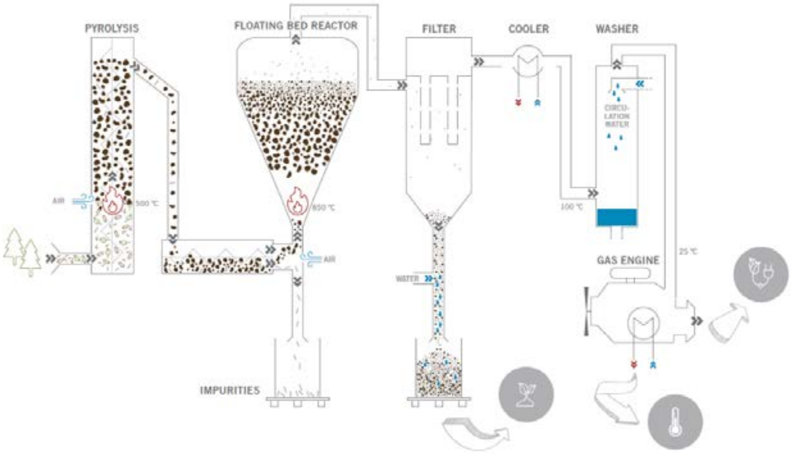


Figure 12: SynCraft – floating fixed bed gasification system

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.

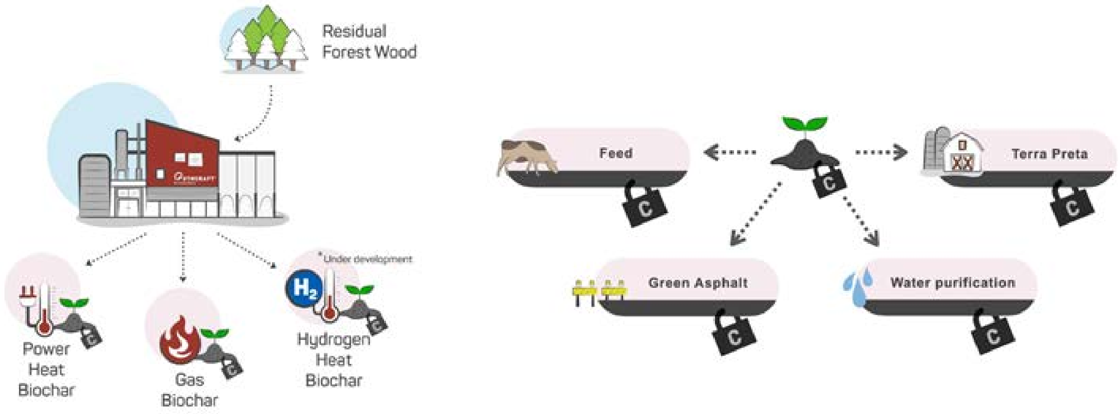
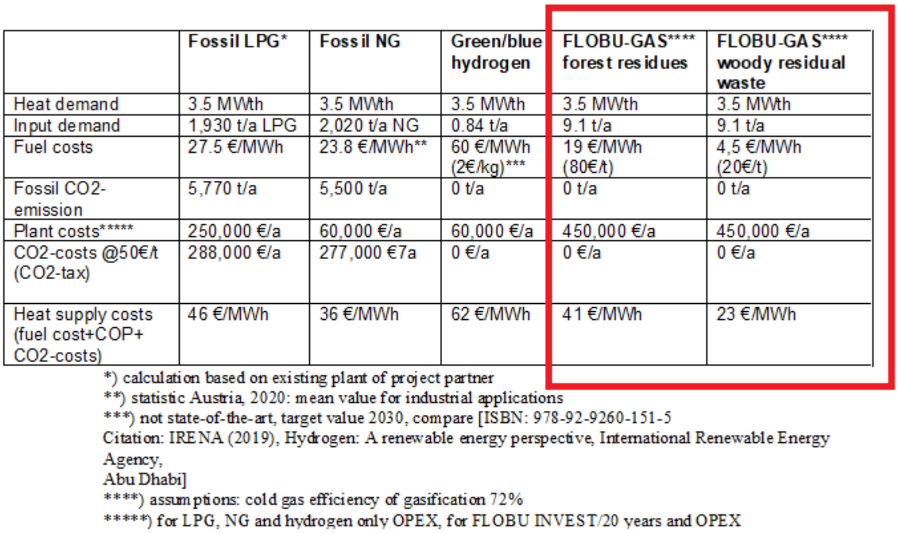


Figure 13: Utilization ways of SynCraft´s products

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.

Evaluation

Table 2: Evaluation – Woodfire gas costs



	Fossil LPG*	**Fossil NG**	**Green/blue hydrogen**	**FLOBU-GAS**** forest residues**	**FLOBU-GAS**** woody residual waste**
Heat demand	3.5 MWth	3.5 MWth	3.5 MWth	3.5 MWth	3.5 MWth
Input demand	1,930 t/a LPG	2,020 t/a NG	0.84 t/a	9.1 t/a	9.1 t/a
Fuel costs	27.5 €/MWh	23.8 €/MWh**	60 €/MWh (2€/kg)***	19 €/MWh (80€/t)	4,5 €/MWh (20€/t)
Fossil CO2-emission	5,770 t/a	5,500 t/a	0 t/a	0 t/a	0 t/a
Plant costs*****	250,000 €/a	60,000 €/a	60,000 €/a	450,000 €/a	450,000 €/a
CO2-costs @50€/t (CO2-tax)	288,000 €/a	277,000 €7a	0 €/a	0 €/a	0 €/a
Heat supply costs (fuel cost+COP+ CO2-costs)	46 €/MWh	36 €/MWh	62 €/MWh	41 €/MWh	23 €/MWh

*) calculation based on existing plant of project partner
**) statistic Austria, 2020: mean value for industrial applications
***) not state-of-the-art, target value 2030, compare [ISBN: 978-92-9260-151-5
Citation: IRENA (2019), Hydrogen: A renewable energy perspective, International Renewable Energy Agency,
Abu Dhabi]
****) assumptions: cold gas efficiency of gasification 72%
*****) for LPG, NG and hydrogen only OPEX, for FLOBU INVEST/20 years and OPEX

Evaluation – key figures

Invest: ~3.5 Mio. € (all in)

Building time: 9 month
(during Covid-19)

Power 400kW: sold to grid
FIT; Ökostromtarif

Heat 600kW:
Baseload for district heating; 95 / 65°C

Operating hours: 2021: 8.333h (95,1%)

Total operating hours: 14.600h (in 21

Monaten)	Area: ~500 m² (1000 m² incl. Storage and dryer)
Overall efficiency: 93,1% incl. BioChar	BioChar usage: BBQ

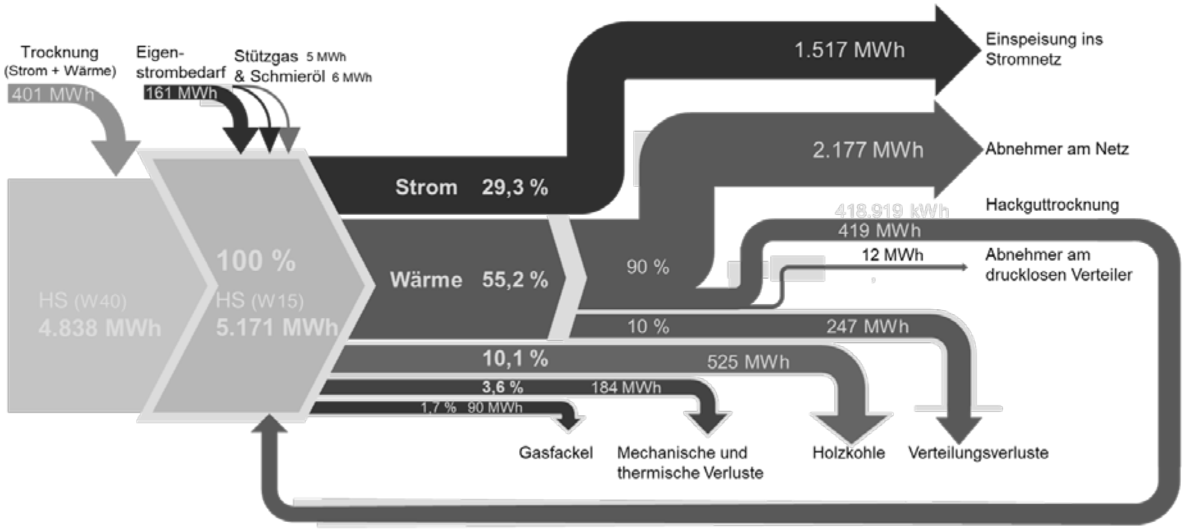


Figure 14: SynCraft- typical process flow diagram

Added value through carbon sequestration in agriculture

/ N. Schaaf, MCI

Currently, the production and use of biochar is experiencing a renaissance; a great value is placed on regional and regenerative products, using biochar.

In the figure below, the production process of biochar can be seen.

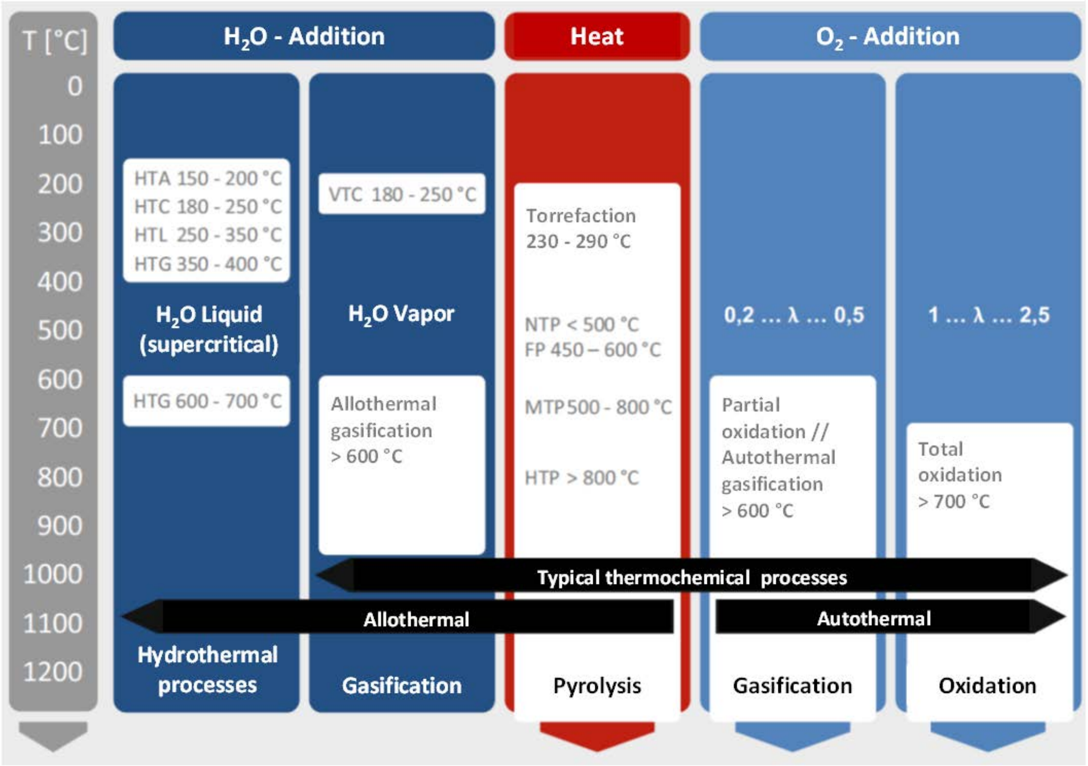


Figure 15: Char production pathways

Biochar can be utilized in many ways, e.g. in agriculture. In this way, nutrient retention, utilization of byproducts, forest management, carbon sequestration and circularity can be seen as an added value.

Results of practical application in agriculture:

- Easy production of compost (no dust emission; no extra handling)
- Can be easily applied on fields with existing machinery
- No loss of yield detected once applied during composting
- A+ (Bio) Certification possible (according national guidelines)
- Carbon sequestration of 2,6 t CO2 per ha/a possible

Examples of results at MCI and literature:

- N-Storage out of liquid manure with gasifier-biochar Mean: 18 %

- Adsorption of NH4+- N is possible
    - Up to 45 mg/g-Biochar

- Odor reduction is determined with olfactometry but no reduction of ammonia detected

- Biochar with high pH (<9) increase ammonia volatilization (AV) greater surface area initially reduce AV

The quality of biochar is dependent on many parameters:

- Input material, process conditions

- pH, Water Content, Fixed Carbon Content cFix, Organic Carbon Content corg.
- Nutrients and Distribution, Particle Size, Particle Distribution
    - BET: Brunauer-Emmett-Teller surface area analysis
    - BJH: Barrett-Joyner-Halenda pore size and volume analysis
- Contaminations:
    - Organic: PAH, PCDDs, PCDFs
    - Inorganic: Heavy metals (Pb, Cd, Hg,…)

Depending on the use of biochar different parameters have to be determined.

These parameters are usually prescribed by authorities or specialist circles to the respective user for documentation and control. Furthermore, the different measuring methods which are to be used for the various parameters are described in the different regulations or standards.

Thus, there are authorities ensuring the quality of biochar.

EBC (European Biochar Certification):

- Ensures sustainable production of biochar
    - Includes detailed rules on production and quality criteria
    - Transparent and measurable quality for biochar users
- Certificates with different thresholds for before mentioned parameters
    - EBC-Feed
    - EBC-AgroOrganic
    - EBC-Agro
    - EBC-Urban
    - EBC-ConsumerMaterials
    - EBC-BasicMaterials

Conclusions:

- Biochar used in agriculture:
    - sequestrates carbon
    - empowers renewable energy and local value creation
    - increases agricultural efficiency
- To be considered
    - Different quality and properties for specific applications
    - Local conditions (regulations, environmental conditions, …)
    - Choice of production methods can influence the application
    - Organic (PAH, PCDD, PCDF, …) and inorganic (heavy metals) contamination preclude some applications

Negative CO_2- emissions by gasification of torrefied biomass into syngas, biochar and liquid CO_2

/ R. Berends, Torrgas

Table 3: Torrgas solution: two-stage gasification of torrefied biomass

item	Feature
Step 1: low temperaturegasification (< 750ºC) with steam/oxygen	+ Removal of ash from pyrolysis gas => no ash in high temperature gasifier => reduction in operational problems (no slagging)
	+ High quality byproduct: char
	- Lower efficiency to syngas
Step 2: high temperature gasification (~ 1200ºC)	+ Cracking of tars => robust technology, high syngas quality for application in catalytic processes (tar levels < 0.1mg/Nm^3 dry basis)
Step 2: oxygen based gasification	+ nitrogen free syngas => high quality syngas for application in the process industry

Products from Torrgas gasification process

Syngas as platform chemical for production of

- bioSNG
- bioH2
- bioMeOH

Biochar for application of

- Fertiliser (clean A wood: forestry residues, agricultural waste)
- Active coal (water purification, gas cleaning, dashboards, carpets)
- (Co-)fuel
- bioCO_2 (foodgrade)
- biosteam

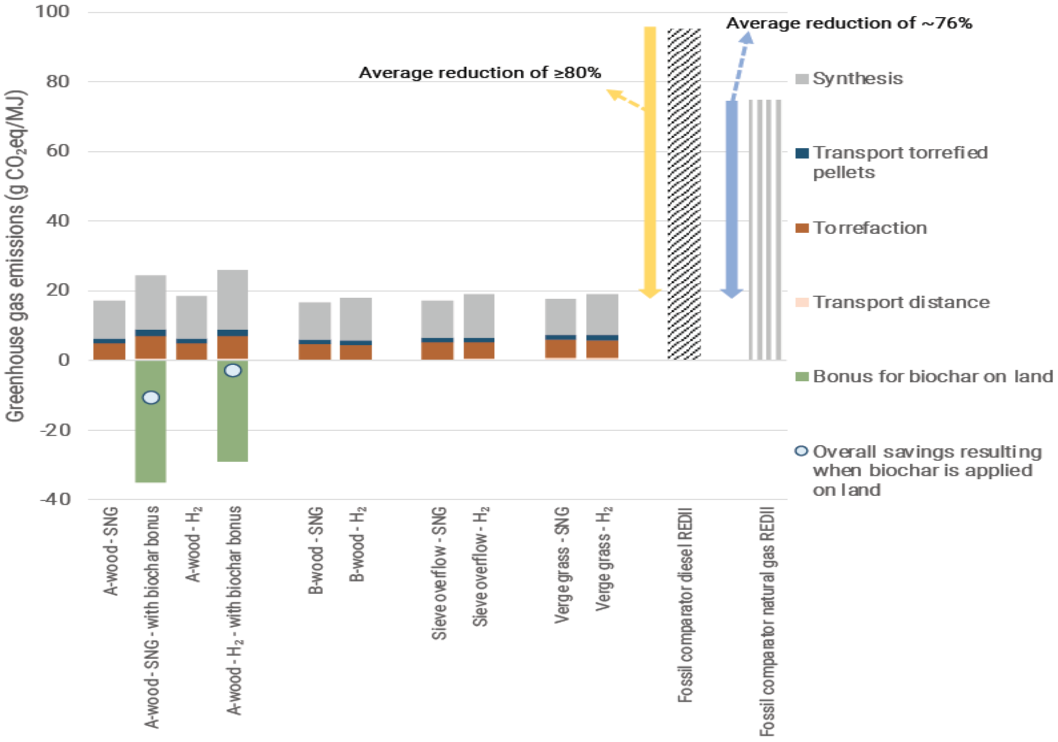


Figure 16: CO2 emission reduction - summary

Conversion of renewable synthesis gas
/ R. Rauch, KIT

Synthesis gas conversion pathways were introduced.

Fischer Tropsch (FT) synthesis

$$CO + 2H_2 \Rightarrow -(CH_2)- + H_2O$$

Table 4: Low- and high-temperature FT synthesis - comparison

Parameter	**Low-temperature FT**	**High-temperature FT**
Products	Waxes and/or diesel fuels	Gasoline, light olefins
Temperature [°C]	220 - 250	330 - 350
Pressure [bar]	25 - 60	25
CO + H_2 conversion [%]	60 - 93	85

Methanol synthesis

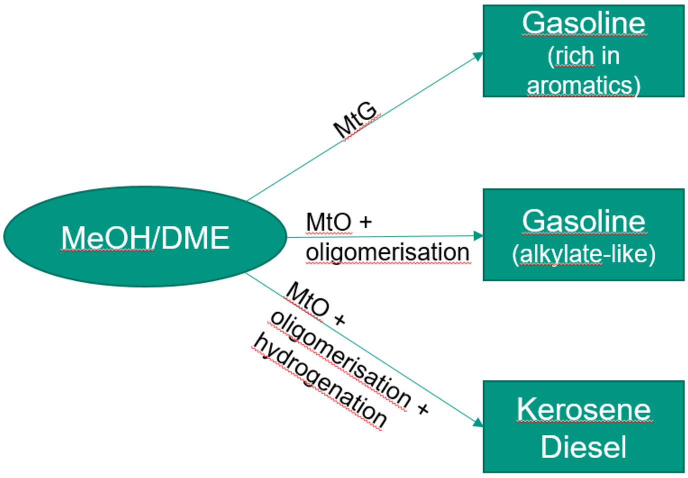


Figure 17: Production pathways from MeOH/DME to end-products

Products from synthesis gas:

- Acetate
- Acrylate monomers
- Alkyl benzene
- Alkyl phenol
- C6+ alcohols
- Explosives
- Fertilisers
- Glycol ethers
- Hydrocarbon blends (white spirits)
- Inorganics
- Ketones
- Lacquer thiners
- Light alcohols
- Mining chemicals

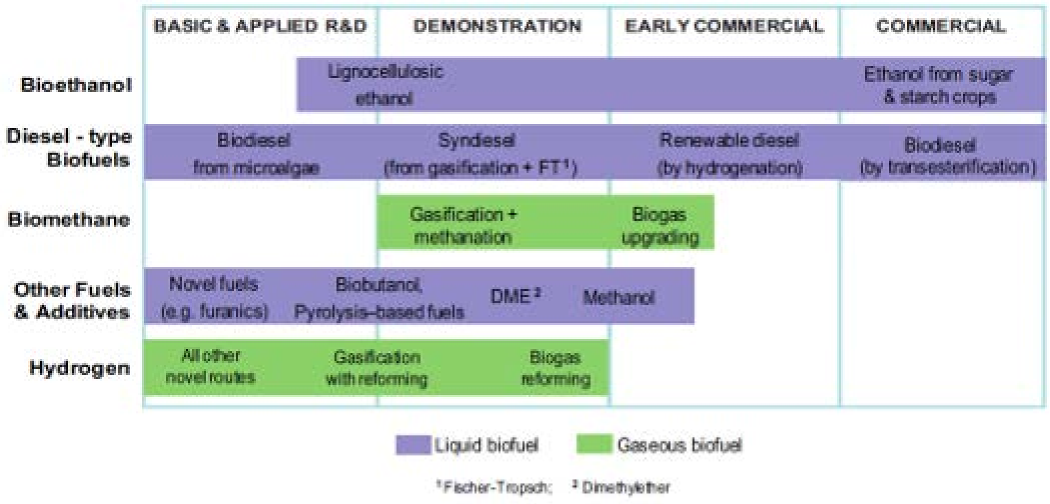
- Phenolics or cresylic acids
- Polymers
- Wax
- Argon
- Xenon
- Bitumen
- Fuel oils
- Lubricants

Food and feed: oils and fats from FT

- Developed in 1935 in Germany by Arthur Imhausen to produce synthetic soap and/or butter from coal
- Production capacity for butter was about 600 t/month
- After WW II the production was stopped and the FT plants were dismantled
- Principle is oxidation of paraffin's
- Byproducts are CO2, organic acids, peroxides, aldehydes, alcohols
- By combination with glycerin synthetic fats can be produced

Table 5: Comparison between synthesis products

synthesis	**Educts**	**Ratios**	**Selectivity**	**Conversion per pass**	**Status**
MeOH	CO, CO_2, H_2	$SN = \frac{(H_2-CO_2)}{(CO+CO_2)} \sim 2,1$	>99%	~40	Commercial (fossil)
FT	CO, (CO_2), H_2	H_2:CO > 2:1 (Co) H_2:CO ~ 1-2 (Fe)	ASF-distribution	~60 (LT) ~85 (HT)	Commercial (fossil)
Mixed alcohols	CO, CO_2, H_2	H_2:CO ~ 1-2 (MoS)	CH_4 as by product	~10-30	R&D
hydrogen	CO, H_2	-	-	>90	Commercial (fossil)



E4tech. 2009. Internal Analysis, www.e4tech.com

Figure 18: Development status

Conclusions:

- Synthesis gas conversion for fossil syngas is commercial, for BtL the progress could be better
- Power to Liquids is developing
- There are many similarities between PtL and BtL, the synthesis step is almost the same, main difference are:
    - Gas composition
    - Operation mode, as BtL is steady state and PtL is fluctuating
- Economy of scale is one major hurdle for BtL and PtL compared to fossil technologies
- Hybrid systems, where BtL and PtL are combined could offer some advantages for locations in Europe, like winddiesel (www.winddiesel.at)

Development of gasification solutions towards production of materials based on the experiences from the GoBiGas demonstration

/ H. Thunman, Chalmers University of Technology

GoBiGas - Gothenburg Biomass Gasification Project, 0.8 TWh/year SNG production by 2020.

In the GoBiGas project, a first-of-its-kind industrial scale biorefinery was built for the purpose of demonstrating and enabling commercial production of biomethane from woody biomass via gasification. The GoBiGas plant, with a production capacity of 20 MW of biomethane gas delivered to the natural gas grid in Sweden, is located in Gothenburg. The plant was built by Göteborg Energi AB with the support of the Swedish Energy Agency and the project was initiated in 2005. Nowadays is GoBiGas is on hold and mothballed.

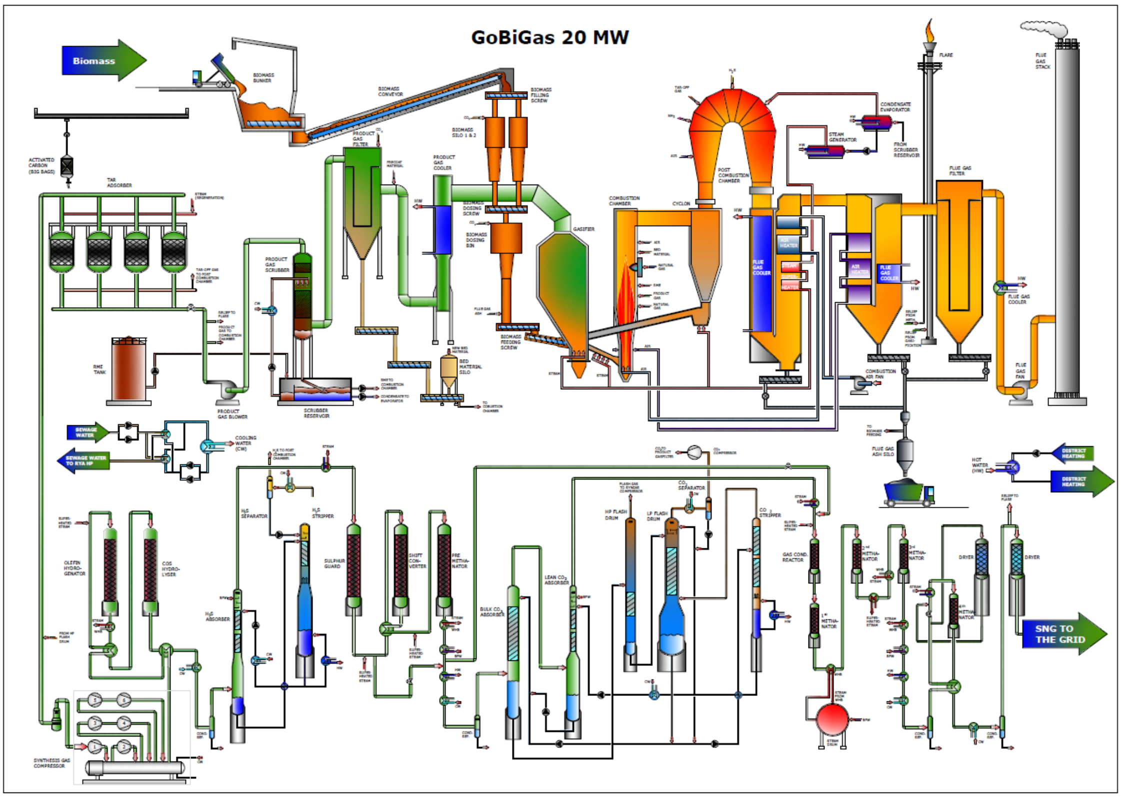


Figure 19: GoBiGas – flow sheet

Experimental equipment at Chalmers

- Experiments has been done in scale of 5 tons plastics /day, which correspond to 250 000 plastic bags/day

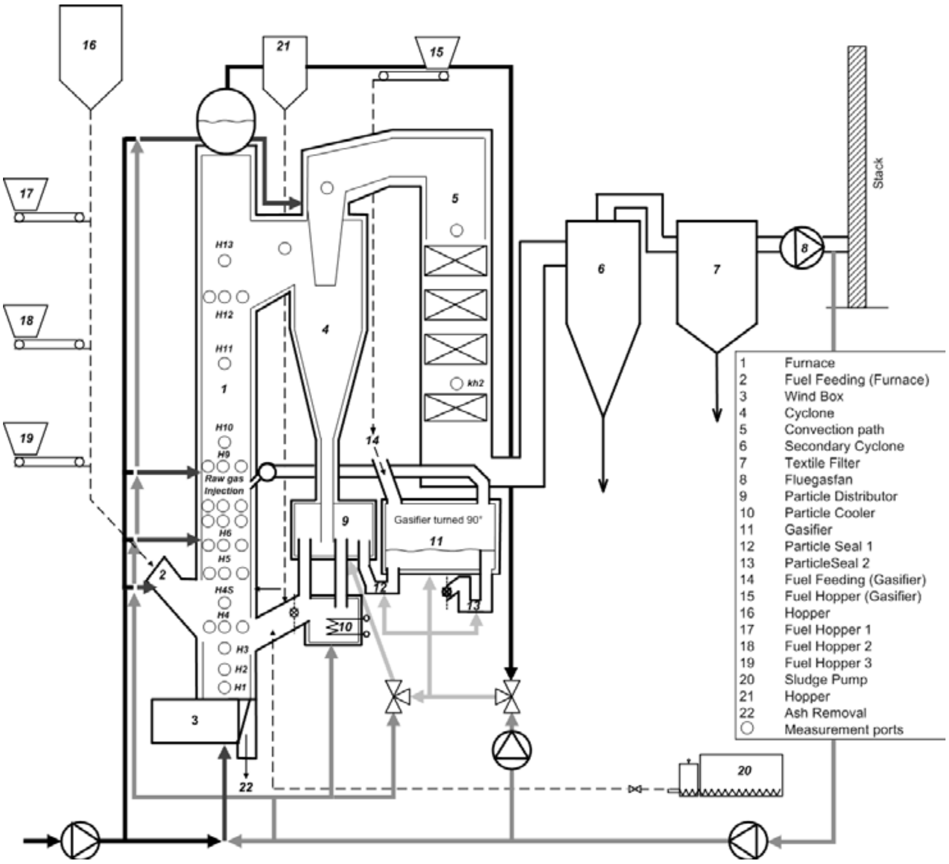


Figure 20: Reactor at Chalmers

In the figure above, a reactor at Chalmers University can be seen. Biomass/waste provide heat to process are fed in 2. At 9 plastics for recycling are fed as pieces or melt.

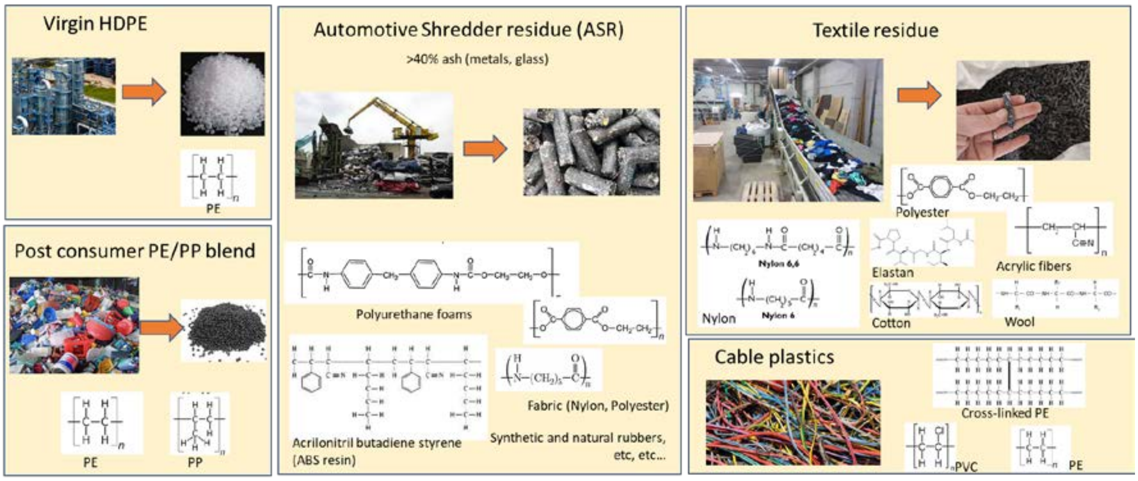


Figure 21: Global carbon balance for a circular system

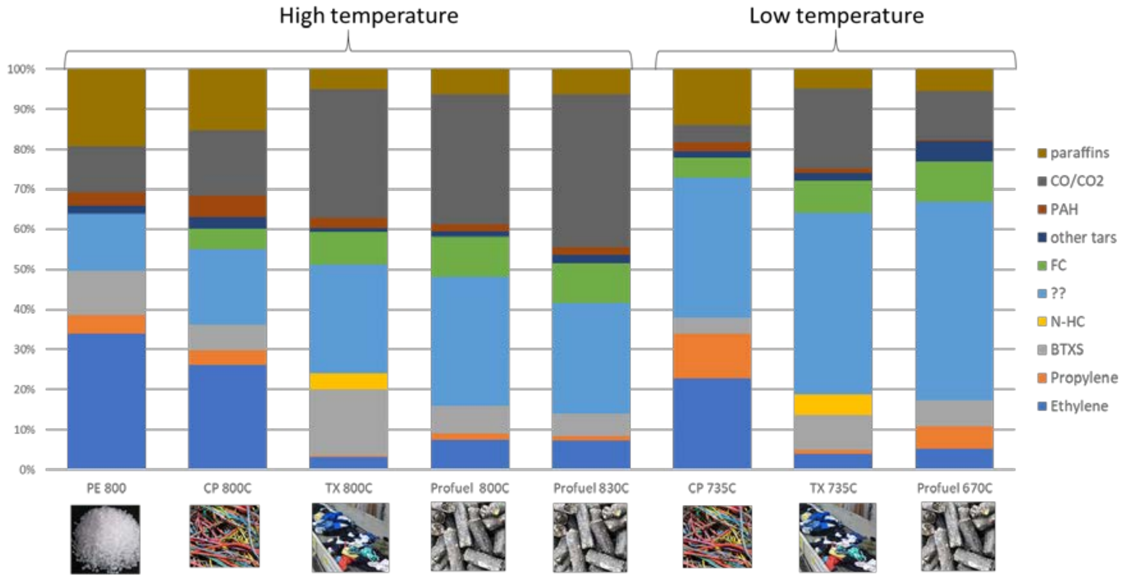


Figure 22: Carbon balance – example of results

Overview on research activities at TU Wien for the production of sustainable fuel-based energy carriers

/ F. Benedikt, TU Wien

Technology developments were presented. TU Wien was/is a scientific project partner by many research of commercial projects.

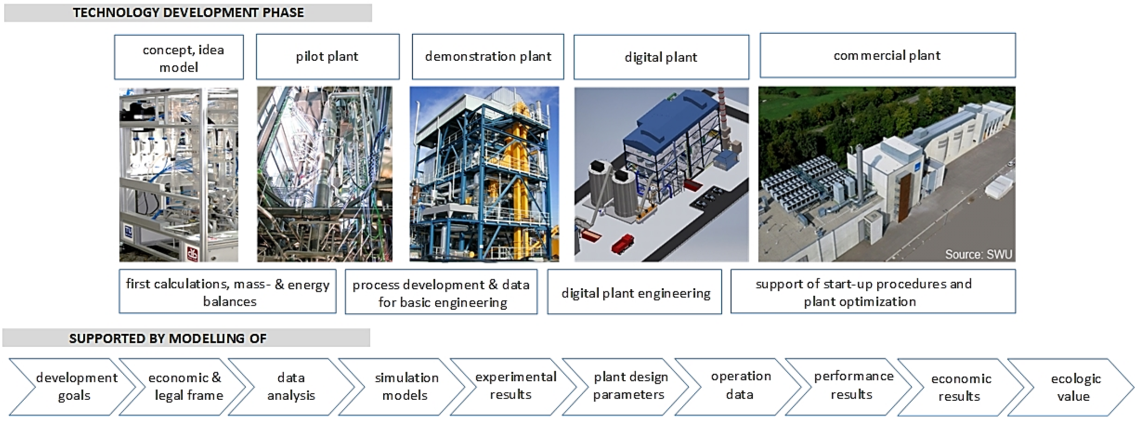


Figure 23: Developments of pilot and commercial units

At TU Wien dual fluidized bed steam gasification was developed, for the details se the figure below. The technology is based on circulating bed material, which brings the necessary heat from combustion zone into the gasification one. The producer gas is cleaned and can be used e.g. in gas engines of for synthesis of many fuels or chemicals.

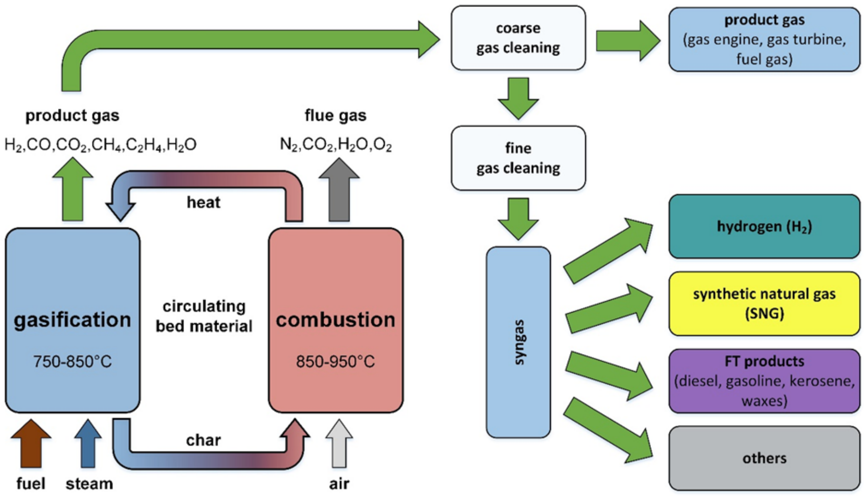


Figure 24: Dual fluidized bed gasification system

Using the DFB gasification unit already many different feedstock types were tested. Not only clean woody biomass, but also agricultural waste, industrial waste etc. The DFB system is very flexible and enables employment of a bride spectrum of feedstock.

The producer gas is cleaned and can be used in different ways, e.g. for SNG production. TU Wien has the whole process chain for SNG production via fluidized bed methanation.

Beside of SNG, the production of hydrogen is of interest at TU Wien.

An actual project is FCTRAC:

- Production of sustainable hydrogen by purifying product gas from gasification of wood chips and utilization of the hydrogen produced in a fuel cell tractor.
- Targets:
    - Demonstration of an entire zero-emission value chain in the agricultural sector
    - Development of a stand-alone solution for decentralized hydrogen production based on biomass

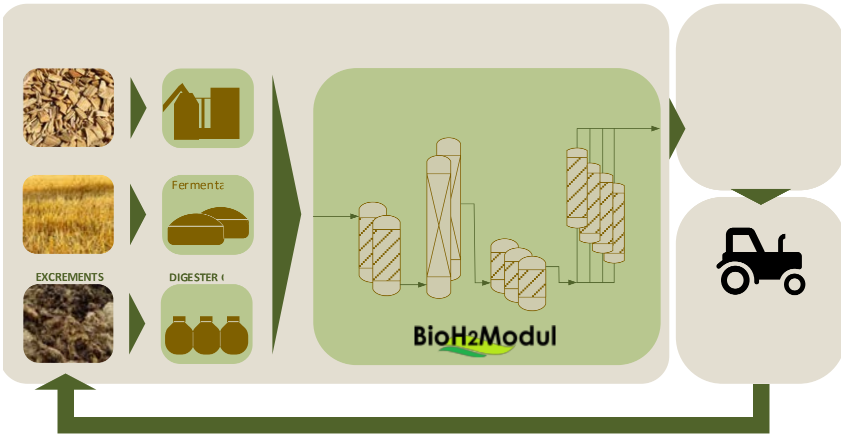


Figure 25: Project FCTRAC

Waste-2-Value project

/ M. Kuba, BEST

The aim of the Waste-2-Value project is a production of syngas from biomass and waste materials and its synthesis into biofuels. As a feedstock different mixtures of waste materials should be used. The technology is a DFB 1 MW intput gasification unit coupled with 250 kW FT synthesis.

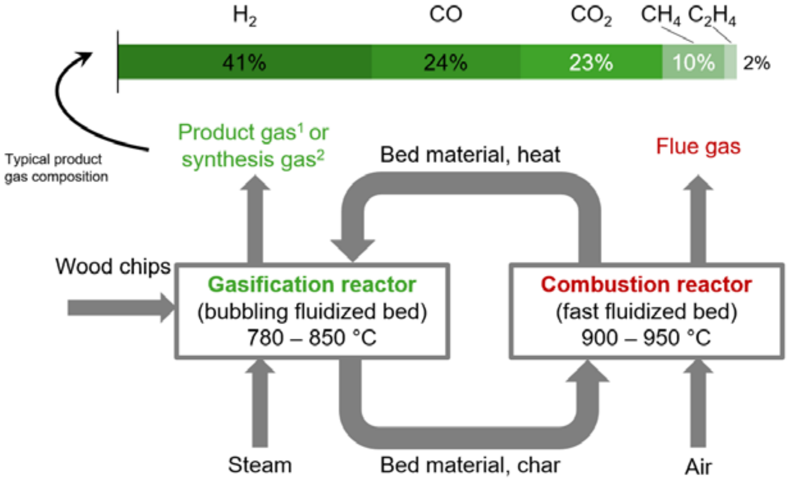


Figure 26: Process principle and producer gas composition

The advanced design of the gasification reactor enables better contact between bed material and feedstock, which causes higher conversion and lower amount of undesirable tars in the producer gas. In the figure, the design of the DFB can be seen. The gasification part of the reactor consists of several constrictions, where the gas flow velocity is changed and due to whirl of the bed material a better contact between the gas and solid phase is ensured.

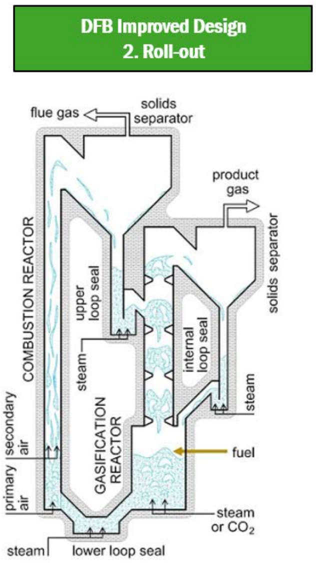
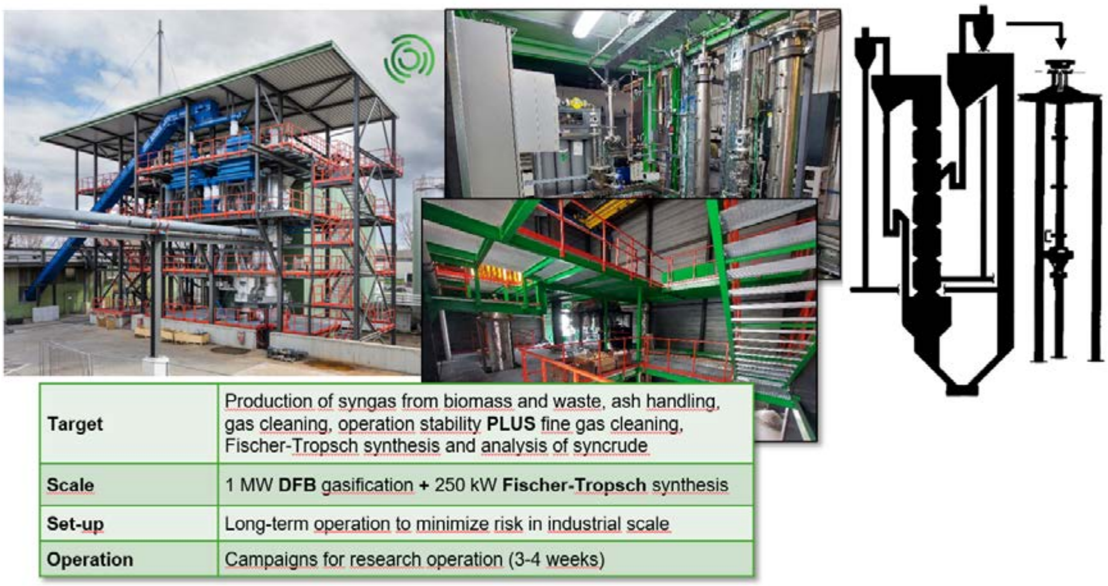


Figure 27: DFB design



Target	Production of syngas from biomass and waste, ash handling, gas cleaning, operation stability **PLUS** fine gas cleaning, Fischer-Tropsch synthesis and analysis of syncrude
Scale	1 MW **DFB** gasification + 250 kW **Fischer-Tropsch** synthesis
Set-up	Long-term operation to minimize risk in industrial scale
Operation	Campaigns for research operation (3-4 weeks)

Figure 28: Waste-2-Value, operation details

With the end of 2022 first experiments for the whole chain tests are planned. The aim is to produce FT liquids from the waste material.

Additionally to FT production also hydrogen production is planned.

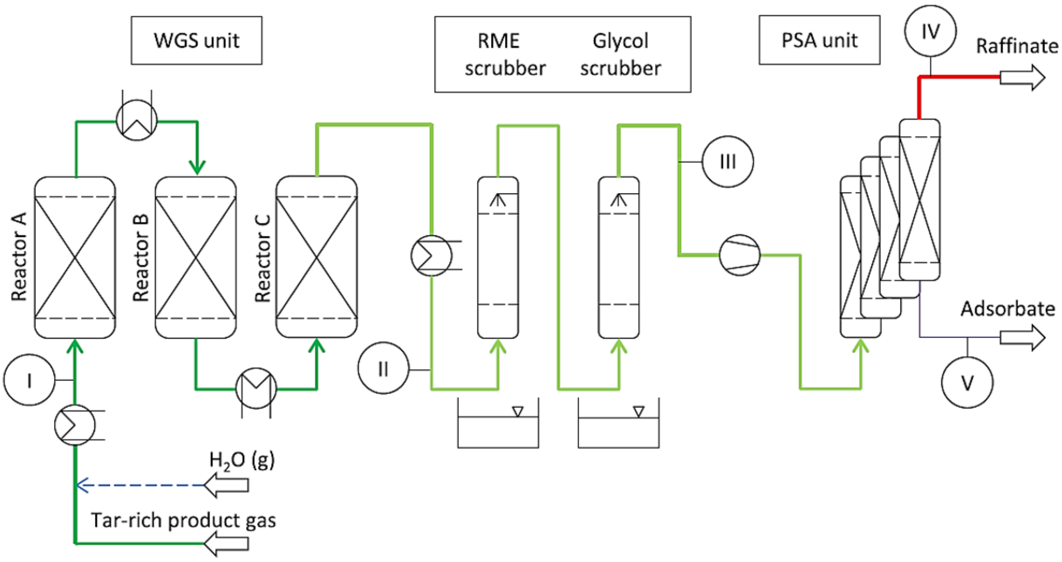
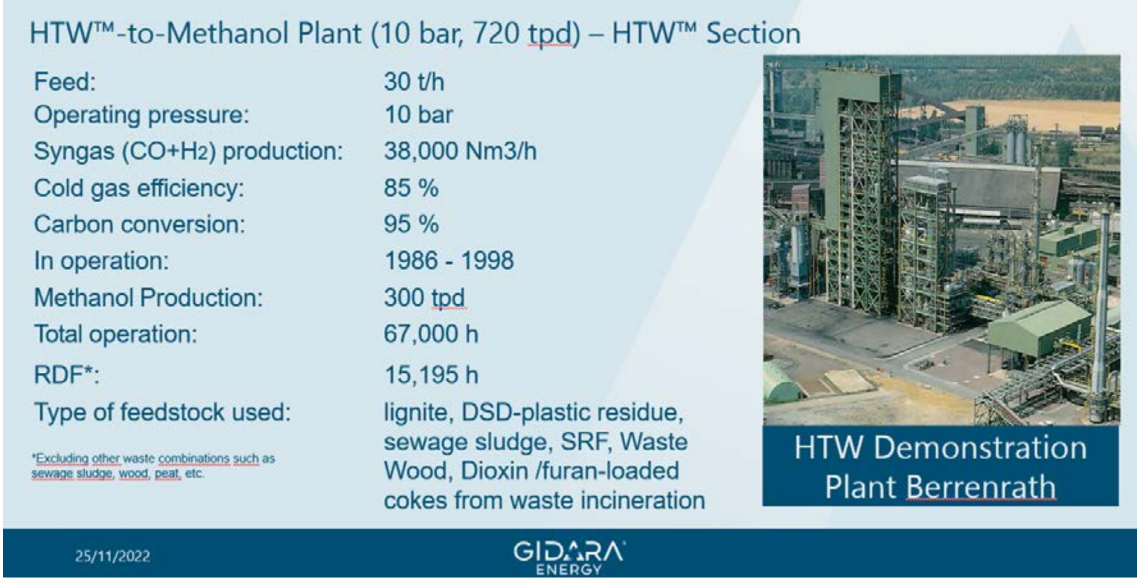


Figure 29: Process chain for syngas conversion to hydrogen

Gasification of RDF in high temperature Winkler (HTW 2.0) process

/ E. M. Moghadam, Gidara

GIDARA Energy’s process and highly flexible HTW®2.0 technology with adapted purification design allowing a utilization of broad range of feedstocks (with minor to no incremental CAPEX). The technology is proven for more than 10 years.



HTW™-to-Methanol Plant (10 bar, 720 tpd) – HTW™ Section

Feed:	30 t/h
Operating pressure:	10 bar
Syngas ($CO+H_2$) production:	38,000 Nm3/h
Cold gas efficiency:	85 %
Carbon conversion:	95 %
In operation:	1986 - 1998
Methanol Production:	300 tpd
Total operation:	67,000 h
RDF*:	15,195 h
Type of feedstock used:	lignite, DSD-plastic residue, sewage sludge, SRF, Waste Wood, Dioxin /furan-loaded cokes from waste incineration

*Excluding other waste combinations such as sewage sludge, wood, peat, etc.

HTW Demonstration Plant Berrenrath

25/11/2022

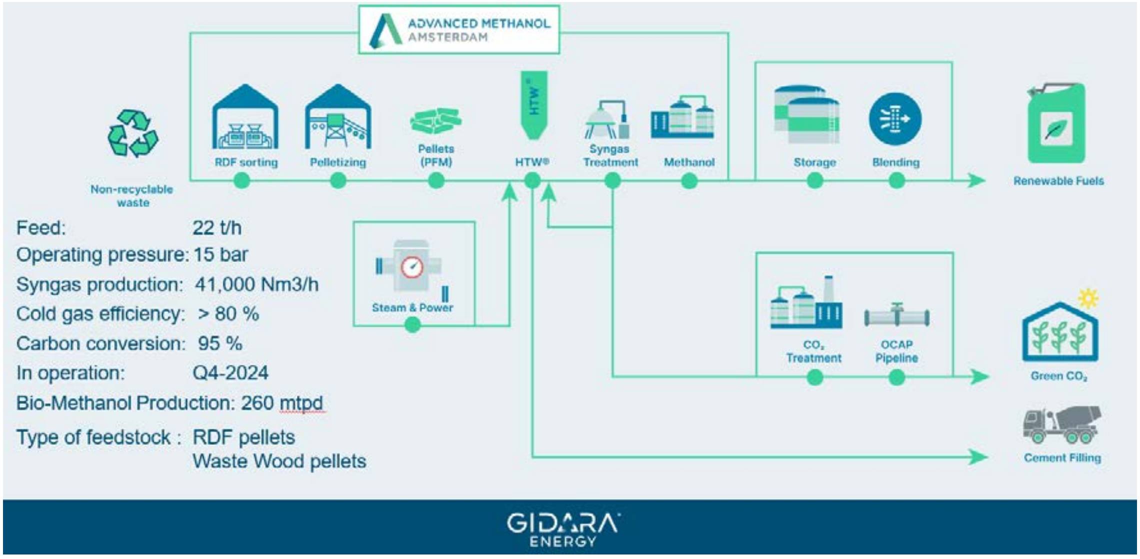
GIDARA ENERGY

Figure 30: Experience from Key reference plant

Based on the experience the HTW™2.0 Fluidized Bed Technology was developed:

- Low oxygen consumption due to moderate temperatures
- Optional use of air or pure oxygen as an oxidant
- Simple feedstock preparation
- Good partial load behavior over a wide range of operating conditions
- Simple start-up and shut-down procedures
- High operational availability
- No by-products in the syngas, such as tars, phenols and liquid hydrocarbons; low waste-water discharge, easy to treat
- Proven and robust sub-systems such as: dry dust removal and Waste heat recovery
- High cold gas efficiency (over 85 %)
- Great variety of feedstock (lignite, coal, peat, biomass, MSW, RDF etc)

In Amsterdam a flagship facility “Advanced Methanol Amsterdam (AMA)” was built. The process flow diagram can be found below.



Feed: 22 t/h
Operating pressure: 15 bar
Syngas production: 41,000 Nm3/h
Cold gas efficiency: > 80 %
Carbon conversion: 95 %
In operation: Q4-2024
Bio-Methanol Production: 260 mtpd
Type of feedstock : RDF pellets
Waste Wood pellets

Figure 31: HTW™2.0-to-BioMethanol Plant: Process Flow Diagram

Outlook for GIDARA:

- Future-Proof Technology
- Road Transport fuels
- Marine fuels
- Aviation fuels
- Chemicals
- Roll out of multiple facilities in Europe, UK and USA

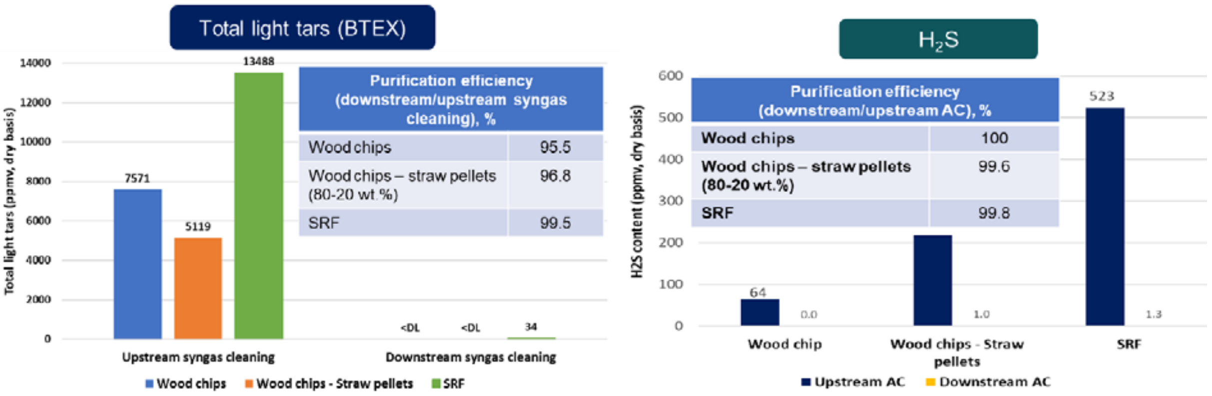
Gaya: Production of SNG from dry biomass and waste pyrogasification in France

/ M. Maheut, ENGIE

Gaya is a 10-years R&D program with 11 partners. It is a unique R&D demo platform at semi-industrial scale covering the whole process chain of bio-SNG production from gasification.

Results:

1. The whole process chain has successfully been operated and proven to be robust and flexible to covert several feedstock (woody residues, agricultural res., non-hazardous waste)
2. The syngas cleaning process chain efficiently removes pollutants (tars, inorganic compounds)



Purification efficiency (downstream/upstream syngas cleaning), %	
Wood chips	95.5
Wood chips – straw pellets (80-20 wt.%)	96.8
SRF	99.5

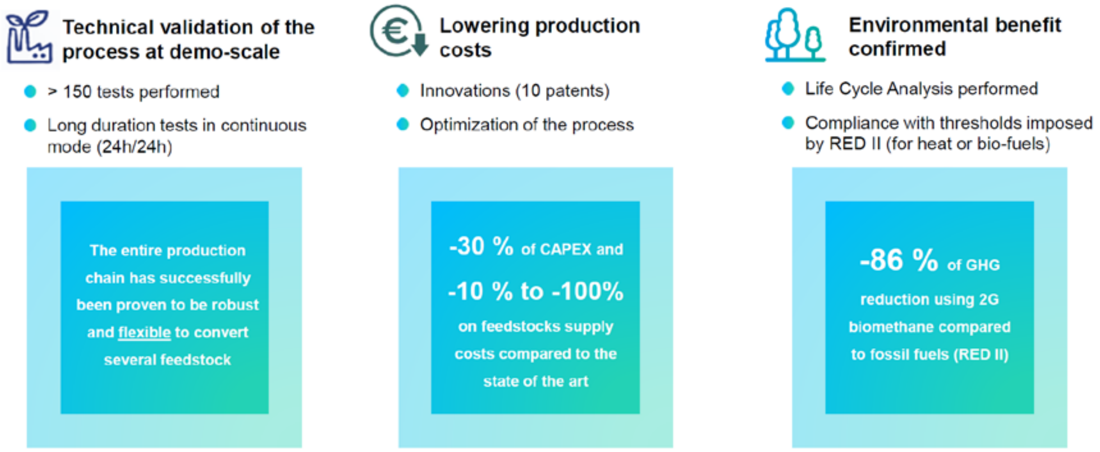
Purification efficiency (downstream/upstream AC), %	
Wood chips	100
Wood chips – straw pellets (80-20 wt.%)	99.6
SRF	99.8

Syngas reach the quality requirements prior to catalytic methanation:

H2S < 1 pmmv, BTEX < 1 ppmv (independent of the feedstock)

Figure 32: Syngas cleaning

3. Demontstration at semi-industrial scale (400-600 kW$_{LHV}$ SNG) of an innovative, highly flexible methanation solution to convert syngas into SNG
4. A high quality of SNG produced compatible with existing biomethane standards and French grid specifications to be injected into the gas grids or used as biofuels



Technical validation of the process at demo-scale

- > 150 tests performed
- Long duration tests in continuous mode (24h/24h)

The entire production chain has successfully been proven to be robust and flexible to convert several feedstock

Lowering production costs

- Innovations (10 patents)
- Optimization of the process

-30 % of CAPEX and -10 % to -100% on feedstocks supply costs compared to the state of the art

Environmental benefit confirmed

- Life Cycle Analysis performed
- Compliance with thresholds imposed by RED II (for heat or bio-fuels)

-86 % of GHG reduction using 2G biomethane compared to fossil fuels (RED II)

Figure 33: Technical, economic and environmental overall results

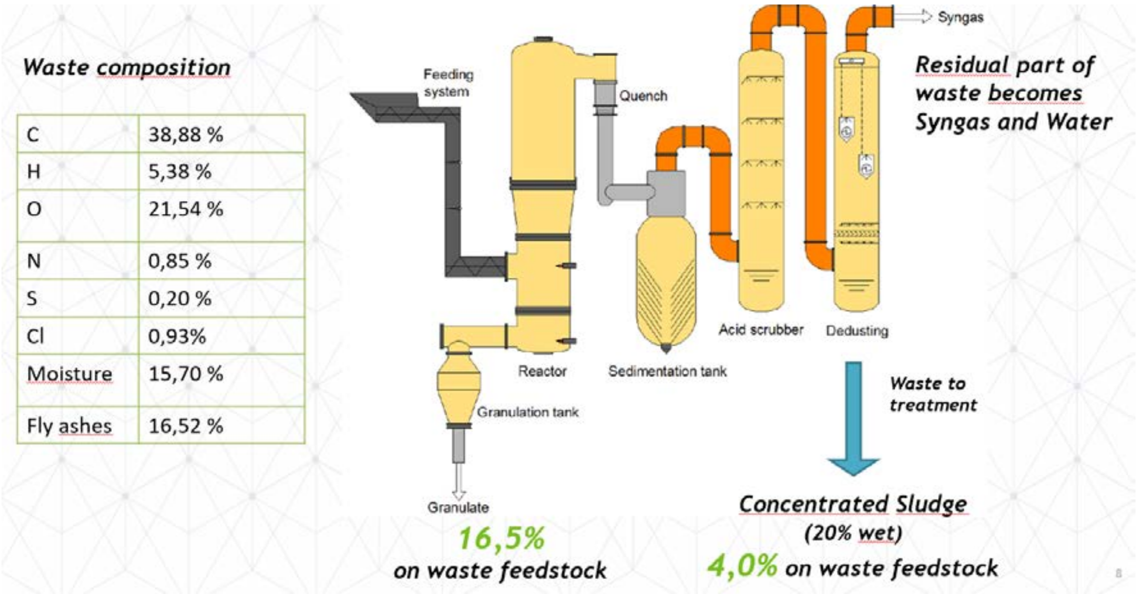
The Gaya project – outlook:

Figure 34: Development of a Gaya project

Salamandre project:

- 170 GW of SNG
- 70 000 t/y of non-recyclable waste recovered
- Public-private partnership and funding with the French state

Waste to chemicals
/ A. Angeletti, NextChem



Waste composition

C	38,88 %
H	5,38 %
O	21,54 %
N	0,85 %
S	0,20 %
Cl	0,93%
Moisture	15,70 %
Fly ashes	16,52 %

Figure 35: Waste to chemicals technology – the overall balance

Studies carried out by the University of Modena and Reggio Emilia "UNIMORE" have shown the following results:

- Chemical analysis classified the granulate as an INERT AMORPHOUS MATERIAL (vetrified)
- Elution test passed. It can acquire the qualification of “product”. IT IS NOT A WASTE.
- The material is suitable for use in the field of bricks, steels, cements and abrasives

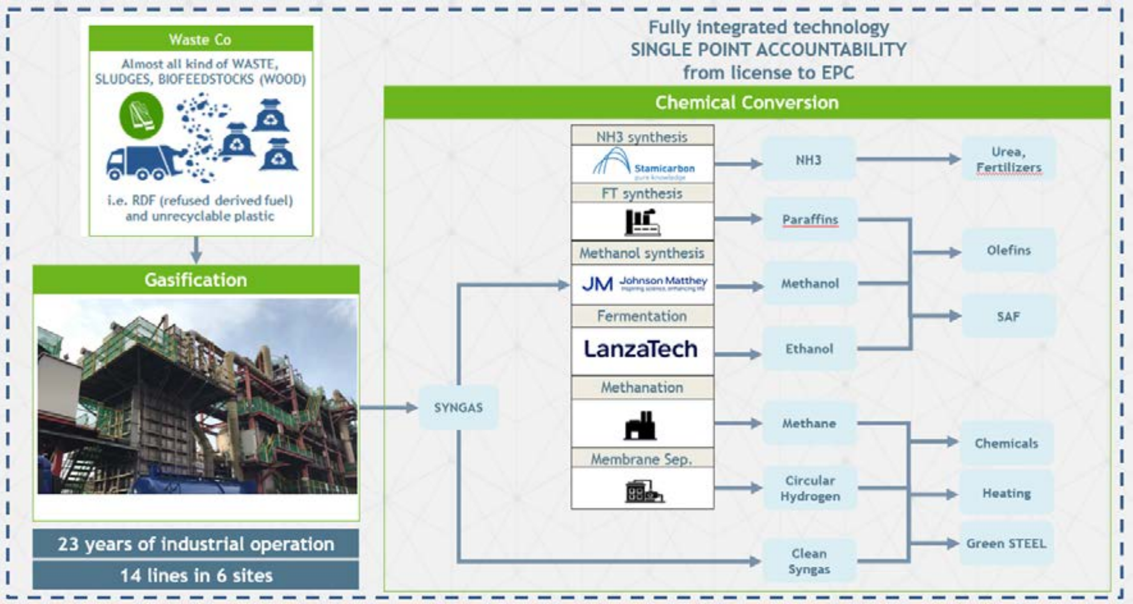


Figure 36: Waste conversion to hydrogen, chemicals, fuels, fertilizers and green steel

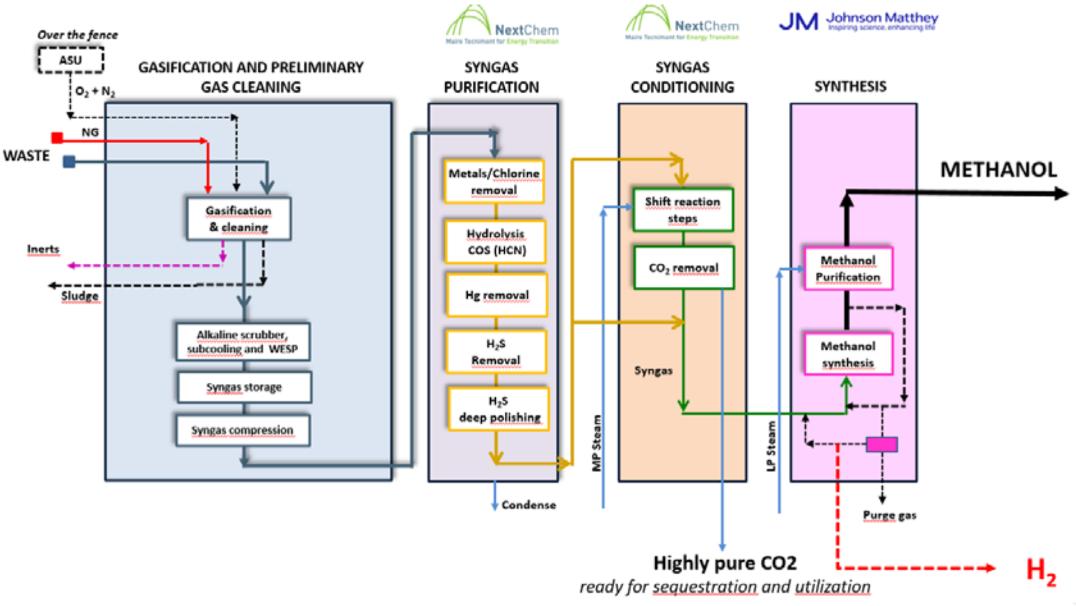


Figure 37: Waste to methanol and hydrogen

In the presentations also waste to methanol coupled with electrolysis, waste to ethanol and projects developments were presented.

IPCEI – HY2USE

- Grant of €194 million assigned to NextChem as a part of the EU project for the development of the first waste-to-hydrogen plant in the world
- NextChem's Waste to Chemicals technology, commercialized through MyRechemical, represents the state of the art for the recovery of non-recyclable waste.

- The recent award of €194 MN grant by the IPCEI EU Project for the Hydrogen Valley of Rome has demonstrated how Waste to Chemicals overcomes waste-to-energy.

- The European Commission has decreed that Waste to Chemicals and the H2 produced through this technology are perfectly compatible with European decarbonization policies and therefore considered Taxonomy Compliant.

Conclusions:

- Robuste and commercially proven process units for gasification, purification and chemical synthesis.
- NextChem W2C technology represents a process economically competitive with a low carbon footprint.
- Waste is a valuable source of carbon for replacing traditional fossil feedstocks
- The chemical conversion of solid waste is a valid alternative to conventional landfill or thermal valorization.
- The proposed technology fits perfectly into the concept of Circular Economy, which promotes the use of waste as a feedstock for the synthesis of new products.
- Integration of waste to chemical scheme with hdyrogen produced by electrolyzers can increase overall yields and further reduce carbon foot print down to ZeroCO2

Novel gasification with bio-thermochemical coupling technology

/ B. Yan, Tianjin University

In 2020, the total agroforesty biomass was 3.047 billion tons and 650 million tons of industrial waste in China.

- Biomass production is huge and utilization efficiency is low, so there is an urgent need for effective disposal means to reduce environmental risks
- Biomass is the best choice for developing sustainable clean energy because of its rich nutrition and relatively high calorific value
- 1 ton of biomass gasification power generation can reduce 1~1.5 tons of carbon dioxide emissions, effectively contributing to the double carbon target

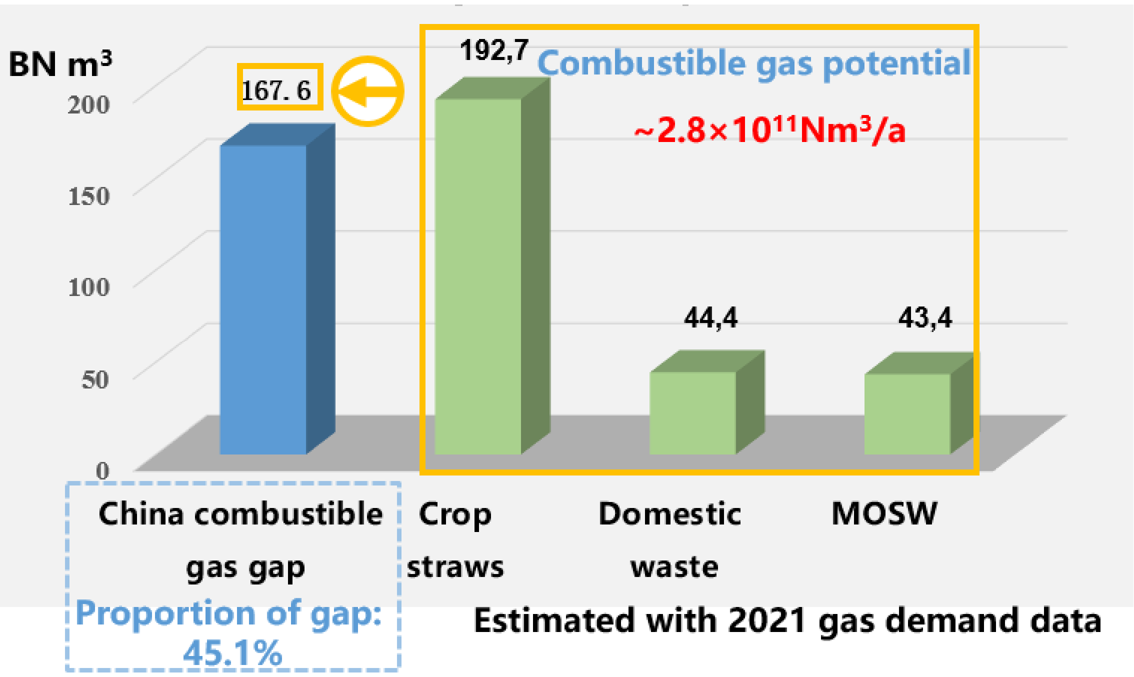


Figure 38: Comparison of combustible gas gap and biomass gasification potential

As a novel gasification concept the coupling of anaerobic digestion with gasification can be seen. There are several advantages:

- Conversion efficiency is improved
- Digestate is further utilized
- The tar content is reduced
- Gas applications are extended

Research updates:

Ash fusibility

- Ash fusion point （1180°C） of biogas residue is much higher than the maximum monitored temperature（1000°C） of oxidation section in gasifier chamber
- Biogas residue ash is soft, easy to pulverize; no slag is formed during air GS of biogas residue at 600~800°C, technically feasible

Effect of gasification temperature

- High temperature enhances endothermic reaction, promoting the formation of combustible components（H_2+CO）
- High temperature enhances tar cracking, reducing tar content
- GS effect is best at 800°C, LHV=4.78MJ/Nm^3 CGE=67.01% Tar=3.34g/Nm^3

Effect of ER

- The effect of ER on the GS characteristics of biogas residue is nonlinear (Oxygen supply is a function of ER & Temperature & N2 is diluted as ER increasing)

- ER=0.3, violent oxidation, high temperature enhances tar cracking, Tar=1.61g/Nm^3 (1/3 conventional biomass)
- Low tar content and improved H_2/CO of biogas residue GS are of great application value
- GS residue: limited specific surface area（24.28m2/g）， a large content of inorganic components（49.54%）. Not suitable for carbon adsorption material or activated carbon precursor, but suitable for soil organic fertilizer.
- GS residue is rich in P：Slow release、Match the growth rate of crop、Reduce the risk of eutrophication

Future perspectives and outlook of gasification were presented.

Gasification at TJU and TJCU

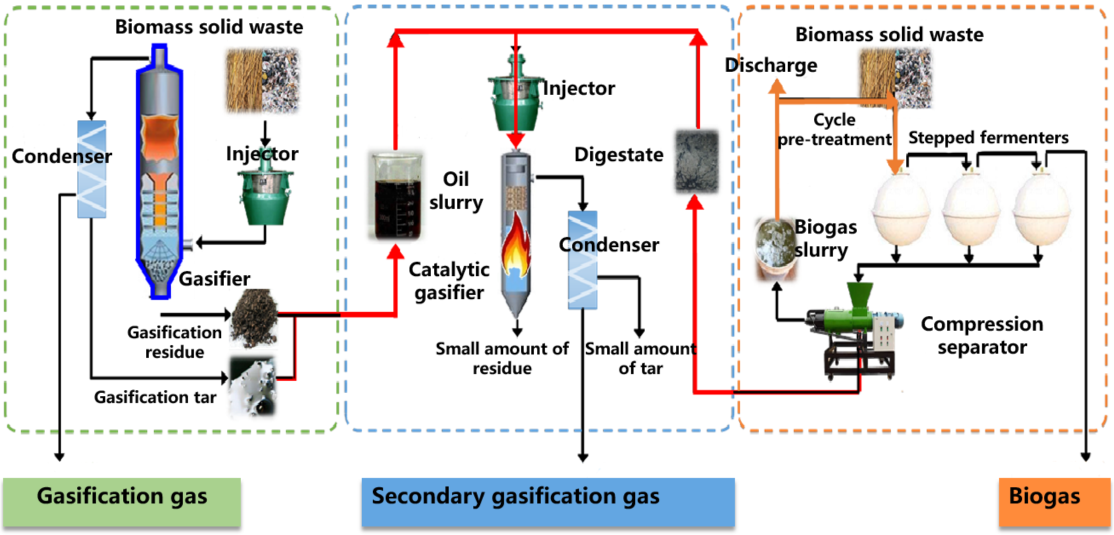


Figure 39: New type clean gasification for multiple biowaste

Conclusions

The thermochemical gasification offers several benefits. It is suitable for a broad variety of feedstock, 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 valuable (by-)products were in focus during the workshop, several pathways for production of biofuels, biochemical or renewable power and heat were presented. Furthermore, the coupling of biomass gasification with anaerobic digestion for better efficiency was presented.

The gasification technology will play a significant role in energy transition, where no place for fossil fuels will be left over. 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.[1]

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[1] www.task33.ieabioenergy.com,
http://www.ieatask33.org/content/home/minutes_and_presentations/2022_Oct_WS

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Technology Collaboration Programme