IEA Bioenergy

# Waste gasification

Aston University, Birmingham, 26. Nov. 2019

## Workshop Report

IEA Bioenergy: Task 33: 01 2020

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## INTRODUCTION

Gasification is a technology that is widely applied for the production of heat and power. Many developments focus on utilizing low-quality feedstock in order to improve business cases, as well as providing solutions for emerging problems. Waste (biogenic) is a major global challenge today, especially waste containing plastic. As incineration and land-filling becomes more and more unpopular, gasification is gaining momentum and the number of solution providers in this area is growing. Furthermore, waste gasification is more complex than using clean biomass, and therefore requires new R&D.

## SPEAKERS

P. Thornley, Supergen Bioenergy Hub
H. Stone, REA
J. Isaksson, Valmet
J. van Leeuwen, Synova
P. Winstanley, ETI
M. Johnson, KEW
J. Maric, Chalmers
C. Mourao Vilela, TNO
M. Materazzi, UCL
C. Pfeifer, BOKU
Fanxing Li, NCS University

## GOAL

The goal of the workshop is to share new knowledge, status and ideas about waste gasification.

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# Introduction

Gasification is generally acknowledged as one of the technologies which enable production of heat and power, biofuels and chemicals from biomass and/or waste. Waste in this respect is the combination of biogenic and plastic residues (as can be found in municipal solid waste) or biogenic residues (agricultural residues). Especially the first stream is of increasing interest, since incineration and/or landfilling are under increasing scrutiny. Gasification is a solution to this waste problem, as the waste could be used as a feedstock for the conversion into valuable products on one hand and to avoid incineration or landfilling on the other way.

The workshop provided a good overview on how waste is being managed by different technology providers. It showed that from small to large scale, solutions exist that allow at first the production of heat and power. From the R&D part of the workshop we learned that there is value to be created from waste, through new innovations. Aromatics and olefins being the first components that stand out in the gas mixture after waste has been gasified.

The combination of waste gasification to produce heat and/or power in combination with the production of base chemicals is something we will see further developing in the coming decade.

Presentations details can found on the Task 33 website:

http://www.ieatask33.org/content/home/minutes_and_presentations/2019_Nov_WS/

## Rationale for gasification in the UK

P. Thornley, Supergen Bioenergy Hub

The structure of Supergen Bioenergy Hub can be seen below. There are four topic groups:

1. Resources
2. Pretreatment
3. Vectors
4. Systems

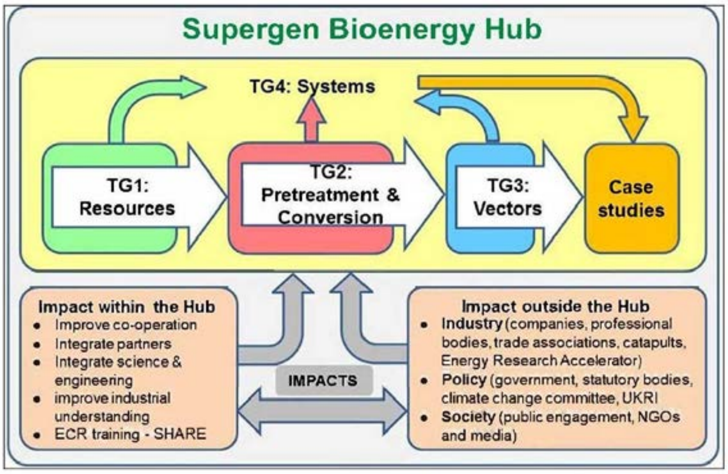



Figure 1: Supergen Bioenergy Hub - structure

Topic group "Resources" focuses on biomass and waste for energy and transport fuels and searches for the answers how the biomass can be grown on lower grade land, make crops more resilient to extreme weather events, and deliver ecosystem services.

The aim of the group "Pre-treatment and Conversion" is to find interface between biomass and its conversion and the important interactions.

The group "Vectors" identifies preferred bioenergy pathways that will produce appropriate bioenergy vectors to meet the UK's demands and aims to reduce emissions, reliance on fossil fuel and improve national and regional resilience through bioenergy.

Topic group "Systems" focuses on Role and impact of bioenergy on the current and future energy system and interfacing sectors, and its implications for the UK's policy objectives (eg, climate change, sustainability, land use, ecosystem services, waste and circular economy, regional and international development).

Bioenergy offers a several ways for production of electricity, heat, chemicals or transport fuels as can be seen in the figure below.

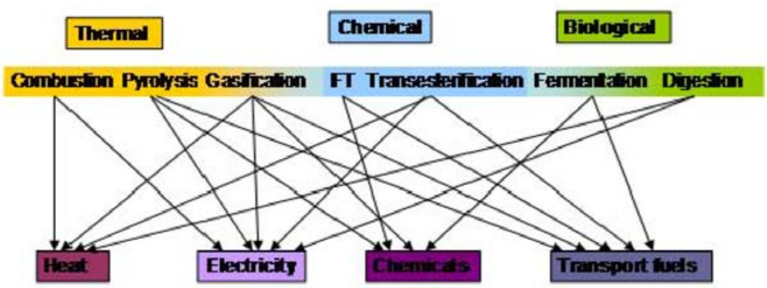



Figure 2: Bioenergy range of pathways and products

Potential of bioenergy in UK is as following:

- Up to 45% of UK bioenergy demand
- 10% electricity (baseload)
- 50% heat (industrial, district, gas)
- 20% liquid fuels (aviation, shipping, heavy duty/mobile plant)

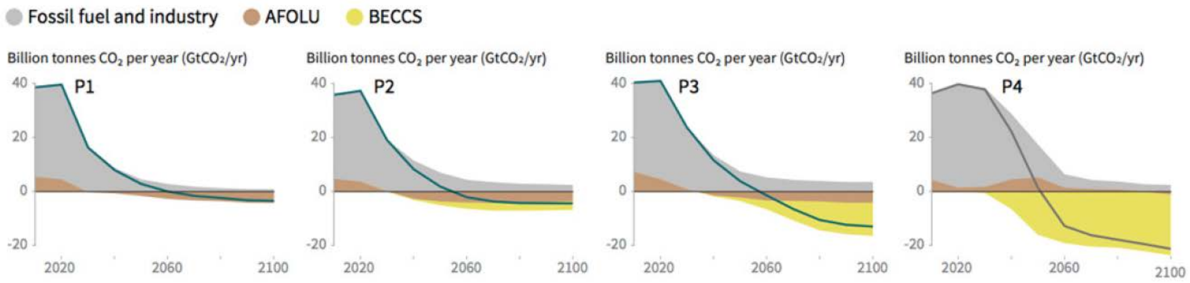



Figure 3: Breakdown of contributions to global net $CO_2$ emissions in four illustrative model pathways

Bioenergy is particularly valuable in achieving future GHG/climate targets because of its ability to sequester carbon dioxide from atmosphere.

## Gasification: an industry perspective

H. Stone, REA

REA Gasification and Pyrolysis Working Group was founded in 2010 and consists of technology providers, Project developers, owners, operators and others making energy from waste (EfW) projects a reality in the UK incorporating gasification and pyrolysis.

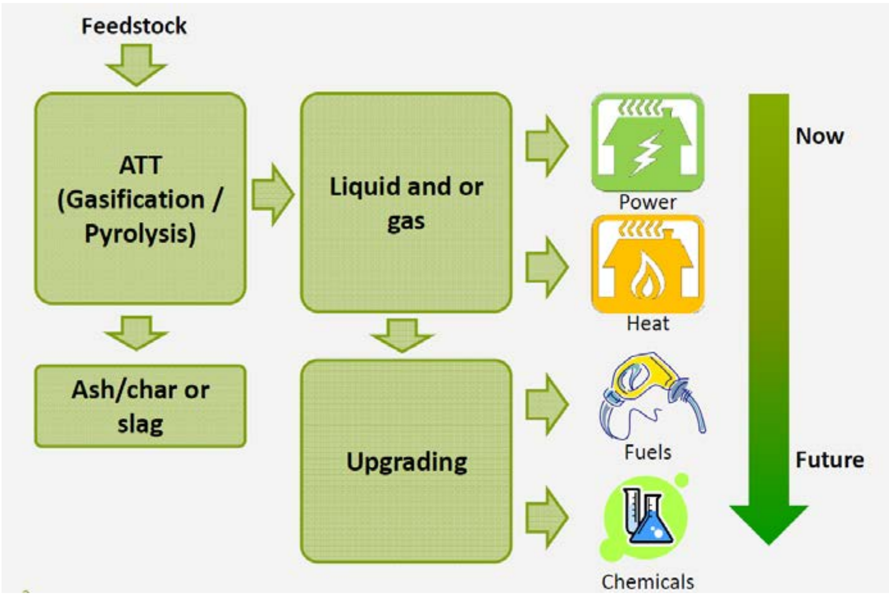



Figure 4: Energy recovery process and purpose 2011

REA was originally focussed on electricity production, now it is looking toward development of biofuels.

The electricity production became harder for the producers because of many reasons as e.g. policy uncertainty and investment risk. On the other hand, production of biofuels offers following:

- The Renewable Transport Fuel Obligation requires obligated suppliers to supply 10.637% sustainable biofuel pa by 2020 (4.987% in 2018)
- Compliance is demonstrated through a mixture of redeeming Renewable Transport Fuel Certificates (RTFCs) and/or by paying a fixed sum (currently £0.30) for each litre of fuel for which they wish to 'buy-out' of their obligation.
- RTFCs are obtained by obligated suppliers through the supply of renewable fuels.

Other way is also bioenergy with carbon capture and storage, thus the REA recommends increasing the UK total carbon price to around £50t/$CO_2$ from 2020 with a clear trajectory to at least 2035 in order to promote rapid emission reductions.

The UK should also explore a mechanism which rewards negative emissions, such as tradeable negative emissions allowances under a domestic emissions trading scheme.

Finally, the UK should incentivise the deployment of demonstration projects at several scales that prioritise the use of lowest carbon feedstocks whilst making BECCS plant eligible for support under existing UK policy, such as the Contracts for Difference (CfD) mechanism.

## Valmet CFB gasifier

J. Isaksson, Valmet

In Vaskiluodon Voima Oy Gasification Project Valmet realized the substitution of existed coal fired power plant by biomass.

Existing 560 MW coal-fired power plant was adjoined with a 140 MW biomass gasifier and dryer. Up to 40 percent replacement of coal by local fuel sources. Contract was signed in June 2011 and in December 2012 the plant was operational. Commercial operation was from 2013.

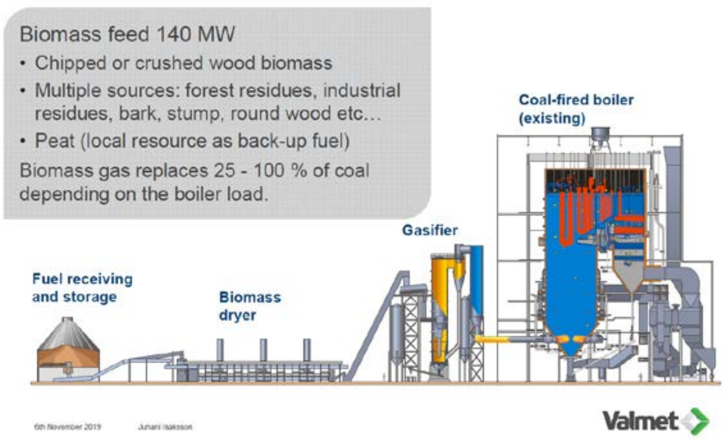



Figure 5: Vaskiluodon Voima Oy Gasification Project

The waste gasification was the focus of another Valmet project named Kymijärvi II - Waste Gasification plant. It is the world´s largest waste gasification power plant in operation (start up 2012), it processes 250 ktpa of waste fuels (RDF & contaminated wood) to produce:

- 50 MW of electricity
- 90 MW of district heat
- CHP efficiency of 87,5 %
- Total investment ~ 160 M €

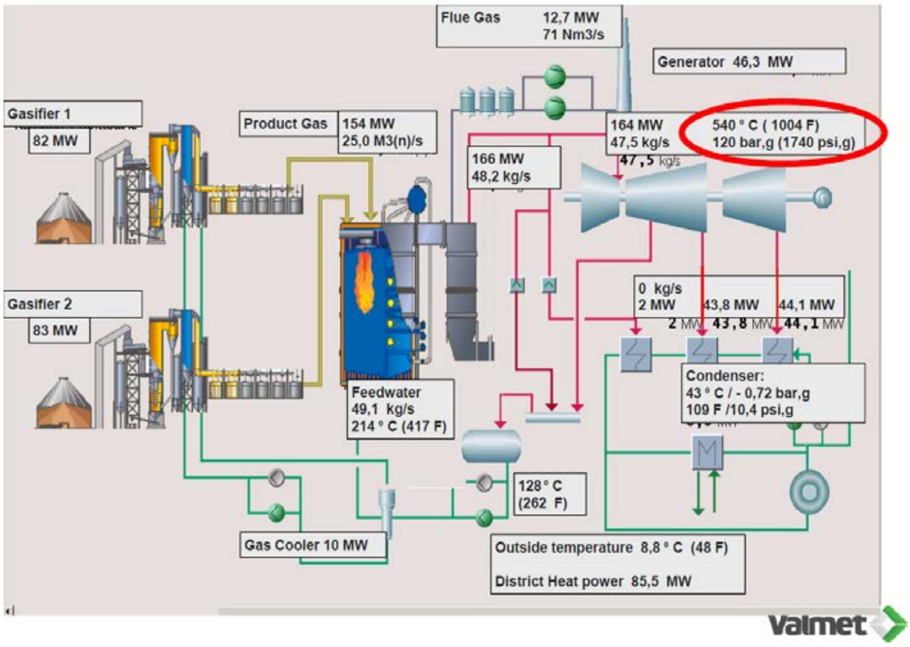



Figure 6: Waste gasification Kymijärvi II

Valmet focuses also on CFB gasification in large scale. Capacity range can be seen below.

| Capacity Range | |
|---|---|
| Size | 20 – 140 (300) $MW_{th}$ |
| Fuel | Biomass, waste (RDF) |
| Gasification media | Air |
| Operating temperature | 750 – 900 °C |
| Operating pressure | 5-30 kPa(g) |
| Gas heating value | 3-7 $MJ/nm^3$ (LHV) |
| Applications | • RDF/SRF gasification for power generation<br>• Biomass gasification for power generation<br>• Biomass gasification for industrial furnaces |

6th November 2019

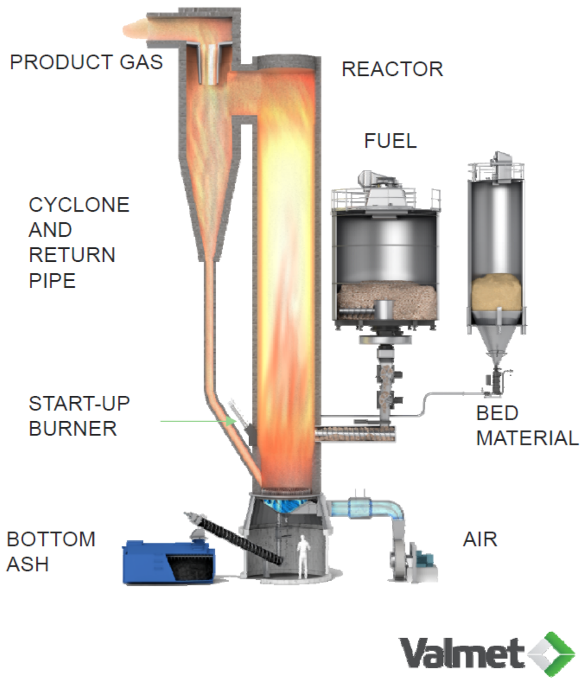



Figure 7: CFB gasifier by Valmet

Valmet CFB gasifiers can be used in following applications:

Product gas for industrial kilns

for power boilers

for power production

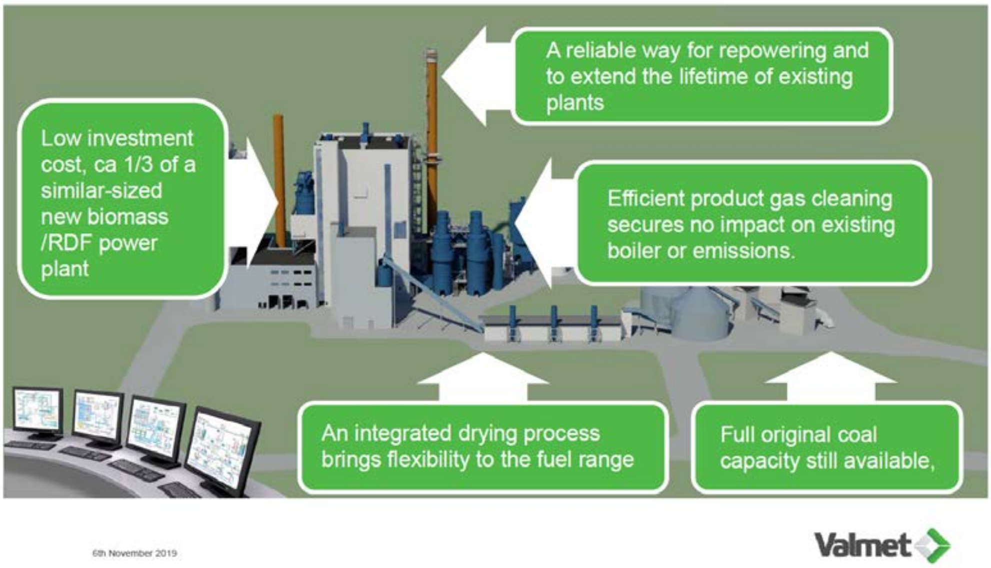



Figure 8: CFB gasification benefits

## Synova renewable technology: Building a pure world

J. van Leeuwen, Synova

The gasification technology of Synova is based on MILENA fluidized bed gasification and OLGA (oil based gas cleaning)

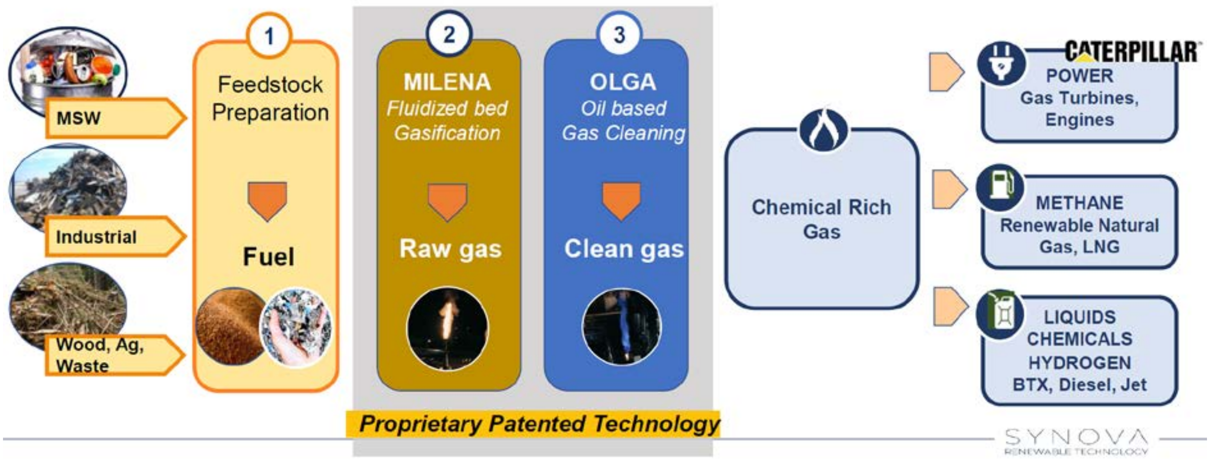



Figure 9: Synova conversion chain

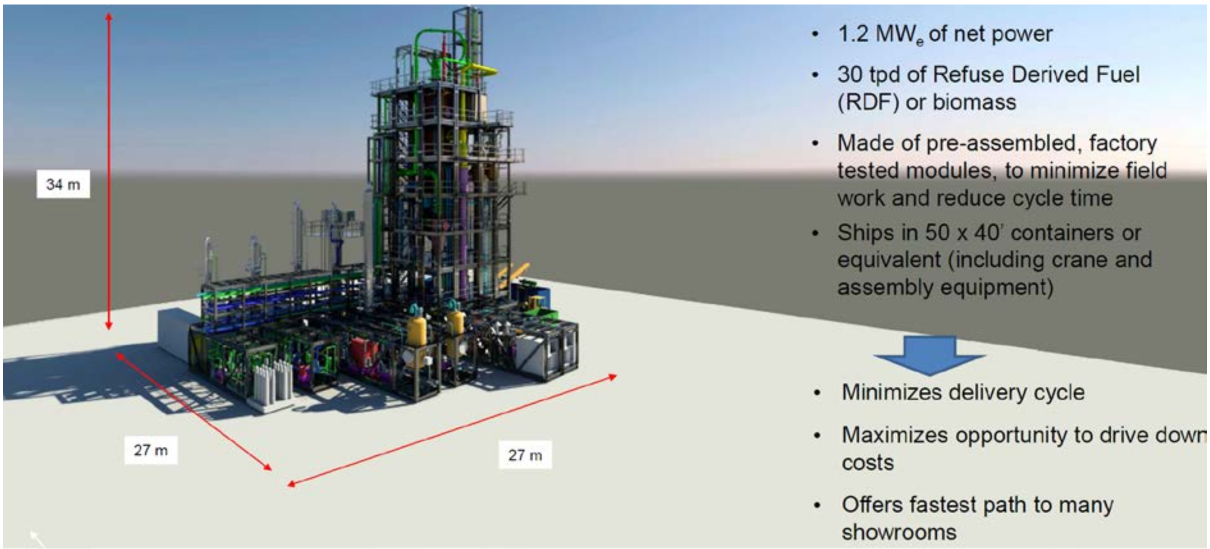



Figure 10: Standard Modular MILENA

**Cost-effective to harvest vs synthesize**

- MSWhas 40%-50% carbon from plastic today
- Chemical recycling uniquely preserves molecules vs previous alternatives
    - Chemicals like BTX can be isolated
    - Virgin plastic feedstocks can be harvested
- Capital efficient path to a “circular economy”

“If global waste were converted to chemicals, it would be equivalent to 30% -40% of all petrochemical / plastics production”

Synova potential is to generate $ 70-350 of value per ton of household waste and save $ 50-150 of cost/ton of disposing MSW as well as vert 0,5-4 tons of $CO_2$ per ton waste.

## Delivery and establishment of the first UK commercial scale plant to deliver ultra clean syngas

P. Winstanley, ETI

The ETI is a public-private partnership between global energy and engineering companies and the UK government.

Waste gasification project:

- Construction of a 1.5 MWe demonstration project
- Feedstock –mix of C&I and MSW
- Fluimax pressurised fluidised bed gasifier with a high temperature treatment to produce a high quality, hydrogen rich syngas
- Power generation via a specially adapted syngas engine
- Will incorporate unique syngas testing facility
- Commissioning 2019 2020 –followed by feedstock testing

## 3rd Generation gasification

M. Johnson, KEW

KEW´s vision is to play a substantive role in the sustainable energy revolution by enabling the high-efficiency conversion of wste and biomass into valuable energy products, whilst utilising waste heat.

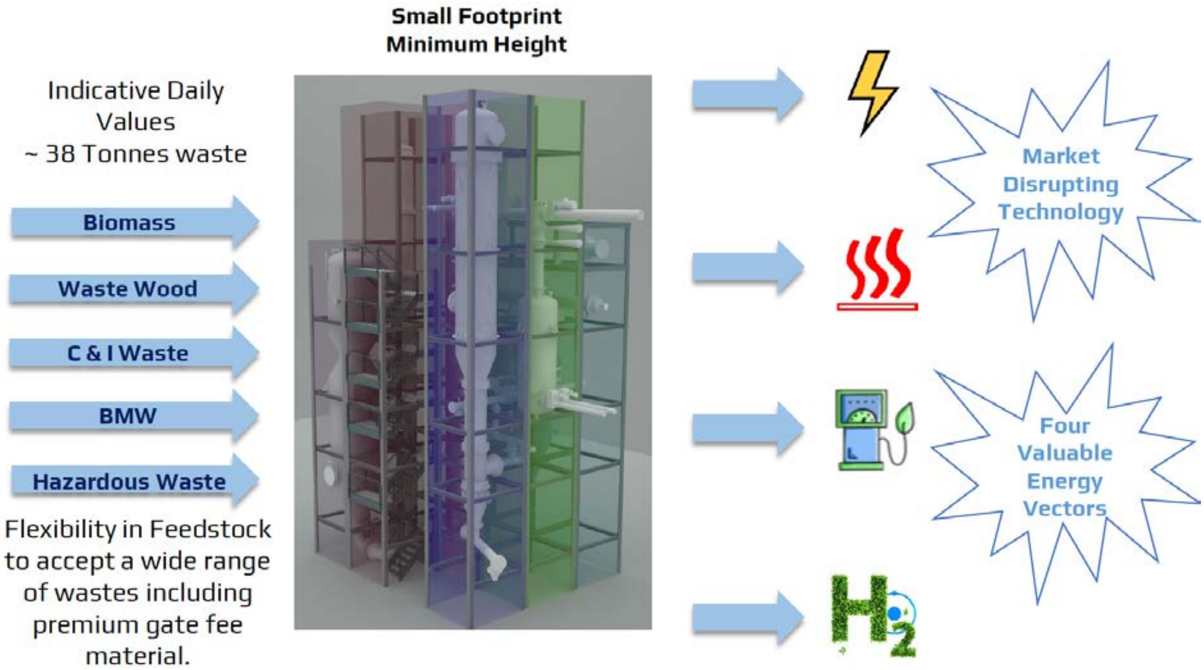



Figure 11: KEW plant

First continuous operation high-efficiency waste to power and heat plant will start the operation during 2020.

- 15,000 tonnes p.a. waste
- 2 MW electrical output
- Heat to local users Heat to local users Heat to local usersHeat to local users Heat to local users Heat to local usersHeat to local users Heat to local users
- Centre of excellence: addition of other technology technology demonstrations:
    - Fuels
    - Chemicals
    - $H_2$
    - Hydroponics

## Valorization of plastic waste via gasification – Chalmers experience

J. Maric, Chalmers

The presence of contaminants and additives complicates the mechanical recycling of plastics, down-grading the produced products and/or requiring the use of virgin materials. In Sweden, where advanced collection and sorting systems already exist, 51% of the 1600 kt of PW handled in Year 2017 was in the form of unsorted streams, which are not suitable for mechanical recycling.

Thermochemical recycling: can build an upgrading bridge between PW streams and a phase of new use. The increase in value of the carbon atom in the PW, compared to that obtained using any other existing recycling route, such as mechanical recycling, where the new use phase is ensured, albeit with a product of lower quality.

Using the Chalmers gasifier polyethylene, automotive shredder residues and cable waste were tested.

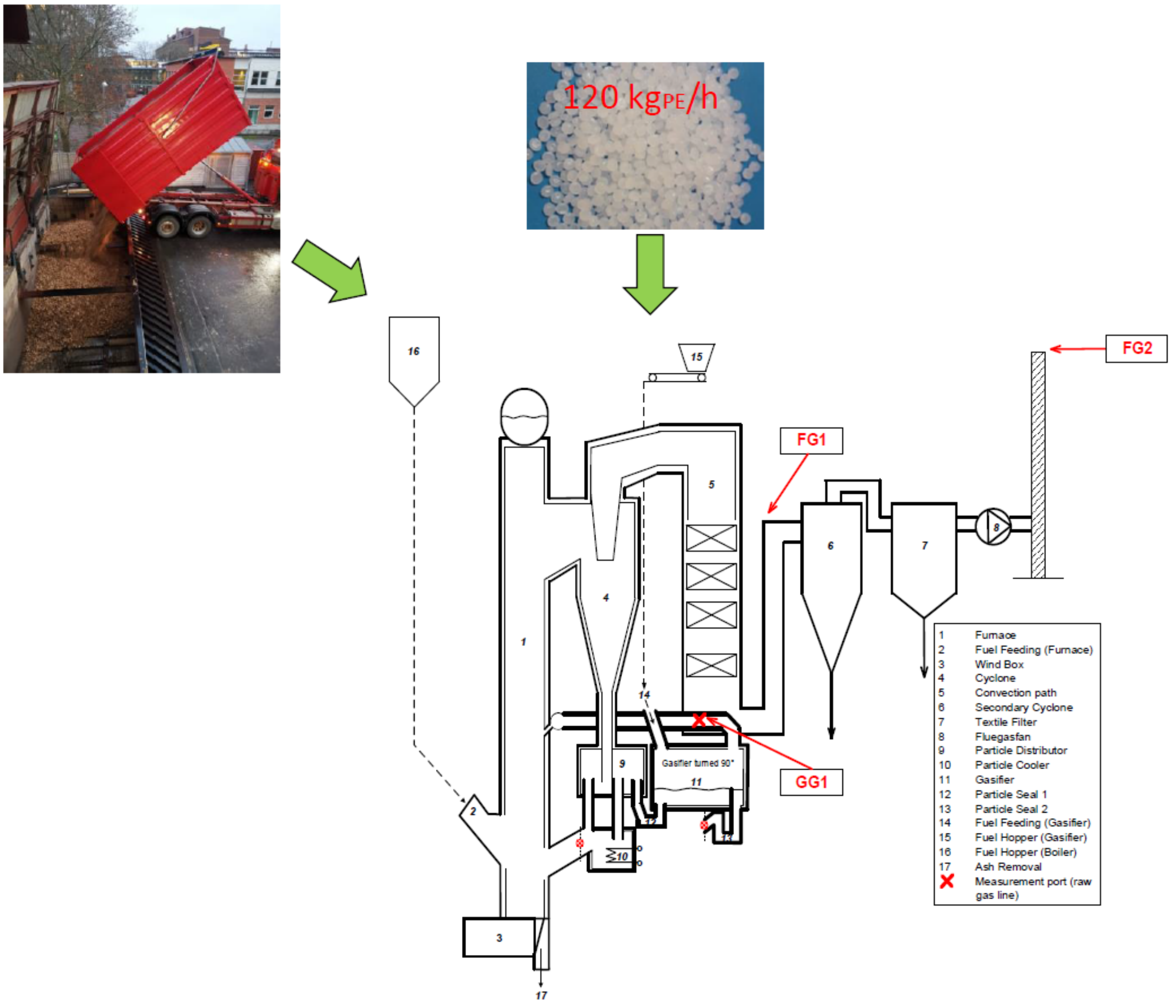



Figure 12: Gasification of polyethylene at Chalmers

Table 1: PE tests

| Polyethylene tests (PE) | |
|---|---|
| Operational conditions | Results |
| • Fuel feed: 120 kg/h<br>• Temperature: 655-780°C<br>• Steam feed: 160-220 kg/h<br>• Active olivine bed used in the process | • Carbon balance closure showed significant yield of non-measurable fraction (aliphatic species ≥ 4 )<br>• High olefin content in the produced gas<br>• At a higher temperature (780 °C), the olefin yield decreases, mainly in favour of CO and CO2<br>• High percent of total measured tar is BTXS fraction |

Table 2: ASR tests

| Automotive shredder residues tests (ASR) | |
| --- | --- |
| Operational conditions | Results |
| • Fuel feed: 390 kg/h<br>• Temperature: 775-840°C<br>• Steam feed: 160-220 kg/h<br>Olivine bed used in tests | Closure of the carbon balance showed significant yield of nonmeasurable fraction (aliphatic species ≥ C4 and fixed carbon)<br>• High CO2 content in the produced gas<br>• No significant change with temperature change<br>• High levels of aromatic hydrocarbons were detected in the gas, with 60% of these compounds being considered as valuable products for the chemical industry<br><br>The application of catalytic bed materials, such as olivine, does not confer additional benefits on the gasification of ASR, and the same is likely to be true for any other ash-rich fuel<br>• No agglomeration of the bed even after 3 weeks of the process operation without bed regeneration |

Table 3: CPW tests

| Cable plastic waste tests (CPW) | |
| --- | --- |
| Operational conditions | Results |
| • Fuel feed: 190 kg/h<br>• Temperature: 735-800°C<br>• Steam feed: 160 kg/h<br>• Silica-oxide based bed | Under evaluation |

Table 4: Products distribution

| ***Wt %*** | ***PE (780C)*** | ***PE (655C)*** | ***ASR (840C)*** | ***ASR (790C)*** | ***Naphta*** |
| --- | --- | --- | --- | --- | --- |
| Methane | 12 | 10 | 6 | 7 | 17 |
| H2 | 4 | 2 | 2 | 2 | 1 |
| Olefins | 28 | 48 | 8 | 11 | 44 |
| BTXS | 5 | 9 | 9 | 10 | 15 |
| Total others* | 52 | 31 | 75 | 71 | 24 |
| ***Of which:*** | | | | | |
| *Other aromatics* | *1* | *13* | *5* | *7* | |
| *Other C2-3* | *4* | *6* | *1* | *1* | |
| *CO* | *10* | *6* | *9* | *9* | |
| *CO2* | *37* | *6* | *61* | *54* | |

Product distribution (% wt. in the identified cracking products). Dry gas composition free of aliphatic hydrocarbons ≥ $C_4$, due to measurement limitations
*Includes aromatics other than BTXS, CO, CO2 and C2–3 alkanes/alkynes.

Summary:

The composition of the cracking products produced by steam cracking of PE and ASR in the Chalmers DFB system is comparable to the typical gas composition obtained from a naphtha/alkane cracker.

The yield of olefins is clearly dependent upon the type of feedstock applied and the operating temperature.

At 655 °C, the concentration of olefins in the product gas derived from PE is similar to that derived from naphtha cracking; at a higher temperature (780 °C), the olefin yield decreases, mainly in favour of CO and CO2.

The yield of carbon oxides is one of the most remarkable differences- possibly due more intensive gasification and steam reforming of the hydrocarbons in the DFB system, which was not optimised for olefins production, due to, for example, the higher residence time of the gas and the presence of catalytic olivine.

## Gasification of end-life plastics

C. Mourao Vilela, TNO

Plastic waste was tested using MILENA gasification unit, OLGA tar removal and AREA (BTX scrubber). The experimental set up can be seen in the figure below.

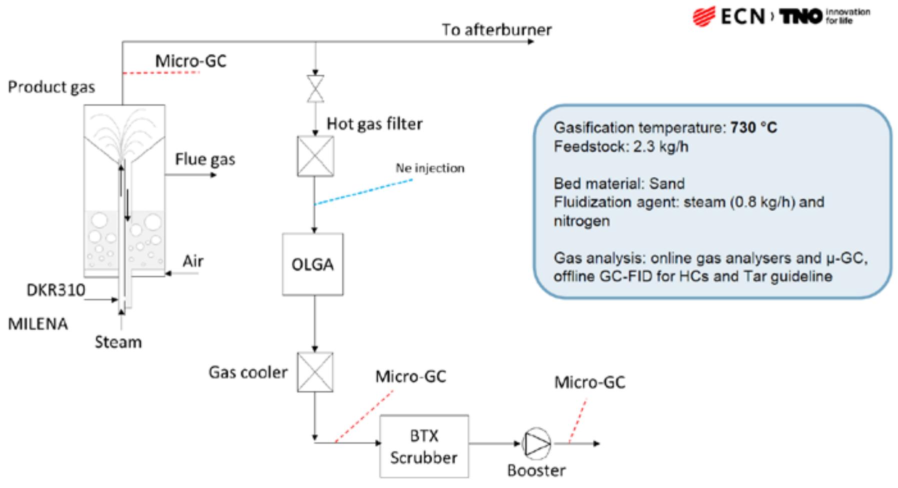



Figure 13: Eperimental setup

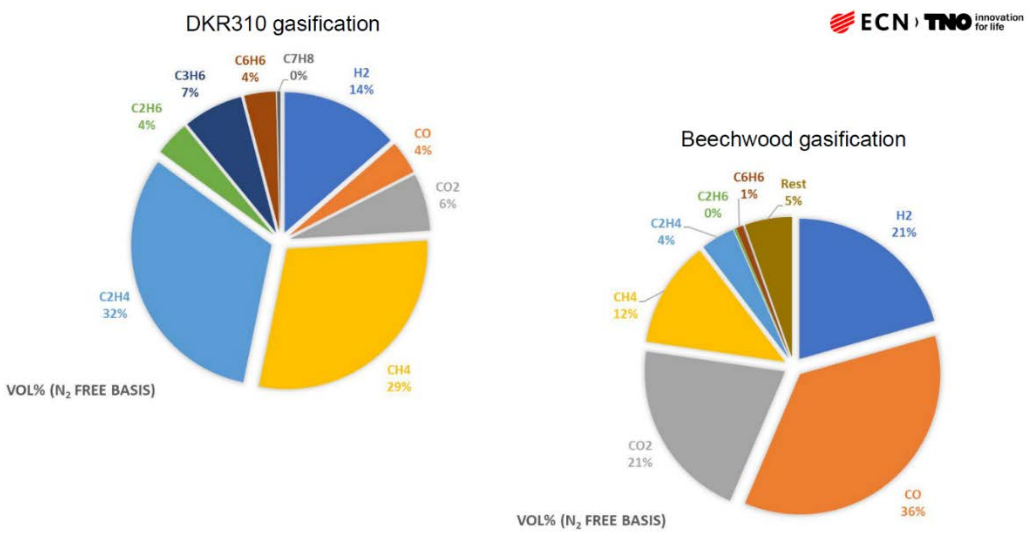



Figure 14: Product gas composition – comparison end-of-life plastic (DKR310) and beachwood

Conclusions:

- The main components in the product were ethylene and methylene
- CO and $CO_2$ presented in low amounts, accounting for about 5 wt% of the initial carbon
- Almost 10% of the initial carbon converted into benzene
- Close to 99% of BTX removal from the product gas achieved

## Recent advances in plasma-assisted gasification for waste-to-fuel applications

M. Materazzi, UCL

Challenges by gasification of waste:

- Agglomeration risk
- High tar content
- Organic suphur
- Increase rates of ash deposition in the ducts and on heat transfer surfaces

Stratified” conversion: volatile matter mostly released above the bed and bypassing bed solids:

• loss of beneficial effects of bed solids as thermal flywheel

• prevalence of “flaming” over “flameless”

• reaction loss of potential catalytic effects of bed solids (e.g. tar cracking)

• burn-out of fine particles in the freeboard/upper riser, higher conversion

Plasma assisted gasification:

- Formed by DC or AC electric arcs, radio-frequency or microwave electromagnetic fields
- Highly ionised (typically 100%, at least 5%)
- Strong radiative emission
- Local Tgas = 2,000-20,000K (close to equilibrium)
- Highly electron density (~1023 m-3)
- Very widely used in manufacturing and other industries (ash smelting, metal recovery, etc.)
- Quick start-up, possibility to couple with renewable electricity

The plasma used in combination with fluidized bed gasification offers several advantages:

- Applies plasma energy to transform traditional char and tars from FBGs to clean, simple syngas components (H2 + CO)
- Possibility to operate at optimal Equivalence Ratio (staging the oxidant stream)
- Independent optimization of each operation
- Captures and vitrifies most of the ash generated from the FBG, producing an non-leachable,
- mechanically strong product that can be used as an aggregate material

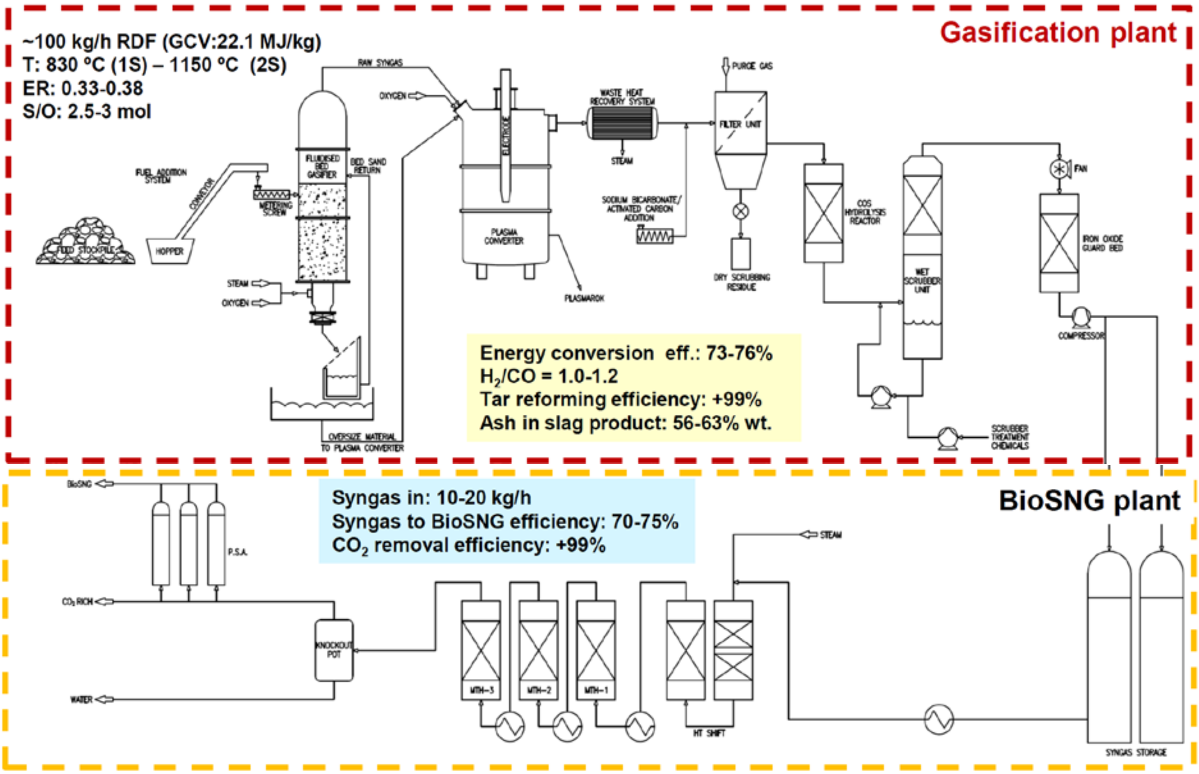



Figure 15: Pilot plant configuration

Project progress

- Construction and mechanical integration almost completed
- Single units commissioning undergoing
- Team of 20 to operate plant following completion of commissioning.
- Operating manuals currently being produced based on experience from pilot plant, supplier information and experience in other waste to energy plants
- Delivery of 1 million kilogrammes of BioSNG in 2020

Conclusions

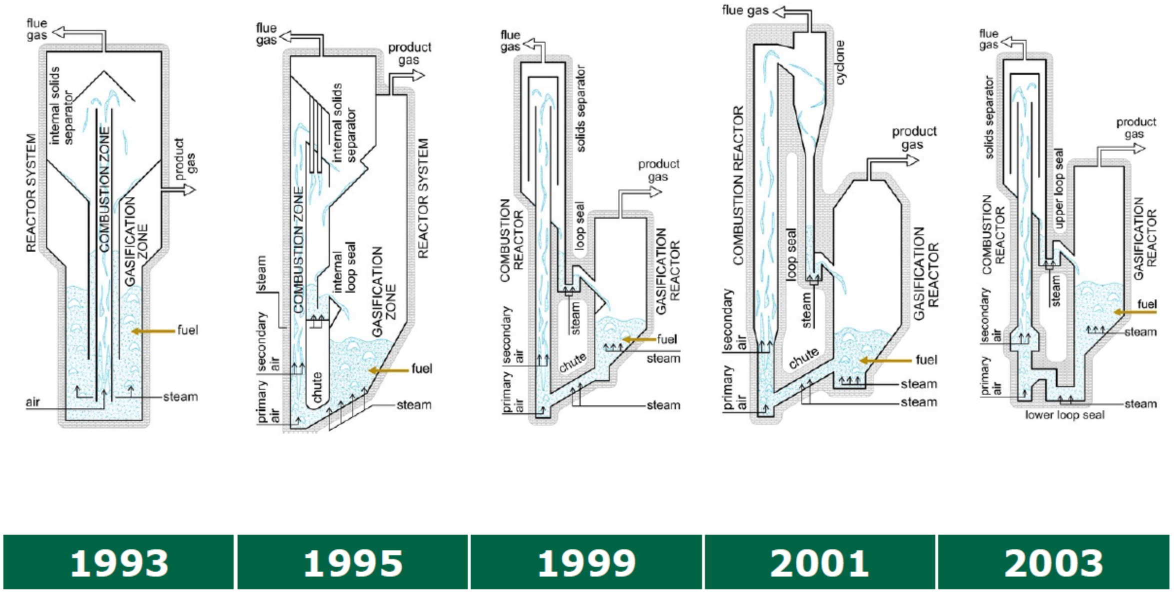
- Waste derived fuels are very complex materials that need extensive understanding of the physical, chemical, and thermochemical behaviour.
- FBG(indirect or directly heated) can accommodate a wide range of feedstock but need adequate control and ad hoc design requirements for specific applications.
- Plasma in multiple stage processes is proven efficient for tar reforming and ash inertization, with relatively limited parasitic load (when compared to single stage plasma)
- Successful demonstration of methane production from waste, at the design output of 50KW. This endorses several key strategic technical approaches:
    - o The importance of producing a high-quality true ‘synthesis’ gas from the onset
    - o Simplified catalytic processes

## Waste gasification in Austria

C. Pfeifer, J. Hrbek, BOKU

Since many years the gasification of waste has been a focus of research projects in Austria.

At Vienna University of Technology, a dual fluidized bed has been developed, where different materials have been tested.




Source: Schmid J.C. 2016

Figure 16: Development of dual fluidized bed gasifier at Vienna University of Technology

An important issue by gasification of waste is fouling and slugging inside the gasifier which causes disturbances in the fluidized bed.

Thus also ash behaviour was a topic of many research projects such as projects VergRestWert or Flash.

In Austria, company Syncraft focuses on gasification of waste wood in the floating fixed bed gasifiers. The results of the tests should be known with the beginning of 2020.

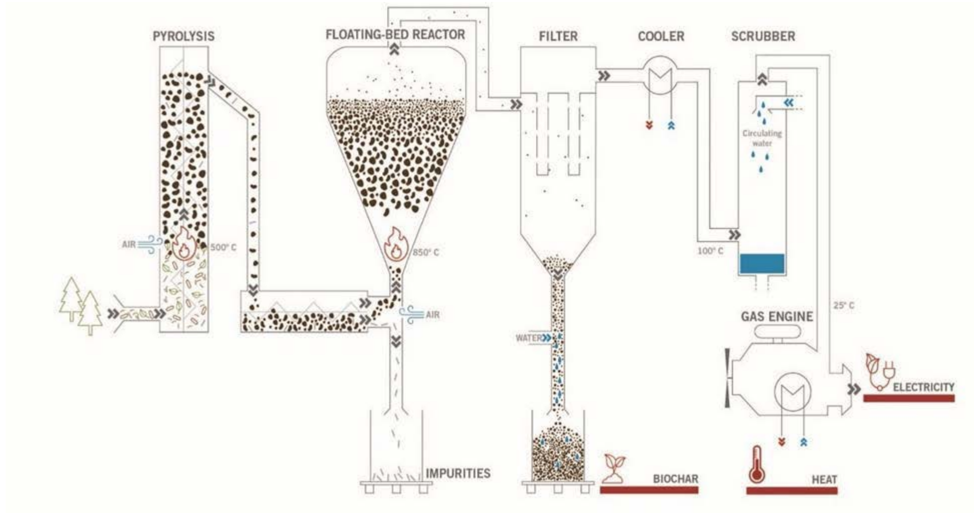



Figure 17: SynCraft technology

GET (Güssing Energy Technologies) has been developed a municipal garbage gasification technology with Tough Gas Gasifier, which should be installed in China.

The gasifier should process 50 t per day of municipal waste with 40% water content.

Estimated performance of the gasifier:

- Gas amount: 1500 –2000 $Nm^3/h$ with a heating value of about 6 $MJ/Nm^3$
- Heat capacity of the fuel: 4 MW

- Electrical Output: 1 MW
- Thermal Output: 2-2,5 MW

Investment costs:

- Tough Gas gasifier (incl. primary gas cleaning unit and burning in combustion chamber –without heat utilization!) about 7-9 Mio. EUR
- Gas utilization with CHP gas engine about 2-3 Mio EUR

BEST together with Wien Energie is constructing a 1 MW DFB gasification and FT synthesis unit. The construction should start in 2020 and operation in 2021. The project name in Waste2Value.

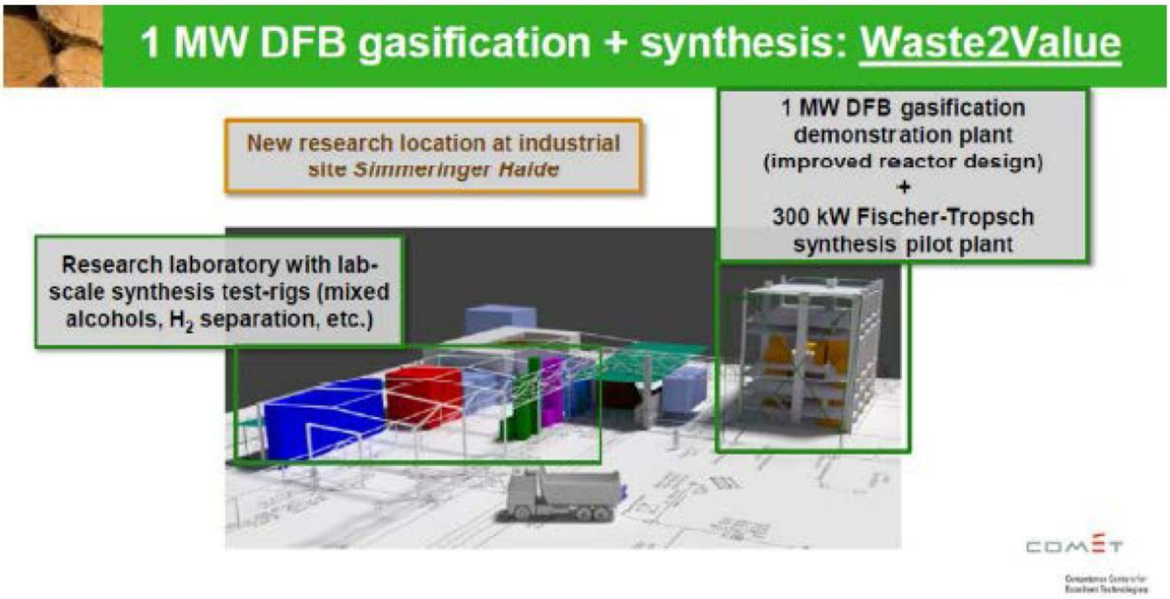
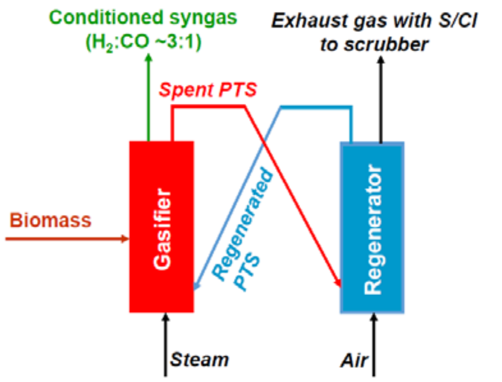



Figure 18: Waste2Value project

## Renewable natural gas from carbonaceous wastes via phase transition $CO_2$ / $O_2$ sorbent enhanced chemical looping gasification

Faxing Li et al., NCS University

Intensified sorbent enhanced chemical looping Gasification (SE-CLG) using circulating fluidized bed integrates together biomass gasification, air separation, and syngas conditioning and cleaning. Production of syngas with H2/CO ratio of 3:1, what is ready for methanation.




Gasifier: $C_nH_mO_x + SrFeO_3 \rightarrow SrCO_3 + FeO/Fe + CO + 3H_2$ ($\Delta H$ = -14 kJ/mol $H_2$)

Regenerator: $SrCO_3 + Fe/FeO + Air \rightarrow SrFeO_3 + CO_2 + N_2$ ($\Delta H$ = -150 kJ/mol $SrFeO_3$)

Figure 19: Sorbent-enhanced chemical looping gasification (SE-CLG)

Project objectives:

- Develop phase transition sorbents (PTSs) for biomass gasification with integrated air separation and $CO_2$ sorption
- Demonstrate ash and contaminants resistance of PTS for C&D waste and poultry litter feedstock
- Design, construction and demonstration of 5 kW CFB gasifier to produce clean and conditioned syngas from biomass
- Validate >35% reduction in LCOE comparing to steam gasification process

Technical approach is divided into 3 years:

Year I: Collect, characterize, and pretreat biomass waste feedstocks. Design, characterize and optimize PTS for SE-CLG. Perform preliminary process and cost analysis.

Year II: Demonstrate robustness of PTS for various biomass wastes including poultry and C&D wastes. Design and construct a 5 kWthCFB based SE-CLG gasifier.

Year III: Synthesize 20 kg batches of PTS sorbents. Demonstrate a 5 kWthCFB to produce methanation ready syngas for 100+ hours. Perform detailed techno-economic and life cycle analyses.

Market transformation plan

- RNG cost from SE-CLG technology including byproduct (i.e., fertilizer via chicken litter pretreatment and electricity co-product) credits is estimated as $2.39/mmBtu, competitive to conventional natural gas prices
- Aim to either enter a joint technology development agreement with commercial partners (candidates include Duke Energy and Aries Clean Energy) or license out the technology
- Demonstrate auto-thermal, long term operation of the SE-CLG gasifier (4 –7 year timeline) prior to full-scale commercialization

## Summary

The state-of-the-art thermal treatment technology is waste incineration with energy recovery to mainly power, i.e. a thermal power cycle composed of combustion of the waste to generate steam used to drive a steam turbine generator (often denoted waste-to-energy, WtE). There are on the order of some two thousand such installations world-wide of which maybe one hundred are using various gasification technologies*.

Waste gasification is a promising way for waste disposal and production of power/heat, biofuels and chemicals.

During the workshop, waste gasification projects and developments in UK, Finland, the Netherlands, Sweden, Austria and USA were presented.

All presentations can be found at the Task website:

http://www.ieatask33.org/content/home/minutes_and_presentations/2019_Nov_WS/

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- L. Waldheim: Gasification of waste for energy carriers