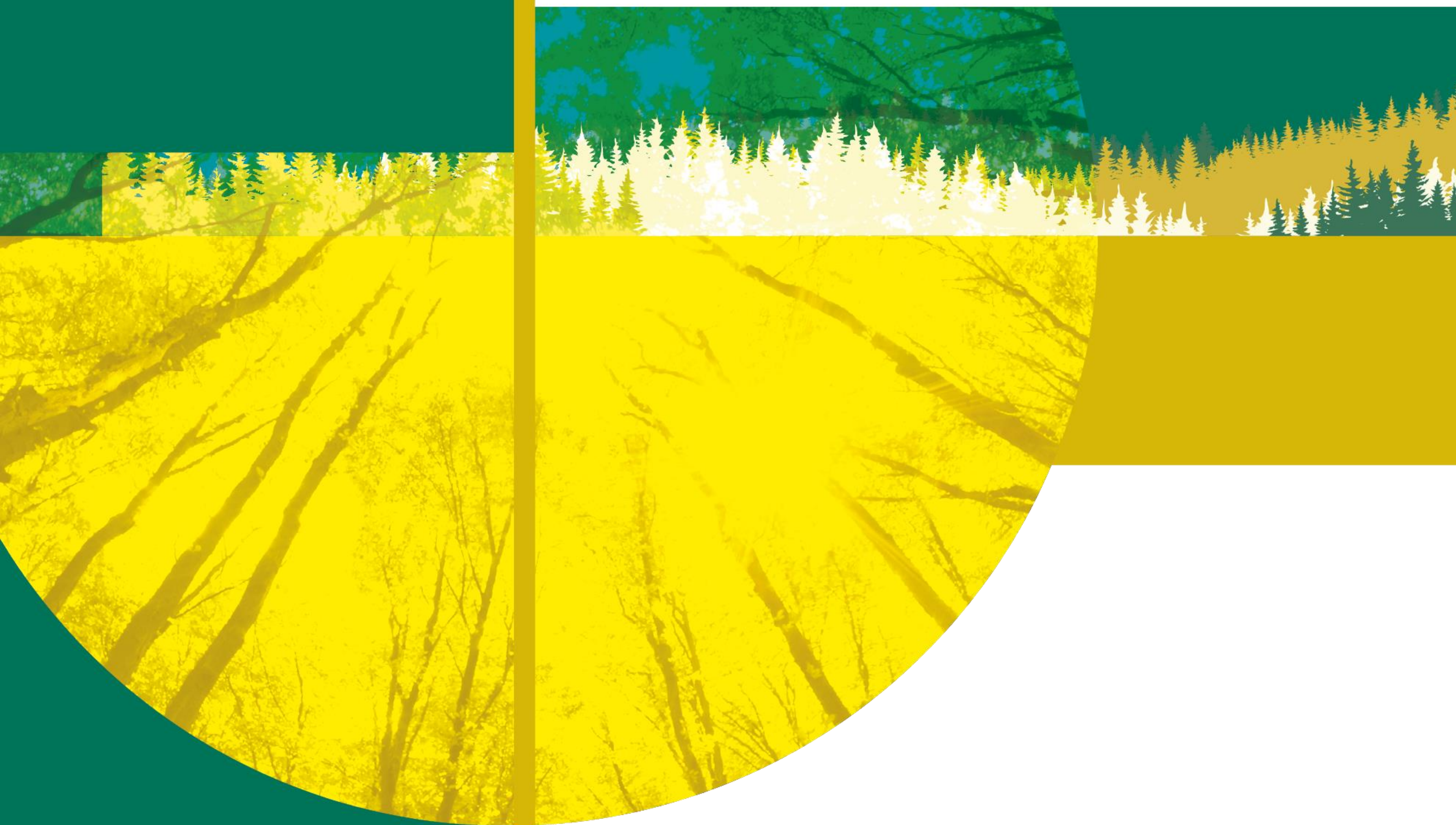
Status report on thermal gasification of biomass and waste 2019

IEA Bioenergy Task 33 special report



IEA Bioenergy

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Status report on thermal gasification of biomass and waste

IEA Bioenergy Task 33 special report

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Abstract

In order to monitor the status of thermal gasification in IEA Bioenergy Task 33 member countries the Status report will be published each triennium.

This report is based on contributions from member countries representatives (NTLs) and offers an overview on pilot, demonstration and commercial gasification projects in each IEA Bioenergy Task 33-member country.

The full version of Country reports from each member country, including also research activities on thermal gasification of biomass and waste can be found at the Task 33 website (www.task33.ieabionenergy.com) in the section "Participants and Country Reports".

An overview on participating countries in triennium 2016-18 can be seen below.

Country	Representative(-s)
Austria	Jitka Hrbek
Denmark	Morten Tony Hansen
Germany	Thomas Kolb, Mark Eberhard
Italy	Donatella Barisano
The Netherlands	Berend Vreugdenhil
Norway	Judit Sandquist
Sweden	Lars Waldheim
Switzerland	Martin Rügsegger
USA	Kevin Whitty

This report includes also a brief information about the policy frame of bioenergy, even if it was not the focus of this Status report, anyway it should be mentioned at least. The summary report on bioenergy policies and status of implementation, together with separate country reports was prepared from IEA statistical data, combined with data and information provided by the IEA Bioenergy Executive Committee and its Tasks. All individual country reports were reviewed by the national delegates to the IEA Bioenergy Executive Committee, who have approved the content.

The main focus of this Status report is the implementation of gasification projects, which could be found in chapter 3, where the gasification projects from Austria, Denmark, Germany, Italy, the Netherlands, Norway, Sweden, Switzerland, and USA could be found.

The report is finalized by the lists of gasification facilities from the Task 33 database, where the detailed description of each facility could be found. The lists of gasification facilities could be found at the Task 33 website as Annexes to this report.

This Status Report updates the Report from April 2016.

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1. Introduction

One of the IEA Bioenergy Task 33 scopes is status monitoring of the unit operations and unit processes that constitute biomass and waste gasification (BMG) process, and identifies hurdles to advance further development, operational reliability, and reducing the capital cost of biomass and waste gasification systems.

This Status report 2019, which is based on information from National Team Leaders (NTLs) of each Task 33-member country, offers an overview on implementation of thermal gasification projects and updates the Status report published in 2016.
(http://www.task33.ieabioenergy.com/content/Task%2033%20Projects).

In the last years, the shift in the area of thermal biomass and waste gasification can be observed. Let's begin with feedstock. That times when only clean woody biomass was used are nearly gone. The price of this feedstock is increasing each year, thus also the waste wood, or other waste materials (e.g. sludge), are more and more in focus of scientists as well as of producers and operators of thermal biomass gasification facilities.

Other parameter, which changed with the time is the purpose of utilization of product gas. In small scale gasification, still dominates the heat or combined heat and power (CHP) production, whereas in large scale, the production of gaseous or liquid biofuels or cofiring is more and more relevant.

The combination of different technologies such as wind power or PV together with electrolysis and thermal gasification for increasing of amount of biofuels production (hybrid systems) or thermal gasification as a technology for balancing the electrical grid are further ideas, how to push this thermochemical technology ahead to be competitive at the market also without subsidies.

Anyway, it is high time (or may be, too late) to use and further develop the energy technologies based on renewable sources to meet the climate and energy framework.

The 2030 climate and energy framework includes EU-wide targets and policy objectives for the period from 2021 to 2030.

Key targets for 2030:

- At least 40% cuts in greenhouse gas emissions (from 1990 levels)
- At least 32% share for renewable energy
- At least 32.5% improvement in energy efficiency

On 28 November 2018, the Commission presented its strategic long-term vision for a prosperous, modern, competitive and climate-neutral economy by 2050.

The strategy shows how Europe can lead the way to climate neutrality by investing into realistic technological solutions, empowering citizens, and aligning action in key areas such as industrial policy, finance, or research – while ensuring social fairness for a just transition.

Following the invitations by the European Parliament and the European Council, the Commission's vision for a climate-neutral future covers nearly all EU policies and is in line with the Paris Agreement objective to keep the global temperature increase to well below 2°C and pursue efforts to keep it to 1.5°C.

Let us see, if the targets would be reached, or if the new put-offs would appear.

2. Country reports on bioenergy

The summary report on bioenergy policies and status of implementation, together with separate country reports was prepared from IEA statistical data, combined with data and information provided by the IEA Bioenergy Executive Committee and its Tasks. All individual country reports were reviewed by the national delegates to the IEA Bioenergy Executive Committee, who have approved the content.

The summary report, as well as all Country reports on bioenergy can be found at the IEA Bioenergy website at: https://www.ieabioenergy.com/iea-publications/country-reports/2018-country-reports/

The reports mentioned above are focusing only on bioenergy policies and its implementation in European Union in general as well as in following countries:

- Australia
- Austria
- Belgium
- Brazil
- Canada
- Croatia
- Denmark
- Estonia
- Finland
- France
- Germany
- Ireland
- Italy
- Japan
- Republic of Korea
- Netherlands
- New Zealand
- Norway
- South Africa
- Sweden
- Switzerland
- United Kingdom
- United States of America

3. Implementation

In this chapter, the implementation of thermal gasification projects in each IEA Bioenergy Task 33 member countries will be described. The representatives of Austria, Denmark, Germany, Italy, the Netherlands, Sweden and USA updated their Country reports, which served as an information source for this Status report. The contributions of Switzerland and Norway in this report are based on CRs presentations from the Task 33 meeting in the Netherlands in 2018.

3.1 Austria

In comparison to the last report from 2016, the boom of small scale gasification facilities could be

observed on one hand and shut down of the two biggest gasifiers in Guessing and Oberwart because of economic reasons on the other hand.Anyway, it could be said that the dual bed gasification technology, invented in Austria, is a very successful one, not only in Austria but also in abroad. Based on this technology, the gasification facilities in Sweden, France, Thailand and Germany were built. An overview on dual fluidized bed or fast internal circulating fluidized beds (FICFB) is given in the following table.

3.1.1 FICFB gasification plants

Table 1: Dual fluidized bed gasification facilities in Austria and abroad

Location	Usage / Product	Fuel / Product MW, MW	Start up	Supplier	Status
Guessing, AT	Gas engine	8.0_{fuel} / 2.0_{el}	2002	AE&E, Repotec	On hold
Oberwart, AT	Gas engine / ORC / H_2	8.5_{fuel} / 2.8_{el}	2008	Ortner Anlagenbau	On hold
Senden/Ulm,DE	Gas engine / ORC	14_{fuel} / 5_{el}	2011	Repotec	Temporary shut down in 2019
Burgeis, IT	Gas engine	2_{fuel} / 0.5_{el}	2012	Repotec, RevoGas	Operational
Göteborg, Sweden	BioSNG	32_{fuel}/20_{BioSNG}	2013	Repotec/ Valmet	On hold
California	R&D	1 MW_{fuel}	2013	GREG	Operational
Gaya, France	BioSNG R&D	0,5 MW_{fuel}	2016	Repotec	Comissioning
Nongbua, Thailand	Gas engine	4_{fuel} / 1_{el}	2018	GRETHA	Operatioal

3.1.1.1 Guessing plant

In Guessing a Biomass CHP with the concept of the FICFB gasification system was realised.

The basic idea of the FICFB concept was to divide the fluidised bed into two zones, a gasification zone and a combustion zone. Now, this technology is called double fluidized bed technology.

Between two zones a circulation loop of bed material was created, anyway the gases remained separated. The circulating bed material acted as heat carrier from the combustion to the gasification zone. The fuel was fed into the gasification zone and gasified with steam. The gas produced in this zone was therefore nearly free of nitrogen. The bed material, together with some charcoal, circulated to the combustion zone. This zone was fluidised with air and the charcoal was burned. The exothermic reaction in the combustion zone provided the thermal energy for the endothermic gasification with steam.

With this concept, it is possible to get a high-grade product gas without the use of pure oxygen.

Figure 1: FICFB gasifier in Guessing

The construction of the demonstration plant started in July 2000 and it was in operation from November 2001 (gas engine from April 2002) to October 2016.

With this demonstration plant, the scale up of the FICFB gasification process was realised at the first time. Therefore, the plant in Guessing can be seen as a reference plant for other facilities based on dual fluidized beds such as plants in Oberwart, Senden/Ulm, Göteborg etc.

Due to the favourable characteristics of the product gas (low nitrogen, high hydrogen content), there were several research projects, which used a slip streams of the product gas. The most important were:

- production of Fischer Tropsch diesel
- production of SNG
- usage the gas in a SOFC
- catalytic cracking of the tars

After almost 100.000 hours of operation, the biomass CHP Guessing was shut down by end of October 2016, due to economic reasons.

In Austria renewable electricity production is supported by feed-in tariffs and for biomass plants these tariffs are valid for 13 years. The feed-in tariff of the biomass CHP Guessing ended by end of October 2016 and without this tariff, no economic operation was possible, so the owner decided to stop the operation. Anyway, from a technical viewpoint, the plant could be still operated for several years.

3.1.1.2 Oberwart plant

In Oberwart the second biomass CHP with the concept of the FICFB gasification system was realized.

It consisted similar to the biomass CHP Guessing of gas generation in a DFB system; gas cooling and gas clean up in a bag filter followed by a tar scrubber. The cooled and cleaned producer gas was fed into two gas engines for power generation.

In addition to Guessing plant, there was a biomass drying unit and an organic ranking cycle (ORC) integrated, to increase electric efficiency. For the ORC all heat at the biomass CHP was collected by thermo-oil and transferred in the ORC in electricity.

The construction was completed in December 2007 and the facility was in operation between 2008 and 2015.

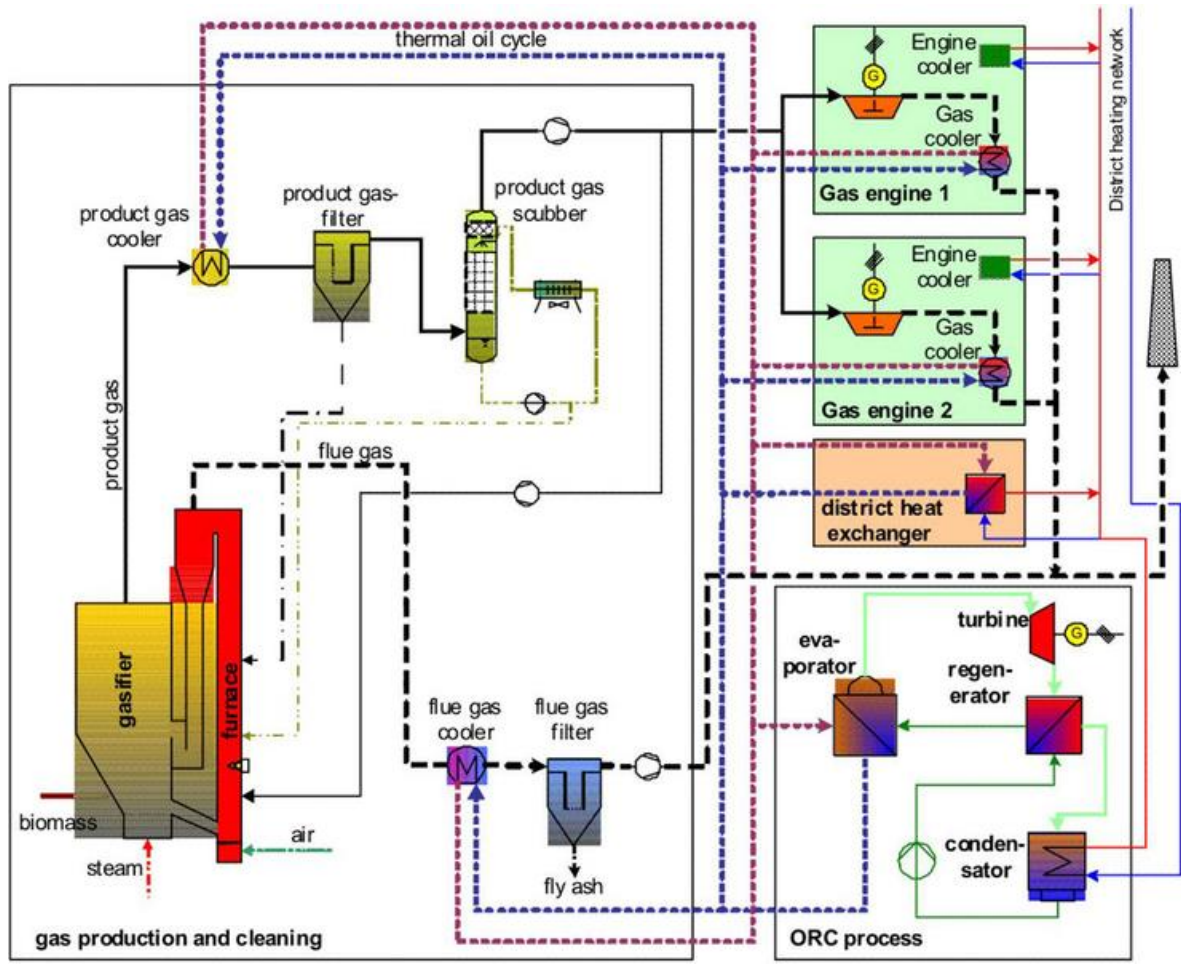

Figure 2: FICFB plant in Oberwart with ORC - flow sheet

The description of gasification plants based on DFB principle, which were built in Germany (Senden), Italy (Burgeis), Sweden (Göteborg) and California could be found in German, Italian, Swedish and USA Country reports and will be therefore not described at this place. Thus France and Thailand are not Task 33 members, description of Gaya and Nongbua gasifiers could be seen below.

3.1.1.3 Gaya DFB gasifier

The Gaya Project[1] was launched in 2010 on the initiative of 11 partners from the industrial, institutional, and academic worlds in France and Europe. It is a research and development project that aims to approve innovative technology choices and the applications for so-called biomethane from dry biomass-to-gas, which is biomethane that primarily comes from lignocellulose materials (wood, straw, etc.).

[1] http://www.projetgaya.com/en/a-sizeable-project-and-energy-for-the-future/

The research and development effort focuses on the two key stages for the biomethane from dry biomass-to-gas production process, namely gasification and methanation. The experiments conducted on the R&D platform are aimed at increasing the availability of the process, and its effectiveness, which is already high. The aim is to fine-tune its operation in order to reduce production costs and to increase the range of accessible biomasses.

The platform is currently an experimental model pilot for future biomethane production plants, which could emerge from 2023. This green gas will be low-cost and environmentally-friendly. For more information please visit: **http://www.projetgaya.com**

Figure 3: Gaya project- photo of the site[1]

3.1.1.4 Nongbua DFB gasifier Thailand

The plant in Nongbua uses the same DFB gasification technology as the Guessing plant. In Thailand, new engineering design and improvements from Guessing plant on certain equipment are conducted including improved fuel feeding system, biomass dryer, gasifier design, tar scrubber design, and heat exchanger system.

With all the advanced and improved technology, the 3.8 MWth input prototype DFB gasifier is the first DFB gasifier plant that can be operated with various biomass resources such as wood chips, sugarcane leaf, corncob, and other biomass renewable resources. The output is 1 Mwel and 1,25 MWth.

3.1.2 Fixed bed gasifiers

3.1.2.1 URBAS gasification facilities

URBAS[2] is a privately owned company, which operates internationally in three main business fields, Steel Construction, Steel Hydraulic Engineering and Energy Technology. The youngest section of the company, Energy Technology, utilizes this experience combined with the latest scientific findings to realize the complete potential of biomass technologies.

Urbas fixed bed gasification technology:

A combustible gas, wood gas, is drawn from wood through a means of thermochemical processes which take place in a specially designed reactor. The raw gas is then separated of dust and tars through a filtering system. This cleaned gas is then used to produce combined heat and power through a gas engine and generator. Unlike other CHP technologies, which are based on the combustion of biomass, and require a working medium, (water in a steam turbine, heat oil in the ORC-process) wood gas cogeneration requires no intermediate medium thus resulting in a higher electrical efficiency throughout the entire system.

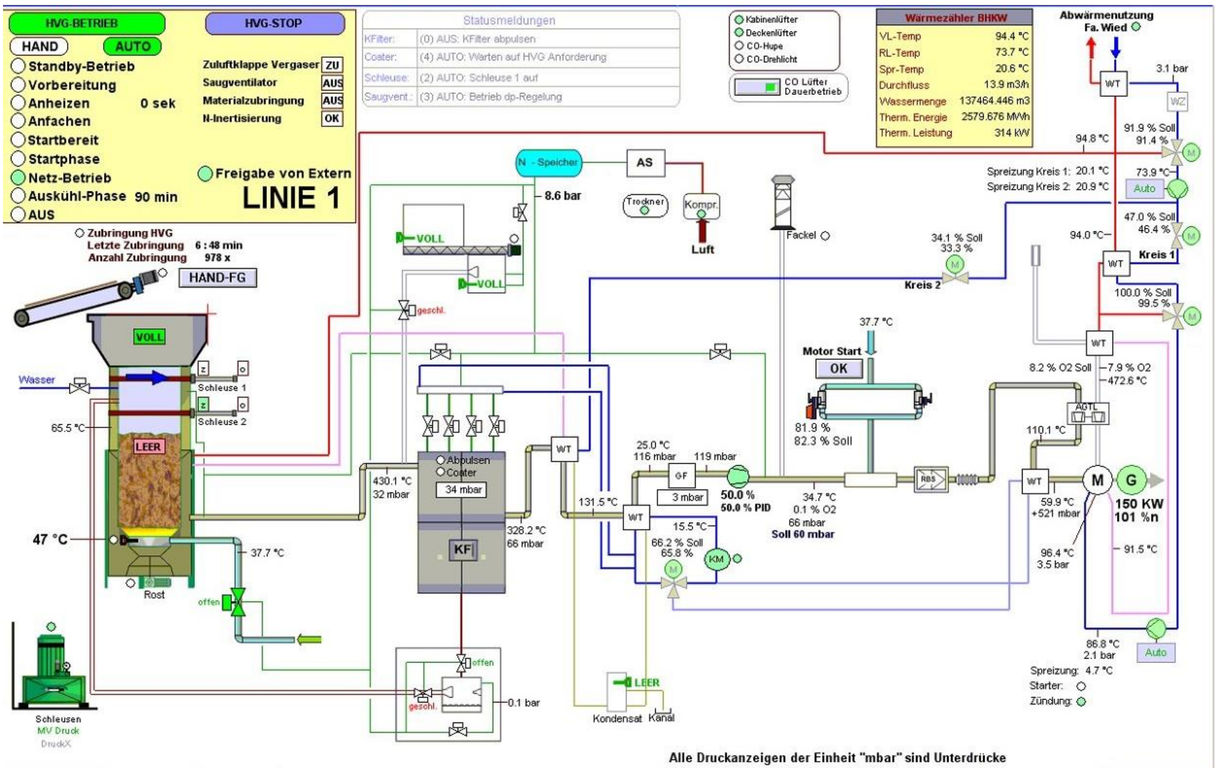

Figure 4: Flow sheet – Urbas gasifiers

URBAS has realized many CHP plants based on the steam cycle, which are available as turnkey, URBAS biomass cogeneration plants. Systems and technology developed by Urbas make it possible to produce electricity and heat at a very impressive efficiency and low cost from a containerized unit using specific dry wood. From 0,9 kg of dry wood 1 kWh of electricity and 2 kWh of thermal energy could be produced. **0,9 Kg Wood = 1 kWh Electricity + 2 kWh Thermal.**

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2 www.urbas.at

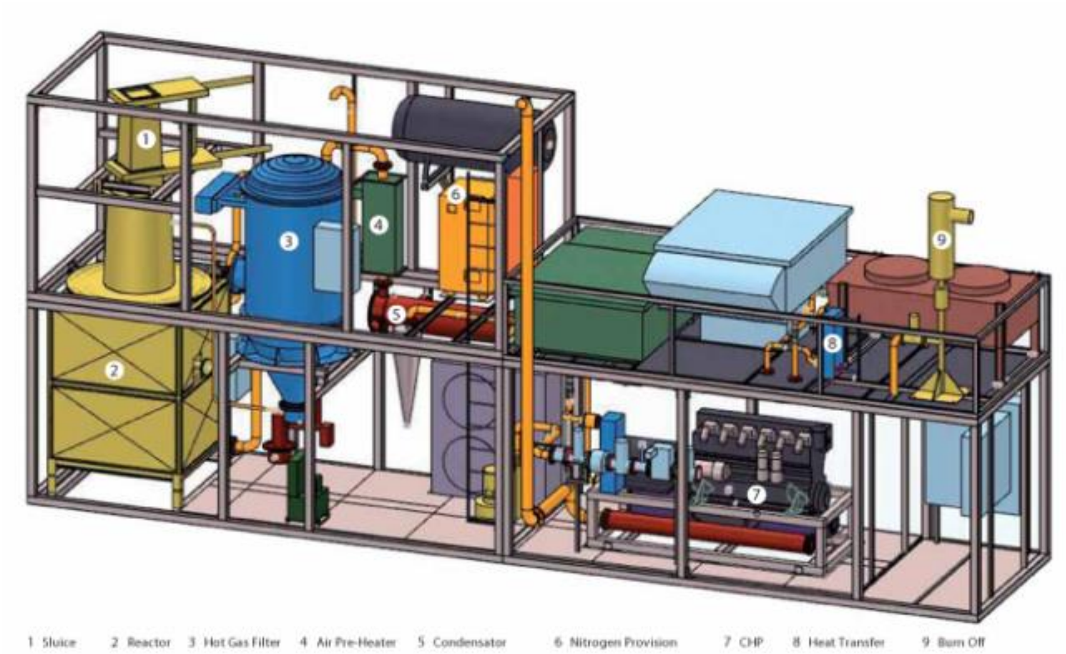

Figure 5: Urbas gasifier – container type

Output: 150 $kW_{el.}$ ŋ el. = 27%

310

$kW_{th.}$ ŋ th. = 57%

Feedstock: Wood chips (8-15 % moisture, size < 150 mm)

The wood gasification system requires a very specific fuel type. Clean factory or industrial off cuts with no fines and a moisture content of less than 10%.

Table 2: Urbas gasification plants (1/2)

	Project	Year of commissioning	Power	Utilization	Fuel		Note
					Wood chips	Off-cuts	
1	**Demonstration Plant URBAS** A - 9113 Ruden	Development since 2001	150 kWel +300 kWth + Boiler	CHP – Process heat, internal heating supplies	x	x	Development and Demonstration plant
2	**Fernwärme Neumarkt Ges.m.b.H. & Co KG** A - 8820 Neumarkt	August 08 - June 18	2 x 120 kWel + 580 kWth	CHP - district heating	x		heat-guided operation
		December 18	2 x 150kWel + 280kWth	CHP - district heating	x		heat-guided operation
3	**Friedrich Wahl GmbH & Co. KG** D - 74429 Sulzbach Laufen	October 09	1 x 130 kWel + 280 kWth	CHP – Process heat, internal heating supplies		x	heat-guided operation
4	**Holzstrom GmbH** A - 5145 Neukirchen an der Enknach	July 11	2 x 175 kWel + 2 x 300 KWth	CHP - district heating	x		Full operation
5	**Stadtwerke Konstanz GmbH** D - 78467 Konstanz	January 12	1 x 140 kWel + 300 kWth	CHP - district heating	x		heat-guided operation
6	**Biowärme Mallnitz Gmbh** A - 9822 Mallnitz	November 13	1 x 250 kWel + 540 kWth	CHP - district heating	x		Full operation
7	**Rau GmbH** D - 72336 Balingen	December 13	1 x 150 kWel + 280 kWth	CHP -Process heat	x	x	Full operation
8	**Energieversorgung Vals GmbH** I - 39037 Mühlbach	January 15	1 x 296 kWel + 550 kWth	CHP - district heating	x		only partial operation
9	**Azienda Agricola Isca di Calvello** I - 85010 Calvello	January 15	1 x 199 kWel + 340 kWth	CHP -Process heat	x		only partial operation
10	**Biowärme Eberndorf** A - 9141 Eberndorf	L1: March 15 L2: Installed since 06	1 x 130 kWel + 250 kWth; 1 x 300 kWel + 600 kWth	CHP - district heating	x		heat-guided operation
11	**Green Power GmbH** A - 8230 Hartberg	July 15	1 x 200 kWel + 320 kWth	CHP - district heating	x		Full operation
12	**Lamprecht GmbH** I - 3902 Kastelbell	January 16	1 x 199 kWel + 320 kWth	CHP -Process heat	x		Full operation
13	**Azienda. Agri. S.A.B.I** I - 47010 Galeata	January 16	1 x 199 kWel + 320 kWth	CHP - district heating	x		Full operation

Table 2: Urbas gasification plants (2/2)

	Project	Year of commissioning	Power	Utilization	Fuel		Note
					Wood chips	Off-cuts	
14	**Toplana AD Prijedor** BIH - 79101 Prijedor	February 16	1 x 250 kWel + 530 kWth	CHP - district heating	x		only partial operation
15	**FHW Mals** I - 39024 Mals	February 16	2 x 149 kWel + 2 x 280 kWth	CHP - district heating	x		Full operation
16	**Genboku** JP - 773-0007 Tokushima	End of 2017	1 x 250 kWel + 530 kWth	CHP -Process heat	x		Full operation
17	**Stubenberg** A - 8223 Stubenberg	June 2017	1 x 220 kWel + 340 kWth	CHP -district heating	x		Full Operation
18	**Ligna Calor** I-39030 La Villa in Badia	July 2017	1 x 300 kWel + 580 kWth	CHP -Process heat	x		Full operation
19	**Lamprecht GmbH** I - 3902 Kastelbell	December 17	1 x 400 kWel + 650 kWth	CHP -Process heat	x		Full operation
20	**Marchesi Frescobaldi** I-50065 Pontassieve	End of 17	1 x 199 kWel + 320 kWth	CHP -Process heat	x		Full operation
21	**Fernwärme Neumarkt Ges.m.b.H. & Co KG** A - 8820 Neumarkt	End of 17	1 x 150 kWel + 280 kWth	CHP - district heating	x		Full operation
22	**Brana Energana Virovitica** HR - 33000 Virovitica	July 18	1 x 450kWel + 765kWth	CHP - Process heat	x		Full operation
23	**Brana Energana Daruvar** HR - 43500 Daruvar	July 18	1 x 450kWel + 765kWth	CHP - Process heat	x		Full operation
24	**Energija Vocin** HR - 33522 Vocin	November 18	1 x 450kWel + 765kWth	CHP - Process heat	x		Full operation
25	**Energija Invest** HR - 43290 Grubisno Polje	November 18	1 x 450kWel + 765kWth	CHP - Process heat	x		Full operation
26	**Le Bufalaie** I-06061 Castiglione del Lago	2019	1 x 199kWel + 360kWth	CHP - Process heat	x		Plant is in planning / installing phase
27	**Biowärme Obervellach GmbH** A-9821 Obervellach	2019	1 x 250kWel + 380kWth	CHP - Process heat	x		Plant is in planning / installing phase

3.1.2.2 SynCraft

In 2007, a team of process engineers succeeded in the development of the floating fixed bed gasifier, a revolutionary process for the generation of heat and power from solid biomass. With an electrical efficiency of 30% and a fuel utilization rate of up to 92%, SYNCRAFT® wood power plants are among the most profitable in the entire bioenergy sector.

By-product of the process is biochar, which is of such high quality that it is used as a base to produce Terra-Preta (black earth), as a feed additive (stabilization of digestion) or as the highest quality wood-BBQ charcoal. Thus, biomass power plants from SYNCRAFT® correspond to the concept of bioenergy with carbon storage (bioenergy with carbon capture and storage) and thus contribute to the negative CO_2 emissions.

"SYNCRAFT® Engineering" plans and installs turnkey wood power plants in the range between 200 and 500 kW electrical power. In addition, the adaptation or reconstruction of existing systems for efficient heat and basic load supply is one of the core competences of the privately owned and Austrian company based in Tyrol.

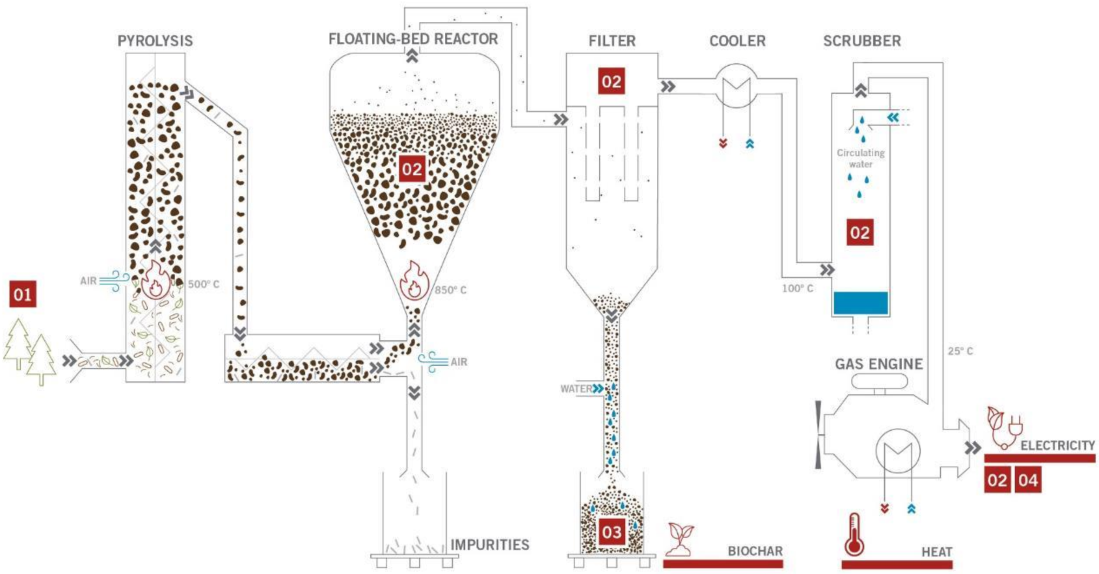

Figure 6: SynCraft technology – flow sheet[3]

1. Feedstock: the plant operates on low quality, dry wood chips including bark and fines
2. Gasification and gas cleaning: no need for additives. Still the condensate is as clear as water and free of tar
3. By-product: premium quality charcoal
4. 30% overall electric efficiency due to high-tech gas engines

[3] www.syncraft.at

SynCraft gasification plants

SYNCRAFT®Werk Alpha / Schwaz / Austria

The biomass co-generation plant CraftWERK Alpha was founded on site of Stadtwerke Schwaz in 2009 and has since served as the development platform of the floating bed gasification technology. At this plant, the continuous development of the technology takes place together with our project partners and the MCI - Internationale Hochschule Gmbh. Also the use of alternative, biogenic raw materials such as bark, straw and waste wood is studied and researched in depth. The plant has a thermal capacity of about 500kW and allows operation without supervision.

Figure 7: Photo of CraftWerk Alpha

SYNCRAFT®Werk Beta / Vierschach / South Tyrol / Italy

Figure 8: Photo of SYNCRAFT®Werk Beta

The biomass cogeneration plant CraftWERK Beta was built 2011/12 in addition to an existing biomass district heating plant in Innichen / San Candido and went to the grid by the end of 2012.
This demonstration plant offers a thermal capacity of 990 kW and an electrical power output of around

250 kW. CraftWERK Vierschach makes use of commercially available, dried wood chips (G30 / G50), including barks and fines.

The power generation of the product gas takes place in an agenitor 312 gas engine of 2G, which was specially developed for the efficient processing of wood-gas and promises the highest efficiency.

SYNCRAFT®Werk CW700 / Dornbirn / Austria

SynCraftwerk Dornbirn was built in 2014 and the same year connected to the grid.

The plant of type Craftwerk 700 has a thermal capacity of 650 kW and produces 180 kW electrical and more than 350 kW thermal power. CraftWERK Dornbirn makes use of commercially available, dried wood chips (G30 / G50), including barks and fines. The power generation of the product gas takes place in an agenitor 406 gas engine of 2G with an electrical efficiency of 40%.

SYNCRAFT®Werk 1000 / Innsbruck / Austria

The turbo-charged CHP unit with 8 cylinders and 16.7-liter capacity already achieved an electrical output of 300 kW in the first week after commissioning in November 2016.

The SYNCRAFT® wood power plant, built in only 4.5 months of construction, achieves a heat output of 892 kW, 261 kW of electrical and 393kW of thermal power. Common forestry chips are used with bark and fine portion. Three drivable drying boxes were installed at the site, in which the low-temperature heat generated is used to dry the fuel requirement.

Figure 9: CHP unit in Innsbruck

SYNCRAFT®Werk 1200 / Stadl / AT

The SYNCRAFT®Werk 1200 has a fuel heat output of around 1200 kW and about 324 kW electrical power. The system is designed to cover the entire heat base load of the local district heating network. It is used for commercial woodchips, including bark and fine particles. This allows the plant to be operated economically and, with a fuel utilization level of 92%, will provide both heat and, above all, an above-average power output of around 30%.

The heat flows directly into Stadl's district heating network - the electricity flows into the regional grid. In sum, the biomass HFC will produce 2.5 million kilowatt hours of electricity and about 5.9 million kilowatt hours of heat a year. In addition to the outstanding yield, the operators of the Bio-Nahwärme Stadl also enthuse the unique by-product of the active carbon or charcoal, which is only achieved by the patented technology of SYNCRAFT® Das Holzkraftwerk is possible.

Thus, SYNCRAFT® was able to convince the operators of Stadtwerke Murau and another wood power plant with 500 kW electrical power is planned.

Figure 10: Impressions from SYNCRAFT®Werk SCW1200 in Stadl

SYNCRAFT®Werk in Japan

The first SYNCRAFT®Werk, a CHP gasification facility will be built in Japan. Detailed engineering for a quadruple facility (4x CW 1200-400) has been already succesfully started.

Figure 11: Planed Syncraft facility in Japan

3.1.2.3 Hargassner

The company was founded in 1980es and focuses on thermochemical conversion of biomass, in the first place combustion but in the last couple of years thermal gasification as well.

Hargassner offers compact gasification units with 20 kW electrical output. The scheme of the unit could be seen bellow. At the moment there are 10 Hargassner units in operation and till the end of 2019 additional 20 units are planned.

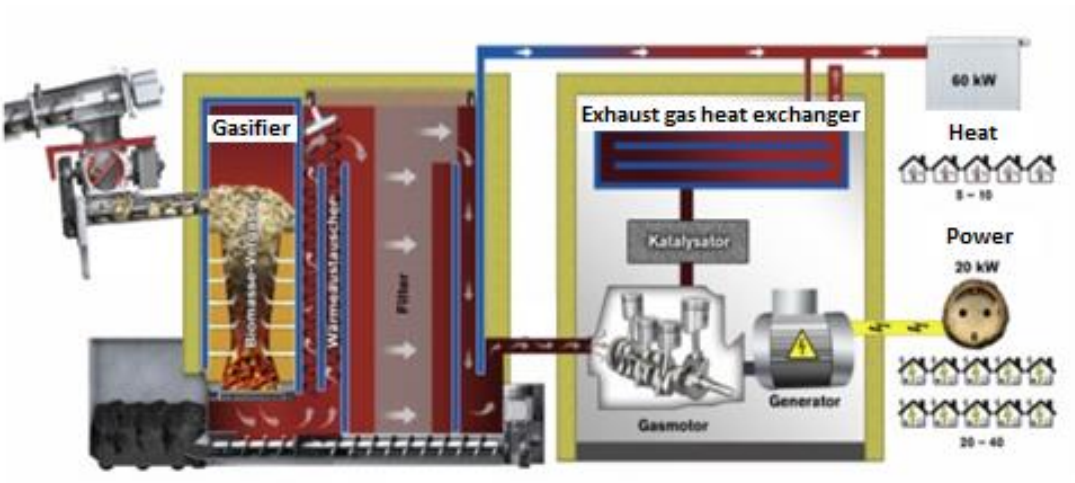

Figure 12: Scheme of Hargassner unit

Table 3: Technical details of Hargassner gasification facilities

	El. output	kW	20
	Thermal output	kW	61
	Allover efficiency	%	95,3
	Feedstock consumption by 5000 op. hours	m^3	approx. 500
	Feedstock quality	Standard	A1, P16S-P31S, M15
	Temperature for heating	°C	85/65
	Dimensions of gasifier	mm	1600 x 750 x 1370
	Dimensions of the unit	mm	1500 x 850 x 1370

[4] www.hargassner.at

3.1.2.4 Glock Oekoenergie

The company Glock Oekoenergie offers fixed bed gasification systems, which are based on Imbert principel. Details can be seen in the following figure.

Figure 13: Glock Oeko gasification system[5]

Before the feeding wood chips into the gasifier they cross a dryer, where the moisture below 30 % is achieved. After gasification in fixed bed gasification unit the produced gas is cleaned and cooled down to use the gas for production of the electrical power and heat.

The gasification systems are offered in two sizes as GGV 1.7 and GGV 2.7 with following technical data.

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5 https://www.glock-oeko.com/

Table 4: Glock Oekoenergie gasification units – technical data

Technical data	GGV 1.7	GGV 2.7
	18 kWel./44 kWth output 19 kg/h chips consumption 400 V/50 Hz el. output Max. 90°C thermal output 5.209 x 2.221 x 2.620 mm dimensions	55 kWel. /120 kWth output 50/60 kg/h chips consumption 400 V/660 Hz el. output Max. 90°C thermal output 5.000 x 2.700 x 3.400 mm dimensions

Table 5: Glock Oeko References

Location	Type	Output gasification unit	Note
BEVZ GmbH Kirchberg an der Raab	2 x GGV 1.7 Prototypes & 1 x GGV 1.7 Series maschine	54 kWel 132 kWth	
Mayer GmbH Zeltweg, Murtal	2 x GGV 1.7	36 kWel 88 kWth	
Biowärme Lassnitz Steirisch Lassnitz. Murau	1 x GGV 2.7	55 kWel 125 kWth	
FM Holzstrom GmbH St. Lambrecht, Murau	2 x GGV 2.7	110 kWel 250 kWth	
Heizwerk Fritzer Sirnitz, Feldkirchen	3 x GGV 2.7	165 kWel 375 kWth	
Kirchheimerhof Bad Kleinkirchheim Spittal ander Drau	1 x GGV 2.7	55 kWel 125 kWth	
Regionalwärme St. Margareten St. Margareten in Rosental	1 x GGV 1.7	18 kWel 44 kWth	
Heim AG-Fischer Schleitheim-Schaffenhausen, Switzerland	1 x GGV 1.7	18 kWel 44 kWth	1.076 operating hours (Status 20.08.2018)
Haffhus GmbH Hotel und Ferienanlage, Ueckermuende, Germany	1 x GGV 1.7	18 kWel 44 kWth	683 operating hours (Status 20.08.2018)

3.1.2.5 Froeling

The newly-developed Froeling CHP fixed bed gasifier is available with an electrical capacity of 46/50/56 kW or thermal capacity of 95/105/115 kW, and has an overall efficiency rating of 85%.

The first devices have been in operation since 2013.

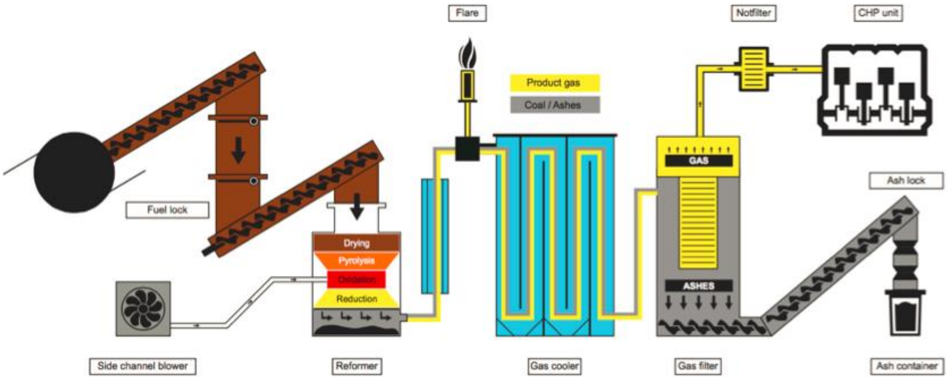

Figure 14: Froeling Fixed bed gasifier CHP 50

Table 6: Technical data Froeling CHP 50

Power output	kW	49/51
Heat output	kW	~107
Feedstock (wood chips) **consumption by 6000 op.hours**	t	300
Overall efficiency	%	~83
Power efficiency	%	~27

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[6] https://www.froeling.com/

Table 7: References Froeling

Biowaerme Grabner **Wenigzell, AT**	Initially 3 facilities (3x50 kWel.) In 2016 4th facility Over 8.400 operating hours per year
Fernwaerme und Brennholztrocknung **Suhodolnik, SI**	10 facilities in operation
Osserhotel **Silbersbach, DE**	Since 2014 – 1 facility in operation
Fernwaerme Jennersdorf	District heating + 200 kW electricity
Molzbachhof **Kirchberg am Wechsel**	Heating for hotel and school 2 facilities – 100 kWel + 200 kWth

3.2 Denmark

In Denmark, three biomass gasifiers are in operation on a commercial basis. The gasifiers form the core of three CHP facilities that successfully generate heat for the district heating consumers in the respective towns and electricity for the grid. All three plants are situated in the Northern part of Jutland as it is shown in the Task 33 database. All three have been subject to some level of public funding for demonstration purposes.

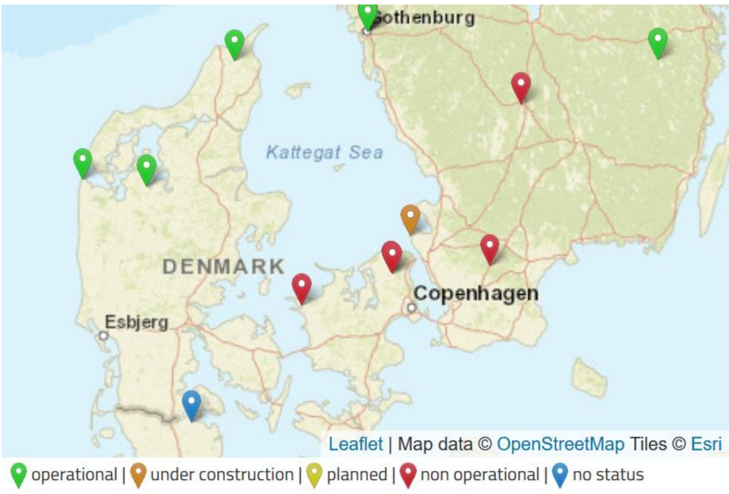

Figure 15: Situation of Danish gasification plants

General data about the plants can be seen in the table below.

Table 8: Thermal gasification facilities in Denmark

Project name/ location	Technology	Input/ Feedstock	Output/ El./Th.	Usage/ Product	Start up/ Status
Harboøre CHP plant /Harboøre, DEN	Fixed bed - updraft	3,5 MW /forest wood chips	1 MW electric 1,9 MJ/s heat	CHP generation	1993 (CHP in 2000) /operational
Sindal CHP plant /Sindal, DEN	Staged updraft	5.5 MW /wood residues	0.8 MW electric 5 MJ/s heat	CHP generation	2018 /operational
Skive CHP plant /Skive, DEN	Bubbling fluidised bed	20 MW /wood pellets	6 MW electric 11,5 MJ/s heat	CHP generation	2008 /operational

3.2.1 Harboøre CHP plant

Figure 16: Photo of the gasification plant in Harboøre

In 1993 Harboøre Varmeværk established a demonstration gasification plant based on the development achievements at pilot scale by the supplier, Babcock and Wilcox Vølund, and numerous university studies. In 1997, after a large development effort by Vølund and the heating company, the gasification process was considered commercial, and in the course of 2001 the district heating plant was converted into CHP and was taken into commercial operation. Since then, the plant has operated 8,000 hours per year and supplies heat to approx. 698 heat consumers including the municipal buildings of the town.

The Harboøre gasification plant is in operation all year round. It burns bio-oil when the gasifier has its main renovation one week per year. The bio-oil is a residue from the process; it is also useful in times of special need, during peak load hours of a cold winter, for instance, when you need more hot water than usual for the district heating grid.

The gas is produced in a modern updraft gasifier designed as a vertical, cylindrical furnace with ceramic insulation. Freshly chipped forest wood chips with a moisture content of 39-50% are used as feedstock. The plant is controlled 100% on the basis of the heat requirement. The gasifier has an output of 4 MWth, and the gas can be burnt in a Low-NOx gas burner built onto a 4 MW hot water boiler.

The Harboøre plant can be divided into the following main components:

- 3.7 MWth up-draft gasifier with fuel feed, ash extraction system, and air humidifier
- Gas cooling and cleaning system
- Two gas engines with generators and exhaust boilers
- Waste water cleaning system named the Tarwatc system
- Heavy tar fired boiler with storage tank for heavy tar
- Product gas fired boiler

The diagram below shows the flow sheet of the plant.

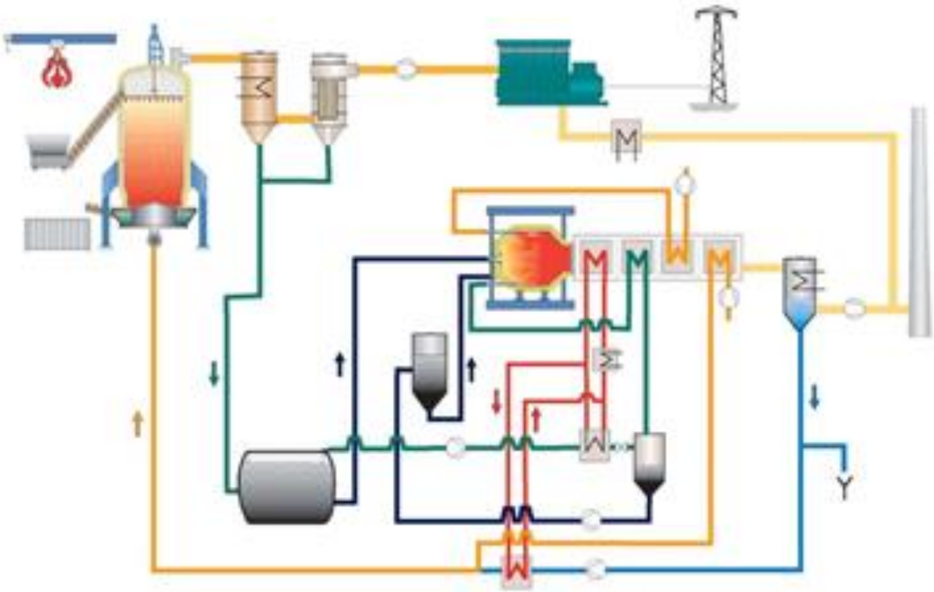

Figure 17: Flow sheet of Harboøre plant

Public funding for the R&D parts of the project came from the Danish Energy Agency EUDP and the European Commission and the US Department of Energy.

Further information about the Harboøre plant and the technology can be found at the Task 33 Status report 2016 and brochure from Vølund (http://www.volund.dk/References_and_cases/Biomass_energy_solutions/Harboore).

Contact information:

Harboøre District Heating Company:
E-mail (contact person): Mr. Kim Jensen (harvarme@mail.dk)
Website: http://harvarme.dk

Babcock & Wilcox Vølund A/S (supplier):
E-mail (contact person): Mr. Robert Heeb (roh@volund.dk)
Website: http://www.volund.dk/Biomass_energy/Technologies/Gasification_of_biomass

3.2.2 Sindal CHP plant

Sindal District Heating company was until 2018 using natural gas for district heating, partly by running IC engines and partly by gas boilers. The company was searching for cheaper and more environmentally friendly fuels and chose to build a Dall Energy gasifier with an ORC turbine.

The technology consists of

- An updraft biomass gasifier with partial oxidation
- An afterburner
- A thermal oil heater
- A scrubber system for recovery of heat
- An ORC unit

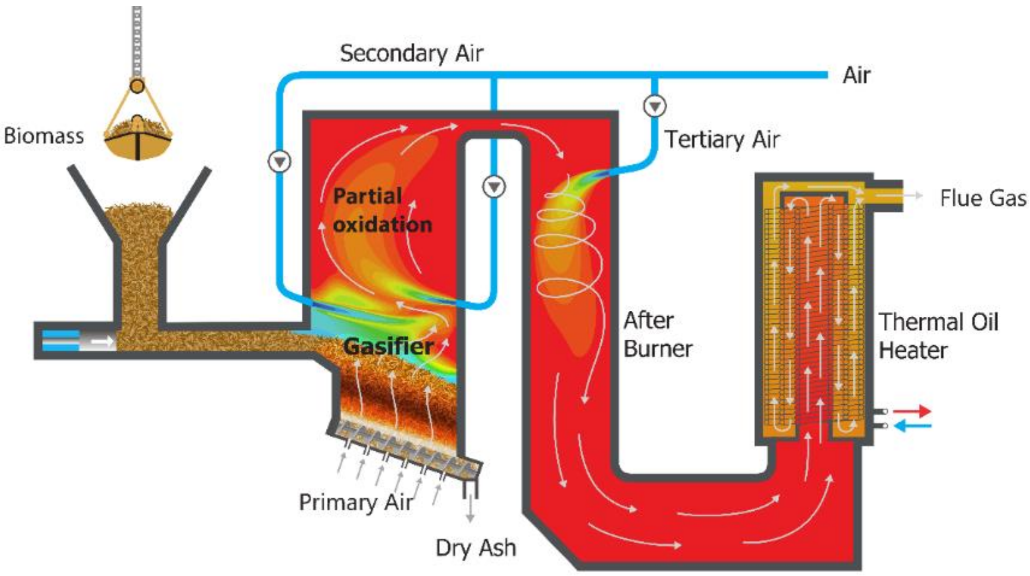

Figure 18: Sindal CHP plant scheme

The plant is a third generation "Dall Energy Furnace" where the first generation was built in Bogense (Denmark) and second generation built in Sønderborg (Denmark) and Warwick Mills (USA). The first plants have verified that the "Dall Energy Furnace" technology offer a number of advantages compared to other biomass solutions for district heating. With this plant, Sindal District Heating Company obtains:

- Cheap & environmentally friendly fuels (Garden waste, wood chip)
- To run biomass both summer and winter in just one plant
- Low NOx emissions
- Low CO emission
- Low dust emission
- Co-production of heat and power

The project is a demonstration project supported by the Danish R&D fund "EUDP".

Contact information:

Sindal District Heating Company:
E-mail: info@sindalvarmeforsyning.dk
Website: www.sindal-varmeforsyning.dk

Dall Energy (supplier):
E-mail (contact person): Mr. Jens Dall Bentzen (jdb@dallenergy.com)
Website: www.dallenergy.com

3.2.3 Skive CHP plant

Figure 19: Photo of Skive gasification plant

At the Skive gasification demonstration project in Denmark, a bubbling fluidized bed (BFB) gasifier is used to produce gas from wood-based biomass. This gas is then cleaned catalytically and used in three IC engines in a combined heat and power (CHP) application. The capacity of the plant is 6 MW electricity and 11.5 MJ/s heat based on input of 20 MW wood pellets. The heat is consumed in the local district heating network in Skive and the electricity is sold to the grid.

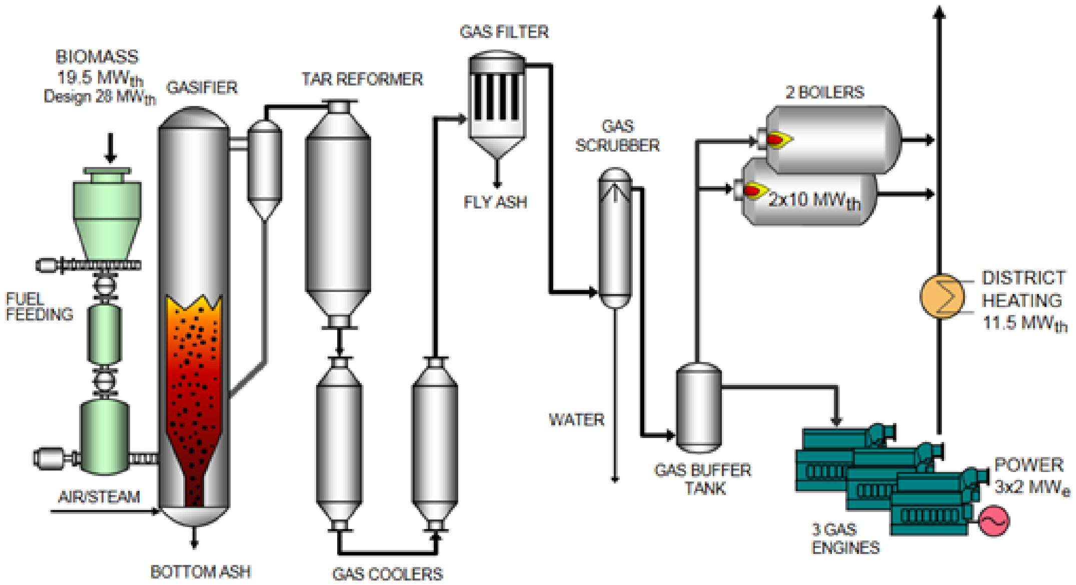

Figure 20: Flow sheet of Skive gasification unit

The commissioning of the plant started in late 2007 and, using one gas engine, operations initially began in the early summer of 2008. The second and third gas engines were installed during summer 2008.

The local district heating company, Skive Fjernvarme, is the owner and acted as the main contractor in the project, having the responsibility for integrating the various components. The gasifier is from Andritz Carbona while the catalytic gas cleaning system was supplied by Haldor Topsøe. Aaen Consultants (now acquired by Niras) were responsible for engineering of the plant. The building is designed by C.F. Møller Architects. Public funding for the R&D parts of the project came from the Danish Energy Agency, the European Commission and the US Department of Energy.

After several years of intermittent operation, the plant has now reached a high availability and operation and outage is fully under control. Persistent efforts to improve fuel quality and alter the catalytic tar reformer have helped decreasing the forced outage and time consumption when maintaining the catalysts. This means that the energy consumption in Skive now primarily is covered by renewable sources. Further on the improvement on the catalytic gas gleaning can be read in[7].

Skive Fjernvarme and Haldor Topsøe has in an EUDP funded project been looking into the opportunity to utilise the gas for production of gasoline and other fuel products via the TIGAS process. The results are described in[7]

Contact information:

E-mail: Managing director, Mr. Tage Meltofte (tm@skivefjernvarme.dk)
Website: www.skivefjernvarme.dk

3.2.4 Other gasification plants

Several pilot plants and demonstration plants have been built in Denmark over the past years. All have ceased operation, and some have been dismantled. The reasons vary but have typically not been related to the core operation of the thermal gasification technology. Three plants should be mentioned here.

Kalundborg co-firing, Pyroneer (Ørsted (previously DONG Energy))

Based on R&D activities at the Danish Technical University (DTU) and Danish Fluid Bed Technology (DFBT), a 6 MWth Pyroneer demonstration unit was commissioned at the Asnæs power station in Kalundborg in spring 2011. The gasifier was fed with straw, manure fibres or local residue to co-fire gasified feedstock into the coal fired unit.

The Pyroneer gasifier is a low temperature CFB type and consists of three main components; a pyrolysis chamber, a char reactor and a recirculating cyclone. Cleaning of the producer gas may simply be done with a second cyclone when the gas is co-fired into a coal boiler. Stable and safe unmanned long-time operation was demonstrated. It was demonstrated that the ash and char can be used for fertiliser field tests with impressive results.

There were plans to upscale the technology for a 60 MWth unit and to license or sell the technology. Status by the end of 2015 was that the technology was not sold, the project got mothballed and the staff was moved from Pyroneer or dismissed.

Research is still ongoing at the DTU and the technology is available for interested parties that wish to utilise agricultural residues for energy generation while removing trace metals and maintaining the nutrients in the ash and biochar.

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[7] Bodil Voss, Jørgen Madsen, John Bøgild Hansen, Klas J. Andersson, Topsøe Tar Reforming in Skive: The Tough Get Going, The Catalyst Review, May 2016

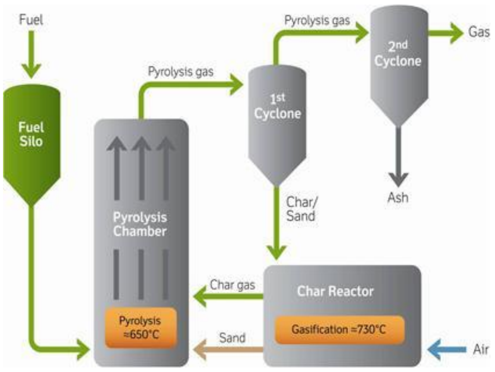

Figure 21: Pyroneer gasification facility

Contact information:

Danish Technical University (DTU):
E-mail: Mr. Jesper Ahrenfeldt (jeah@kt.dtu.dk)
Website: https://www.kt.dtu.dk/english/research/chec/research-areas/gasification

Danish Fluid Bed Technology (DFBT):
E-mail: Mr. Peder Stoholm (psto@dkfbt.dk)
Website: https://www.linkedin.com/in/peder-stoholm-81394223/?originalSubdomain=dk

Ørsted A/S
E-mail: Mr. Benny Gøbel (info@orsted.dk)
Website: www.orsted.dk

Hillerød CHP, Weiss

Based on RD&D activities at the Biomass Gasification Group at the Danish Technical University (DTU) and the development of the staged gasifier - the Viking gasifier - the concept was upscaled by DTU, COWI and the boiler manufacturer Weiss to be built for unmanned CHP operation on wood chips (500 kWe/1,000 kJ/s heat) at the district heating company in Hillerød north of Copenhagen.

The unit consists of a dryer where the feedstock is dried with superheated steam followed by a conveyor where the feedstock is pyrolysed and an air-blown gasifier vessel where the char is gasified along with a cracking process that eliminates tar. The concept generates a very clean gas that is ideal for IC engine operation without advanced gas cleaning. Unparalleled electric efficiency for this plant size as well as stable operation has been demonstrated by this concept.

The plant in Hillerød was built and quickly reached stable operation, however, due to factors that look like poor management decisions and poor craftmanship at the supplier level, the plant faced a breakdown that was never repaired due to funding problems and changing ownership at the supplier. Thus, the plant never came into commercial operation and was dismantled in 2016[8]. The supplier later filed bankruptcy.

Research is still ongoing at the DTU to upscale the technology and it is available for interested parties that wish to utilise forest residues for efficient energy generation.

[8] Partnerskab for Termisk Forgasning, Status for termisk forgasning i relation til danske forhold, Delrapport nr. 2 i WP1, EUDP 14-I j.nr: 64014-0138, October 2016

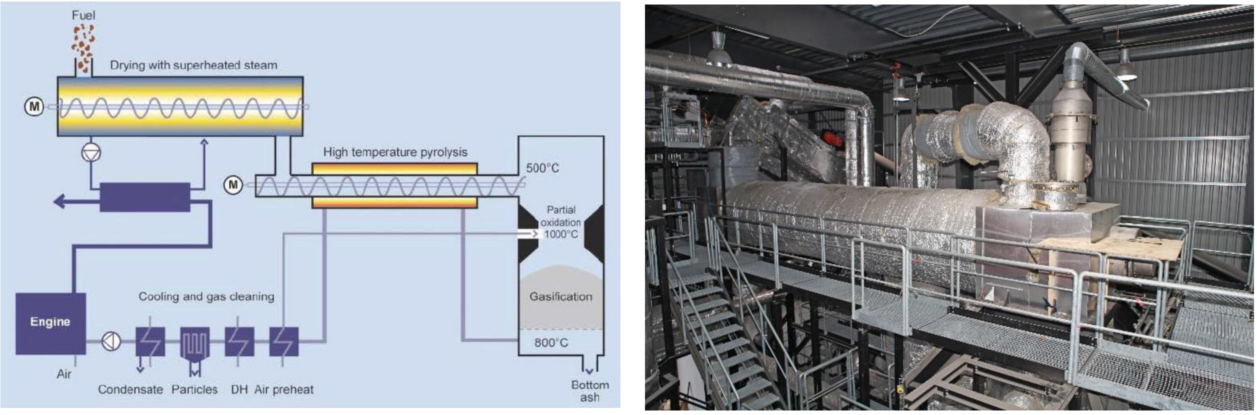

Figure 22: Viking gasifier

Contact information:

Danish Technical University (DTU):
E-mail: Mr. Jesper Ahrenfeldt (jeah@kt.dtu.dk)
Website: https://www.kt.dtu.dk/english/research/chec/research-areas/gasification

Hillerød CHP, Biosynergi

Based on several years of development and 4,000 hours of demonstration of a patented open core down draft gasifier concept for efficient CHP generation based on fresh wood chips, the supplier teamed up in an investment company with private and public investors to facilitate upscaling of the technology to capacities of 300 kWe and 750 kJ/s heat to be installed at the district heating company in Hillerød north of Copenhagen.

The main vision of the gasifier concept is to develop a unit based on simple processes and commonly available materials to facilitate inexpensive production for the supplier as well as low investment and low operational costs for the owner. The gasifier is set up with a gas cooler and filtering systems to feed an IC engine genset. Heat from the engine is used for the integrated drum dryer to dry the fuel. The feedstock is freshly chipped wood chips with a typical moisture content of 40-55%. Heat for district heating is produced at three points in the plant:

- Cooling water from the gas engine
- Cooling of product gas in heat exchangers
- Heat from cooling and condensation of flue gas.

The plant was designed for unmanned, automatic operation and has a nominal overall efficiency of 86%. An advantage of having a small CHP plant is that the production of electricity and heat can take place close to the forest areas where the wood for the chip production grows. It reduces the need for road transport of biomass - and thus the CO2-emissions of trucks. All parts of the plant in Hillerød were installed and have been in unmanned operation during 2017. Minor technical challenges in combination with lack of further funding forced the company to cease activities in the last part of 2017. The plant has subsequently been dismantled.

Contact information:

BioSynergi Proces ApS:
E-mail: Mr. Henrik Houmann Jakobsen (hhj@biosynergi.dk)
Website: www.biosynergi.dk

3.3 Germany

3.3.1 Large scale gasifiers

3.3.1.1 Bioliq-Pilot plant

The bioliq process, developed at the Karlsruhe Institute for Technology (KIT) aims at the production of synthetic fuels and chemicals from biomass. The bioliq technology is based on a two-step process with decentral pyrolysis for the production of a transportable slurry from residual biomass (e.g. straw) and central slurry gasification and BtL production.

The pilot plant with 2 MW fast pyrolysis for biosyncrude production and 5 MWth high pressure entrained flow gasifier operated up to 8 MPa (both in cooperation with AirLiquide E&C, Frankfurt), as well as the hot gas clean-ing (MUT Advanced Heating GmbH, Jena), dimethylether and final gasoline synthesis (Chemieanlagenbau Chemnitz GmbH) are in operation.

The pilot plant aims at demonstration the bioliq technology on a TRL level of 6. Reliable mass and energy balances will be provided; practical experience in operation and on equipment used will be gained. Furthermore, fuel flexibility and product quality have to be verified. Also, the bioliq pilot plant acts as a research platform which is embedded in a broad R&D framework, forming the basis for a knowledge-based optimization and further development of the technical processes, also allowing to explore applications of the products and technologies involved.

The facility is operated in the 24/7 continuous mode for individual measurement campaigns to collect operating data for a broad spectrum of feed materials, and to provide synthesis gas for the downstream synthesis of gasoline. Since commissioning, roughly 900 tons of slurry were successfully converted into raw synthesis gas in 1200 h of operation.

The construction and erection of the bioliq pilot plant was facilitated by substantial funding. Of 64 Mio. EUR investment costs, the Germany, Ministry for Food and Agriculture along with Agency for Renewable Resources, FNR funded ca. 30 Mio. EUR, the state Baden-Württemberg, partly by use of EU EFRE funds, ca. 2 Mio. EUR. The Helmholtz Association of large research institutions in Germany, KIT belongs to, supported the plant construction with ca. 5.4 Mio. EUR. The partners from industry contributed to one quarter of the investment.

Email (contact person): Nicolaus.Dahmen@kit.edu, Web: www.bioliq.de

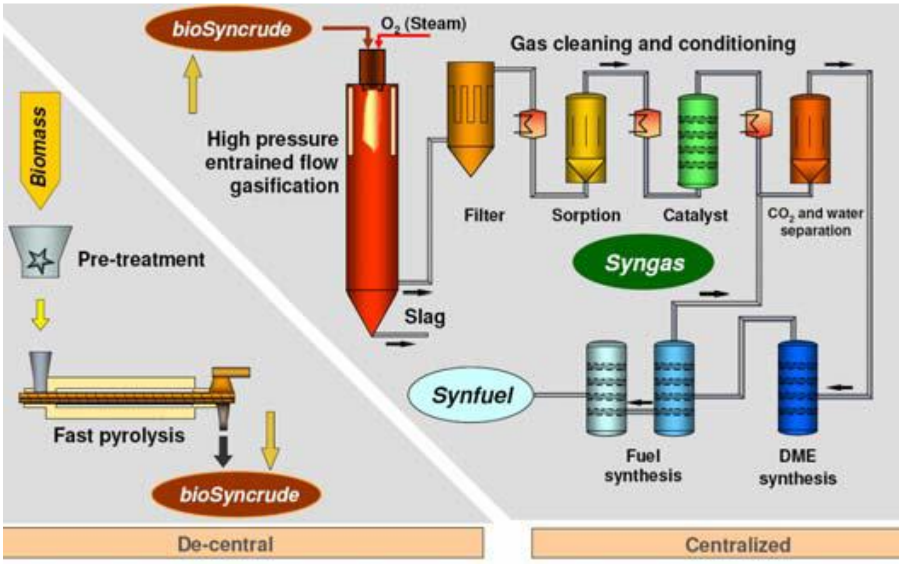

Figure 23: The bioliq® - process technology

Figure 24: The bioliq® plant

3.3.1.2 Blue Energy Wood-CHP Senden

The biomass CHP-plant of Blue Energy Syngas GmbH in Senden[9] operates with wood chips. The thermal load of the plant is 15,1 MWth (4,55 MWel). The technology is based on the FICFB Guessing (repotec) gasification technology. The plant provides power and heat for 21,000 inhabitants of Senden. Figure below shows details of the technology of the plant. The power plant was sold by the Stadtwerke to the operating company Blue Energy at the beginning of 2018[10]. At the end of 2018 the power plant has been shut down and technical improvements and economic aspects are being investigated[11].

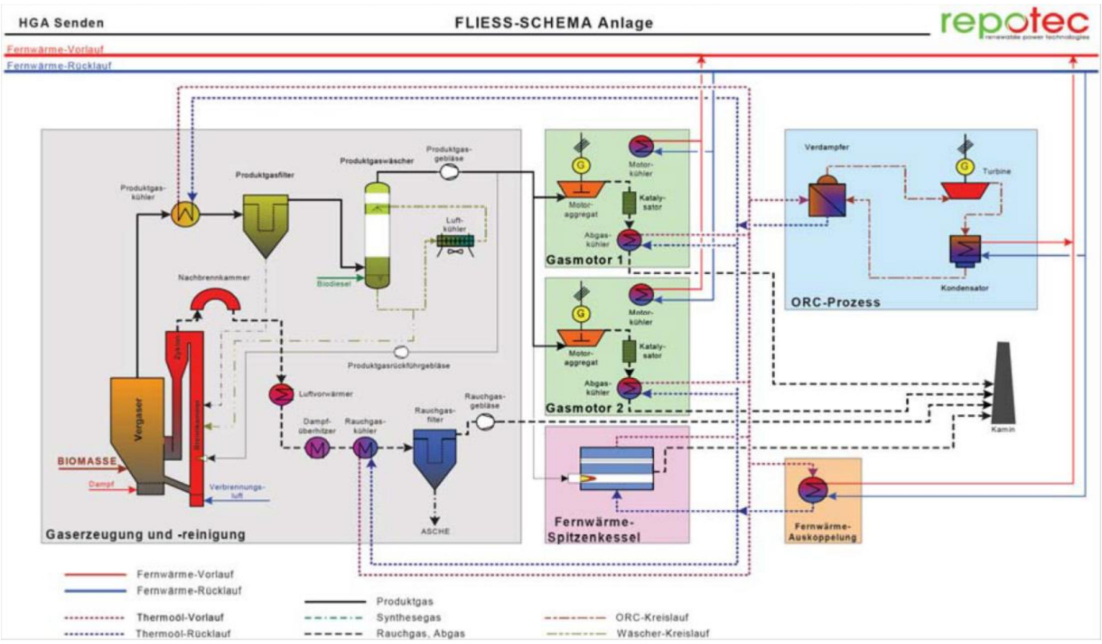

Figure 25: Flow sheet of the CHP plant in Senden

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[9] Vitek, Matthias: Vortrag Effiziente Biomasse-Konversion zur KWK durch Vergasung fester Biomasse am Beispiel HGA Senden. Projekttag, 25 Nov. 2009, Ulm,Germany

[10] https://www.swp.de/suedwesten/landkreise/kreis-neu-ulm-bayern/sendener-holzgas-heizkraft-wird-wohl-stillgelegt-28972085.html

[11] https://www.augsburger-allgemeine.de/neu-ulm/Warum-das-Sendener-Holzkraftwerk-still-steht-id53137721.html

3.3.2 Entrained Flow gasifiers

3.3.2.1 AirLiquide EC

AirLiquide Engineering & Construction is a plant manufacturer that offers a process portfolio for large scale syngas plants. They took over the MPG™ gasification technologies from Lurgi GmbH. Within the bioliq®-project in Karlsruhe AirLiquide Engineering & Construction built the high pressure entrained flow gasifier for the conversion of suspension fuels (slurry) produced via pyrolysis from biogenic residues. AL E&C is an ongoing research partner for KIT in the bioliq®-project.

Web: https://www.engineering-airliquide.com/de/synthesegas

3.3.2.2 ThyssenKrupp Industrial Solution (TKIS)

ThyssenKrupp Industrial Solutions is a plant manufacturer that offers a process portfolio for large scale syngas and chemical plants. They took over the PRENFLO® and HTW® gasification technologies from former Uhde GmbH. With the BioTfuel®-Project in northern France ThyssenKrupp Industrial Solutions and their French partners develop and demonstrate a process for synthetic fuels (Jetfuel and Diesel) from biomass residues like waste wood or straw using the PRENFLO PDQ gasification technology. The feedstock for the gasifier is produced via a torrefaction process.

Web:https://www.thyssenkrupp-industrial-solutions.com/en/products-and-services/chemical-plants-and-processes/gasification/

BioTfuel:https://www.thyssenkrupp.com/en/company/innovation/processes-that-conserve-resources/biotfuel.html

3.3.3 Fluidized bed gasifiers

3.3.3.1 SÜLZLE KOPF SynGas

Since 2000 SÜLZLE KOPF SynGas is a developer and producer of bubbling fluidized bed gasification systems for sewage sludge for heat, or combined heat and power (CHP) applications. KOPF SynGas has built a pilot plant with 250 kWth for sludge drying, a commercial Gasification-CHP plant with 390 kWel and 460 kWth, as well as a plant delivering synthesis gas to a burner providing heat (1,5 MWth) for sludge drying. All gasifier systems are fed with dried sewage sludge.

Address: Derendinger Straße 40, 72072 Tübingen

Email: b.v.deest@kopf-syngas.de

Web: www.kopf-syngas.de

References:

- Waste water treatment plant Mannheim
- Waste water treatment plant Balingen
- Waste water treatment plant Koblenz

3.3.3.2 Burkhardt GmbH

Since 2010 Burkhardt GmbH is a producer for wood gasifiers for combined heat and power (CHP) applications. The gasification of the biomass takes place in a co-current stationary fluidized bed. Burkhardt offers 3 sizes of gasifier systems, 50 kWel, 165 kWel and 180 kWel that are fed with wood pellets. All systems produce power from gas engines.

The company has delivered more than 240 plants.

Address: Kreutweg 2, 92360 Mühlhausen

Email: energy@burkhardt-gmbh.de

Web: www.burkhardt-gruppe.de

References:

- Ladbergen, 32 Plants, Airport / District Heating
- Hinterschmiding, 2 Plants, Wood tryer / Pellet production
- Hohenburg, 7 Plants , Sewage Sludge trying
- St. Peter, 1 Plant, District Heating
- Grafenau, 1 Plant, District Heating
- Wunsiedel, 2 Plants , District Heating
- Garrel, 7 Plants, Turkey Breeding
- Lupburg, 1 Plants District Heating
- Horb, 2 Plants, District Heating
- Plößberg, 4 Plants, Sawmill
- Achental, 2 Plants , District Heating
- Winden im Elztal, 1 Plant Hotel

3.3.3.4 Stadtwerke Rosenheim GmbH

Since 2015 Stadtwerke Rosenheim is a producer for wood gasifiers with staged pyrolysis and co-current fluidized bed reactor. The system is used for combined heat and power (CHP) applications, wood gas is used in gas engines. Stadtwerke Rosenheim offers their gasifier with 110 kWth and 50 kWel that are fed with untreated wood chips.

The company operates 1 pilot plant and delivered a second one.

Address: Bayerstraße 5, 83022 Rosenheim

Email: yves.noel@swro.de

Web: http://www.swro.de/kraftwerke/holzvergaser.html

3.3.4 Fixed bed gasifiers

3.3.4.1 LiPRO Energy GmbH&CO.KG

Since 2016 LiPRO Energy GmbH&CO.KG is a producer for a multi-stage gasification system with a pyrolysis step, a gas cracking step and a coal gasification with rotating grid. The system is used for combined heat and power (CHP) applications. LiPRO Energy offers their gasifiers from 60 – 100 kWth and 30 – 50 kWel that are feed with wood chips. All systems produce power from gas engines.

The company has delivered 9 plants.

Address: Ostkamp 22, 26203 Wardenburg

Email: info@lipro-energy.de

Web: www.lipro-energy.de

References:

- Hude, 1x LiPRO Contracting-Plant
- Deggenhausertal, 2x LiPRO Contracting- Plant
- Hilders-Brandt, 1x LiPRO Customer - Plant
- Wüstenrot, 3x LiPRO Operating Company - Plant

3.3.4.2 SPANNER RE² GmbH

Since 2006 Spanner is a producer for co-current fixed bed gasifiers for wood. The system is used for combined heat and power (CHP) applications. The modular design of the wood gasifier makes it possible to combine several plants in a cascade. Spanner offers units for 22 kWth – 3 MWth and 9 kWel – 2 MWel. They are fed with wood chips, pellets and briquettes. The systems produce power from gas engines.

The company has delivered more than 700 plants worldwide.

Address: Niederfeldstraße 38, 84088 Neufahrn

Email: info@holz-kraft.de

Web: http://www.holz-kraft.com

References:

- Bio-energy village Engelsberg, LK Neumarkt
- Organic Farm Braun, LK Freising
- Wellnessresort Stemp, Passau
- District Heating Steinhausen, LK Ebersberg
- Parquet floor Factory Hofer, LK Landshut
- Carpentry Heckel, LK Unterallgäu

3.3.4.3 REGAWATT GmbH

Since 2010 REGAWATT is a producer for a counter current fixed bed wood gasifier. The system is used for combined heat and power (CHP) applications. REGAWATT offers their gasifier from 600 – 4300 kWth and 300 – 2000 kWel. The gasifiers are fed with wood chips and lumpy biomass. All systems produce power from gas engines or gas turbines.

The company has delivered 6 plants.

Address: An den Sandwellen 114, 93326 Abensberg

Email: info@regawatt.de

Web: http://www.regawatt.de

References:

- Naturenergie Hersbruck, District Heating
- Moos Kombi Power System® Arco Clean Energy
- Sengenthal CHP Max Bögl
- Bad Füssing Bio-Energie Holmernhof

3.3.4.4 Biotech Energietechnik GmbH

Biotech Energietechnik GmbH is a producer for a multi-stage gasification system. The system is used for combined heat and power (CHP) applications. Biotech Energietechnik GmbH offers their gasifier with 75kWth and 25 kWel that are fed with natural wood chips. All CHP systems produce power from gas engines.

Address: Biotech Energietechnik GmbH, Plainfelder Straße 3, A-5303 Thalgau

Deutschland Mitte: Roter Weg, D-36163 Poppenhausen

Deutschland Süd: Nessensohn GmbH, Steigäckerweg 6, Hochdorf, D-88454 Hochdorf

Email: m.kurz@biotech-heizung.com

Web: https://www.biotech-heizung.com

References:

- District Heating, Ebersburg, 36157 Weyhers
- Medical Centre Neue Rhön, 36151 Burghaun

3.4 Italy

Italy has long been involved in the energy exploitation of residual biomass and waste. Among the various processes adopted, the way based on the thermochemical process of gasification has certainly attracted considerable interest. The process of thermal gasification of biomass and waste has found favour both in public research organizations and in private companies, which currently supply gasification plants on the market based on their own design. Details, regarding ongoing research and programs in Italy could be found in Italian Country report at the Task 33 website:
(http://www.task33.ieabioenergy.com/content/participants/country_reports)

An overview of numbers of operational gasification plants in region of Italy can be seen in the following figure.

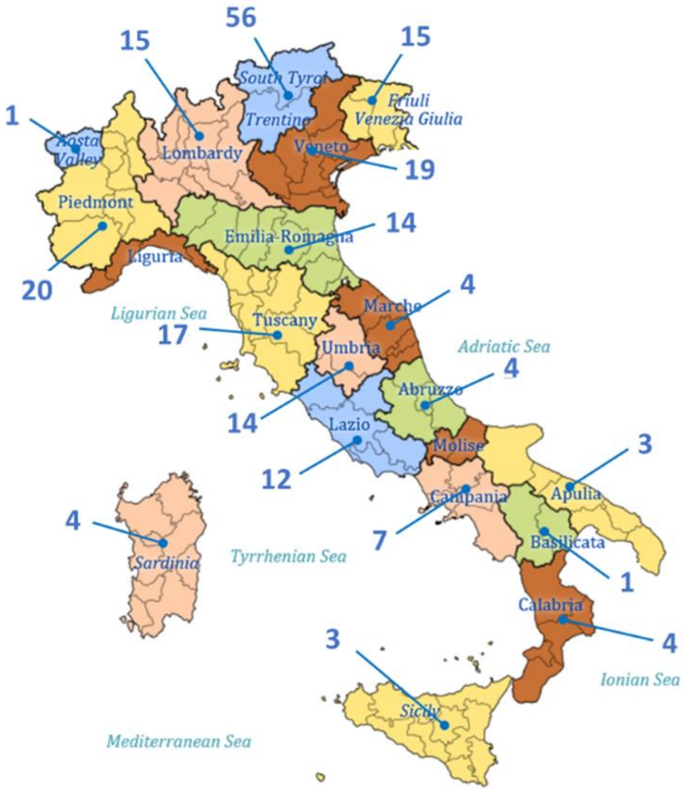


Figure 26: Overview on operational thermal gasification plants in Italy

Table 9: Thermal gasification plants installed in Italy

Geographical area	N° Plants	%	kWel.	%
Northern Italy	140	64.2	32,141	73.8
Central Italy	51	23.4	7,141	16.4
Southern Italy and islands	27	12.4	4244	9.8
Total	**218**	**100.0**	**43,526**	**100.0**

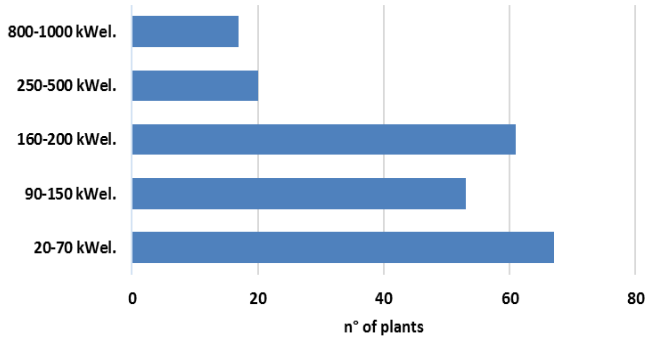


Figure 27: Distribution of the number of plants in Italy by electrical output

The distribution of the number of plants per sub-range of electric power is shown above. The plant size varies in the range from 20 to 1000 kWel. This range is the result of combination of different factors which take account of logistical and operational aspects, such as the availability of residual biomass from short supply chain and the easiness of plant running (i.e. without the need of dedicated and permanent staff), as well as the availability of incentives by size of produced power.

In fact, it appears rather evident that most of these plants are in the power side not exceeding 200 kWel, that is from micro to small size. Altogether they represent over 80% of the total number, while the remaining limited part indicating the plants with dimensions up to 1000 kWel.

Most of the plants and installed power are located in the area of northern Italy, in accordance with the fact that in this area of the country the presence of forested areas and companies that work wood is significant. Trentino-South Tyrol is the region with the larger number of gasification plants and power production.

Most of the facilities come from foreign manufacturers, which technology was described at other place of this report, thus only Italian thermal gasification technology will be described here.

3.4.1 CMD S.p.A

Producer of fixed bed gasifiers.

Address: Via A. Pacinotti, 2; 81020 San Nicola La Strada (CE), Italy

Email: info@cmdengine.com

Web: http://eco20cmd.com/cmd-eco20/?lang=en

The CMD mCHP plant

CMD ECO20x is a mCHP (Micro Combined Heat & Power) System transforming biomass into syngas (synthesis gas) from which electric energy and heat are produced. Internal combustion engine, connected to a synchronous alternator, can produce 20kW_{el} (peak value). Heating system can produce till 40kW_{th} of heat power (peak value), using the heating inside cooling liquid of the engine and that released by exhaust. Furthermore, mCHP system is suitable even for a trigenerative purpose (production of electric energy, heating, thermal and refrigerator), coupling with an absorption chiller.

Thanks to an innovative reactor section and specific pre-treatments, the biomass to be used in CMD ECO20x can be selected among a wide range of products and by-products: forestry waste, urban waste wood, waste from mixture of wood, mushroom manure, olive kernel, olive pomace, sawdust, rice husk, hazelnut shells, chestnut shells, almond shells, etc. olive pits, apricot pits, peach pits, tobacco stalks, corn stalks, cane residues. Biomass have been tested according to different combinations.

According to figure below, the energy box with its innovative design, can include both hopper and equipment in one space, making it more efficient and compact. Moreover, installation times are substantially reduced. ECO2Ox can be used in several applications:

- Forestry: farms, greenhouses, cheese factories, livestock, farming products transformation.
- Industry: logistic platforms for distribution and production of wooden scraps, carpenters'shops, food, paper factories, ceramic industry, glass, chemical, engineering, textile, handcraft industry.
- Residential/Commercial: shopping malls, hotels, swimming pools, urban areas and district heating, wellness centers.
- Public: Municipalities, districts, care homes, public swimming pools, hospitals, schools.

Figure 28. Internal details of ECO20X MICRO CHP SYSTEM

ECO20x working principles for electric energy production are shown in 29. The plant is based on a downdraft fixed bed gasifier of specific design. The cochlea, activated by M1 electric motor, pours biomass into the reactor. Thermochemical decomposition produces syngas needing to be cooled and cleaned before to be used in internal combustion engine. For this reason, it is conducted into a cyclone reactor for ultra-faint ashes removal, a cooler able to remove tars inside the syngas by condensation process (obtained through cooling water circulation inside the cooler), a biological filter to further remove ultra-faint ashes and residual tars, a cyclone close to the engine allowing the mixture with the external air and the final removal of condensation.

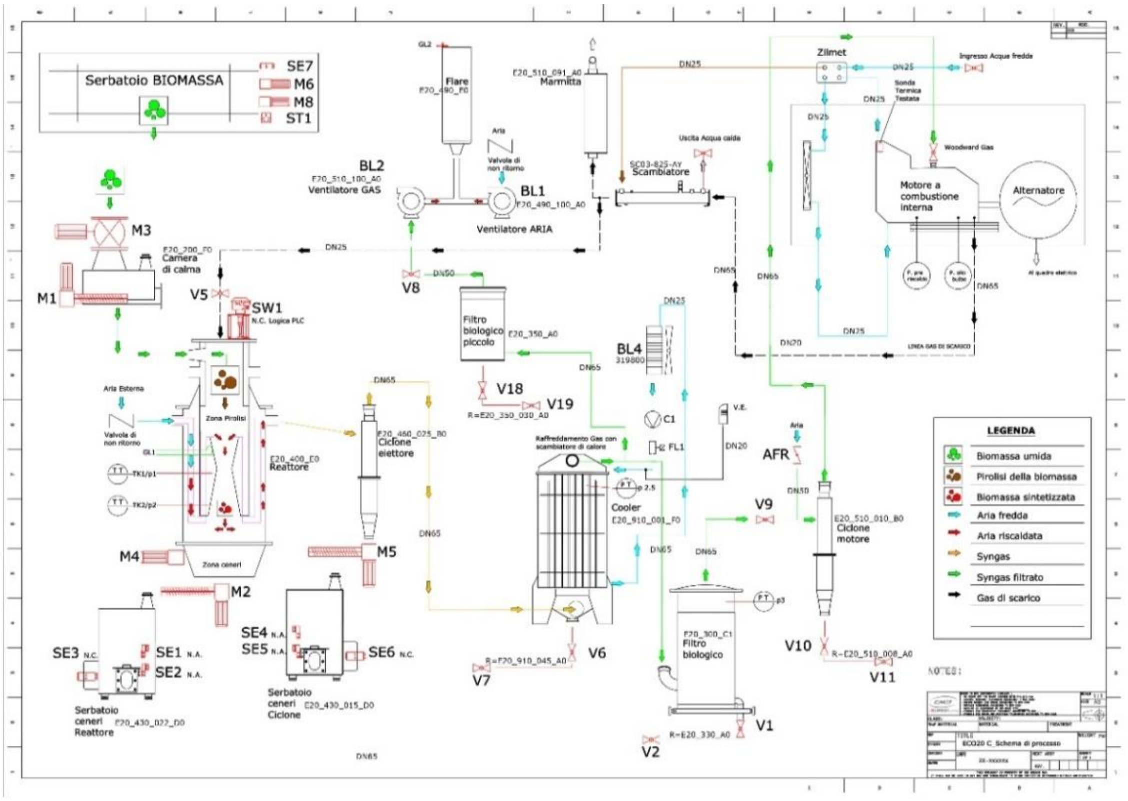


Figure 29. ECO20X MICRO CHP SYSTEM – Plant layout

Electric energy produced is fully released inside the electric grid, while engine's exhaust gas passes in the thermal recovery section. Concerning thermal recovery section, CHP system can get a first recovery at low temperatures using engine's cooling water by a plate heat exchanger, a further recovery at high temperature using engine's exhaust gas by a shell and tube heat exchanger. CHP system's exhaust gas, after releasing the heat inside the shell and tube heat exchanger, are released in the atmosphere, in line with current regulations on emissions, in conformity with Legislative Decree 152/06.

An overview of the container system is presented in the following figures.

Figure 30: ECO20X MICRO CHP SYSTEM: container version

Contact person: Domenico Cirillo (domenico.cirillo@cmdengine.com)

Web: http://eco20cmd.com/cmd-eco20/?lang=en

Table 10: Reference list of CMD S.p.A facilities

Supplier	Technology	Project/Location	Year of commissioning	Feedstock		Input/ Feedstock	Output El./Th.	Usage/ Product	Start up/ Status
				Wood chips	Off-cuts				
CMD SpA	Downdraft Fixed bed (Mod. ECO20x)	Via A. Pacinotti, 2 - 81020 San Nicola La Strada (CE) - Italy	05/2013	x		87.70 kW/ Wood chips	20 kWel (off-grid)	mCHP production	Demonstration Plant
		Via A. Pacinotti, 2 - 81020 San Nicola La Strada (CE) - Italy	05/2014	x		87.70 kW/ Wood chips	20 kWel (on-grid)	mCHP production	Demonstration Plant
		Via A. Pacinotti, 2 - 81020 San Nicola La Strada (CE) - Italy	06/2015	x		87.70 kW/ Wood chips	20 kWel (on-grid)/ 40 kWth	mCHP electric and thermal suppliers	2015/operational
		Via A. Pacinotti, 2 - 81020 San Nicola La Strada (CE) - Italy	06/2016	x		87.70 kW/ Wood chips	20 kWel (on-grid)/ 40 kWth	mCHP electric and thermal suppliers	2016/operational
		Via A. Pacinotti, 2 - 81020 San Nicola La Strada (CE) - Italy	01/2019	x	x	87.70 kW/ Wood chips	20 kWel (on-grid)/ 40 kWth	mCHP electric and thermal suppliers	2019/operational
		Manni Energy Via Augusto Righi, 7 - 37135 - Verona - Italy	01/2017	x		87.70 kW/ Wood chips	20 kWel (on-grid)/40 kW_{th}	mCHP electric and thermal suppliers	2017/operational
		Lavuri Contrada Camami, Piazza Armerina (EN) - Italy	05/2017	x		87.70 kW/ Wood chips	20 kWel (on-grid)/40 kW_{th}	mCHP electric and thermal suppliers	2017/operational

		Roveroni Localita' Ostia Parmense - 43043 Borgo Val Di Taro (Parma) - Italy	11/2017	x		87.70 kW/ Wood chips	20 kWel (on-grid)/40 kW_{th}	mCHP electric and thermal suppliers	2017/operational

3.4.2 ESPE SRL

Producer of downdraft fixed bed gasifiers.

Address: Via Dell'Artigianato, 6, 35010 Grantorto (PD), Italy

Email: espe@espe.it

Web: http://www.espegroup.com/en/biomass/cogenerator/

The CHiP50 Cogenerator

The company has developed CHiP50 Cogenerator, a gasification plant designed for small and medium sized businesses that need both heat and power. The gasification technology used in CHiP50 is the "Downdraft (DG)" reactor. ESPE has made use of this technical solution because it allows for extremely clean synthesis gas without a need for filters, and therefore allows for increased system reliability over the long term and simplifies daily management. The biomass used by such cogenerator is virgin wood chips, or rather very tiny pieces of wood. This chipped timber is generally obtained via local supply chain. Each component of the system is designed, tested and assembled within ESPE. The Syngas produced by wood biomass is conveyed into a cogenerator equipped with an Otto cycle motor for electrical production. The CHP asset allows to maximise biomass energy output with total efficiency (electricity + heat) that reaches as high as 90%. A typical scheme of process implemented in the CHiP50 Cogenerator plant layout is presented in following figure.

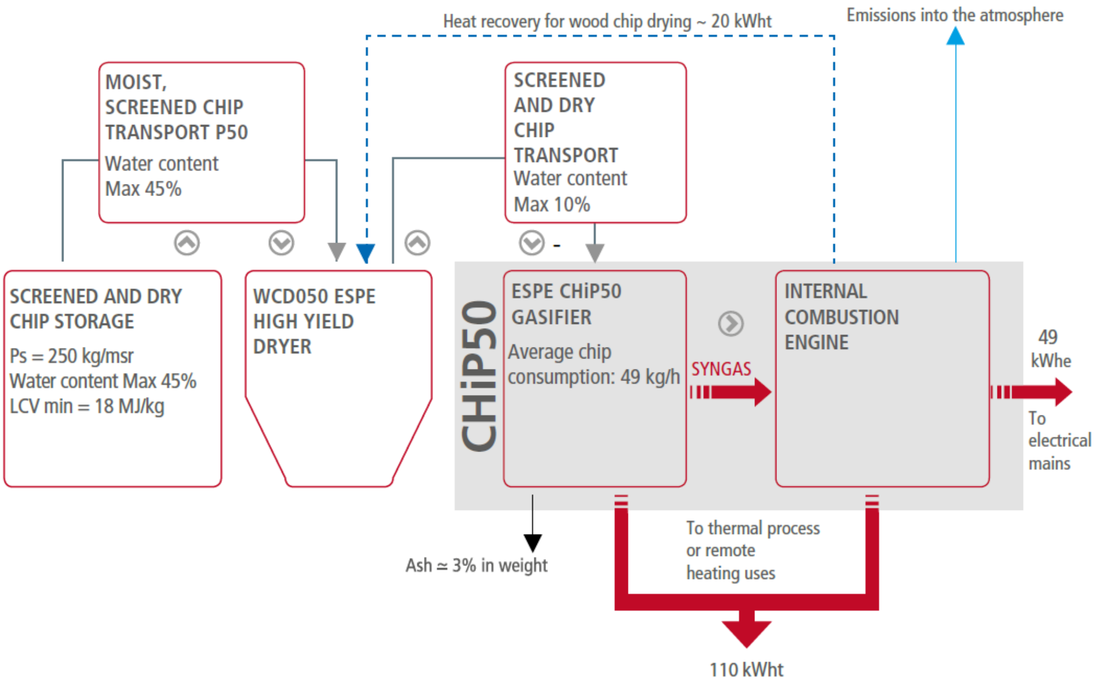


Figure 31. CHiP50 COGENERATOR SYSTEM – Process diagram

During operation, each phase is kept under constant control to maintain high levels of efficiency and reliability: temperature, pressure, and flows are continuously measured and recorded. Thanks to the insertion of a post-reformer, gas coming out from the gasification chamber is further purified with a simultaneous increase in the calorific value.

CHiP50 is equipped with proprietary software for controlling processes both locally and remotely. The ESPE CHiP50 cogenerator is equipped with a single centralised control unit, which automatically manages and controls all the functions of the gasification and cogeneration sub-units, allowing the entire process to be controlled and monitored without the need to access the panel installed on the machine. Through the general panel the entire machine can be controlled using a user-friendly and intuitive touch screen interface.

Figure 32: 49 kW electrical and 110 kW thermal cogeneration system for a greenhouse.

Figure 33: 196 kW electrical and 440 kW thermal cogeneration system containerized unit for heating and drying processes

Contact person: Matteo Vecchiato (m.vecchiato@espe.it)

Web: http://www.espegroup.com/en/biomass/cogenerator/

Table 11: Reference List of ESPE S.R.L gasification plants

Supplier	Technology	Project/Location	Year of commissioning	Feedstock		Input/Feedstock	Output El./Th.	Usage/Product	Start up/Status
				Wood chips	Off-cuts				
ESPE S.R.L.	Downdraft Fixed bed (Mod. CHiP50)	Santo Stefano Belbo (CU;Piedmont) Italy	2017	X		440 kW/ Wood chips	98 kWel./220 kWth	Micro-CHP production	2017/operational
		Incisa Scapaccino (AT; Piedmont) Italy	2017	X		880 kW/ Wood chips	196 kWel./440 kWth	Micro-CHP production	2017/operational
		Messima (ME;Sicily) Italy	2015	X		220 kW/ Wood chips	49 kWel./110 kWth	Micro-CHP production	2015/operational
		Lunano (PU; Marche) Italy	2016	X		440 kW/ Wood chips	98 kWel./220 kWth	Micro-CHP production	2016/operational
		Belluno (BL; Veneto) Italy	2016	X		440 kW/ Wood chips	98 kWel./220 kWth	Micro-CHP production	2016/operational
		Gubbio (PG; Umbria) Italy	2015	X		440 kW/ Wood chips	98 kWel./220 kWth	Micro-CHP production	2015/operational
		Peveragno (CN; Piedmont) Italy	2015	X		440 kW/ Wood chips	98 kWel./220 kWth	Micro-CHP production	2015/operational
		Roma (Lazio) Italy	2016	X		440 kW/ Wood chips	98 kWel./220 kWth	Micro-CHP production	2016/operational
		Cogne (AO; Valle d'Aosta) Italy	2015	X		220 kW/ Wood chips	49 kWel./110 kWth	Micro-CHP production	2015/operational
		Piacenza (PC; Emilia-Romagna) Italy	2014	X		220 kW/ Wood chips	49 kWel./110 kWth	Micro-CHP production	2014/operational
		Ravenna (RA; Emilia-Romagna) Italy	2015	X		440 kW/ Wood chips	98 kWel./220 kWth	Micro-CHP production	2015/operational
		Perugia (PG; Umbria) Italy	2014	X		220 kW/ Wood chips	49 kWel./110 kWth	Micro-CHP production	2014/operational
		Padova (PD; Veneto) Italy	2014	X		440 kW/ Wood chips	98 kWel./220 kWth	Micro-CHP production	2014/operational

		Lucca (LU; Toscana) Italy	2014	X		220 kW/ Wood chips	49 kWel./110 kWth	Micro-CHP production	2014/operational
		Pesaro (PU; Marche) Italy	2014	X		440 kW/ Wood chips	98 kWel./220 kWth	Micro-CHP production	2014/operational
		Mantova (MN; Lombardia) Italy	2014	X		220 kW/ Wood chips	49 kWel./110 kWth	Micro-CHP production	2014/operational
		Vicenza (VI; Veneto) Italy	2014	X		880 kW/ Wood chips	196 kWel./440 kWth	Micro-CHP production	2014/operational
		Cuneo (CN; Piedmont) Italy	2014	X		880 kW/ Wood chips	196 kWel./440 kWth	Micro-CHP production	2014/operational

a) ESPE SRL has installations also abroad (e.g.in UK and Japan).

3.4.3 RESET s.r.l.

Engineering and manufacturing of small scale, containerized biomass gasification and cogeneration systems.

Highlights

Small scale plants from 50 kWe to 200 kWe; Fully automatic, integrated, plug and play solution; Containerized and modular;No syngas cleaning waste production; High grade biochar.

Registered office: Viale Giulio Cesare, 71 – 00192 Rome, Italy

Headquarters: Via delle Industrie snc - 02015 Cittaducale (RI)

Email: info@reset-energy.com

Web: www.reset-energy.com – www.syngasmart.com

RESET

Renewable Energy Solutions Environmental Technology

The RESET SyngaSmart microCHP

RESET is a cleantech company founded in 2015 that has developed and marketed SyngaSmart, a range of containerized micro CHP systems (from 50 to 200 kWe) based on a proprietary biomass gasification technology. SyngaSmart plants allow to generate electricity and heat by first converting organic feedstock (i.e. woodchips or dry organic briquettes) into producer gas. The fuel generation process is based on multiple downdraft fixed bed gasifier specifically designed, engineered and developed by RESET R&D dept.

SyngaSmart typical layout is reported in figure below.

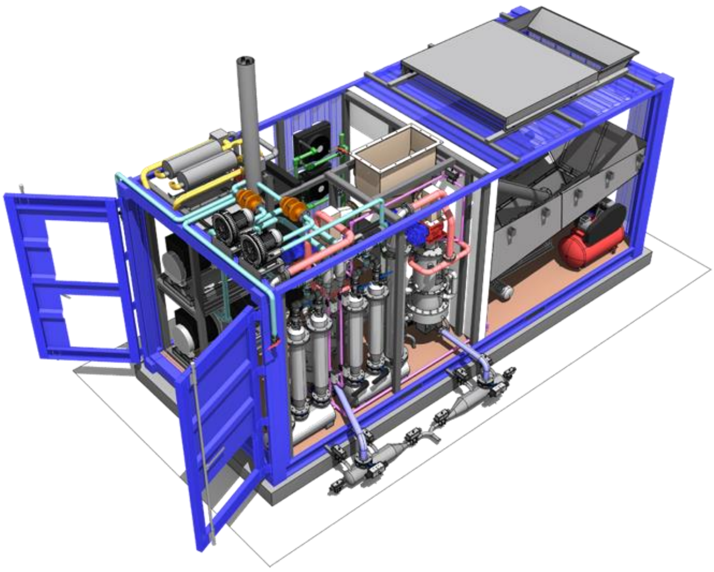


Figure 34: SYNGASMART 50 CHP SYSTEM – Plant layout

SyngaSmart plants enclose all the equipment required for 24 hrs continuous operation inside standard shipping containers: biomass storage and pretreatment (drying), gasification unit, syngas cleaning, biochar collection, genset, thermal recovery and automation/power panel. SyngaSmart can be operated both on site and through remote connection using a proprietary SCADA interface, thus minimizing plant supervision. The generation process is carbon negative since it is capable of storing carbon from biomass into a stable form of high-grade biochar, whose properties as soil amendment are universally acknowledged.

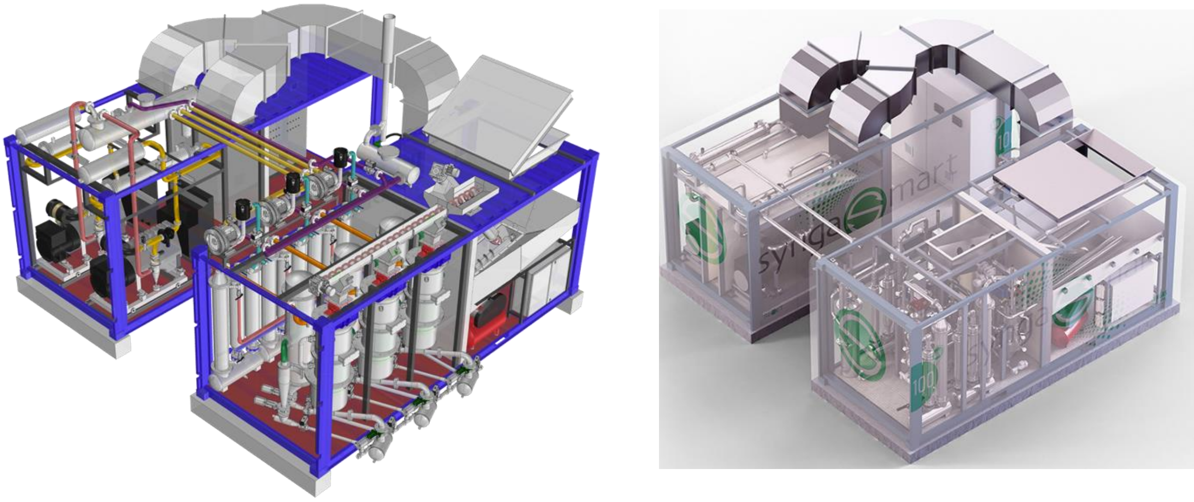


Figure 35: Sketches of a multi-reactor system, four gasifiers are visible

Contact person: Valerio Manelfi (valerio.manelfi@reset-energy.com)

Table 12: Reference list of RESET s.r.l. facilities

Supplier	Technology	Project/Location	Year of commissioning	Feedstock		Input/Feedstock a)	Output El./Th.	Usage	start up	status
				Wood chips	Off-cuts					
RESET s.r.l.	Downdraft Fixed bed	SAN COSMO ALBANESE (CS)	2018	X		50 kg/hr	50 kWe / 75 kWth	Micro cogeneration	2019	operational
		STRANGOLAGALLI (FR)	2016	X	X	50 kg/hr	50 kWe / 75 kWth	Micro cogeneration / waste wood processing	2017	operational
		RIETI (RI)	2016	X		100 kg/hr	100 kWe / 150 kWth	Micro cogeneration	2018	operational
		TERNI (TR)	2016	X		50 kg/hr	50 kWe / 75 kWth	Micro cogeneration	2017	operational
		CERRETO DI SPOLETO (PG)	2017	X		50 kg/hr	50 kWe / 75 kWth	Micro cogeneration	2018	operational
		SASSOFERRATO (AN)	2017	X		100 kg/hr	100 kWe / 150 kWth	Micro cogeneration	2018	operational
		MENFI (AG)	2018		X	100 kg/hr	100 kWe / 150 kWth	Micro cogeneration	-	under construction
		SIRACUSA (SR)	2018	X		100 kg/hr	100 kWe / 150 kWth	Micro cogeneration	-	under construction

		BISIGNANO (CS)	2018	X		100 kg/hr	100 kWe / 150 kWth	Micro cogeneration	-	under construction
		ROMA (RM)	2018	X		100 kg/hr	100 kWe / 150 kWth	Micro cogeneration	-	under construction
		ROMA (RM)	2018	X		100 kg/hr	100 kWe / 150 kWth	Micro cogeneration	-	under construction
		ROMA (RM)	2018	X		50 kg/hr	100 KWe./150 kWth	Micro cogeneration	-	under construction
		CITTADUCALE (RI)	2018	X		100 kg/hr	100 kWe / 150 kWth	Micro cogeneration	-	under construction
		SIGILLO (PG)	2018	X		50 kg/hr	50 kWe / 75 kWth	Micro cogeneration	2019	Operational
		PIACENZA (PC)	2018	X		100 kg/hr	100 kWe / 150 kWth	Micro cogeneration	-	under construction
		PIACENZA (PC)	2018	X		100 kg/hr	100 kWe / 150 kWth	Micro cogeneration	-	under construction
		PIACENZA (PC)	2018	X		100 kg/hr	100 kWe / 150 kWth	Micro cogeneration	-	under construction
		PIACENZA (PC)	2018	X		100 kg/hr	100 kWe / 150 kWth	Micro cogeneration	-	under construction
		LODI (LO)	2018	X		50 kg/hr	50 kWe / 75 kWth	Micro cogeneration	-	under construction

a) LHV in the range 16-19 MJ/$kg_{Biomass}$, on dry basis.

3.5 The Netherlands

3.5.1 Bio Energy Netherlands

Bio Energy Netherlands (BEN) is a company with a vision on using sustainable alternatives to fossil fuels. They start their company producing heat and power using gasification as base technology, but in the future will use this platform to produce biogas, hydrogen and CO_2, all used in the chemical industry.

BEN uses modular plants, and because of the modular structure, BEN can respond flexibly to the local demands for its end products.

Green heat for district heating and/or industrial applications

- Green electricity
- Green hydrogen
- Green Gas
- Green CO_2

The gasification plants of BEN use biomass, mainly in the form of residual wood. 'Biomass' (in this context) means all organic and biologically degradable materials that may be used as resources or fuel. The use of biomass is only sustainable under the right conditions. This is why the gasifiers of Bio Energy Netherlands exclusively use residual flows and regional biomass, making sure that the biomass was never harvested for the production of energy and improving the sustainability.

In November 2017 the construction of a wood gasification plant started in the Port of Amsterdam. The technology used is supplied by Zero-Point Clean Tech, which is fixed bed technology. This will result in low tar content gas, making cleaning easier. The first phase is expected to be operational in May 2019. An observation from the start-up phase is that permitting such technology takes longer than normal, since it is not well established.

The gas that is produced by Bio Energy Netherlands can be used to generate heat and electricity. There is a collaboration with Jenbacher and excellent results with Jenbacher 620 syngas engine have been achieved. The plant in Amsterdam is designed for a total of 15 MWh of combined heat, power and hydrogen. There is an agreement with AEB for heat delivery to city of Amsterdam and electricity delivered to Nuon and Van de Bron. When the CO_2 pipeline is extended to the AEB location BEN will also be delivering CO_2 to the greenhouses in "Westland".

Here too, emissions of greenhouse gasses are reduced by replacing heat and electricity from fossil fuels. Because windmills and solar panels are mainly utilized for generating electricity, the gasified biomass of BEN is especially useful for improving the sustainability of heat production. As a matter of fact, heat production is responsible for the largest amount of energy usage in the Netherlands. Currently this heat is mostly produced using natural gas. A lot of greenhouse gas emissions reduction can be achieved by improving the sustainability of the Dutch heat production.

Bio Energy Netherlands location: Keizersgracht 534-6,1017 EK Amsterdam

Bio Energy Netherlands Website: https://bioenergynetherlands.nl/

3.5.2 Essent/RWE

Essent/RWE owns and operates a waste wood gasifier connected to a 600 MWe coal-fired power station with 42% net electric efficiency. The plant is situated in Geertruidenberg and is called Amer-9.

The coal plant co-fires biomass in two different ways. Approximately 25% (energy) of clean wood pellets are directly co-fired and another 5% is co-fired indirectly through a gasifier. The gasifier was built in 2000/2001 and did undergo several hardware modifications that were merely related to fuel feeding and gas cooling and cleaning.

Figure 36: The Amer-9 coal-fired power station with the waste wood gasifier

The capacity of the gasifier amounts 85 MWth and is a near-atmospheric Circulating Fluidized Bed (CFB) reactor based on Lurgi technology. The fuel is waste wood category B in the Netherlands, meaning that it contains painted wood, MDF, plywood as well as glass, metal and other inorganic materials. The gasifier is operated on preheated air and steam and operates at approximately 850°C. The gas is cooled in a water-tube cooler producing 310°C superheated steam. The gas then passes a cyclone, or actually two parallel cyclones, and is directed to the main coal boiler at 400-450°C.

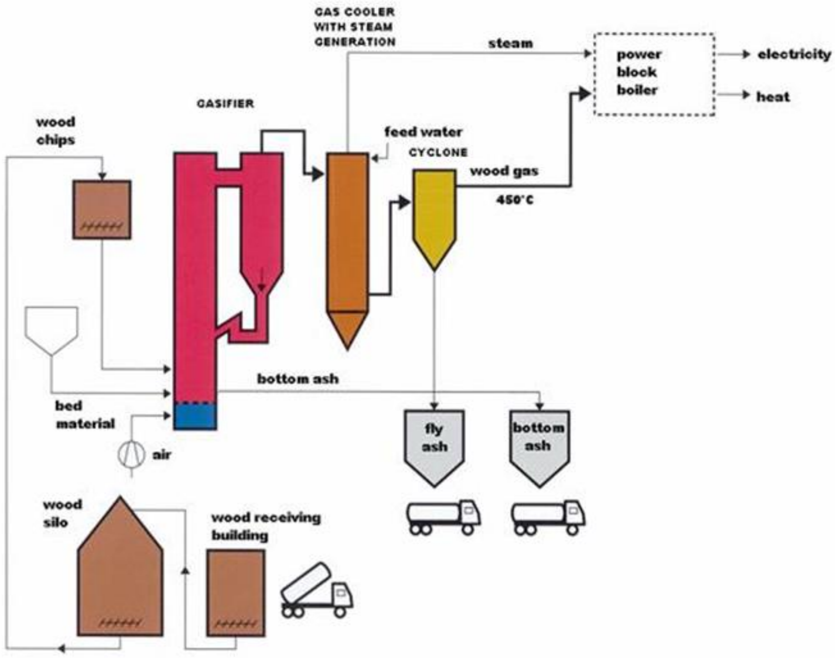


Figure 36: The system of the Essent 85 MW waste wood gasifier for indirect co-firing

The gasifier/cooler/cyclone plant operates approximately 5000 h/year. This has been limited mainly due to feeding issues and cooler fouling due to tar deposition.

Currently RWE is developing a new strategy for the Geertruidenberg site to become 100% sustainable. This means that the location can be seen as a hub/incubator site for bio based developments, where the power plant can be used as an installation taking care of the bio-waste that is produced in these processes. This will replace coal and eventually it will make coal obsolete. The first step is to replace the coal with wood pellets, which should be realized by the end of 2019. Next is the change of the gasifier in order to keep using this, a decision on how to proceed will be taken during 2019.

RWE location: Amerweg 1, 4931 NC Geertruidenberg

RWE Website: www.rwe.com

3.5.3 ESKA

Eska is the leading global manufacturer of recovered paper based substrates for a wide variety of industries and applications, including hardcover books, stationery, luxury packaging, puzzles and games and many more. Eska has sustainability on their agenda for many years, making them currently one of the best performing companies in the paper and board industry. One of the latest implementations is the use of gasification for replacement of natural gas. Eska is using CFB technology to gasify paper rejects and using the product gas as a feed to a boiler. The technology they use is supplied by Leroux & Lotz and implemented in 2016. Using gasification will save 18 million m^3 of natural gas per year.

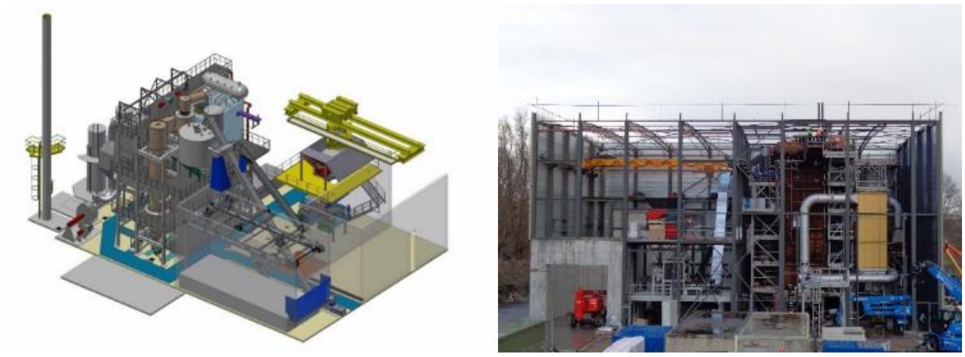


Figure 38: 3D model (left) of the plant at Eska and a photo of the site erection on the left

The installation is a 12 MW_{th} CFB boiler processing 25 kton/a of reject to produce steam for the onsite processes. The boiler produces 5 – 16 ton/h steam (196°C,13.6 barg). The plant started October 2016 and reached >10000 hours of reject operation since then in which >20.000 tons of rejects were processed.

Eska location: Meint Veningastraat 114-116, 9601 KJ Hoogezand

Eska Website: www.eska.com

3.5.4 Mavitech Green Energy

In 1991 Dupps Europe started as an exclusive representative of The Dupps Company. The Dupps Company was already active in the rendering industry from the year 1935. In 2002 Dupps Europe was merged into Mavitec. At the early stages Mavitec mainly sold spare parts and single components for existing Rendering plants. Later, under the name Mavitec, they exploited their activities to designing, building and installing turnkey rendering projects. In 2008 Mavitec's core business remained serving the rendering industry and in addition they developed a system for the food recycling industry under the name Mavitec Green Energy.

Within Mavitech Green Energy, gasification plants are sold turn-key. Their technology is a down-draft fixed-bed gasifier which is capable of converting various feedstocks (different manure and sludges) into a product gas (CO, H_2 and CH_4), which is combusted directly after the gasifier and the heat can be used to produce steam, power or heat. This all depends on the local requirements. The system also produces char, which is being sold as a product by Mavitech. This EcoChar contains minerals and fixed carbon, which has economic benefits. The outlets range from feed, soil improver, animal bedding etc.

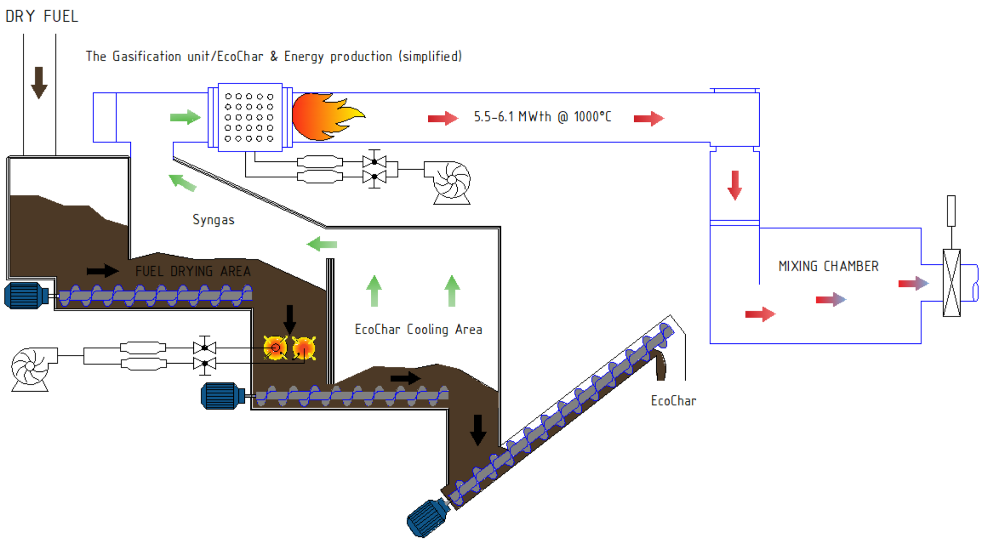


Figure 39: Schematic lay-out of the Mavitech process

Mavitech Green Energy Headquarters: Galileistraat 20, 1704 SE Heerhugowaard

Mavitech Green Energy Website: http://www.mavitecgreenenergy.com/gasifications/

3.5.5 Synova

Synova is Waste-to-Energy company providing technology and projects based on gasification. Although Synova started as an American company developing Waste-to-Energy projects, it soon got the rights on the technologies developed at ECN (now TNO). Synova has offices in the US, Netherlands, and Thailand. In 2017, Synova acquired the renewable part of Royal Dahlman that originally got the licenses on the technologies from ECN. This is now Synova's technology division based in the Netherlands.

The technologies developed by ECN concern the indirect fluidized bed gasifier MILENA and the tar removal technology OLGA. Synova considers these units particularly suitable for the conversion of waste feedstock to power with high efficiency. Synova however, also sees a bright future for applications where the clean gas is upgraded to Renewable Natural Gas or used to separate/synthesize chemicals.

Synova developed a standardized modular unit based on MILENA and OLGA of approx. 6 MW input (depending on the feedstock). This so-called SMM can be used to couple to a power block to make circa 1.5 MW$_e$ electricity. It also will be the basis for an RNG project in the Netherlands called Ambigo. Synova identified a large market for these units that will be built in containers, have a short production time with quick local assembly, and several options to adapt to specific conditions or wishes by the client. The first SMM to power will be in Thailand, North-East from Bangkok. Synova will own and operate the plant.

A larger unit producing approx. 8 MW$_e$ to the grid is designed and ready for EPC bids. These projects will often include the facility needed to convert Municipal Solid Waste (MSW) to Refuse Derived Fuel (RDF), which is the feedstock for the gasifier. The power plant will include a turbine from Caterpillar, that is one of the investors in Synova. There are currently several options for this 8 MW$_e$ unit in Thailand. A unit for circa 25 MW$_e$ will be the largest unit that Synova is developing.


Figure 40: Synova's waste-to-power plant with power block for 1.5 MW$_e$ in two different designs


Figure 41: Synova's waste-to-power project (right) in Thailand with 8 MW$_e$ net production on an existing landfill/dump (left)

Synova Address: Scheldeweg 10, 3144 ES Maassluis

Synova Website: https://synovapower.com

3.5.6 Synvalor

Synvalor is a new Dutch company, founded by Jacques Poldervaart, who previously owned the company Polow Energy Systems BV (PES for short). PES supplied a so-called Torbed® gasifier plant to a Dutch client in Nieuwdorp near Vlissingen in the Netherlands. This plant was based on the technology of Torftech, that also later became the basis for the torrefaction technology developed by the company Polow Energy Systems, who merged later with Topell BV to Topell Energy BV.

Figure 42: The Synvalor pilot gasifier

Synvalor developed a new multi-stage vortex reactor for the gasification of all kind of fuels, but specifically difficult fuels. It aims at producing low-tar producer gas for e.g. gas engines. The goal is to keep the investment below 2500 Euro/kW_e. The technology is called Synvator®. Synvalor built a pilot test facility of approximately 50 kW_e capacity and has been tested with wood dust, wood chips, reed, grass, straw, and digestion residue. Synvalor is confident about the technology and is working towards two plants in Europe.

Currently there is a CHP plant in commissioning at a Gerbera grower (Fa. S.C. Zwarts in Mijdrecht) in the Netherlands. The first results are expected in 2019.

Synvalor Headquarters: Schattekerkerweg 1, 3641 PM Mijdrecht

Synvalor Website: www.synvalor.com

3.5.7 Torrgas

Torrgas is a company founded in 2012 that specializes in the development of biomass-to-energy and biomass-to-chemicals projects. Torrgas aim is to be a leading provider of value chain solutions for plant scale (10-100 MW) syngas from torrefied biomass. First step in its role out strategy is to develop a series of repeatable, reliable and highly scalable torrefaction - gasification value chains that can rely on the team’s ability to combine gasification know how with strong biomass supply chain networks.

The objective of Torrgas is to develop and technically and commercially proof the operation of a biomass gasification process to produce chemically grade syngas, which is free of nitrogen and tar. This with the following boundary conditions:

- The process is scalable;
- The process is financially feasible (in the near future without subsidies);
- The process is easy to operate;
- The process is reliable.

Torrgas focused the last 7 years on a new solution towards a more bio-based society. This by developing a technology concept that concerns a two-step gasification system consisting of a pyrolysis step (or formally a mild gasification step) and a high temperature gasification step. In addition, Torrgas applies torrefied biomass as the feedstock. This because torrefied biomass has clear advantages over fresh biomass. Biomass is not a fuel but a feedstock: It requires a pre-treatment process that transforms the wide variety of feedstocks into one homogeneous fuel. This process is called torrefaction and it transfers heterogeneous, fibrous and low energy density feedstock into a homogeneous, pulverisable, high energy density bio-fuel. This essential pre-treatment step results in a series of benefits in downstream processing ranging from price, quality and supply security to higher product yields and process stability.

Figure 43: Torrgas thermal gasification facility

Based on the features of torrefied biomass compared to fresh biomass the objectives of Torrgas to develop a reliable technology and easy to operate can be fulfilled, because of the homogeneity of the torrefied feedstock. Furthermore, from safety point of view (rotting) a storage (hydrophobic) torrefied wood is much better to handle eventually expected to lead to higher efficiencies and lower losses. Torrgas has successfully commissioned their first demonstration plant at DNV-GL at 0.7 MW_{th} and finished the Basic Engineering of 25 MW_{th} (2*12,5 MW) gasification plant in Delfzijl. The syngas produced in the Delfzijl project will be converted into SNG. This project is together with Gasunie, Pörner, and DBI. The Delfzijl project is intended to start construction in 2019.

Torrgas Headquarters: Herikerbergweg 292, 1101 CT Amsterdam

Torrgas Website: www.torrgas.nl

3.5.8 SCW

SCW Systems is a young company focusing on the development of supercritical water gasification. This technology is different from the others described, since it goes to very high pressure and high temperature. Typical operating conditions are at high pressure >221 bar and high temperature > 375°C. Under these conditions water changes into the supercritical phase and salt will crystallize whilst organic material will dissolve. The solids can be taken out of the supercritical phase and the dissolved components can react to produce methane, hydrogen and CO_2. The feedstock is per definition quite wet in order to have a pumpable slurry, which simplifies the compression compared to solids.

A first demonstration plant is constructed in Alkmaar and the commissioning started in the second half of 2018. This installation has been connected to the high pressure transport grid round December 2018. Gasunie New Energy is directly involved in this development. Expected Green Gas production in 2019.

Figure 44: Connection to high pressure grid (courtesy Oosterhof Holman)

SCW Headquarters: Diamantweg 36, 1812RC Alkmaar

SCW Website: www.scwsystems.com

3.5.9 HoSt

HoSt is one of the largest suppliers of bioenergy systems in Europe. The expertise of HoSt focuses on the technological development of the processing of biomass and waste streams and the supply of systems for renewable energy from biomass and waste. HoSt offers a range of technologies from anaerobic digestion and biogas upgrading to biomass CHP plants and boilers. In their range of technology offers is also CFB gasification technology for boiler applications.

Their CFB technology has been proven on various feedstock and their offers are in the range of a standard installation of 1-5 t/h or specialty plants of >5 t/h. In figure below the system layout for their CFB gasifier is given.

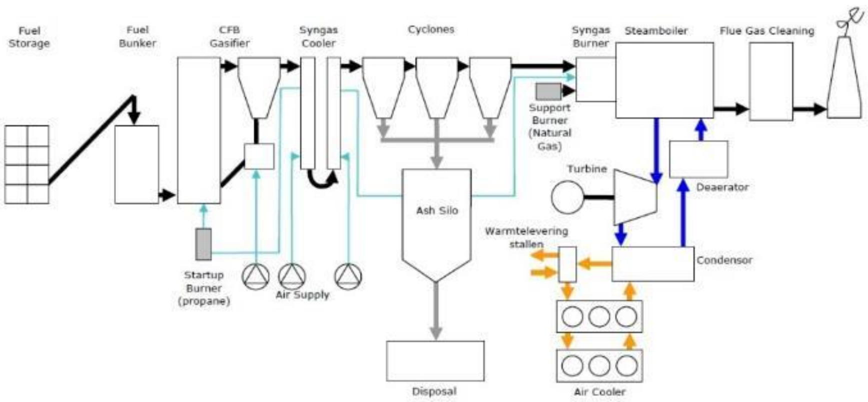


Figure 45: HoSt gasification system for difficult fuels with CFB gasifier and syngas boiler

HoSt supplied two gasification systems for chicken manure to a Dutch client and a Portuguese client. Another system was supplied to a Romanian customer operating on sunflower husks. In the Dutch and Romanian plant, the syngas is burned in a boiler at high-temperature with a HoSt burner design to produce steam/heat. The Portuguese plant is equipped with an OLGA tar removal system and connected to a 1 MWe Caterpillar gas engine.

HoSt Headquarters: Thermen 10, 7521 PS Enschede

HoSt Website: www.host.nl

3.5.10 ECN part of TNO

ECN is the Dutch Energy Research Institute, which merged with TNO on the first of April 2018. The activities that ECN used to do will continue under the flag of TNO. The new name for this institute is ECN part of TNO.

Biomass gasification is an important topic within ECN part of TNO for almost 25 years now. In these 25 years various technological successes have been achieved. ECN part of TNO has developed a Circulating Fluidized Bed gasifier (CFB), which is commercialized by HoSt.

ECN part of TNO has developed a technical route to convert biomass into substitute natural gas. This technology is based on the MILENA indirect gasifier combined with the first gas cleaning OLGA. This technology is commercialized through a joint venture between ECN part of TNO and Dahlman Renewable Technology (part of Synova).

At ECN part of TNO there is extensive knowledge on these two (CFB and indirect) gasification technologies, but also on fixed bed, fluidized bed and super critical gasification.

Currently the developments at ECN part of TNO have to major focus points:

1. Biobased economy through biofuels and biochemicals production
2. Circular economy through processing of plastic containing waste streams with recovery of monomers

ECN part of TNO Location: Westerduinweg 3, 1755 LE Petten

ECN part of TNO Website: https://www.tno.nl/en

3.6 Norway

3.6.1 Small scale gasification

First Norwegian small scale CHP based on gasification of locally sourced wood chips, located at Evenstad campus started up in 2016. The facility was produced by Volter and delivered by ETA Norge. The feedstock quality was a challenge thus a new reactor for pellets was developed.

In Norway, the prices of energy are relatively low, thus CHP production based on gasification is too expensive in comparison with other energy sources.

3.6.2 Other projects

3.6.2.1 Quantafuel

Currently plastic waste, biomass and non-captured natural gas are unused resources causing huge environmental and financial problems, thus this project focuses on plastic waste further processing and utilization as a source for liquid biofuels.

Quantafuels[12] first European plant is now officially established at GreenLab green industrial park in Skive, Denmark. The purpose of GreenLab Skive is to create one of Europe's leading centres for renewable energy.

The Quantafuel plant in Skive will source plastic from local suppliers and produce local, environmentally friendly, high-quality fuel.

The Skive plant will have an initial capacity of 60 metric tonnes of plastic waste per day, and will convert approximately 18 000 tons of plastic waste per year. This is plastic waste which would otherwise be exported or incinerated.

Quantafuel will produce more than 15 million litres of high-quality recycled fuel.

The pilot plant will function as the first step (of two) in a pre-commercialization process. The verification of the technology and process will set the foundation for a demonstration scale, in near-full-scale facility.

Preliminary capacity targets for full scale facilities are around 7 million litres of jet-fuel/year. The BtL technology is planned further developed and commercialized in collaboration with leading aviation industry partners, as well as the Norwegian scientific community.

[12] https://quantafuel.com/

3.6.2.2 BioFuel

This project focuses on sustainable economic production of aviation biofuel from household waste.

The project embraces two phases:

A. Commercial Demonstration Plant

B. Commercial Facility with full potential

A: Commercial Demonstration Plant

- Capacity: About 300 tonnes per day
- Feedstock: Household waste
- Production capacity:
  - 8,6 million liters FT-liquids
- Objectives: Prove and optimize processes
- Total project cost: Est. 150 MUSD
- Location: Fredrikstad, Norway

B: Commercial Facility with full potential

- Operational start date: 2026
- Capacity: About 2000 tonnes per day
- Feedstock: Household waste
- Production capacity:
  - 50 million liters aviation biofuel
  - 10 million liters biodiesel
  - 12 million liters bionaphtha
  - 10.000 tonnes of LPG
- Total project cost: Est. 876 MUSD
- Location: Haugesund, Norway

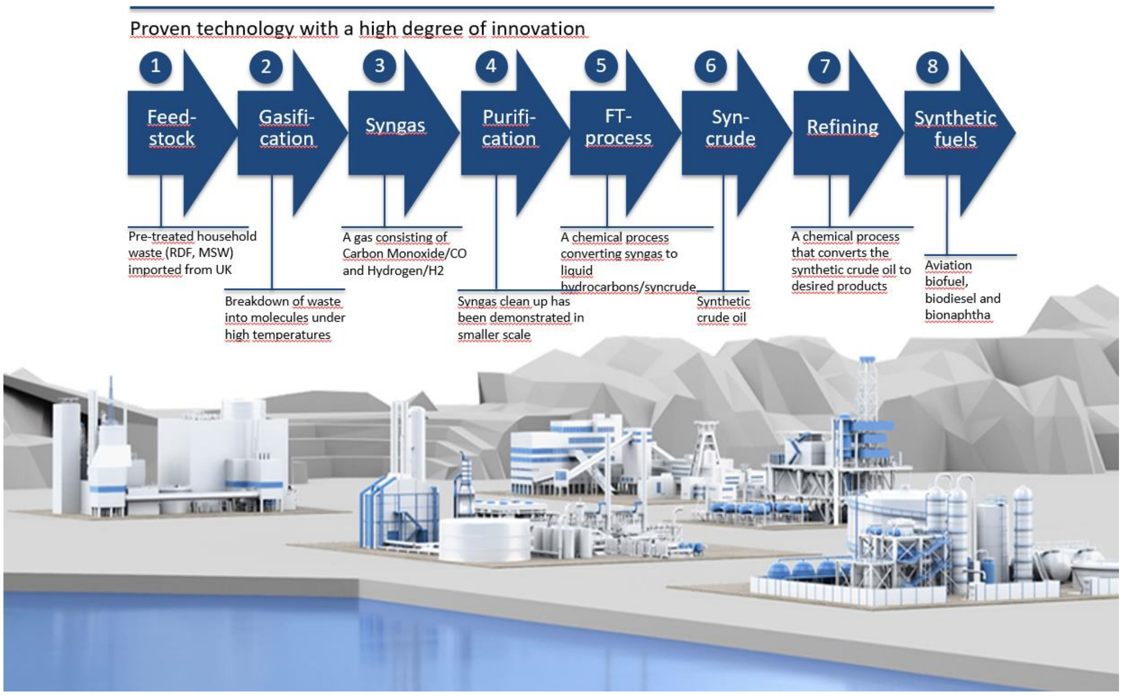


Figure 46: Production process BioFuel

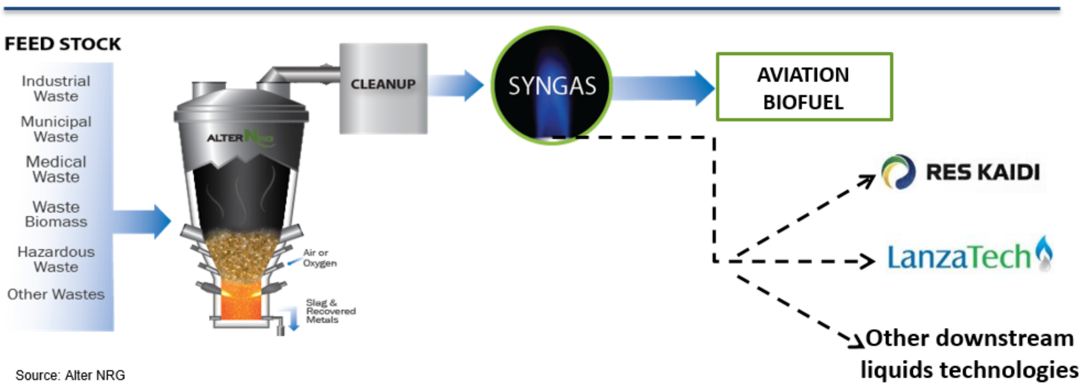


Figure 47: Flow sheet of the BioFuel process

Providers:

ALTER NRG   Westinghouse (Westinghouse Plasma Corporation)   RES KAIDI   KAIDI

Alter NRG

Canadian company that develops and/or owns projects using Westinghouse Plasma Corporation (WPC) gasification technology

30 years+ of research and development. USD 2 bn+ invested in projects/technology.

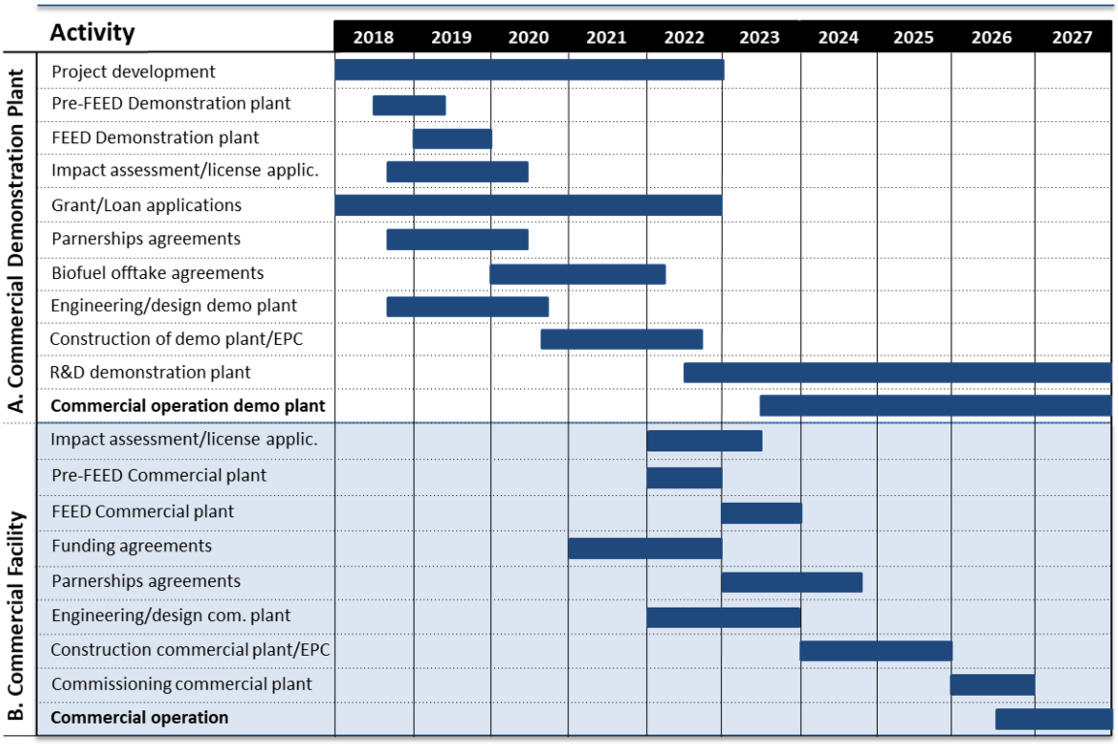
RES Kaidi

- US renewable and alternative energy technology and engineering services company. The Fischer Tropsch technology of RES Kaidi generates valuable fuels, chemicals and other products starting with a variety of feedstocks.
- (Alter NRG and RES Kaidi are owned by Sunshine Kaidi New Energy Group)

KAIDI

- Builds, owns and operates a portfolio of power plants
- Turns for more than USD 8 billion
- The company produces more than 1400 MW of electric power
- Are going to build more than 3000 MW for the next 5-7 year period in China
- EPC competence - has been responsible for more than 200 projects
- Has shown expertise in hydropower, wind power and concentrated solar energy
- Technologies in removing sulfur, wastewater treatment and gas purification
- Fischer-Tropsch technology (Iron and Cobalt Catalysts)

Table 13: Estimated time schedule of the biofuel project



3.6.2.3 Scandi Energi - Projects

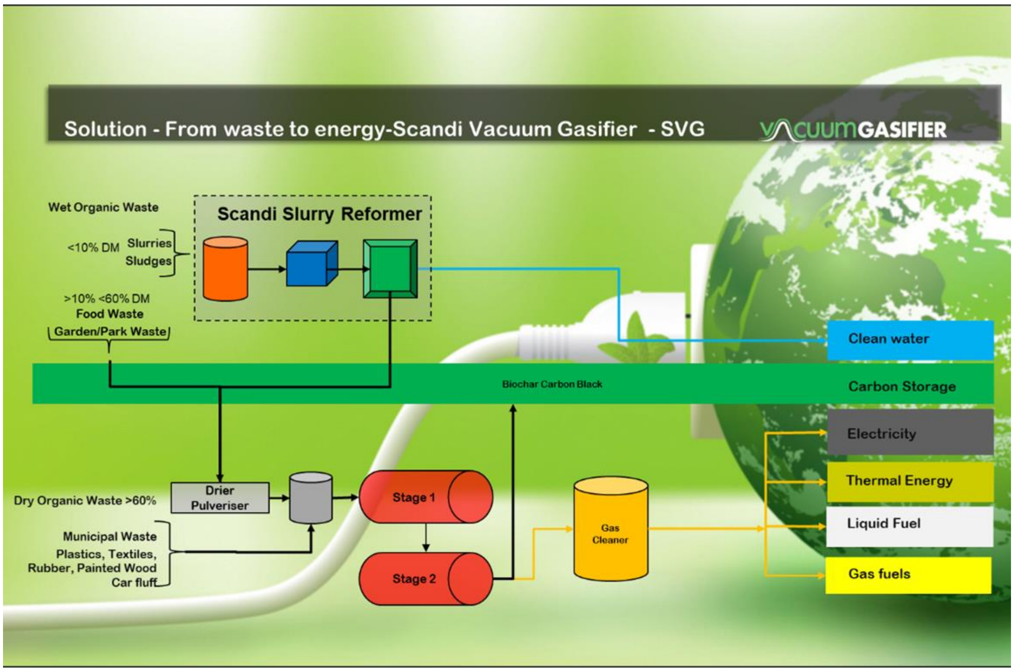


Figure 48: Flow sheet vacuum gasifier Scandi

Drier supplied with residual heat from the gasifier for the drying of feedstock to a level of 85% dry matter.

Vacuum Gasification: The first stage of gasification is under a partial vacuum to reduce the formation of tars and oils.

Steam Gasification: The biochar, oils/tar and gas are passed to the second gasifier where the injection of steam enhances the cracking of remaining hydro-carbons.

Gas Cleaning cyclonic filter first to remove any ash and char particles before being quenched. The cooled gas is cleaned in a water scrubber and then dried through a series of venture filters that dry and remove any remaining particles.

3.6.2.4 SINTEF – Projects

GAFT - Gasification and FT-Synthesis of Lignocellulosic Feedstocks

- Norwegian competence building project with industry
- Experiments in, and modelling of the complete value chain, from biomass and waste to FT-products
- Gasification and synthesis experiments
- Value chain analysis
- CFD modelling
- 2015-2018, 20 MNOK

GASPRO

- Fundamental research project
- Experiments and modelling of gasification processes
- CFD modelling; from DNS to RANS
- Supported by small and larger scale experiments
- 2017-2022; 16.5 MNOK

Bio4fuels

- Norwegian centre
- WP2.1 Gasification
- 50% fundamental research (thermodynamic modelling and small scale experiments) , 50 % applied research with industrial relevance (gasification experiments)
- Focus: ash
- 2017-2024, 8 MNOK

Flash

- Predicting the FLow behavior of ASH mixtures for production of transport biofuels in the circular economy
- Fundamental research, focus: ash
- 2018-2021, 9.9 MNOK

3.7 Sweden

3.7.1 Plants in operation or under construction (status April 2019)

3.7.1.1 Emåmejeriet, Hultsfred (www.bkvab.se, energikontorsydost.se)

The biomass gasification plant at the dairy Emåmejeriet is the only example in Sweden of something that has become more and more common in central and southern Europe, small scale gasification CHP plant.

The dairy plant had been using a 500 kW light fuel oil boiler to provide its process heat, and where the temperature is required to be up to 105 °C. This has been replaced by the system depicted in Figure figure, i.e. an integrated fuel storage and dryer container feeding the gasifier, a modular biomass gasifier package unit from the Finish company Volter and two heat accumulators of a total volume of 10 m^3. The accumulators have the purpose of balancing the heat demand variations in the dairy operation and as a short-term back-up while the oil boiler is maintained for redundancy. The nominal output of the gasification plant is 40 kW_e and 100 kW_{th}.

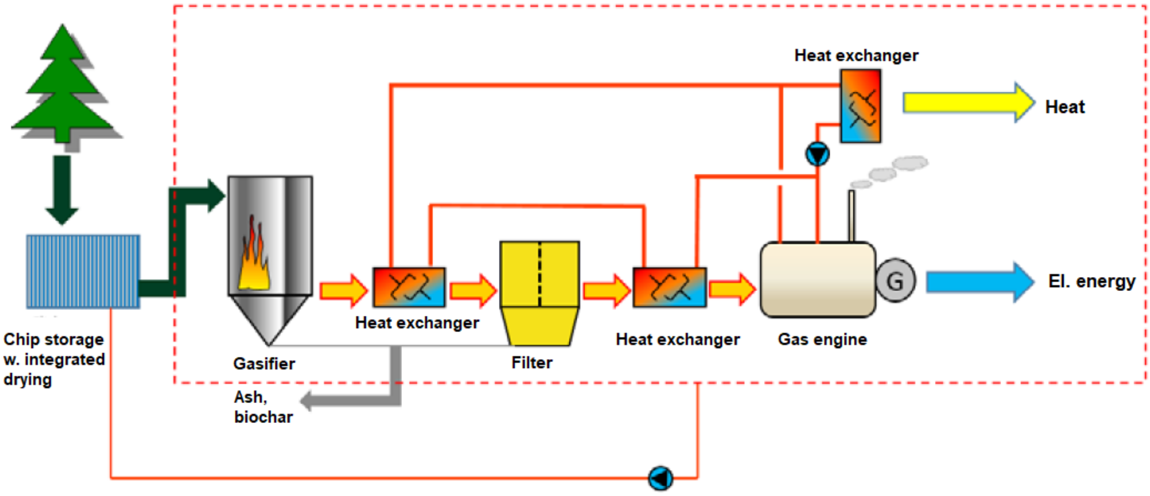


Figure 49: The gasification system at Emåmejeriet

The plant uses whole-tree wood chips from thinning and other forest residues and is dried from approximately 40 % down to 10-18 % in the containerized dryer/storage by an air stream heated by in the gasification plant.

The plant investment cost was approx. 0.3 MEuro or 7 500 Euro/kW_e, of which 25 % was provided via a demonstration project for small-scale CHP operated by Energikontor Sydost (Energy Agency for Southeast Sweden Ltd). The demonstration project had in turn been financed by Energimyndigheten and the EC Life+ Program. Energikontor Sydost was established in 1999 as an EU project. Since 2007 activities have been operated as a non-profit company owned by an association of regional councils, counties and municipalities in the counties of Blekinge, Kalmar and Kronoberg, respectively. The mission of the agency is to coordinate and implement projects increasing the energy efficiency and the supply of renewable energy in all sectors of society by linking local initiatives and projects to EU and international activities.

Since 2015 and after correcting some initial teething issues, the plant is now in regular operation. The gas composition is shown in table below.

Table 14: The gas composition of the Emåmejeriet plant

CO Vol.%	H_2 Vol.%	CO_2 Vol.%	CH_4 Vol.%	N_2 Vol.%	Gas LCV MJ/Nm3
25	17	8	2.5	47.5	5.75

The plant has a nominal fuel consumption of 4.5 m^3 of chips per day. This can be estimated to be 56 kg/hr at 40 % moisture content and with a net heat content of 3 MWh/kg wet, this gives 168 kW_{th} input. Out of the net generation of 40 kW_e plant consumes 2 kW_e for mainly fuel feeders and fans, i.e. an estimated efficiency to electric energy of approximately 22 %, and when including heat, a total efficiency of 82 %. The electric energy and heat energy produced covers some 12 % and 80 %, respectively, of the annual power and energy usage in the dairy. The savings in the use of import power and fuel oil gives a nominal pay-back time of 8-9 years for the project.

3.7.1.2 The GoBiGas project (gobigas.goteborgenergi.se)

Göteborg Energi (Gothenburg Energy), which is owned by the city of Gothenburg, has the mission to actively contribute to the sustainable development of the city. Gothenburg Energy has in the past invested heavily in biogas from AD plants including upgrading to bio-methane. The use of bio-methane in transport is seen as both a low GHG emission alternative and a means to improve the local air quality from a reduced traffic air pollution. The company set a target in 2005 to produce 1 TWh of renewable gas by 2020. This represents about 30 percent of current natural gas deliveries in Gothenburg or fuel to approximately 100 000 cars. Gothenburg Biomass Gasification Project, GoBiGas, has been Göteborg Energi's largest investment in biogas production (biomethane or Bio-SNG), and the first investment outside of conventional biogas production plants. The aim of the project was to supplement conventional biogas production through gasification of solid biofuels and forestry wastes. The project is described in detail in "The GoBiGas Project. Demonstration of the Production of Biomethane from Biomass via Gasification. Anton Larsson, Ingemar Gunnasrsson, Freddy Tengberg. Göteborg Energi AB 2018".

After a review of the technology status showing that no similar plant was in operation and the technology had not been validated at large scale, the project was split into two phases to reduce the technical risks, a first demonstration phase of 20 MW product gas to be followed by a second phase of 80-100 MW output of bio-methane gas. However, in terms of the economic viability of the project, it should be emphasized that the GoBiGas first phase was never intended as a self-sustaining project, only in the context of also going forward on phase 2 to reach 100 MW gas output would the global project give returns to allow a capital recovery over a reasonable time, this also being subject to that the bio-methane price would follow the projections. However, the actual price of bio-methane did not follow the projections, it became lower than anticipated due to a drop-in energy prices in general, less demand of bio-methane due lower sales of CNG vehicles than expected and also due to imports of bio-methane from Denmark, where producers received a subsidy.

The GoBiGas 1 project was initiated in 2005. In 2006, Göteborg Energi conducted a feasibility study which in 2007 was followed by more in-depth studies of various gasification technologies. The choice for the first phase was for indirect gasification with technology from the Austrian company Repotec. For the methanation technology, the choice fell on the technology of Haldor Topsøe. In 2008 -2009, a Basic Design was carried out for the phase 1 plant, in figure below.

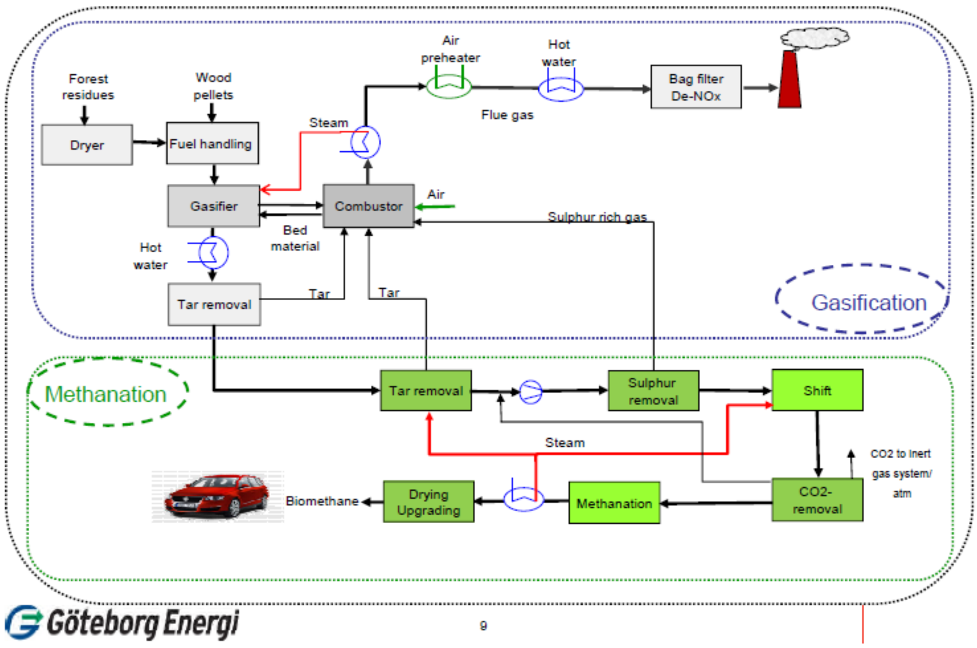


Figure 50: The GoBiGas technical concept

The solid biomass fuel is converted to a gaseous intermediate in the gasification plant at atmospheric pressure. The gas product gas is cooled, filtered to remove particulates and scrubbed for tar removal. Finally, light tar remnants and BTX is removed in beds of activated carbon, and then compressed to a synthesis pressure of around 2.5 MPa. This so-called synthesis gas is purified further by sulphur removal; the hydrogen ratio is adjusted by water gas shift after which CO_2 is removed. The conversion to methane is then done in a series of catalytic reactors to SNG/biogas. After cooling and drying, the gas is compressed and fed into the gas grid.

GoBiGas phase 1 received a grant of 22.2 MEuro in 2009 from the Swedish Energy Agency, after an EU state-aid scrutiny. The investment decision was taken in December 2010. The estimated cost in 2008 was 80 MEuro, but at the time of the decision it had risen to 108 million Euro. In late 2011, it was announced that the costs had risen to an installed cost became 142 MEuro, however, following some debate, the city council still decided to continue the project. The demonstration costs totaled 160 million up to May 2018.

The plant is located at the western harbour area of Rya, adjacent to other energy installations of Gothenburg Energy including a biomass pellet-fired district heating boiler and the 220 MWe combined-cycle CHP plant. The planned location of phase 2 is a nearby plot with possibilities for both ship and rail supply of fuel.

Planning work for Phase 2 was on-going in parallel to the work on Phase 1. This resulted in a successful application to the EU NER300 program in 2011, and in 2012 a grant of 58.8 MEuro was made available for Phase 2.

Figure 51: The GoBiGas plant site

For the construction of Phase 1, Göteborg Energi contracted experienced l companies for the construction project. The Finish company Valmet (*fka* Metso Power) was selected to deliver the gasification section based on a license from Austrian Repotec. The methanation section of the technology was delivered by Haldor Topsøe, with technology references such as the largest coal-based commercial installations in the world for SNG from syngas in China. The Dutch engineering company Jacobs was engaged as the EPCM contractor for the overall installation.

The project aimed to achieve as high efficiency as possible, while also co-generate district heating, even if it was built as a demonstration, the target was to be commercially and economically viable when run in combination with a plant five times larger, once the demonstration phase ended. This set the performance target very high; 65% energy efficiency from biomass-to-bio-methane and 90% in total from the combined output of bio-methane and district heat relative to the fuel in. The main project data is shown in the following figure.

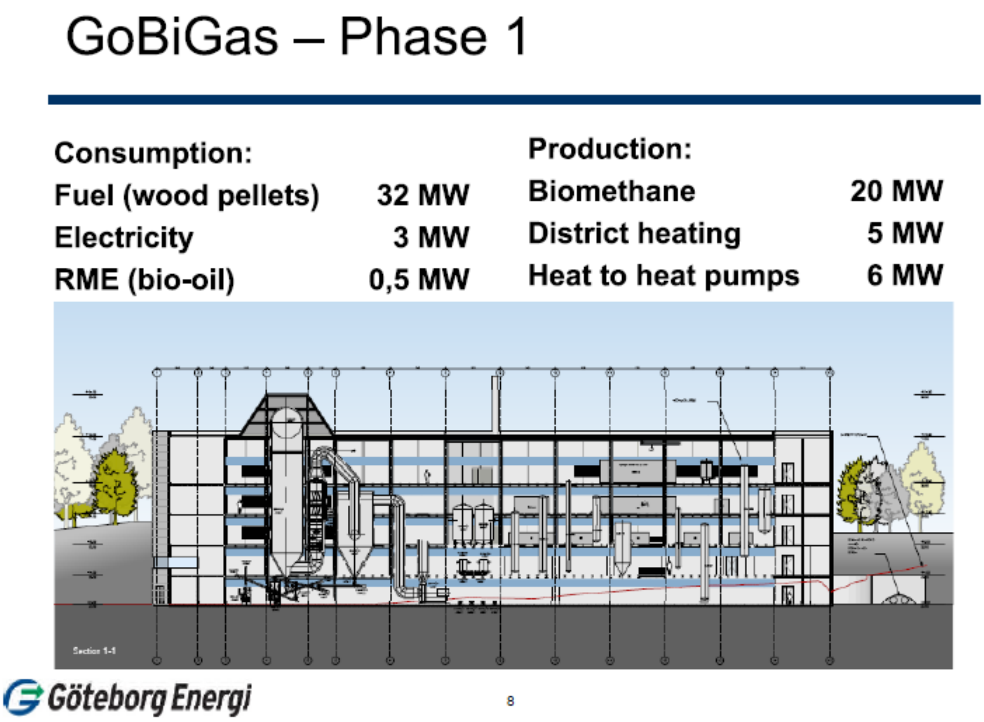


Figure 52: Main data for the GoBiGas phase 1 project

The plant was planned to receive fuel, initially wood pellets and later pre-treated and dried bark and forest residue chips from third parties, such that on the site the fuel handling was limited to fuel reception and storage.

A more detailed flow sheet is shown in the following figure. The gasification section is shown in the upper right section, including feed system, the gasifier, the combustor and the heat recovery and flue gas cleaning sections. To the left of the gasifier is the gas cooler and gas scrubber. Following this, a compressor raises the pressure somewhat and the gas passes activated carbon vessel at the upper right side.

The entire bottom part of the flowsheet shows the gas upgrading and synthesis part of the plant, where the cleaned gas is compressed, sulphur removed by an amine wash, the hydrogen/carbon monoxide ratio adjusted in a water gas shift unit, followed by removal of CO_2 and methanation in several steps. Finally, the biomethane is dehydrated in a molecular sieve unit and the gas delivered to the grid company for final compression to grid pressure and injection into the grid. The plant was also connected to the district heating network such that excess heat recovered from the plant was exported via an intermediate exchanger.

A time-line for holds the following main project events;

- October 2013. Mechanical completion of gasification section and start of commissioning
- November 2013. First gasification
- December 2013. Full mechanical completion.
- March 2014. Official inauguration of the plant.
- April 2014. Artificial activation of biomass gasification for the first time, allowing the gasifier to start up without clogging the downstream heat exchanger with tar (condensable and, in most cases, reactive hydrocarbons).
- December 2014. Biomethane produced via gasification for high-pressure gas grid.
- September 2015. The book value of GoBiGas is written down to 0 value.
- Autumn 2015. First continuous operation of advanced biofuel production for over 1,000 hours, achieving over 90% of design capacity. Tests on completion finished.
- November 2015. The City Council Board decides to cancel Phase II
- 2016 to autumn 2017. Successful gasification of bark, wood chips, waste wood.
- February 2016. Performance tests completed.
- March 2017. A fire in the fuel storage stops operation for 3 months.
- April 2017. The board of GEAB decides to try to divest the plant.
- August 2017. It is decided to revert to operate on pellets to achieve nameplate capacity and to accumulate operating hours
- February 2018. Achieved over 1,800 hours of continuous operation and 100% of designed capacity.
- May 2018.The plant is shut down and mothballed.

The main reason for stopping the project in 2018 was that for the reasons explained initially in this section, the sales value of the bio-methane had not followed the projections, such that the production of bio-methane in the plant was running at a significant direct operating net loss, i.e. not only was there no means to recover the investment, but the itself operation would also require continued capital injections, and with no relief in sight.

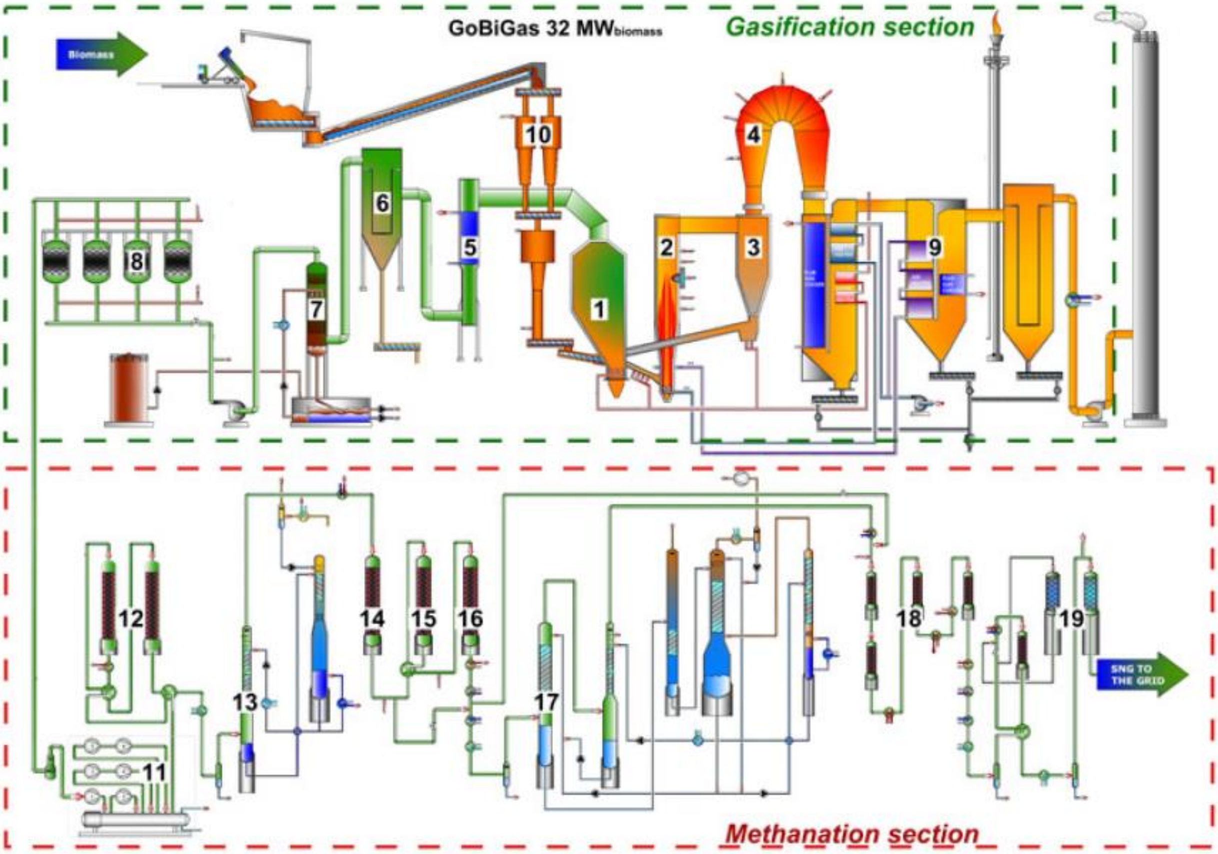


Figure 1. Process schematic of the Gothenburg Biomass Gasification (GoBiGas) biomass to biomethane plant: 1, gasifier; 2, combustion chamber; 3, cyclone; 4, post-combustion chamber; 5, raw gas cooler; 6, raw gas filter; 7, rapeseed methyl ester scrubber; 8, carbon beds; 9, flue gas train; 10, fuel feeding system; 11, product gas compressor; 12, hydration of olefins and COS; 13, H_2S removal; 14, guard bed; 15, water–gas shift reactor; 16, pre-methanation; 17, CO_2 removal, 18, methanation; and 19, drying. [Colour figure can be viewed at wileyonlinelibrary.com]

Figure 53: A schematic flow diagram for the GoBiGas 1 plant

The plant has operated for over 12 000 hours in total since being commissioned in November 2014, see figure below.

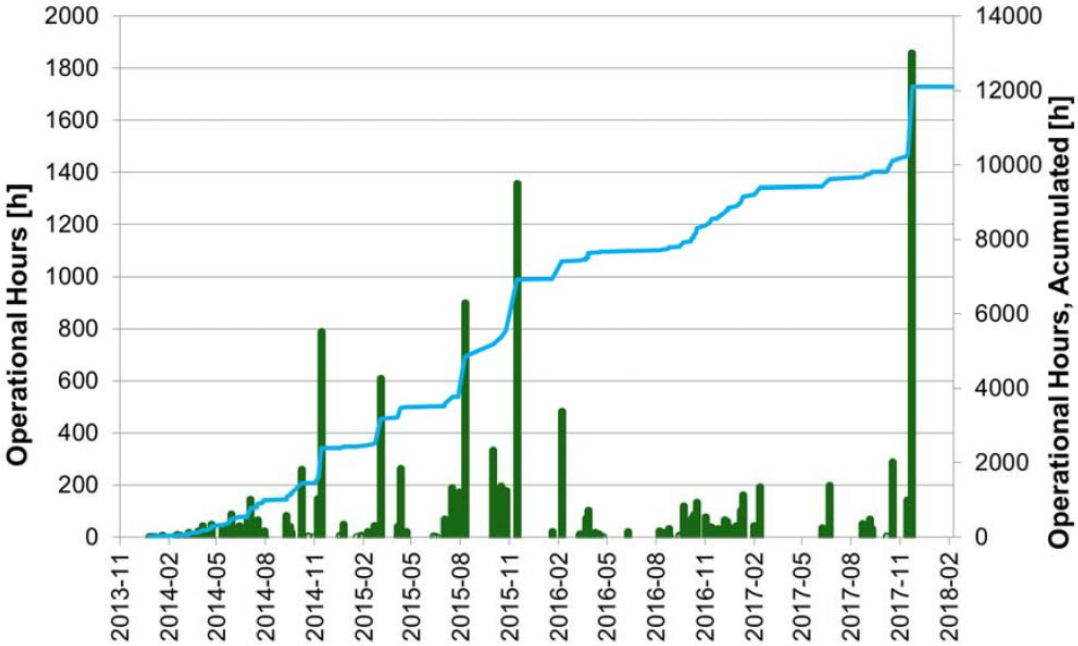


Figure 54: Operational history for the gasification section of GoBiGas (each bar represents a continuous run. The line represents the accumulated number of operational hours)

In the following figure, the corresponding graph for the biomethane production is shown. A total of 68 GWh of biomethane was produced until the plant was shut down in May 2018.

The plant was initially operated on wood pellets to avoid feeding issues. Nevertheless, the fuel feeding system was the main issue initially and tuning and some equipment changes were required. Having come this far, the operational time in gasification increased and by the end of 2014 it amounted to more than 1 000 hours. However, overcoming feeding problems meant that the next challenge was encountered, too much heavy tar in the gas causing fouling of the gas cooler and issues in the gas filter. After a cooperation with Chalmers, the solution applied in early 2014 was the addition of an alkali carbonate to the fuel and recycling of the coarser ash fraction. The rationale behind this procedure was that the pellets used were from saw dust, i.e. the interior parts of fully-grown trees. Therefore, the ash content was very low and contained less alkali than forest residues in general. For this reason, the "aging and activation" of the bed material used in the circulation loop in the beds, that in other FICBG gasifier have been seen to reduce the tar in the gas, did not proceed at the same pace with this low ash fuel. By adding alkali and by additional ash recirculation, the process was accelerated and the tar content in the gas reduced. It is believed that alkalis form the fuel is volatilized in the combustor and adsorbed on the surface of the fresh bed material, and when returned to the gasifier, the alkali increases the catalytic activity of the bed material.

When the tar issues were overcome the operating periods became longer and this generated problem with the feed screw from clogging of fuel and overheating. By changes to the operating procedures and the screw, also this problem was eliminated. In May 2015 the situation was that the gasification section of the plant has been operated close to 4 000 hours and the MCR load proven on pellets while also the gas quality (relative to design values) was very good. For the gas upgrading and synthesis section downstream of the gasifier the commissioning had not yet reached so far. The bio-methane production was tried in a longer campaign in December 2014, but in May 2015 grid supply of bio-methane, surpassing the design quality, had been accomplished for periods of the order of days on some occasions at 60-70 % of design capacity.

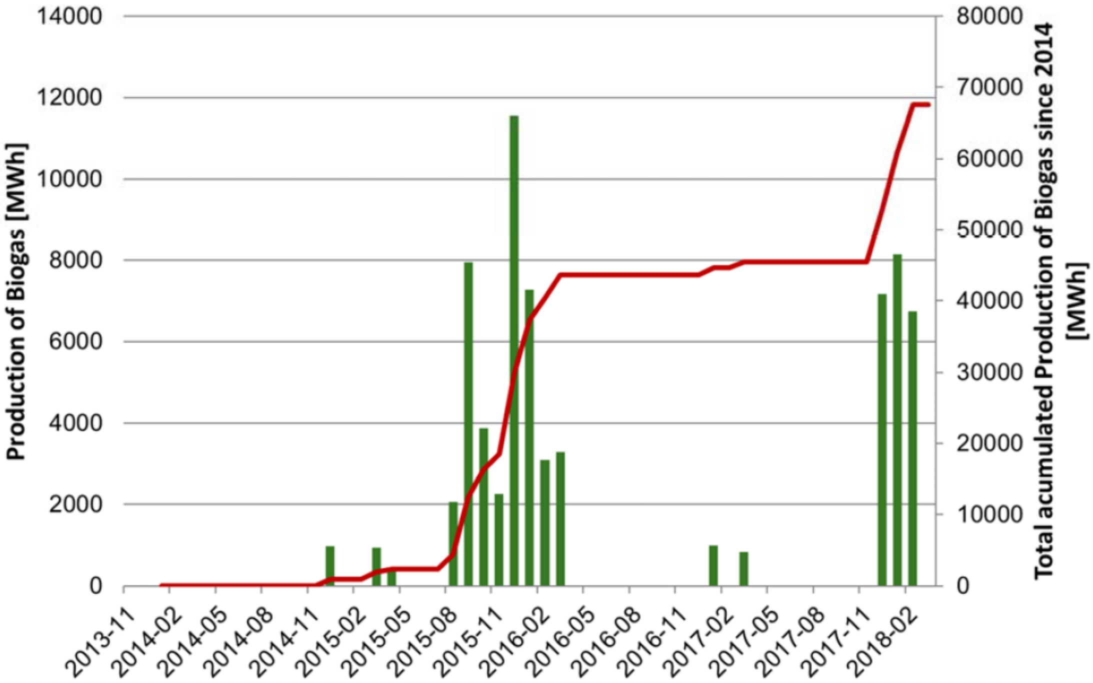


Figure 55: Operational history of the bio-methane production of GoBiGas
(each bar represents a continuous run. The line represents the accumulated number of operational hours)

The period August 2015 to first quarter of 2016 was characterized of long operating periods at high, but not full load, and performance tests were completed, including verification that the emissions fulfilled the environmental permit conditions. Furthermore, the GHG reduction of the bio-methane produced was estimated according to the RED procedures for evaluation. By new year 2016, the plant was operated nearly continuously with wood pellets, producing around 16 or 17 MW of biomethane, corresponding to 80 to 85% of the design goal of 20 MW.

At this point, the first tests with the new reception and storage system for wood residues (chips and bark) was commissioned. There were both commissioning problems and quality issues with the fuel that resulted in few operating hours. In particular, the moisture content of the fuel was high and also varied a lot such causing various problems, including not meeting the operating envelope of the methanation system and only a few hours of operation were logged.

Due to the moisture - related problems with the operation, it was decided to switch back to wood pellets as fuel in the beginning of 2017 to enable evaluation of the changes made to gas cleaning and to demonstrate 20 MW production. The production of biogas could be increased; however, due to a fire in the pellets storage silo in March 2017, the operation was stopped.

The operation was reassumed after inspection of the plant in June 2017, but since the pellet silo was not yet repaired, dried bark was used. However, feeding issues limited operation on bark, so instead it was decided to conduct further tests with recovered wood of class A1 with the goal of producing biomethane. The on recovered wood went well but the availability of recovered wood was limited to 100 hours of operation. Instead a mixture of sawmill residues and naturally dried stem wood but the moisture content varied and the methanation unit could not be operated.

In December 2017, the pellets silo was repaired and the operation on wood pellets was resumed. From mid-December 2017 to the end of February 2018 the gasifier operated continuously for 1 850 hours when a chain drive in the fuel feeding system broke. The methanation section operated continuously during the whole period apart from two days in December and for about one week in January when the methanation process was briefly stopped. The production was increased to record levels during this period, and for the first time the design goal of 20 MW of biomethane production was reached.

Due to the high operating loss, i.e. direct production cost where significantly higher than the sales revenues, the company decided to stop the project in 2018.

The following tables give more specific data on the operational results and on the gas quality.

Table 15: An overview of the operational data and performance for the fuels used

Fuel	Pellets	Wood chips	Bark	Recovered Wood Class A1
Hours of operation (h)	~10,000	~1,150	~750	~100
Fuel moisture (%)	8–9	24–30	20–23	19–21
Load	80–100%	55–70%	40–70%	55–85%
Load-limiting factor	-	Moisture, fuel feed - mechanical	Fuel feed - mechanical	Fuel feed - mechanical
η_{CH4}	50–63%	40–55%*	45–55%*	45–55%*
$CO_{2,eq}$ red.	80–85%**	-	-	-

**Estimation base on gasification performance.*
***During steady-state operation.*

Overall, the main project objective was to demonstrate that high quality biomethane can be produced on a commercial scale with this technology while simultaneously meeting ambitious goals for the performance of the demonstration plant, to reach a grid-acceptable quality of bio-methane, a production capacity of 20 MW at a biomass to biomethane efficiency of 65% (LHV basis, daf fuel energy) and a plant total efficiency including heat recovered to district heating of 90% as well as production during 8 000 hours/year. The goal of a production capacity of 20 MW was met using wood pellets as fuel and there were no problems in meeting, and even exceeding the quality of the product agreed at the grid interface. Efficiency was up to 63% in actual operation while the goal of 65% efficiency or even higher was judged to be within reach through optimization of the process and some minor reengineering of the plant but also integrated biomass drying must be included. The goal of 90% plant efficiency was also possible to reach.

Table 16: An overview of the gasifier product gas for various fuels used

	Wood Pellets	Wood Chips	Bark	Recovered Wood Class A1
Moisture content ($\%_{wt}$)	8–9	24–30	20–25	*19–21*
Gasifier temp. (°C)	870–830	790–830	850–820	820
H_2 ($\%_{vol\ dry}$)	40–42	39–41	39–43	*38–39*
CO ($\%_{vol\ dry}$)	24–25	20–23	17–21	*21–23*
CO_2 ($\%_{vol\ dry}$)	20–24	21–24	23–25	*21–22*
CH_4 ($\%_{vol\ dry}$)	8.3–8.5	7.9–8.6	7.1–8.7	*7.1–8.1*
C_2H_4 ($\%_{vol\ dry}$)	2.3–2.5	2.3–2.6	~2.6	~2.6
Tar (excl. BTX), (g/m_n^3 dry gas)	5.4–8.7	8.9–12.7	7.9–15.0	8.5–14
Tar (Incl. BTX), (g/m_n^3 dry gas)	16.4–23.3	22.1–29.5	21.7–33.4	22–26

A motive for the GoBiGas project was reducing greenhouse gas emissions by producing an advanced biofuel that could substitute natural gas, in particular in transports. The assessment showed that a greenhouse gas reduction factor well above 80% can be reached with this type of technology, i.e. well in excess of the RED I and RED II levels of 60 and 65 %, respectively. As part of this, it was shown that the methane slip to the atmosphere corresponded to less than 0.04% of the bio-methane produced, much less than in AD plants where special measures are used to reduce the slip.

The goal of 8,000 hours/year availability was not reached during the project but was considered possible with further improvements and increased redundancy in the process. The operation had suffered from many issues initially, while with experience and modifications the results had gradually improved. The major limiting factor for availability was related to fuel feeding, feedstock properties and the product gas cooler.

Production costs, assuming continuous operation with wood pellets, production costs (excluding the capital-related cost) were within the range of those projected during the project feasibility phase, 80-100 Euro/MWh. However, with lower-than-expected sales values an operating profit was not possible.

Projections for a plant with higher production capacity of 200 MW using not pellets but forest residues, at an estimated cost of 500 million Euro, could reach a production cost, including capital charges, below 60 Euro/MWh, which is a reasonably competitive production cost.

Göteborg Energi and the GoBiGas plant has also been an object and test bed for R&D activities. Such activities include the mapping of the performance and optimization, e.g. by establishing M&E balances for the plant, studies of bed materials and additives and their interaction with ashes, char conversion. Other topics have been gas cleaning, e.g. ERA-NET project BioPRoGReSS, Biomass Product Gas Reforming Solutions studying syngas cleaning based on chemical-looping reforming but also addressing the carbon bed BTX removal and the gas cooling and scrubbing systems. There have also been projects on novel on-line measurement technologies for e.g. tar in BioPRoGReSS, alkalis, particulates, etc. Such projects have been financed by Göteborg Energy research foundation, the SFC program, from the Swedish Biofuel program and ERA-Net and other sources.

3.7.1.3 LTU Green Fuels AB
(*fka* Chemrec black liquor gasification and Bio-DME pilot)

Chemrec (www.chemrec.se) was formed in the 1980's to develop black liquor gasification. In comparison with conventional Kraft recovery boilers, the recovery of chemicals can be more flexible while the energy contained in the black liquor is more efficiently recovered, either as power or heat or as a synthesis gas.

The core of Chemrec Kraft Recovery is the Chemrec gasifier - a refractory-lined entrained bed reactor in which concentrated black liquor is gasified under reducing conditions at around 1 000°C. The liquor is decomposed in the reaction zone into melt droplets consisting of sodium compounds, and a combustible gas containing H_2 and CO.

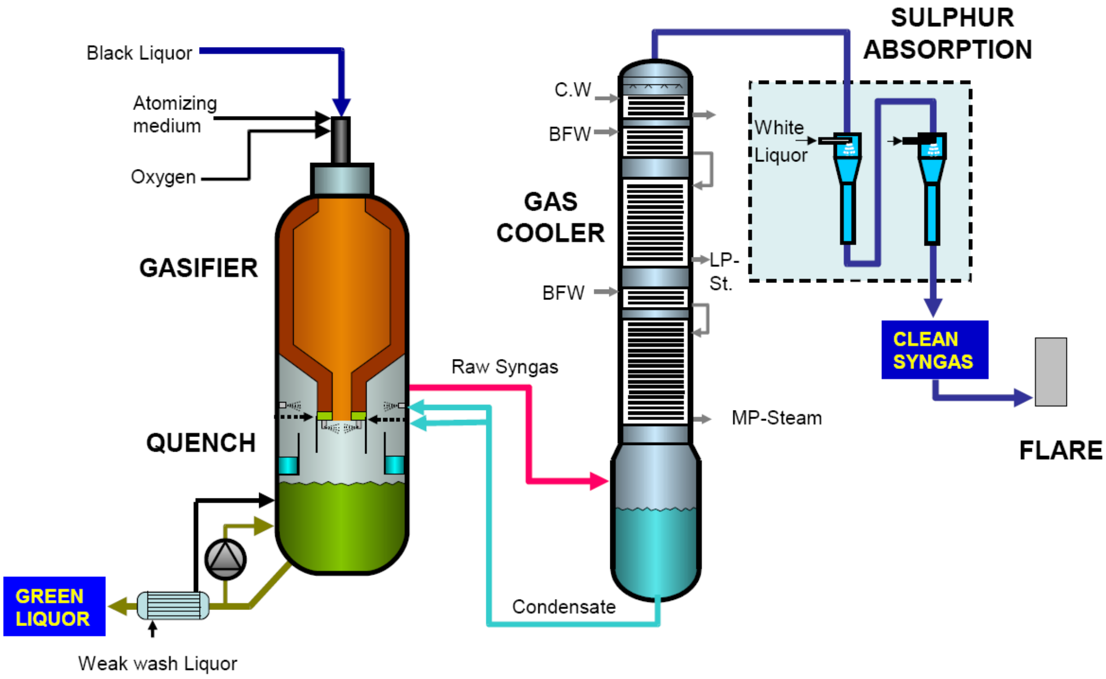


Figure 56: CHEMREC™ black liquor gasifier

The smelt droplets and the combustible gas are separated in a quench dissolver where they are simultaneously brought into direct contact with a cooling liquid. The melt droplets dissolve in the liquid to form a green liquor solution. The gas leaving the quench dissolver is cooled producing LP and IP steam. The cooling is done in counter current mode which means that the gas is efficiently washed of particulate matter. The gas is then free of melt droplets and can be scrubbed for H_2S removal and then used as a clean fuel or syngas.

The history of Chemrec development units and one booster installation dating back to the period before 2010 is described further in the Swedish country report for the period 2010-2012 and 2013-2015, respectively.

The construction of a pressurized development plant, DP-1 of 20 ton dry substance per day capacity was made in 2005 at ETC RISE, a close neighbour the Smurfit Kappa Kraftliner mill in Piteå from where the black liquor is obtained.

Figure 57: Pressurized development plant DP-1 at Kappa Kraftliner pulp mill, Piteå

The plant was used for the Chemrec development program but also for research in two black liquor gasification (BLG) programs from 2004 to 2010.

In 2008, the FP7 Bio-DME project was launched which included the construction of a 4 ton/day BioDME plant based on Haldor Topsøe technology to be connected to the DP-1 gasification plant. The DME was used by Volvo Trucks to operate ten DME trucks for use by different transport companies in four locations in Sweden. DME was produced for the first time in 2011, and the plant was operated by Chemrec up to the end of 2012 within this project. Close to 400 tons of DME was produced and truck operation for over 80 000 km resulted from the project.

The overall plant as well as the flow sheet are shown in figures below. As can be seen, the pilot also contains a novel, once-through methanol reactor.

DME Production capacity:	4 tons / day
Pipe installation:	~10 000 m
Hand valves & on off valves:	~1400 pieces
Instruments:	~450 pieces
Vessels:	~30 pieces
Heat exchangers:	~25 pieces
Process Plant Foot Print	20 x 30 m
Construction cost:	~ € 20 million

Figure 58: The Bio-DME plant and some plant data

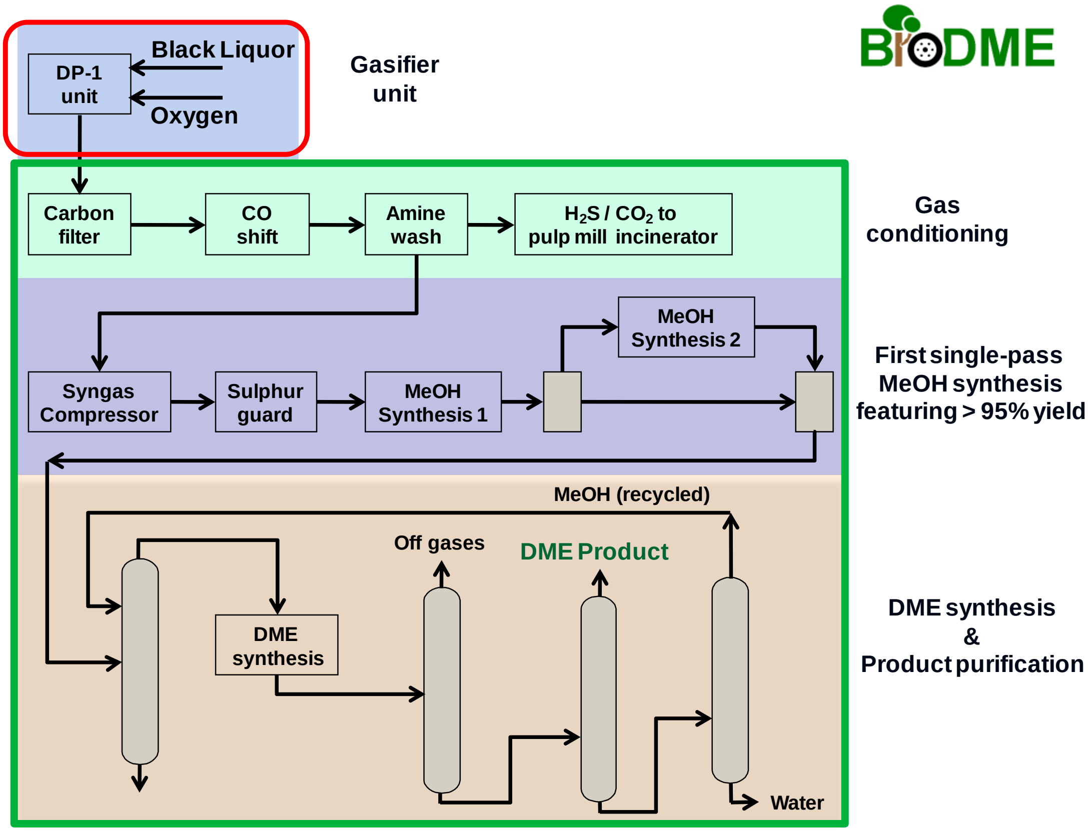


Figure 59: Schematic of DP1 and Bio-DME unit

Chemrec was pursuing a project to scale-up the process to a first commercial plant at the Domsjö sulphite mill in Örnsköldsvik, Sweden. This plant would the Chemrec front-end gasification technology combined with technology from the petrochemical industry to produce 100 000 tons or per year bio-methanol. The investment was calculated to 300 million Euro, and a support of 50 million Euro was awarded for the Swedish demonstration program after EU state-aid scrutiny. Brown liquor from Domsjö Fabriker was gasified in the Chemrec development plant. However, after a change in ownership of the mill, the plant Domsjö decided to not go ahead with the black liquor gasification demonstration project.

Furthermore, when the Bio-DME project ended in 2013, Chemrec could no longer support the cost of the staff and of the continued operation of the Bio-DME plant. In order to save this important gasification infrastructure a program was devised to transfer ownership to LTU, and to continue with more research-oriented activities.

3.7.1.4 Cortus Energy AB (www.cortus.com)

The developer Cortus Energy AB was founded in 2006 by Rolf Ljungren, the present company CEO, as Cortus AB for the purpose developing and exploiting the WoodRoll® technology and has received support in business development, finance and network from business incubator STING as well as financing from the venture capital fund STING Capital. The company has gained a number of rewards of its development of the WoodRoll technology. The company has also protected the rights to the process and its use for several applications via patents.

One of the shareholders, CleanTech East Holding AB, listed on Aktietorget, a share trading market in Sweden, acquired Cortus in 2012 and changed the name of both companies to Cortus Energy AB. Following this, Cortus Energy was introduced on the NASDAQ OMX First North market in Stockholm in 2013. The company has since the listing mainly financed its R&D, operation and investments on the stock market via a series of share emissions, in addition to commercial revenues and support received from funding authorities. Attempts have also been made to find financing from other sources, e.g. the H2020 SME (small and Medium Size Enterprises) Instrument. Cortus was not successful in obtaining funding but was awarded a Seal of Excellence (SoE), a sort of consolation for applicants who met the stringent evaluation criteria to be eligible for funding but fell outside the overall budgetary limitations, and which can facilitate funding from other EU sources such as regional programs, etc., or serve as a quality validation stamp.

In 2010, Cortus and Nordkalk AB, a supplier of lime products, signed a twelve-year contract for supply of fuel gas to the Nordkalk factory in Köping, Sweden, in two stages, 5 MW_{th} in 2011 and 25 MW_{th} in 2013 to replace coal in the Nordkalk operations. As a development stage a 500 kW_{th} test unit was planned. In 2011, Cortus acquired and consolidated the engineering consultancy GEP Group.However, due to falling energy prices and the low cost of emission rights in 2014, the Nordkalk full-scale project was no longer economically viable and the agreement was terminated.

However, this initial set-back for the scale-up did not affect the plans for the test unit were continued for CHP and other applications. The technology and the pilot plant are described below, and commercial activities, as well as the 6 MW_{th} ProBIoStål demonstration plant that started commissioning in late 2018. Finally, other commercial and technical developments are summarised. The WoodRoll technology is a three-stage gasification process.

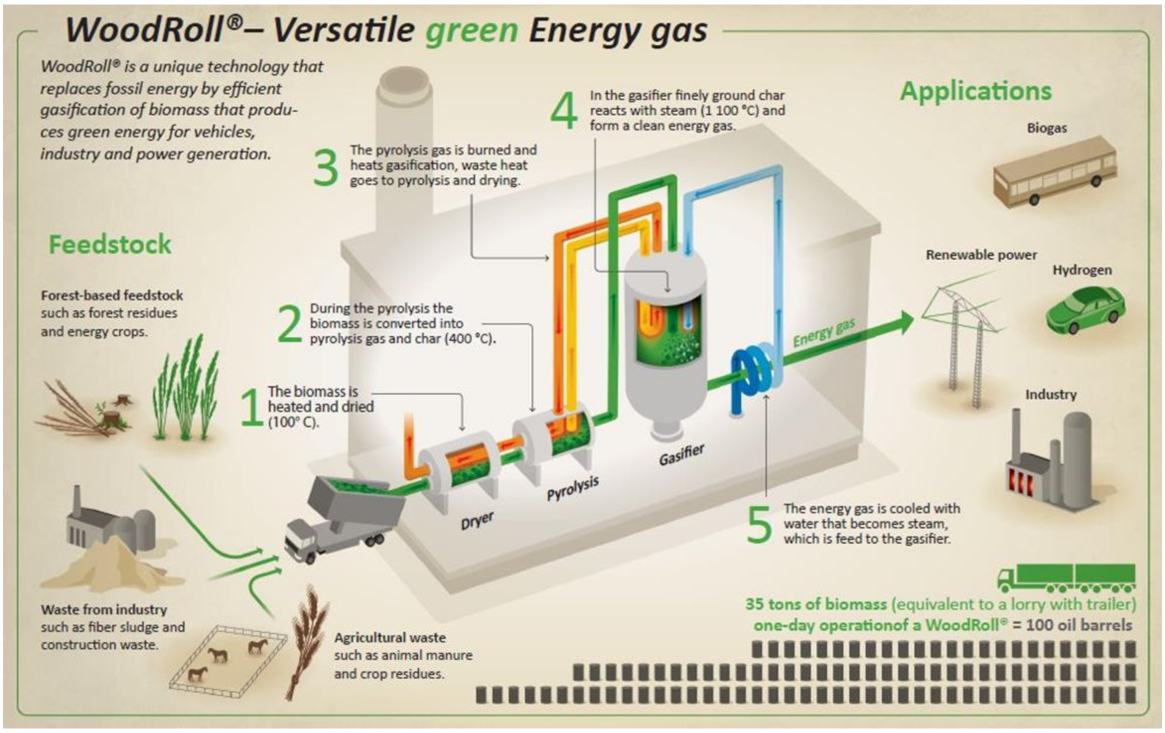


Figure 60: The WoodRoll Technology

The WoodRoll® thermal gasification technology is an integrated process for converting wet solid biomass to clean syngas in three steps, drying, pyrolysis and gasification. The process is fully allothermal from wet biomass to clean syngas. Excess heat is used counter current the biomass processing to syngas. All tars are incinerated internally for heating the process indirectly. The gasifier is indirectly heated by the hot flue gases generated in the pyrolysis process (pyrolysis gas) as the gas is burned in radiation tube burners located on top of the gasifier, see figure above. Furthermore, the waste heat from the gasification process supplies heat to the dryer and pyrolysis reactor in order to keep high efficiency within the system. In this manner a thermal yield of 80% can be reached for wet biomass to clean syngas. The main process equipment and functionality is explained in the following paragraphs:

- The dryer is an indirectly heated rotating drum. Pipes inside the drum enhances the heating and mixing of the biomass during the drying process. Preheated ventilation air carries the water damp released during drying out of the reactor. Further processing of the ventilation air for heat recovery and particulate separation follows. The ventilation air can be treated for minimum emissions if required.
- The pyrolysis reactor is a similar type of reactor as the dryer. The difference is that it is airtight and that the gases and volatiles released during the processing is used for heating of the process in the gasifier and the hot gas generator. The recipe for a particular biomass will control the amount of pyrolysis gas generated and the solid biochar remaining for the gasification.
- The gasifier is an entrained flow gasifier indirectly heated by radiation tube burners. The reaction of finely milled char from the pyrolysis with superheated steam is quick at the high operation temperatures. The whole volume of the reactor is active as the radiation tubes keeps it isothermal. A complete conversion of the char to syngas is reached.
- A cyclone in the bottom of the reactor separates coarse particulates from the

hot syngas. A syngas cooler for steam generation follows. Finally, the syngas conditioned in a textile filter, condenser and blower.

The syngas has a typical composition of: hydrogen 55-60 %, carbon monoxide 25-30%, methane 1-2 % and a balance of carbon dioxide. The advantages of the process are that the product gas produced only emanates from steam gasification of the charcoal, i.e. the tar content but also the content of light hydrocarbons in the gas is low and also other contaminants in the fuel have been reduced during the pyrolysis. Furthermore, as no oxygen is used, a medium calorific value gas is achieved since there is neither a dilution from air nitrogen nor the need for an air separation unit. In addition, since it is based on steam gasification of the char, the hydrogen content is much higher than in other gasifiers and the H_2/CO-ratio more favourable for production of synthesis fuels such as bio-methane and methanol, etc. The medium calorific value gas, unlike low calorific value gas, allows the substitution of fossil fuels in high temperature furnaces, as flame temperatures and other combustion properties are closer to the properties of the common fossil fuels. The low hydrocarbon content facilitates gas cleaning, cooling and conditioning in all applications, but in combination with low nitrogen content the product gas is in particular and suitable as a syngas.

Since 2007 more than 220 laboratory tests for process feasibility of different biomasses have been performed. Since 2009 nearly 20 different biomasses have been tested in pilot scale gasification tests. To prove the concept in view of the scale-up for the Nordkalk project, a 500 kW_{th} gasifier, was constructed in Stockholm in 2011, figure below. After its initial operation, this unit was moved and reassembled at the Nordkalk site at Köping where it was taken into operation in February 2012. After testing with the three stages operating off-line, a fully integrated unit has been constructed and was mechanically complete in early 2015. It has been reported that the gasifier has been operated over 5 000 hours in September 2018, and the dryer and pyrolyzer over 2 000 hours each.

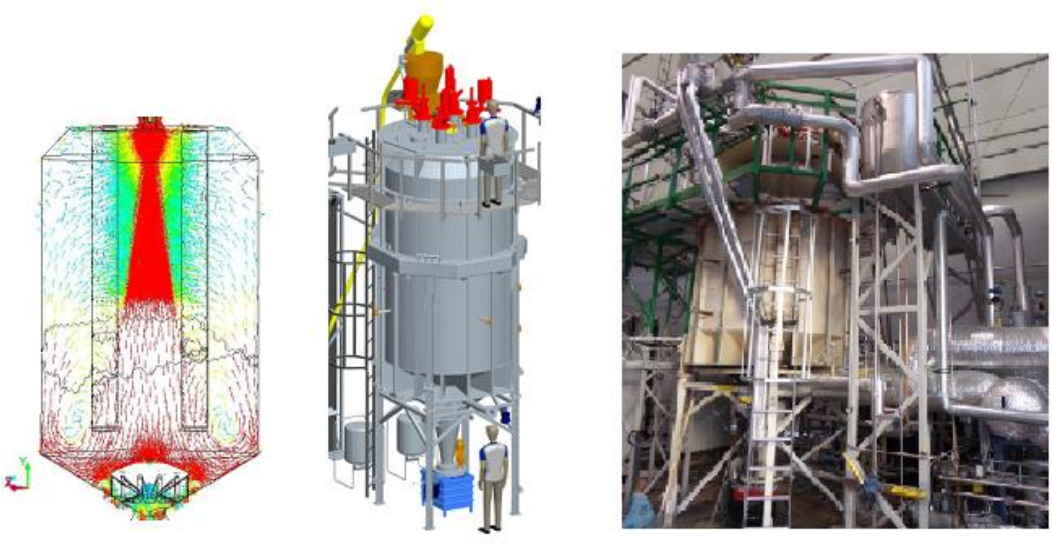


Figure 61: Cortus 500 kW prototype gasifier at Köping; CFD and 3-D models, IRL.

Within a project financed by Energiforsk, also involving KTH and Topsøe, hot gas filtration and catalytic means to stabilize the pyrolysis gas prior to being combusted in the radiant burners is tested. The benefit would be a cleaner burning and higher heat transfer.

Other R&D projects relating to fuel validation, gas cleaning and the production of biofuels and bio-methane have been carried out since 2015 in the pilot plant, as well as process modelling, on the basis of co-financing via grants form thee Biofuels program from Energimyndigheten.

As a further development in the pilot unit, bio-methane (*aka* SNG) production was tested. This is a project cooperation within KIC Innoenergy, who provides 4.5 million Euro to this phase. The project started in 2009 at the coordinator KIT, Germany, where a containerized SNG module was developed and tested at KIT. Partners in this phase are KIT, KTH, Cortus and the Spanish utility company Gas Natural Fenosa. The container has been installed on the Köping site and connected to the WoodRoll unit. Positive results were reported in a press release in June 2018, but no detailed data are available.

Figure 62: The DemoSNG pilot plant

Additional development activities include the Biogasxpose project and the BIO-CCHP project. The Biogasxpose project is funded by Life and has the objective of increasing the production of bio-methane by new technologies. Cortus is looking at the gasification-route to bio-methane by fuel tests, in parallel to development of AD upgrading technology. Additional development of the gasification route of producing bio-methane has been made within projects for the Swedish Energy Agency biofuel program, at the Köping pilot site. The scope of these include both conventional catalytic conversion of syngas to bio-methane and bio-conversion of the syngas.

The objective BIO-CCHP project, funded under ERA-NET, between the beginning of 2018 and the end of 2020 is to develop a novel trigeneration system, including biomass gasification, a Solid Oxide Fuel Cell (SOFC) stack and a cooling machine with the aim to produce electricity, heat and cold (CCHP), thereby maximizing the efficiency and flexibility of the system. For this purpose, 6 different gasification systems will be optimized for the coupling with a SOFC, broadening the range of biomass feedstock which can be employed. Also, a high temperature gas cleaning method will be developed and optimized in tests at gasifier sites. A techno-economic analysis and an industrialization plan of BIO-CCHP will be conducted.

Supporting test work has also been carried out in the pilot plant, e.g. to produce a charcoal by-product that has been evaluated for use within the Höganäs steel process.

In the area of scale-up and commercialisation, instead of the Nordkalk demonstration project that was cancelled in 2014, several opportunities have been explored. On the technical side, a modular approach was taken and the design for a 6 MWth module was developed, see below.

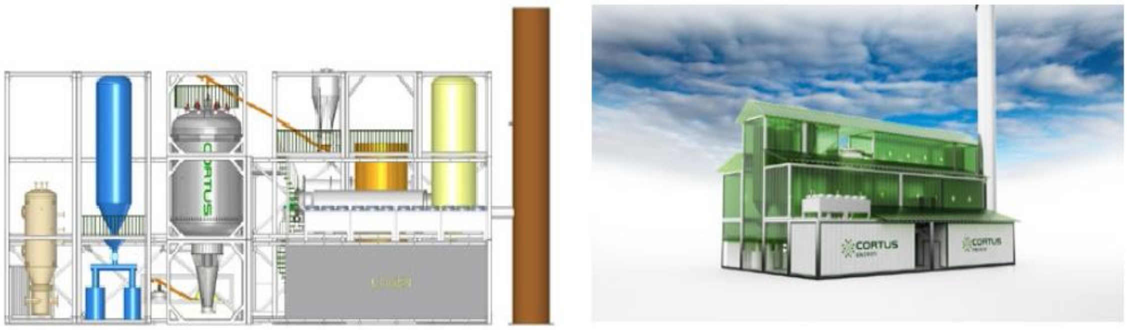


Figure 63: Cortus Wood Roll 6 MW thermal CHP module

During 2018, Cortus has installed a 6 MWth demonstration plant in Höganäs which is a part of project Probiostål, a project started in 2013. The project Probiostål with a budget of 3.8 million Euro, which has resulted in the Höganäs plant, see below, was started in 2014 as a pre-study in which academia and industry participated through coordination of Jernkontoret, the Swedish Steel Association. The purpose was to investigate the possibilities of substituting fossil fuel by producing renewable energy fuel gas on a commercial scale, but initially via a demonstration at 1 MW_{th}. The object of the demonstration was chosen to be the Höganäs steel powder production plant in Southern Sweden. The funding was received from the Swedish Environmental Protection and Energy agencies, Höganäs AB and other industrial partners. The pre-study was followed by a basic engineering study in 2015-2016 at a cost of 0.85 MEuro, with partial financing from Energimyndigheten, where industry, institutes and academy together developed a complete engineering basis the plant at Högnäs. Tests with WoodRoll have been performed at the Köping test facility with good results. Supporting test work has also been carried out in the pilot plant, e.g. to produce a bio-coke by-product that has been evaluated for use within the Höganäs steel process.

The final, demonstration, step in project Probiostål is to construct a complete WoodRoll system at an industrial scale at Höganäs AB where renewable energy gas and bio-coke will replace natural gas and metallurgical coke in the production of iron powder. Following a technical evaluation and contractual negotiations, in 2016 the final investment decision to build a 6 MW_{th} demonstration plant was taken. After the start of the completed plant, a series of tests will be carried out within the framework of Project Probiostål. When tests are completed, the plant is transferred to commercial operations. The WoodRoll plant is operated and owned by Cortus Energy and the renewable energy products produced are sold to Höganäs AB for which a 20-year delivery agreement has been signed.

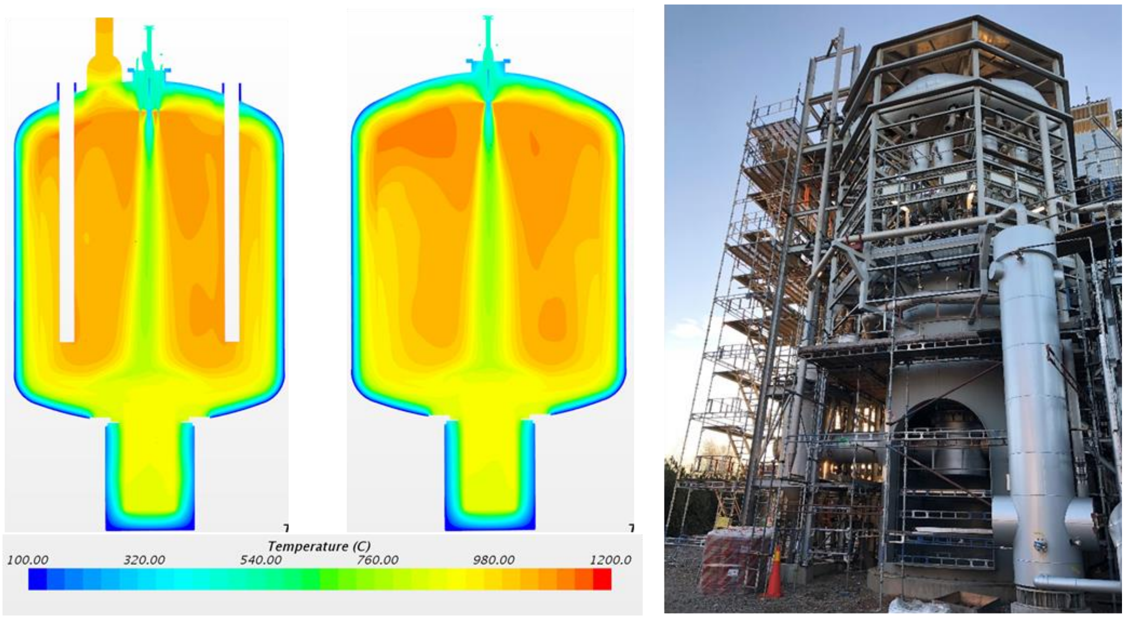


Figure 64*: Cortus 6 MW gasifier in Höganäs; CFD and IRL*

The investment in the Höganäs plant has been given as of the magnitude of 10 MEuro. Project funding has been secured through a combination of grants, bank loans and equity. Support in the form of grants of 3.7 for the investment and 0.8 MEuro for development activities, respectively, has been received from Klimatklivet ("The climate leap"), a central-government investment program for GHG reduction technologies administered by Naturvårdsverket (Swedish EPA), and from the technical demonstration funding program of Energimyndigheten (Energy Afency). The balance of the investment is provided by Cortus via loans and emissions of shares on the market. At Swedbank and ALMI long-term loans have been hedged. Equity for the project is provided through a rights issue. Industrial partners in project Probiostål are: ABB, Calderys, Höganäs AB, Södra Skogsägarna, Sveaskog, SSAB and Outokumpu where the latter two contribute material supplies.

The planning for the project was that the plant, which will also produce charcoal as a by-product for use in the steel plant in addition to the main fuel gas product, should be mechanically complete by mid-2018 and undergo commissioning followed by a test program, to be supervised by KTH, and Swerea, a unit within RISE, until the beginning of 2019, when commercial service would be initiated.

The project has, however, suffered from delays and also cost increases. The ground-breaking ceremony for the plant was held in November 2017 and site installation work started in March. At the time of this report, December 2018, the piping and IE&C installations are being finalized and the control system verified. Cold tests of the biomass feeding system is on-going and the first hot tests are planned for December 2018. In figure below, a recent photo of the plant is shown.

Figure 65: The ProBioStål plant at Höganäs, mid-December 2018

In addition to the first demonstration project at Höganäs, several other project activities have been pursued. Cortus formed a daughter company in Italy, following a 20-year heat supply agreement in 2014 with an Italian farming company in the Veneto region. The basis for the agreement three CHP units at three different sites, using the locally produced biomass wastes. Each unit was planned for a capacity of 6 MW_{th} and produce 2 MW_e from a gas engine and 2.5 MW heat for the client, at an estimated CAPEX of 10 million Euro. The business model was based on that was Cortus the owner-operator, and over the fence supplier of the heat to the agricultural company, while green electricity was to be sold to the grid. The construction was expected in 2015 but the feed-in-tariff PPA was delayed and the project cancelled.

In 2016, Cortus and Japanese Forest Energy (Kuni Umi Biomass Inc.) signed an agreement for a strategic cooperation on biomass small-scale electricity generation on the Japanese market based on realizing a first 2 MW_e electricity pilot project, based on a modular 6 MW WoodRoll® plant, and with several other projects to follow.

In 2017, Cortus announced that it has received a 5 million USD grant from the California Energy Commission to demonstrate new high-efficiency small-scale biomass power technologies in collaboration with a non-commercial local group in Mariposa, California, "Mariposa Biomass Project", (MBP). MBP intends to gasify local forest residues to syngas in a modular 6 MW WoodRoll unit to power a 2.4 MW_e gas engine to produce of electricity for the grid. Investment decision is pending in wait for permits and a PPA.

In early 2018, the French energy company major, Engie, placed an order with Cortus Energy for a basic engineering for a renewable hydrogen plant to be located in France, based on a WoodRoll® modular unit gasifying local biomass. A valuable by-product of the process is green liquid carbon dioxide of food quality. The scope of the order, valued to 55 000 Euro, is the first step of several for a complete Basic Engineering, estimated to 0.750 MEuro, and to be completed within 2018. The second step will involve testing at the WoodRoll® test plant in Köping. Based on the outcome of the preliminary projection, Engie will make an investment decision in 2019.

In mid-2018, Cortus and the German company Infinite Fuels GmbH signed an LoI to cooperate to evaluate the WoodRoll process, using biomass feedstock for the production of bio-methane for grid injection, for a project in Northern Germany, for which there is already substantial financing available. Following the initial work, a realisation of the project could be taken in 2019.

In late 2018, Cortus was also awarded a grant from the Swedish Sustainable Aviation fuel program to study the integration of the WoodRoll system with a FT system producing aviation fuel.

3.7.1.5 MEVA Energy (www.mevaenergy.com)

The originating company Meva AB was founded in 1939. The activities of Meva AB have been development, sales and servicing of energy efficient electromechanical equipment for the energy, mining, steel, pulp and paper industries. Meva Innovation was a joint venture between the mother company and other industrial investors. Meva Innovation's focus was on development and sales of VIPP systems for biomass gasification technology.

The VIPP technology originates from the developments at LTU. A test unit was installed at ETC, Piteå already in the 1990's. The purpose was to develop a small-scale CHP system based on small-scale gas turbines. In 2008, Meva Innovation changed name to Meva Energy AB and acquired the rights for the cyclone gasification technology. In 2012, following the installation at Hortlax, see below, a partnering and distribution agreement is made with global engine OEM Cummins Inc.

In 2017 Molindo Energy a Swedish energy investment fund acquired Meva Energy AB and InnoEnergy, invested 2.9 million Euro in the company. The current staff has grown to 11 persons.

Following the acquisition of the technology, the experimental gasifier was extended to a full pilot plant by adding gas cleaning and by also including a gas engine to verify the full process. The pilot plant at ETC had a input of 500 kW_{th} and includes the gas cleaning process and an engine of 100 kW_e output. It has been operated for development purposes on crushed wood pellet fuels for 800 hours in total; the longest uninterrupted operational time is 12 hours. The engine used has been supplied by Cummins and MEVA has entered into a co-operation with this engine manufacturer. Fuel tests with fuels other than woody biomass have been taking place in the pilot plant since 2012. However, following the scale-up to the Hortlax plant, the pilot was no longer deemed necessary and was dismantled in 2017.

The VIPP-system (Vortex Intensive Power Process), has as its core element a cyclone gasifier.

The gasifier is fed with pulverized fuel by means of the gasification air. The cyclone gasifier is operated between 800-900°C. Downstream of the VIPP gasifier, the VIPP-ECP® (Evidential Cleaning Process) cleaning process is used to achieve the quality standard required for use in the current application. The VIPP-ECP® consists of a three-stage cleaning process where the raw gas first passes through a cyclone for separation of coarse particles, then a scrubber operating with an organic oil and then, as a final step, a wet electrostatic precipitator (WESP) to obtain a guaranteed pure fuel gas. A bleed of oil, into which also the particulate fines are trapped, is re-injected into the gasifier. The temperature is kept above the dew of water vapor throughout the gas cleaning sequence. The fuel gas is then fed to a turbo-charged ICE. It is claimed that an efficiency of 30 and 50 %, to power and heat, respectively can be obtained based on a pre-treated (dried and pulverized) fuel.

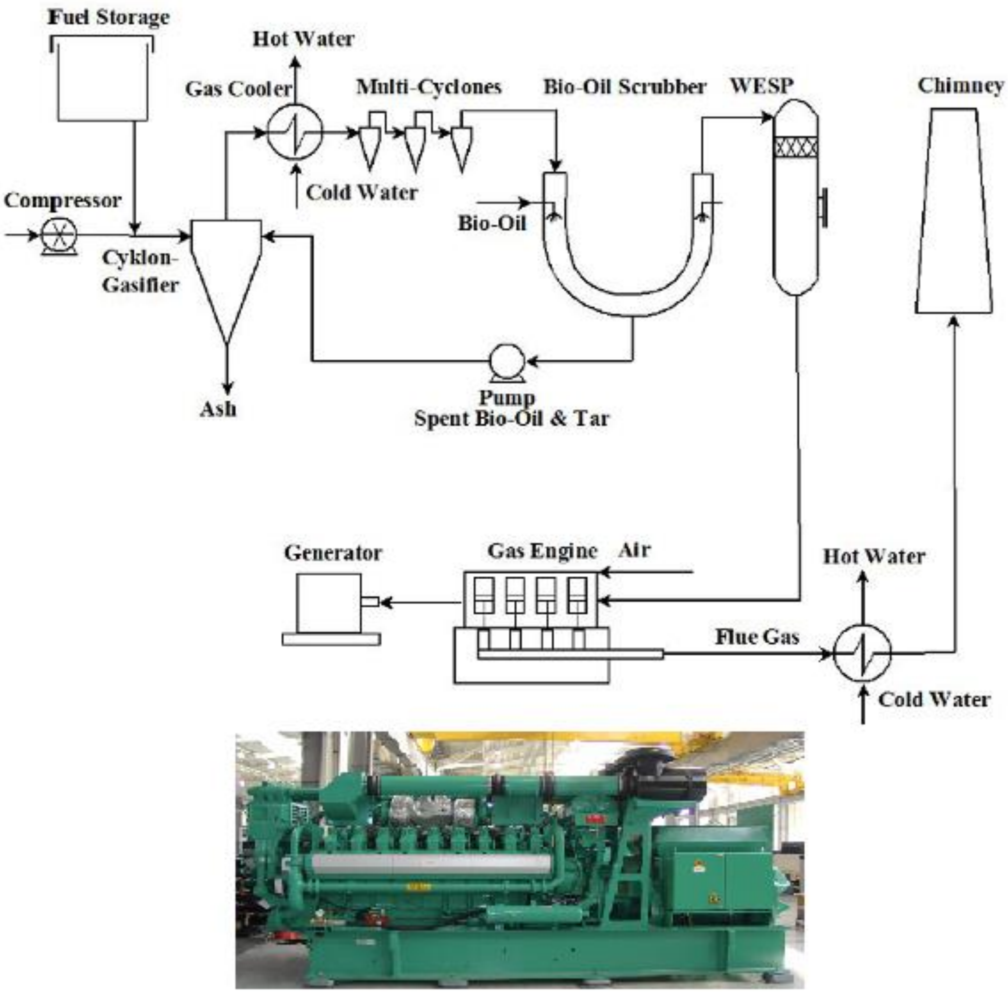


Figure 66: The VIPP system of MEVA and the Cummins V18 engine

In 2011, a first prototype, scaled-up, plant of 5 MWth fuel input, 1.2 MWe and 2.4 MW heat output, was contracted by Pite Energi, the local heat and power utility, to replace an oil-fired installation in the village of Hortlax outside Piteå. The fuel in this installation is crushed wood pellets. For the power production a 91 litre Cummins V18 engine was installed. The plant was constructed in 2011-2012 and commissioning started in early 2012. In early 2013, hot commissioning was started, and the regular operation was said to have been accomplished in the 2014-2015 heating season. The scale up was done with a number of constraints that come from the need to stay within the boundaries of an existing building. The constraints made it necessary to deviate from the pilot plant design on several points. During commissioning it was found that the new design underperformed with respect to reliability and efficiency. Even if the efficiency is higher compared to the pilot plant, it was still below the expectations from a theoretical estimation of the full scale plant performance, mainly caused by less conversion of the fuel to gas. As part of a cooperation with Bio4Gasification, CFD modelling was used to analyse the performance and to suggest improvements to the design. The modelling showed that improvements were possible, and the mechanical design of the cyclone gasifier was physically changed. However, the rebuild of the cyclone gasifier was only part of the solution and several other reengineering modifications of the complete system were made. The rebuild was completed in the beginning of 2016 and an extensive set of tests have been on-going since then, showing that a significant improvement of the performance and reliability has been achieved.

In 2017, the Hortlax plant was bought back from Pite Energi to be used as a stand-alone R&D unit, and thereby avoid the operational constraints of being connected to the district heating grid dispatching hierarchy. Overall, the accumulated operational time of the Hortlax plant exceeds 2 000 hours. There is also an on-going development project, Loreen, with minority owner Innoenergy.

The main market for this small-scale technology is energy plants and wood industries, e.g. saw mill, where there is a continuous heat demand. The market is 1 -10 MW electric with 2-20 MW as thermal heat by-product. A pre-project study for a Swedish paper mill is on-going and could lead to a contract in the first quarter of 2019.

3.7.2 Planned Developments

3.7.2.1 EON Bio2G (www.eon.se)

After the Värnamo IGCC development and after the transition from Sydkraft to EON, new interest for gasification emerged within EON in 2007. The main interest was bio-methane, alone or in combination with an IGCC plant. A Pre-study led to focus on bio-methane while also a special purpose company, EON Gasification Development AB (EGD) was formed.

In 2009, a concept study was started, and a site short-list was made. This led to a focus on oxygen-blown fluidized bed technology for gasification and participation in an engineering design for GoBiGas to learn more about the methanation technology. In 2010, a more focused pre-FEED study was initiated. During the pre-FEED, a complete engineering design for a 300 MW biomass plant was made, Figure. Three locations in southern Sweden, having access to infrastructure in the form of gas grid, district heating network, and port, road and rail access, were studied.

The technical data for the plant planned is a fuel input, including fuel for the auxiliary boiler of 345 MWth. The output is 200 MW of bio-methane of grid quality and up to 55 MW district heating. In addition, 15-23 MW_e is produced for internal use. The thermal efficiency, excluding the oxygen plant, is 60-65 % as bio-methane and 80 % in total including heat delivery. The total investment is estimated to be 450 million Euro.

In parallel, EGD have also participated in tests made by Andritz Carbona and UPM in the GTI Flexfuel plant in Chicago up to 2014. Apart from verification of the pressurized fluidized bed operation on oxygen and steam, these tests also featured integration with high temperature filters from Pall and catalytic reforming of tars using Haldor Topsøe catalysts. Tests were operated with a full stream filter at 500 °C and a slipstream filter at 700 °C, respectively, and with downstream catalytic units. On the clean side of the slipstream filter, an alkali probe with different temperature sections was tired to indicate the on-set of alkali condensation and the deposit formation at different temperatures, while also providing sample material for characterization of the structure and chemical composition of any deposit formed.

A choice is to be made between two sites in the cities of Malmö and Landskrona, while an EIA has been prepared for the permitting, but not submitted yet. A NER300 application was made for the first round in 2011, but as Sweden had three projects approved, Bio2G was put on the reserve list. A renewed application to the NER300 second round was more successful; in 2014 a grant of 203 million Euro was approved. Based on the 2014 NER300 revision schedule, EON needs to take an investment decision before 2020.

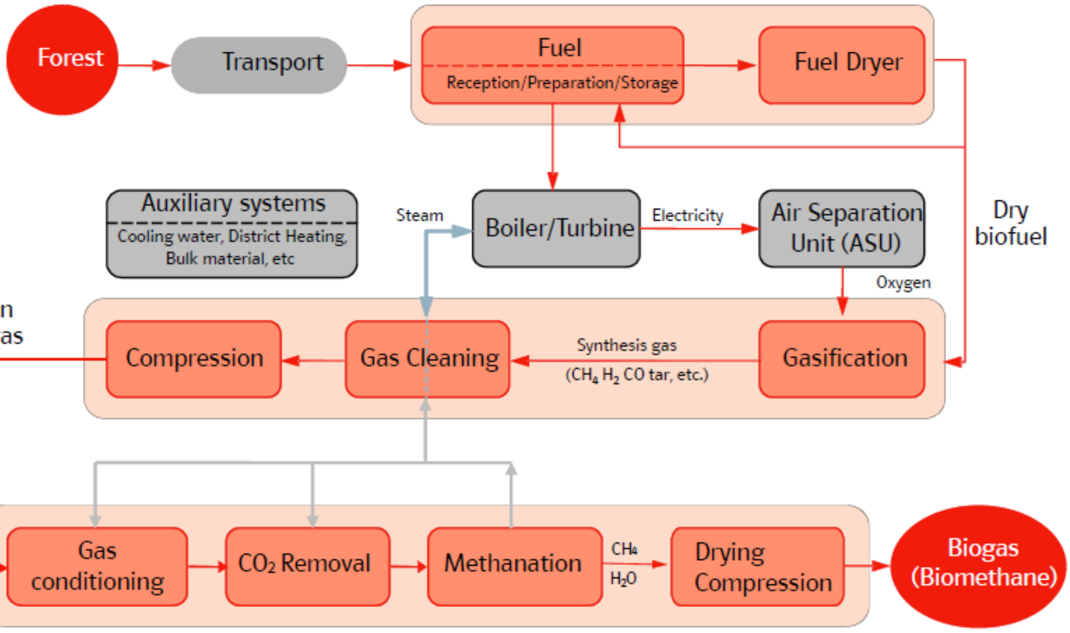


Figure 67: Bio2G technical concept

The present project status is that the project is on hold. However, a decision is pending but the current oil price situation in combination with the uncertainties on the policy side in Sweden does not give a sufficiently clear view of the market to take a decision at present.

3.7.2.2 VärmlandsMetanol (www.varmlandsmetanol.se)

VärmlandsMetanol AB was founded in 2001 and is today based on equity participation by the foundation "Miljöcentrum" (Environment Center), the national farmers' association, LRF, and the local commune of Hagfors as well as to a large number of private (1 500) and enterprise (50) participants. It intends to build and operate a biomass-to-methanol plant in Hagfors, Sweden with an annual production 130 000 m^3 fuel grade methanol based on a 111 MW_{th} wood feed.

On the technical side, in 2011 an advanced conceptual design and feasibility study was carried out by Uhde, a ThyssenKrupp company based on the HTW process. This work was claimed to prove the technical and economic viability of the project. Uhde has also been selected as a technology and turnkey contractor for the entire plant.

The supply of the feedstock, 1 100 tons/day of forest residues, is stated to have been secured by contract. An industrial site (20 ha) has been acquired at Hagfors for the construction of the plant and the development plan for the site has been approved by the Municipality. The site and plant are shown in figure below.

Figure 68: An artist's view of the Värmlandsmetanol plant, the town in the background

Furthermore, the Environmental Impact Assessment (EIA) and a Risk Assessment were the basis of a permit application in 2010, the decision of which is pending. An off-take agreement for the product, which is foreseen to be used as a gasoline blending agent, is being negotiated.

Prior to the start of construction, private investors and a public IPO are expected to raise half of the 3 500 million SEK (€390 million) required for the investment. The remainder is planned to be raised by project financing. Unlike many other projects, no grant financing is being solicited for this project. The currently low oil prices and the political uncertainty on the biofuel support are however not assisting in this process.

3.7.3 Other developers

3.7.3.1 Phoenix BioPower (www.phoenixbiopower.com)

Phoenix Biopower is a company based in Stockholm and is a company in the Innoenergy Business Service program. The aim is to double the efficiency of biomass power generation, setting targets for electrical efficiencies of 50 % by 2022 and 60 % by 2030, while also providing renewable, plannable, and reliable power in a cost-efficient way. To realise this, the company is developing its Biomass-fired TopCycle (BTC) technology, see following figure.

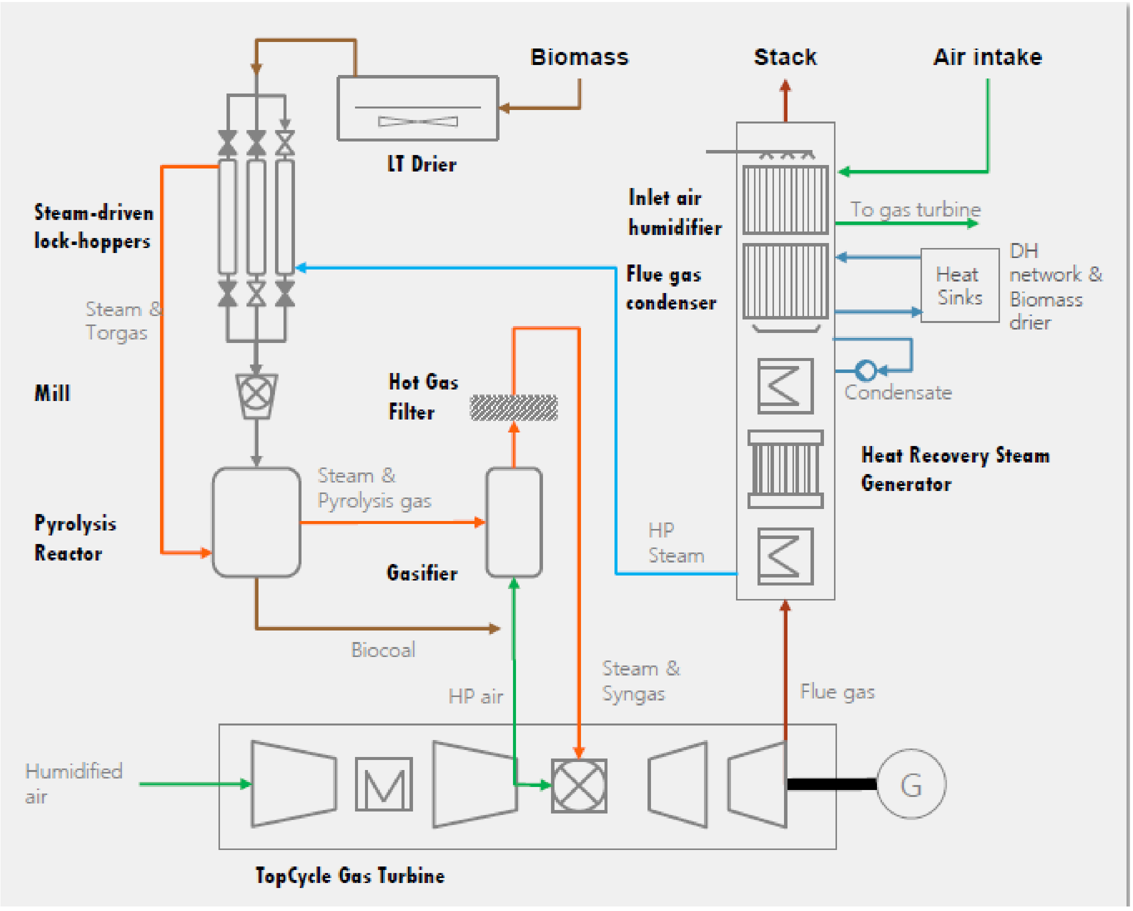


Figure 69: The Phoenix BTC concept

The BTC is a high-pressure, integrated process that converts biomass to electrical power. Gasification of biomass at high pressure, in combination with a high-pressure gas turbine process and massive steam injection in combination with extensive heat integration, achieves these unprecedented conversion efficiencies at low CAPEX and OPEX. At present the concept is studied while the technology elements are being developed at laboratory scale.

3.7.3.2 Boson Energy (www.bosonenergy.com/boson-imbigs-loi-en)

Boson Energy, registered in Luxemburg, but with links to Sweden, and in particular to KTH, is developing an Advanced Thermal Treatment (ATT) process for wastes based is on fixed bed gasification and also using plasma technology. It is a one-step continuous process combining three well proven core technologies (pyrolysis, gasification and plasma treatment), applied in combination or separately, depending on waste stream. The slag coming out of the ATT process is a glassy (or vitrified) material suitable use for filling material in construction of roads and other infrastructure

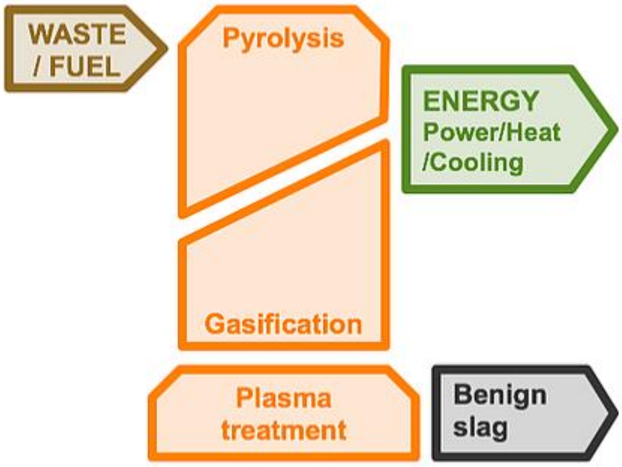


Figure 70: The Boson ATT process schematic

The company claims that tests have been made on MSW/RDF, commercial & industrial waste, non-hazardous/hazardous medical waste and that the performance has been verified by several third parties and authorities leading to environmental permits being granted in two countries. Public information on pilot or commercial plants or more concrete development activities is not available.

3.7.3.3 Bioshare (bioshare.se)

BioShare activities are related to technology and project development for the co-production of fuels and chemicals in large combustion plants. One area is the use of indirect gasification as an integrated part of combustion furnace volume to produce fuel gas for use e.g. in paper and pulp industries or on a longer term to produce material products. The approach off integrating with existing combustion plants also has a large cost-reduction potential for the production of fuels. As an example, a project supported from the Sustainable Aviation Fuel program of the Energy Agenc, the production of FT fuel integrated with the Heden CHP plant in Karlstad, Sweden, is studied.

3.7.3.4 Scanarc (www.scanarc.se)

The plasma gasification technique of Scanarc evolved from the metallurgical process developments by SKF Steel in Sweden starting in the 1970's. In 1989, the company was formed as a buy-out from SKF Steel. After changing ownership several times over the years, in 2011, the management and employee's bough the company.

The origin of the activities where to produce H_2 and CO reducing gas from coal for iron manufacture, using a plasma together with air in the bottom of the shaft. The effectiveness of the plasma in this application was high, leading to a number of proposed processes for metallurgical purposes and coal gasification were designed during the early 1980's. A number of metallurgical installations for the recovery of metals from filter residues, batteries, etc. have been designed and installed since the mid-80's for the metallurgical industries.

The ScanArc gasification process, is a fixed bed, high temperature process producing a molten slag. The gasification is carried out in an updraft shaft, to which the waste is fed from the top via a lock hopper system. A mixture of air and oxygen, if the fuel LHV is low, is injected in the middle of the shaft. Non-combustible material is discharged from the shaft as liquid slag or metal about 1 450°C, while the gas exits from the top of the gasifier at 400-600°C. The gas cleaning is achieved in a second reactor, an empty shaft with a plasma generator on top, where the gas is heated to very high temperatures, causing a decomposition of tar, chlorinated hydrocarbons and ammonia. After the plasma reactor, the gas is cooled and treated by conventional means.

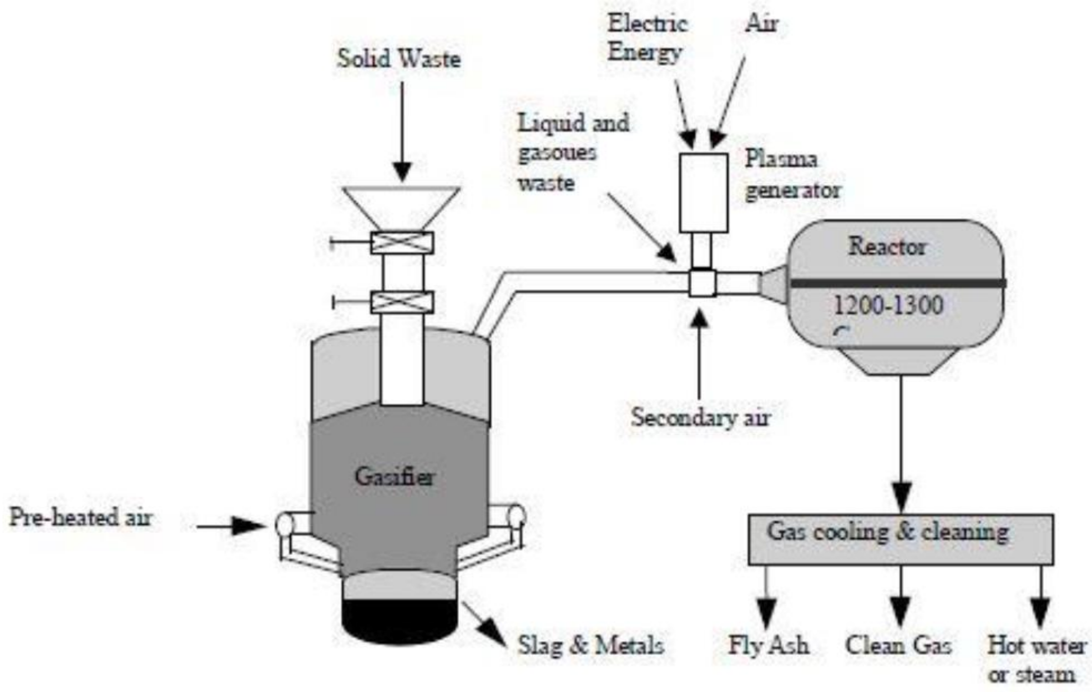


Figure 71: The Scanarc gasification process

The first, and this far only, gasification plant was delivered in 2001 to Osterøy Miljø, Norway, for treatment of tannery waste. The plant was designed to process 700 kg of dried waste per hour, equivalent to 3.1 MW_{th}. The system included a drier for the tannery waste upstream of the gasifier and a 450 kW_e gas engine from Jenbacher fuelled by the gas. The electricity and heat produced in this system was utilised within the tannery. The company also had a licence to treat all types of waste for test purposes. This plant was in operation until 2006.

Offers based on gasification of MSW were made, but no unit has been installed. ScanArc focused for a time on gasification of hazardous wastes where higher requirements on the process can more easily afford the technique.

There has been little apparent activity in Sweden during the last few years, but the company joined the SFC industrial stakeholder group for the third phase of the SFC activities in 2017.

3.8 Switzerland

The operational commercial thermal gasification facilities can be found in the table below. As can be seen in the table, all facilities are small scale gasifiers with electrical output between 40 and 890 kWel and by the most facilities is produced heat used for district heating.

Table 17: Commercial gasification facilities in operation (status November 2018)

	Andreas Mehli Illanz	RE Puidoux	AEW Rheinfelden	Käser Gasel I+II	J. Bucher AG Escholz. I+II	A. Steiner + Cie. AG	Holzstrom in Stans I+II
Gasifier	Volter Fi	Regawatt	Burkhard	Ligento	Wegscheid	Spanner	2 units each 4 gassifier Pyroforce/BR
Type	downdraft	updraft	downdraft	downdraft	downdraft	downdraft	2-zone downdraft
Gas engine	40 kW el	Jennbacher+ ORC; Total = 890 kWel	165 kW	2 x 140 kW el	2 x 133 kW el	45 kW el	2 x 690 kW el Jennbacher
Waste heat therm	district heating	district heating	district heating	for BM drying	district heating drying wood chips	district heating	1,2 MW for district heating
extra BM-Boiler	-	yes	yes	no	Yes	yes	1,6 MW BM 1,7 MW oil
Fuel	Dry clean wood chips	clean wood chips	Pellets	Dry clean wood chips	Dry waste wood chips G 30-100	Dry waste wood chips	demolition wood/scrap wood chips
In operation since	2018	2018	2018	I = 2015 II = 2016	I = 2015 II = 2018	2013	2007

3.8.1 VOLTER

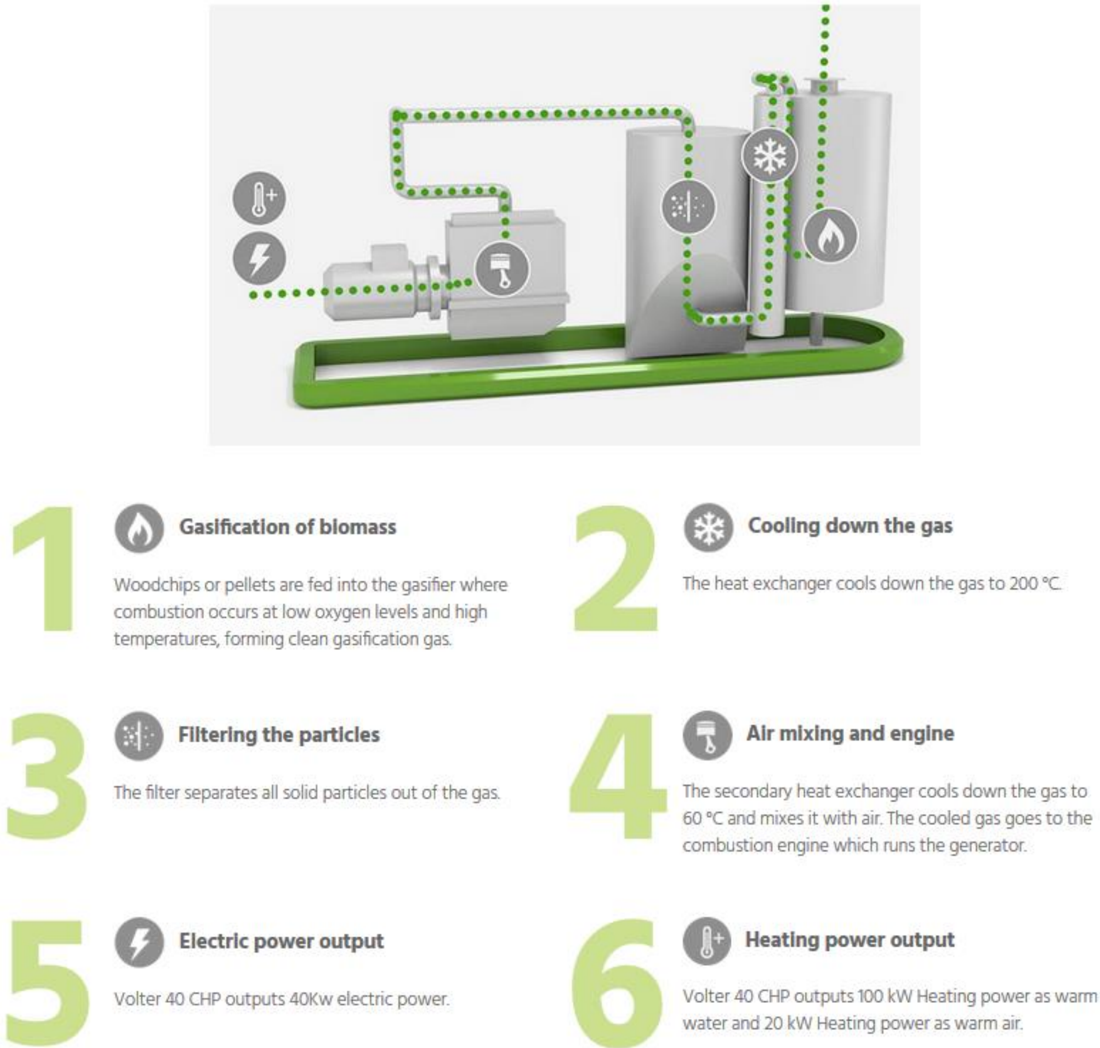


Figure 72: Volter gasification unit[13]

[13] www.volter.fi/technology

3.8.2 Regawatt

The biomass gasification reactor by Regawatt[14] is designed as counter-flow fixed-bed gasifier. In this case, the counter-flow principle describes that the fuel is led (from the top to the bottom) against the flow direction of the air (from the bottom to the top).

The wood fuel is led to the gasifier through gas-tight conveyors (e.g. screws with rotary gate valve). In the gasifier, substoichiometric air is added from the bottom. In the gasifier, the fuel forms vertical layers. With this, the following zones are distinguished (from the top to the bottom).

Figure 73: Regawatt unit in Puidoux

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[14] https://www.regawatt.de/the-gasifier/

3.8.3 Burkhardt

Figure 74: Burkhardt CHP unit

Stage 1: Generation of combustible wood gas in the wood gasifier

The Burkhardt[15] wood gasifiers uses wood pellets as the fuel to produce a combustible gas (wood gas). The central stage takes place in the patented reactor, where the wood pellets are converted into wood gas in several process stages. The wood gas is then processed in various downstream stages for use in the cogeneration thermal power plant. Gas cooling enables heat to be extracted for heating purposes.

Stage 2: Gas conversion in the combined heat and power plant

The cleaned and cooled wood gas is subsequently converted in the combined thermal power plant: The synthesis gas (wood gas) is burned in the engine and drives a generator to produce electricity. The generated electricity can be consumed by the plant itself or fed into the public grid in return for payment. The resulting heat is decoupled and can be used for heating purposes.

Figure 75: Burkhardt gasification unit in Rheinfelden

[15] https://burkhardt-energy.com/en/power-engineering/heat-and-power-from-wood/

3.8.4 Ligento

Ligento manufactures ready-to-use container plants with facilities to dry and store wood chips for the production of power and heat from solid biomass wood.

FEATURES:

240 kWth | 140 kWel

Unadulterated wood, residual wood from forestry, short rotation plants, wood chips

Fixed-bed process in cocurrent flow

Figure 76: Ligento gasification unit in Gasel Könitz

3.8.5 Wegscheid

Principle of Wegscheid facilities [16, 17]:
The woodchips are transported after preparation by a screw conveyor into the downpipe. From there, a continuous feed of the gasifier with the fuel takes place, where the woodchips are burnt under excess air conditions. Once the operating temperature is reached, the wood gas escapes. This is forwarded by means of the suction pressure of a combined heat and power plant (hereinafter referred to as CHP) via a double pipe. The double-walled piping cools the gas by air in the outer tube. The heated air is reverted to the preheating of the oxidation air in the gasifier. The wood gas is now cooled in several steps and cleaned to make it suitable for the engine. After that, the gas enters the hot gas filter, where it is released from the flue ash with a total of 16 filter cartridges. The ash is discharged from the filter by the screw conveyor in the ash box and further transported into the ash cone. In case of deficiency, the residual gas can be discharged through the torch line and burned in the process. Before that, it is cleaned by two cyclones. After passing through the hot gas filter, the gas is then cooled in a controlled manner in the gas cooler. The double-tube heat exchanger extracts the heat from the gas in countercurrent operation and supplies it to the heating coil for further use. Once the cleaned and cooled gas is ready, it passes through the safety filter. This is more for protection in case of accidents, so that we avoid the damaging of the engine. The clean gas floats ashore an MTU gas engine and generates electricity. The resulting heat is also, as with the gas cooler, discharged from the process and fed to the heater.

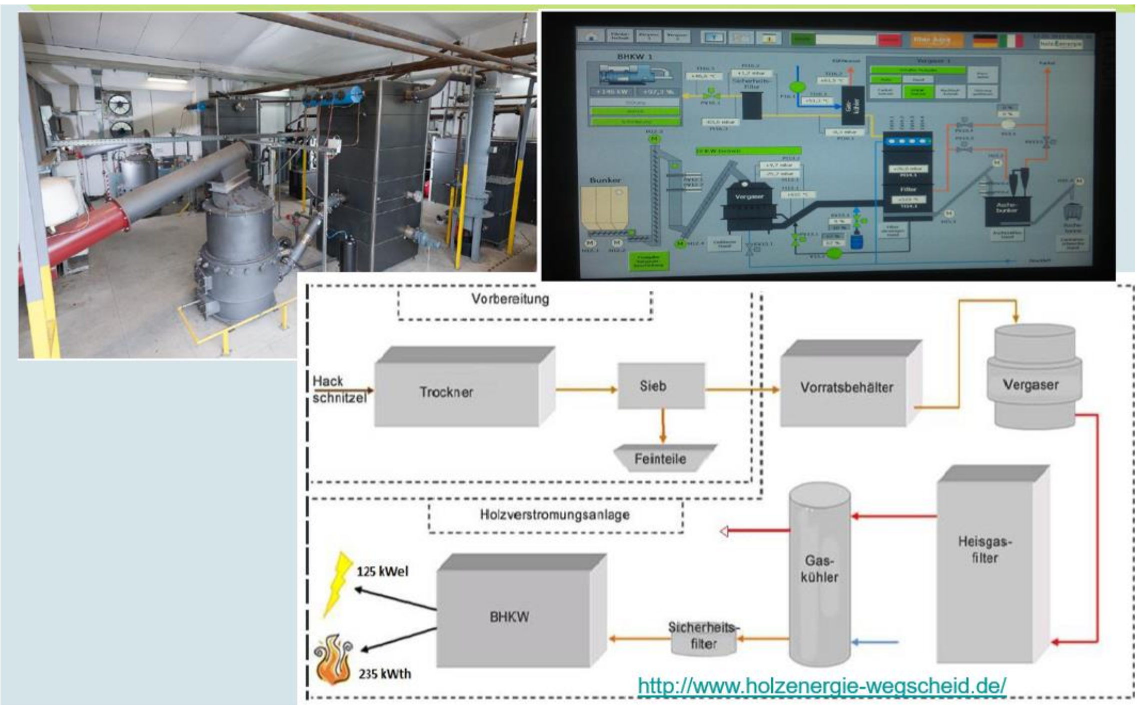

Figure 77: Gasification in Escholzmatt Luzern

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[16] http://www.fee-ev.de/11_Branchenguide/FEE_Industry_Guide_2015.pdf

[17] http://english.holzenergie-wegscheid.de/technik.html

3.8.6 Spanner Re²

The biomass power plant from Spanner Re² generates electricity and heat according to the principle of combined heat and power (CHP)[18]. The biomass power plant consists of a wood gasifier and the combined heat and power unit. The generated power will either be consumed by the owner or sold into the grid.

Figure 78: Spanner Re² biomass power plant (1-feeding, 2-gasification, 3-gas cleaning, 4-electricity/heat production)

Figure 79: Sawmill in Etiswil

[18] https://www.holz-kraft.com/en/products/biomass-chp.html

3.8.7 Pyroforce/BR Group

Figure 80: Development of gasification facility in Stans

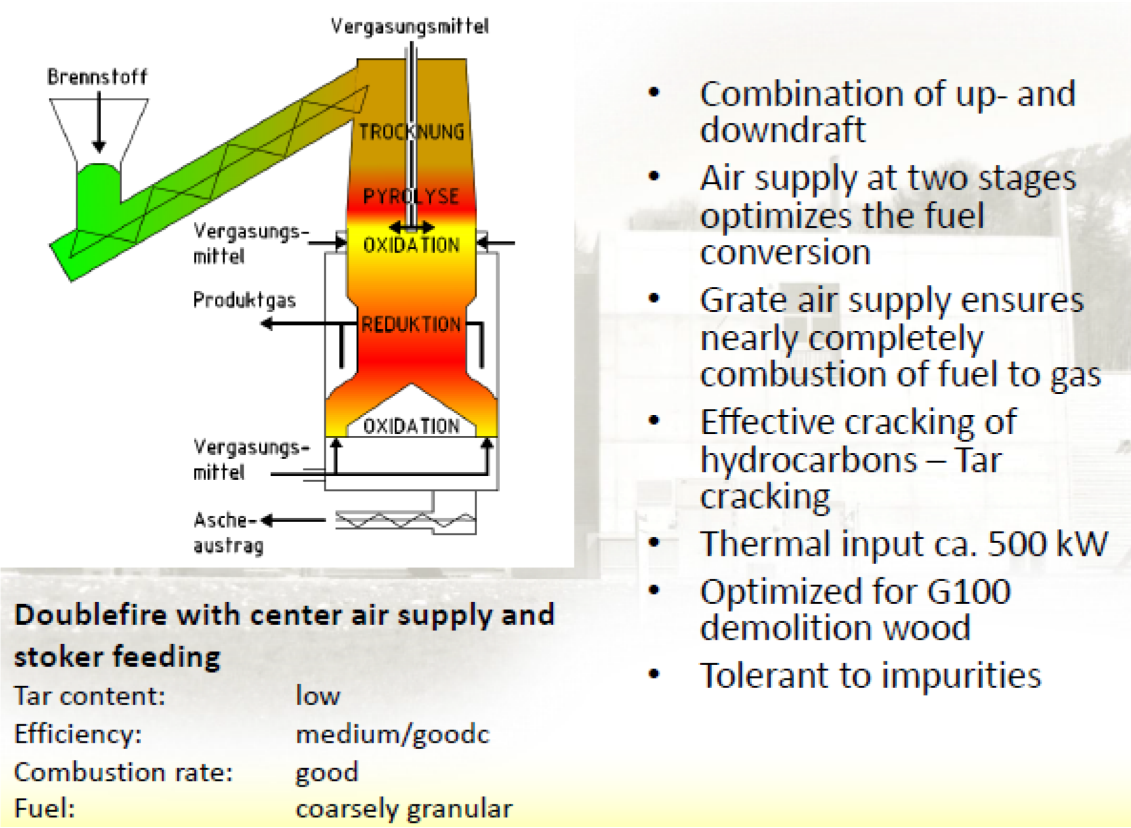

Figure 81: Reactor Sirion (source: B. Böcker-Riese)

Figure 82: SIRION reactor - photo (source: B.Böcker-Riese)

Table 18: Product gas composition (gasifier Stans)

Component	**Range (Vol.%)**
CO_2	8-15
H_2O	Up to 20
O_2	Up to 3
CO	15-25
H_2	10-20
CH_4	0-5
N_2	rest

3.9 USA

This USA contribution to this report summarizes current commercial developments in biomass gasification for the USA, focusing on three high-profile projects that are in progress. The report was compiled from personal interviews and from information available on company and Department of Energy websites.

3.9.1 Red Rock Biofuels

Red Rock Biofuels (www.redrockbio.com) is constructing a an advanced biofuels production facility in Lakeview, Oregon to convert 136,000 tons of woody biomass into 15 million gallons per year of biofuels including jet fuel and diesel. The feedstock is a mix of softwoods and forestry waste/slash materials plus pre-commercial thinnings. The feedstock will be obtained from non-federal land in southern Oregon and northern California in an economic draw radius from the plant. 70% of the annual feedstock requirement is under long-term contract.

Conversion to biofuels is a multi-step process involving feedstock receiving and processing, gasification and syngas cleanup, catalytic conversion to Fischer-Tropsch products, upgrading to fuel products and fuel distribution. The biomass gasification technology a steam reforming process licensed from TCG Global (www.tcgenergy.com/gasification.htm). Syngas cleanup and conditioning, including tar removal, is being designed by Fluor.

Conversion of syngas to biofuels will be achieved using Fischer-Tropsch technology provided by Velocys and EFT, with upgrading achieved through hydrocracking and fractionation technology provided by Haldor Topsoe and others. Approximately 40% of the product will be Fischer-Tropsch jet fuel with an additional 40% diesel fuel. The remaining 20% is naphtha which will be sold for a gasoline blendstock. An offtake agreement for the jet fuel has been established with FedEx.

Red Rocks Biofuels broke ground on the Lakeview facility July 2018 and the plant is currently under construction. Completion is expected by mid-2020 with operations to begin later that year.

Figure 83: Construction progress, Red Rock Biofuels Lakeview facility
(Source: 2019 DOE BETO Project Peer Review Update 5 March 2019)

3.9.2 Aematis/Lanzatech

Aemetis is partnering with InEnTec and LanzaTech to build a new biofuels production facility that will produce up to 60 million gallons per year of ethanol. The plant will be located in Riverbank, California, roughly 150 km east of San Francisco.

Biomass feedstock is a combination of agricultural waste including waste from nut trees, forest waste, dairy waste and construction and demolition waste. The central California region has a significant almond and walnut industry that produces over a million tons of wood waste and nutshells per year.

Biomass will be converted to syngas through gasification using InEnTec's Plasma Enhanced Melter (PEM) technology (www.inentec.com). The PEM process involves several stages including a pregasifier responsible for about converting about 80% of the feedstock, the PEM process chamber in which a plasma arc maintains a molten environment that gasifies the remaining material, and a thermal residence chamber to improve conversion.

Syngas from the gasifier will be fed to LanzaTech's microbial fermentation technology to produce primarily ethanol (www.lanzatech.com). LanzaTech has demonstrated high conversion of industrial offgas and syngas using proprietary microbes. Production capacity at the Riverbank facility is expected to be about 12 million gallons of ethanol.

Aemetis is in the final stages of securing financing for the Riverbank biorefinery and expects construction to begin in 2020.

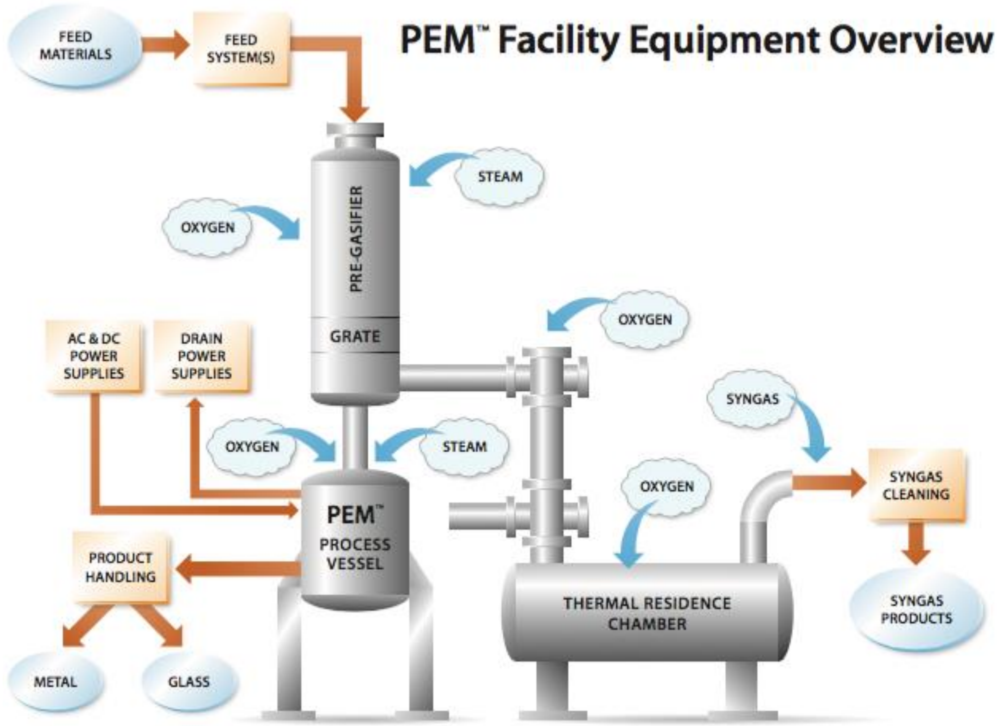

Figure 84: InEnTec PEM gasifier (Source: www.inentec.com)

3.9.3 Fulcrum Bioenergy

Fulcrum Bioenergy's Sierra Biofuels plant near Reno, Nevada will convert approximately 200,000 tons per year of municipal solid waste into more than 10 million gallons of renewable synthetic crude oil through feedstock preprocessing, gasification and Fischer-Tropsch synthesis.

The Sierra Biofuels facility will use sorted municipal solid waste that has been pre-processed in an on-site feedstock processing facility (FPF) to remove inerts and ferrous and non-ferrous metals. The feedstock is said to be very heterogeneous, carbon-rich, and dry and consists largely of paper, cardboard, wood, carpet and other similar materials. The FPF is located adjacent to Waste Management's Lockwood Regional Landfill, one of the largest landfills in the Western U.S. The FPF is also within close proximity to the Sierra Biorefinery and has been in operation for several years.

The gasifier technology is ThermoChem Recovery International's indirectly heated fluidized bed steam reformer (www.tri-inc.net/steam-reforming-gasification). The gasifier specific to the Sierra Biofuels facility employs TRI's commercial biomass gasification technology with some minor modifications to accommodate for variation in energy content of the feed material. Syngas from the gasifier will be treated using Praxair's Hot Oxygen Burner (HOB) technology to partially oxidize hydrocarbons and tars in the syngas, thereby improving syngas quality and overall yield.

Fischer-Tropsch wax is the primary product for the Phase I development. The wax will be processed to jet fuel by Marathon in their Martinez, CA refinery. Additional unit operations are expected be installed in a later phase to manufacture bio-jet fuel on-site.

The feedstock processing facility has been in operation since 2017. The Sierra plant is under construction and scheduled to come on-line in the first quarter of 2020 with fully operational status obtained by the second quarter of 2020.

Figure 85: Construction photos of Sierra Biofuels plant. (Source: Abengoa/LinkedIn)

4. Highlights and summary

In the last years happened a lot in the area of thermal gasification, new thermal gasification facilities were planned / under construction and taken into operation, the other ones were on hold or closed and mothballed.

In Austria, the facilities based on FICFB technology in **Guessing** and Oberwart were closed due to economic reasons. Renewable electricity production in Austria is supported by feed-in tariffs and for biomass plants these tariffs are valid for 13 years. The feed-in tariff of the biomass CHP Guessing ended by end of October 2016 and without this tariff, no economic operation was possible, so the owner decided to stop the operation. Anyway, from a technical viewpoint, the plant could be still operated for several years. After almost 100.000 hours of operation, the biomass CHP Guessing was shut down by end of October 2016.

Anyway, the technology of FICFB or dual fluidized bed systems was approved also in Goetteborg (Sweden), by Gaya project (France) and in Senden/Ulm (Germany) as well as by the project Gretha (Thailand).

In small scale fixed bed gasification are in Austria still active companies such as Urbas, SynCraft, Hargassner, Fröling and Glock, which are successful not only at home market but also abroad.

In Denmark, the thermal gasification facilities in **Harboøre** and **Skive** are well known for their many years lasting successful operation.

In 1993 Harboøre Varmeværk established a demonstration gasification plant based on the development achievements at pilot scale by the supplier, Babcock and Wilcox Vølund, and numerous university studies. In 1997, after a large development effort by Vølund and the heating company, the gasification process was considered commercial, and in the course of 2001 the district heating plant was converted into CHP and was taken into commercial operation. Since then, the plant has operated 8,000 hours per year and supplies heat to approx. 698 heat consumers including the municipal buildings of the town. The Harboøre gasification plant is in operation all year round.

The commissioning of the Skive plant started in late 2007 and, using one gas engine, operations initially began in the early summer of 2008. The second and third gas engines were installed during summer 2008. After several years of intermittent operation, the plant has now reached a high availability and operation and outage is fully under control. Skive Fjernvarme and Haldor Topsøe has in an EUDP funded project been looking into the opportunity to utilise the gas for production of gasoline and other fuel products via the TIGAS process.

In Germany, the **bioliq®** pilot plant aims at demonstration the bioliq technology on a TRL level of 6. Reliable mass and energy balances will be provided; practical experience in operation and on equipment used will be gained. Furthermore, fuel flexibility and product quality have to be verified. Also, the bioliq pilot plant acts as a research platform which is embedded in a broad R&D framework, forming the basis for a knowledge-based optimization and further development of the technical processes, also allowing to explore applications of the products and technologies involved. Within the bioliq®-project in Karlsruhe AirLiquide Engineering & Construction built the high pressure entrained flow gasifier for the conversion of suspension fuels (slurry) produced via pyrolysis from biogenic residues. AL E&C is an ongoing research partner for KIT in the bioliq®-project.

The bioliq® facility is operated in the 24/7 continuous mode for individual measurement campaigns to collect operating data for a broad spectrum of feed materials, and to provide synthesis gas for the downstream synthesis of gasoline. Since commissioning, roughly 900 tons of slurry were successfully converted into raw synthesis gas in 1200 h of operation.

ThyssenKrupp Industrial Solutions is a plant manufacturer that offers a process portfolio for large scale syngas and chemical plants. They took over the PRENFLO® and HTW® gasification technologies from former Uhde GmbH. With the **BioTfuel®**-Project in northern France ThyssenKrupp Industrial Solutions and their French partners develop and demonstrate a process for synthetic fuels (Jetfuel and Diesel) from biomass residues like waste wood or straw using the PRENFLO PDQ gasification technology. The feedstock for the gasifier is produced via a torrefaction process.

In Germany, there are also projects in area of fluidized bed gasification, provided by companies **Burkhardt GmbH** and Sülze Kopf SynGas, which focuses on bubbling fluidized bed gasification systems for sewage sludge for heat or CHP applications.

Since 2010, Burkhardt GmbH is a producer for wood gasifiers for combined heat and power applications. The gasification of the biomass takes place in a co-current stationary fluidized bed. Burkhardt offers 3 sizes of gasifier systems, 50 kWel, 165 kWel and 180 kWel that are fed with wood pellets. All systems produce power from gas engines. The company has delivered more than 240 plants.

Fixed bed gasification units are in Germany produced by companies LiPRO Energy GmbH, SPANNER Re^2 GmbH, REGAWATT GmbH and Biotech Energietechnik GmbH. It worse to mentioned that **SPANNER Re^2 GmbH** has delivered more than 700 plants worldwide.

Italy has long been involved in the energy exploitation of residual biomass and waste. In operation, are now there more than 220, mostly small scale facilities, majority of them in northern part of Italy. The reason is the fact that in this area the presence of forested areas and companies working with wood is significant. Trentino-South Tyrol is the region with the larger number of gasification plants and power production. The plant size varies in the range from 20 to 1000 kWel.

Most of the facilities come from foreign manufacturers, which technology was described at other place of this report. In Italy, three following producers of thermal gasification facilities are now active: CMD S.p.A, producer of **CMD ECO20x** facilities, which are mCHP (Micro Combined Heat & Power) Systems transforming biomass into syngas from which electric energy and heat are produced. The output range is 20kWel (peak value), heating system can produce till 40 kWth of heat power (peak value).

The second company in small scale gasification area is **ESPE SRL**, producing downdraft fixed bed gasifiers. ESPE has made use of this technical solution because it allows production of extremely clean synthesis gas without a need for filters, which increases system reliability over the long term and simplifies daily management. The biomass used by such cogenerator is virgin wood chips, or rather very tiny pieces of wood. At this time, the company has about 20 facilities in operation.

RESET s.r.l provides engineering and manufacturing of small scale, containerized biomass gasification and cogeneration systems from 50 kWe to 200 kWe, which are fully automatic, producing not only heat and power, but high grade biochar as well.

In the Netherlands, many of gasification projects are ongoing.

One of them is the construction of a wood gasification plant by BEN (Bioenergy Netherlands) started in the Port of Amsterdam in November 2017. The technology used is supplied by Zero-Point Clean Tech, which is fixed bed technology. This will result in low tar content gas, making cleaning easier. The first phase is expected to be operational in May 2019. An observation from the start-up phase is that permitting such technology takes longer than normal, since it is not well established.

The gas that is produced by Bio Energy Netherlands can be used to generate heat and electricity. There is a collaboration with Jenbacher and excellent results with Jenbacher 620 syngas engine have been achieved. The plant in Amsterdam is designed for a total of 15 MWh of combined heat, power and hydrogen.

The next project in the Netherlands is Essent/RWE waste wood gasifier called **Amer-9**, located in Geertruidenberg, which is connected to a 600 MWe coal-fired power station with 42% net electric efficiency. The capacity of the gasifier amounts 85 MWth and is a near-atmospheric Circulating Fluidized Bed (CFB) reactor based on Lurgi technology.

Eska, which is a leading global manufacturer of recovered paper based substrates for a wide variety of industries and applications, uses CFB technology to gasify paper rejects and using the product gas as a feed to a boiler. The technology is supplied by Leroux & Lotz and implemented in 2016. The gasification process saves 18 million m^3 of natural gas per year.

Within **Mavitech Green Energy**, gasification plants are sold turn-key. Their technology is a down-draft fixed-bed gasifier which is capable of converting various feedstocks (different manure and sludges) into a product gas (CO, H_2 and CH_4), which is combusted directly after the gasifier and the heat can be used to produce steam, power or heat.

Synova developed a standardized modular unit based on MILENA and OLGA of approx. 6 MW input (depending on the feedstock). This so-called SMM can be used to couple to a power block to make circa 1.5 MWe electricity. It also will be the basis for an RNG project in the Netherlands called **Ambigo**. Synova identified a large market for these units that will be built in containers, have a short production time with quick local assembly, and several options to adapt to specific conditions or wishes by the client. The first SMM to power will be in Thailand, North-East from Bangkok. Synova will own and operate the plant.

A larger unit producing approx. 8 MWe to the grid is designed and ready for EPC bids. These projects will often include the facility needed to convert Municipal Solid Waste (MSW) to Refuse Derived Fuel (RDF), which is the feedstock for the gasifier. The power plant will include a turbine from Caterpillar, that is one of the investors in Synova. There are currently several options for this 8 MWe unit in Thailand. A unit for circa 25 MWe will be the largest unit that Synova is developing.

Synvalor developed a new multi-stage vortex reactor for the gasification of all kind of fuels, but specifically difficult fuels. It aims at producing low-tar producer gas for e.g. gas engines. The goal is to keep the investment below 2500 Euro/kWe. The technology is called Synvator®. Synvalor built a pilot test facility of approximately 50 kWe capacity and has been tested with wood dust, wood chips, reed, grass, straw, and digestion residue. Synvalor is confident about the technology and is working towards two plants in Europe.

Currently there is a CHP plant in commissioning at a Gerbera grower (Fa. S.C. Zwarts in Mijdrecht) in the Netherlands. The first results are expected in 2019.

The next company, which is in the Netherlands very active is **Torrgas**, which aims to be a leading provider of value chain solutions for plant scale 10-100 MW syngas from torrefied biomass. The objective of Torrgas is to develop and technically and commercially proof the operation of a biomass gasification process to produce chemically grade syngas, which is free of nitrogen and tar.

Also the supercritical water gasification is an actual topic and not only in the Netherlands. SCW Systems is a young company focusing on the development of supercritical water gasification. A first demonstration plant was constructed in Alkmaar and the commissioning started in the second half of 2018. This installation has been connected to the high pressure transport grid round December 2018. Gasunie New Energy is directly involved in this development. Expected Green Gas production in 2019.

Also the Dutch technology by **HoSt** should be mentioned here. Their CFB technology has been proven on various feedstock and their offers are in the range of a standard installation of 1-5 t/h or specialty plants of >5 t/h. Biomass gasification is an important topic also within ECN part of TNO for almost 25 years now. In these 25 years, various technological successes have been achieved. ECN part of TNO has developed a Circulating Fluidized Bed gasifier (CFB), which is commercialized by HoSt.

In opposite to central and southern Europe, where the small scale gasification booms, in the northern European countries such as Norway and Sweden, these facilities are mostly an exception.

In Norway, the first small scale CHP unit based on gasification of locally sourced wood chips, located at Evenstad campus started up in 2016. The facility was produced by Volter and delivered by ETA Norge. The feedstock quality was a challenge thus a new reactor for pellets was developed.

In Norway, the prices of energy are relatively low, thus CHP production based on gasification is too expensive in comparison with other energy sources. Thus, the gasification projects do not focus on CHP production, but on other ways of syngas utilization, such as biofuels production.

Currently plastic waste, biomass and non-captured natural gas are unused resources causing huge environmental and financial problems, thus the project **Quantafuel** focuses on plastic waste further processing and utilization as a source for liquid biofuels.

Quantafuels first European plant is now officially established at GreenLab green industrial park in Skive, Denmark. The purpose of GreenLab Skive is to create one of Europe’s leading centres for renewable energy.

The Skive plant will have an initial capacity of 60 metric tons of plastic waste per day, and will convert approximately 18 000 tons of plastic waste per year. This is plastic waste which would otherwise be exported or incinerated. Quantafuel will produce more than 15 million litres of high-quality recycled fuel.

The next interesting Norwegian project is called **BioFuel**. This project focuses on sustainable economic production of aviation biofuel from household waste. The project embraces two phases; commercial demo plant and commercial facility with full potential. Both of these facilities will be located in Norway. Production capacity of 1^{st} phase will be 8,6 million liters of FT liquids, production capacity of the 2^{nd} phase should be 50 mill. liters of aviation biofuel, 10 mill. liters of biodiesel, 12 mill. liters bionaphta, 10 000 tons of LPG.

If one would talk about thermal gasification in Sweden, the **GoBiGas** project have to be mentioned. Initially, two phases of the project were planned. A first demonstration phase of 20 MW product gas to be followed by a second phase of 80-100 MW output of bio-methane gas. However, the actual price of bio-methane did not follow the projections, it became lower than anticipated due to a drop-in energy prices in general, less demand of bio-methane due lower sales of CNG vehicles than expected and also due to imports of bio-methane from Denmark, where producers received a subsidy. The plant has operated for over 12 000 hours in total since being commissioned in November 2014. Due to the high operating loss, i.e. direct production cost where significantly higher than the sales revenues, the company decided to stop the project in 2018. More details regarding this project could be found in the chapter 3.7.1.

Further topic in Sweden was the black liquor gasification, developed by Chemrec. The core of Chemrec Kraft Recovery was the Chemrec gasifier - a refractory-lined entrained bed reactor in which concentrated black liquor is gasified under reducing conditions at around 1 000°C. The liquor is decomposed in the reaction zone into melt droplets consisting of sodium compounds, and a combustible gas containing H_2 and CO. In 2008, the FP7 Bio-DME project was launched which included the construction of a 4 ton/day **BioDME** plant based on Haldor Topsøe technology to be connected to the DP-1 gasification plant. The DME was used by Volvo Trucks to operate ten DME trucks for use by different transport companies in four locations in Sweden. DME was produced for the first time in 2011, and the plant was operated by Chemrec up to the end of 2012 within this project. Close to 400 tons of DME was produced and truck operation for over 80 000 km resulted from the project. Anyway, when the Bio-DME project ended in 2013, Chemrec could no longer support the cost of the staff and of the continued operation of the Bio-DME plant. In order to save this important gasification infrastructure a program was devised to transfer ownership to LTU, and to continue with more research-oriented activities.

The next player on the Swedish market is Cortus Energy AB with the **WoodRoll®** technology. The WoodRoll® thermal gasification technology is an integrated process for converting wet solid biomass to clean syngas in three steps, drying, pyrolysis and gasification. The process is fully allothermal from wet biomass to clean syngas. Excess heat is used counter current the biomass processing to syngas. To prove the concept in view of the scale-up for the Nordkalk project, a 500 kWth gasifier, was constructed in Stockholm in 2011. After its initial operation, this unit was moved and reassembled at the Nordkalk site at Köping where it was taken into operation in February 2012. After testing with the three stages operating off-line, a fully integrated unit has been constructed and was mechanically complete in early 2015. It has been reported that the gasifier has been operated over 5 000 hours in September 2018, and the dryer and pyrolyzer over 2 000 hours each. In mid-2018, Cortus and the German company Infinite Fuels GmbH signed an contract to cooperate to evaluate the WoodRoll process, using biomass feedstock for the production of bio-methane for grid injection, for a project in Northern Germany, for which there is already substantial financing available. Following the initial work, a realisation of the project could be taken in 2019. In late 2018, Cortus was also awarded a grant from the Swedish Sustainable Aviation fuel program to study the integration of the WoodRoll system with a FT system producing aviation fuel.

The **VIPP** technology by MEVA originates from the developments at LTU. The purpose was to develop a small-scale CHP system based on small-scale gas turbines. In 2012, following the installation at Hortlax, a partnering and distribution agreement was made with global engine OEM Cummins Inc. Following the acquisition of the technology, the experimental gasifier was extended to a full pilot plant by adding gas cleaning and by also including a gas engine to verify the full process. The pilot plant at ETC had a input of 500 kWth and includes the gas cleaning process and an engine of 100 kWe output. More details to this project could be found in the chapter 3.7.1.

In Switzerland, mostly small scale gasification units are in operation. These are provided by Volter, Regawatt, Burkhardt, Ligento, Wegscheid, Spanner and Pyroforce.

In the USA, the thermal gasification projects focus on production of biofuels. Here the most important three projects should be mentioned.

Red Rocks Biofuels is constructing an advanced biofuels production facility in Lakeview, Oregon to convert 136,000 tons of woody biomass into 15 million gallons per year of biofuels including jet fuel and diesel. The biomass gasification technology a steam reforming process licensed from TCG Global. Syngas cleanup and conditioning, including tar removal, is being designed by Fluor.

Conversion of syngas to biofuels will be achieved using Fischer-Tropsch technology provided by Velocys and EFT, with upgrading achieved through hydrocracking and fractionation technology provided by Haldor Topsoe and others. Approximately 40% of the product will be Fischer-Tropsch jet fuel with an additional 40% diesel fuel. The remaining 20% is naphtha which will be sold for a gasoline blendstock. An offtake agreement for the jet fuel has been established with FedEx. Red Rocks Biofuels broke ground on the Lakeview facility July 2018 and the plant is currently under construction. Completion is expected by mid-2020 with operations to begin later that year.

Aemetis is partnering with InEnTec and LanzaTech to build a new biofuels production facility that will produce up to 60 million gallons per year of ethanol. The plant will be located in Riverbank, California, roughly 150 km east of San Francisco. Biomass will be converted to syngas through gasification using InEnTec's Plasma Enhanced Melter (PEM) technology. Syngas from the gasifier will be fed to LanzaTech's microbial fermentation technology to produce primarily ethanol. Aemetis is in the final stages of securing financing for the Riverbank biorefinery and expects construction to begin in 2020.

Fulcrum Bioenergy's **Sierra Biofuels plant** near Reno, Nevada will convert approximately 200,000 tons per year of municipal solid waste into more than 10 million gallons of renewable synthetic crude oil through feedstock preprocessing, gasification and Fischer-Tropsch synthesis. The gasifier technology is ThermoChem Recovery International's indirectly heated fluidized bed steam reformer. Syngas from the gasifier will be treated using Praxair's Hot Oxygen Burner (HOB) technology to partially oxidize hydrocarbons and tars in the syngas, thereby improving syngas quality and overall yield. The Sierra plant is under construction and scheduled to come on-line in the first quarter of 2020 with fully operational status obtained by the second quarter of 2020.

It can be seen that the technology of thermal gasification is still further developing. New, for the utilization more complicated but cheaper feedstocks, such as waste materials are in focus. The produced gas is not utilized only for CHP purpose, but more advanced cleaning and conditioning make it possible to produce gaseous or liquid biofuels, which should replace fossil ones in the near future.

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Abbreviations

NTLs	National Team Leaders
CHP	Combined Heat and Power
PV	Photovoltaics
CRs	Country Reports
BEN	Bioenergy Netherlands
FICFB	Fast Internal Circulating Fluidized Bed
PEM	Plasma Enhanced Melter
HOB	Hot Oxygen Burner

Further Information

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