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Research activities on gasification

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Joakim Lundgren

Luleå University of Technology

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GENERAL OVERVIEW

Biomass and waste gasification has been an active R&D area in Sweden for many decades. The focus has however gradually shifted from research to development and demonstration. At present, there is a significant consensus that the technical state of knowledge for gasification is such that the technologies are mature enough to proceed to demonstrations. Continued R&D aims at contributing to and supporting existing and new demonstrations, but never to replace an upscaling to an industrial scale.

Through several ambitious and successful projects since the 1990s, a world-class research infrastructure has been built up in Sweden. At institutes and universities, there are advanced and unique experimental set-ups, and the activities are now conducted in nationally cohesive forums. In particular through the Swedish Gasification Centre (SFC), where previously separate research at KTH Royal Institute of Technology, Chalmers, and Luleå University of Technology as well as parts of Research Institute of Sweden (RISE, former SP) and others, is now coordinated. In addition, process development has been conducted on a larger scale for decades. Special mentions can be made of MINO (2 MW_{th} pressurized synthesis gas in fluidised bed in the 1980s), Växjö Värnamo Biomass Gasification Centre (18 MW_{th} fluidised bed gasifier, integrated with gas turbines for electricity production in the 1990s), Chemrec and since 2013 LTU Green Fuels (3.5 MW_{th} entrained flow black liquor gasifier, integrated with fuel synthesis 4 tons of DME or methanol per day, 2005-2016) and at larger and more industrial scale, the GoBiGas plant (32 MW_{th} dual fluidised bed gasifier, integrated with methane synthesis, 2013-2018). In all these examples, there was an active developer, a company or group of companies, who built and operated the infrastructure with pronounced commercial ambitions, but with a strong connection to one or more universities that conducted supporting research both with their own equipment and in the larger structure. This link between research and operating conditions in a continuous facility provides significant added value for everyone involved, for example with Chalmers University in connection with the commissioning problems in GoBiGas.

Research and development in the field spans from fundamental issues such as kinetics, flow phenomena, catalysis, new measurement technologies to more applied research such as fuel characteristics, modelling, and material related issues as well as development-oriented issues such as up-scaling, gas cleaning processes and process integration. Below are some of the topics for current research:

Gasification and gas cleaning chemistry: There is an economic driving force to use inexpensive and more complex feedstocks and to have a high fuel flexibility. The level of knowledge for thermochemical conversion of different types of inhomogeneous feedstocks of varying quality is currently not high enough. Both gasification kinetics and ash properties are important areas, as is modelling of the entire gasification process, for example via numerical calculation methods such as CFD (Computational Fluid Dynamics) and other types of tools and methods. The modelling often includes advanced models for turbulent heat transfer, radiation, and multiphase flow, which must be validated against robust experimental data to provide reliable results. For different gas purification processes where catalysts, filters and washing liquids are used, an increased understanding of how these materials interact with gas components is needed. In the event of future upscaling of facilities, longer operating times and experience will give rise to issues that cannot be considered in smaller test facilities.

Process design and process integration: The gasification process needs to be adapted to its application in which it is included to achieve high efficiency, high reliability, and low costs. This includes selection of and optimization of processes for gas purification and gas conditioning as well as utilization of waste heat in all sub-steps of the overall process. Issues relating to the integration of technologies into existing industrial infrastructures, such as the forestry, steel making, refinery and chemical industries, or existing biofuel industries, to achieve economies of scale and higher resource efficiency are of great importance. Important methods are process integration (mathematical programming, pinch analysis, etc.), "flow sheet modelling", advanced process simulations and combinations of these.

Containment materials: gasification processes wear hard on the materials used to enclose the various steps of the process. Both ceramic and metallic materials are used in different parts and the impact on these often differs from that in ordinary combustion processes because the environment is reducing. The material issues are strongly linked to the gasification chemistry and both experimental and theoretical results from this area are needed to be able to define the technical material issues. Research focus is on the special conditions that apply in gasifiers of different types.

Functional optimization: there are several different principal solutions for biomass and waste gasification systems. All have advantages as well as disadvantages and there is not one process or technology is optimal in all commercial applications. Each solution has its ideal application. It is therefore of interest to support continued functional optimization so that knowledge increases while at the same time the technical risks of commercialization can be reduced. Functional optimization can take place both theoretically and experimentally, but in the end an experimental validation on an industrially relevant scale is always needed.

Figure 1 shows active industrial and academic actors on biomass and waste gasification R&D as well existing plants indicating the technology status as of 2021.

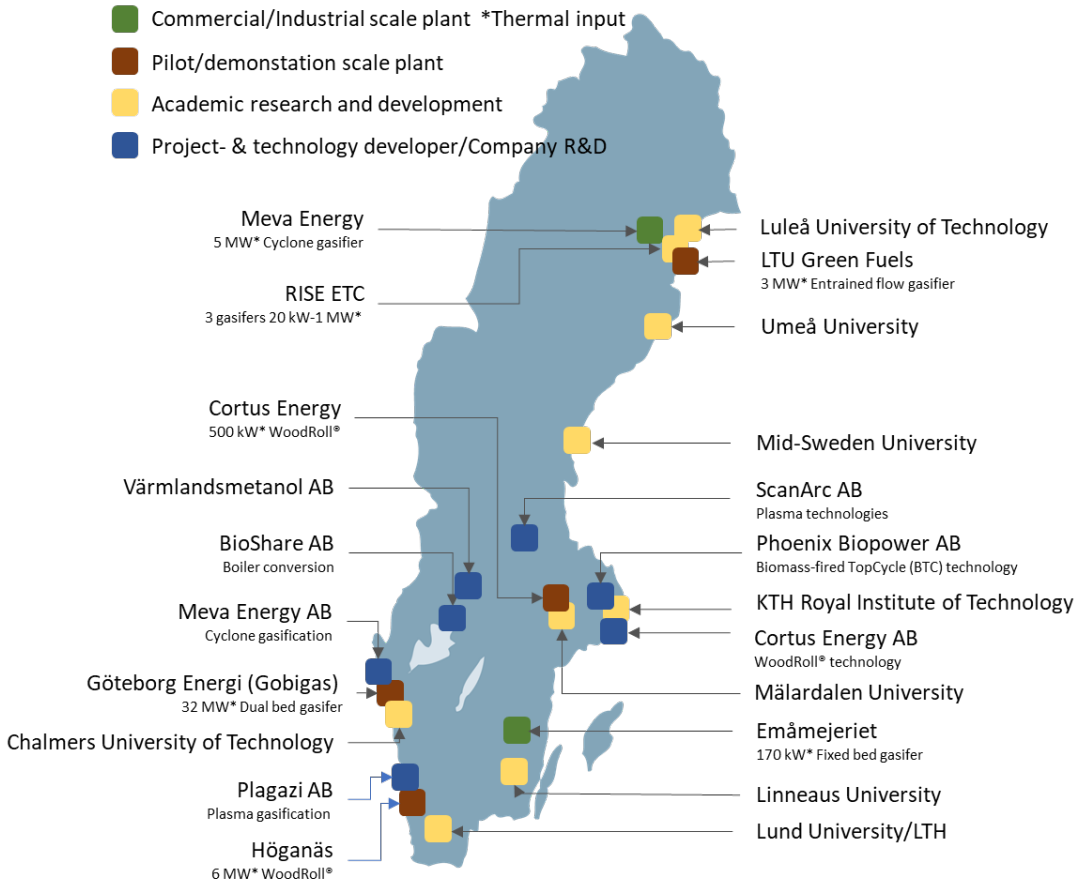

Figure 1. The biomass gasification map of Sweden

GASIFICATION RESEARCH

SWEDISH GASIFICATION CENTRE

The Swedish Gasification Centre was initiated in 2011 as an academic research organization (Centre of Excellence). The formation of the centre was a way of overcoming fragmentation and overlaps of the research and to closely connect the research to industrial needs. The initial budget was approximately 6 M€ for a two-year start-up period during 2011-2012, followed by an annual budget of 6 M€ per year for the second phase 2013-2017 and third phase 2018-2021, respectively.

In total, 19 companies, 8 universities and 1 research institute are currently active in the centre. The funding is provided in equal shares by the Swedish Energy Agency, industrial partners and the universities engaged. There are in the range of 20-30 senior researchers and 30-35 PhD students engaged in the centre.

The organization of the centre is shown in Figure 2. It is composed of three parts, referred to as "nodes", each of which specializes in one generic gasification-related technology, entrained flow (EF) coordinated by Luleå University of Technology, indirect gasification coordinated by Chalmers (CIGB Centre of Indirect gasification of Biomass) and gas cleaning coordinated by KTH Royal Institute of Technology (Cleansyngas). For governance reasons, the nodes, including their industrial partners, have autonomous responsibility within the framework agreement, and where a steering group and an advisory board are responsible for defined joint activities and general supervision ensuring that the framework procedures are being followed.

Even if the nodes are autonomous and follow the activity plan agreed with its industrial partners via node steering groups, there are several horizontal activities. These include the annual program conference, post-graduate courses, arranging workshops on topics common to all nodes and general coordination of reporting and management as well as other outreach activities.

Other universities are associated to these nodes, e.g. MiUn (Mid-Swedish University), LNU, LU (Lund University), UmU (Umeå University), GU (Gothenburg University). The institute involved is RISE, the Research Institutes of Sweden (RISE ETC and RISE Bioeconomy). Industries include power and energy companies such as E.ON, Stockholm Exergy, Göteborg Energi and Pite Energi, bioenergy companies such as Bioenergigruppen i Växjö, Hulteberg Chemistry and Engineering, other industrial companies such as Siemens, Akademiska Hus, Centriair, Tenmat, Stena Recycling , BioShare and Verdant Chemical Technologies as well as gasifier developers such as Cortus Energy, MEVA Energy, Phoenix Biopower, Scanarc, Boson Energy, and Valmet, etc.

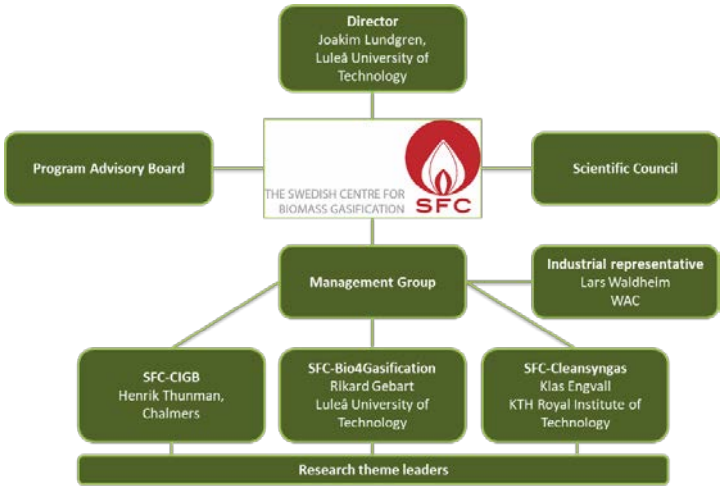

Figure 2. Organization of SFC in Phase 3, 2017-2021

The technical program is illustrated in Figure 3.

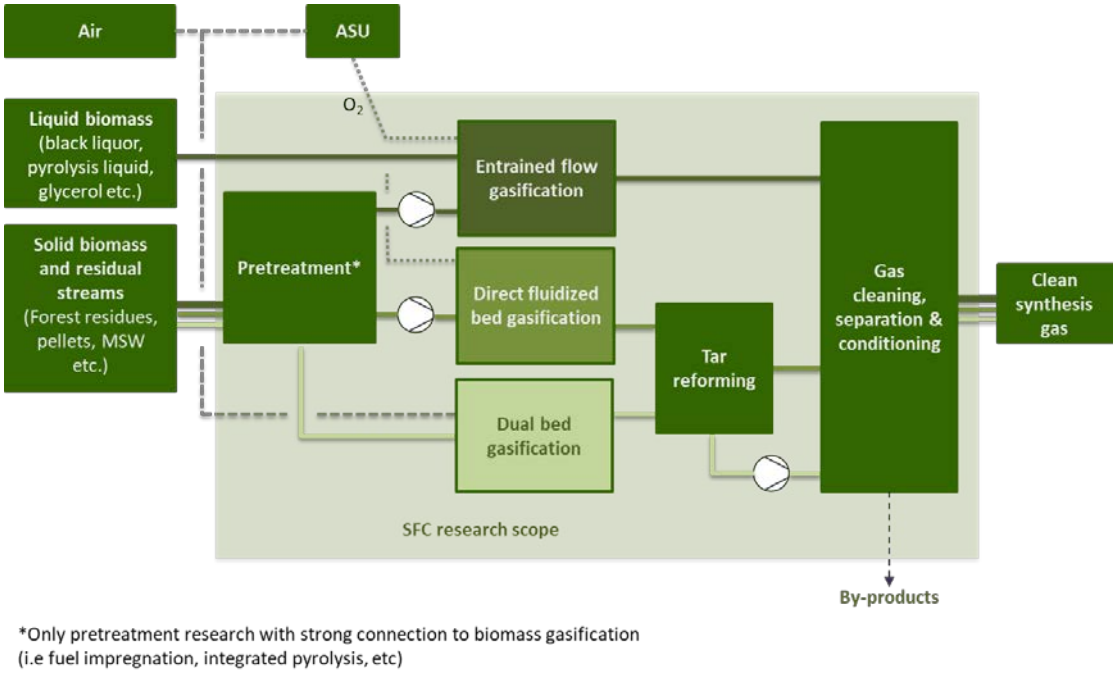

Figure 3. The technical structure of SFC

The system boundary of the program activities is shown as the shaded area, i.e., the research focuses on the gasification and primary gas cleaning sections and should not engage in the synthesis processes or use of the products, or on biomass pre-treatment upstream of the gasifier unless closely integrated with the gasification process.

The third phase of SFC comes to an end in December 2021. Large efforts are currently put on renewing the research program, but with continued strong focus on gasification of biomass and wastes. An application to the Swedish Energy Agency for partial funding of the new program will be submitted during 2021.

The technical activities and resources of the universities involved in the currently ongoing SFC program are in the following further described for each of the participating universities and institutes.

Chalmers University of Technology

Chalmers has a long history and tradition in CFB combustion systems, where most of the research findings came from the experiments on the semi-industrial scale unit used to produce heat to the campus, Chalmers Kraftcentralen (see Figure 4). In 2006, there was a proposal to combine existing CFB co-generation boilers with an indirect gasification system, drawing hot sand from the combustor of the CFB boiler to the piggy-back gasifier, where heat from the sand is released and recirculating char and cooled sand back to the combustor. The proposal resulted in a construction and start-up of a 2-4 MW_{th} gasifier unit, connected to Chalmers 12 MW_{th} CFB heating boiler, in 2007, Figure 5. The unit was built and funded by Göteborg Energi in collaboration with Chalmers University of Technology and Akademiska hus and R&D support was given by the Swedish Energy Agency. The initial aim of the installation was to support the Göteborg Energi GoBiGas project. Some of the activities of Chalmers in conjunction to the GoBiGas project are described under this heading.

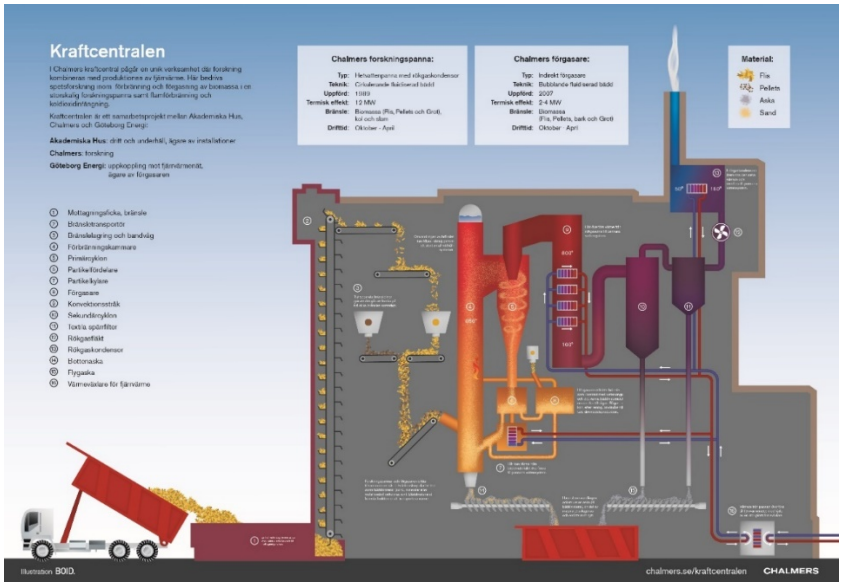

Figure 4. Scheme of DFB gasifier at Chalmers Kraftcentralen

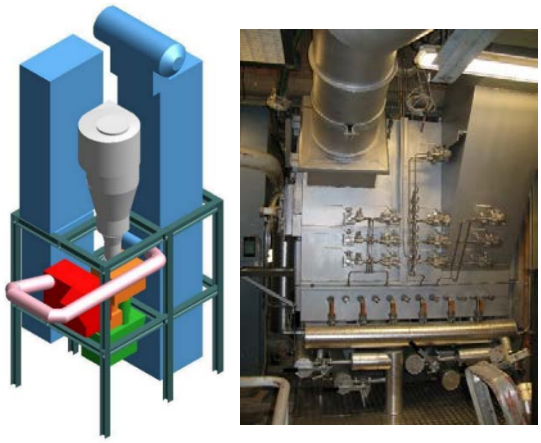

Figure 5. The Chalmers 2-4 MW_{th} gasifier

From a relatively small start, the activities in the Chalmers gasification group have expanded such as that now over twenty researchers are directly engaged. The CFB unit has since the start of operation in 2007, operated for several thousands of hours in gasification mode and with far more hours with sand circulation in as CFB boiler. From the original idea of retrofitting gasifiers onto existing CFB boilers, the goal is now the scale up of indirect gasifiers to unit sizes of 100 MW or more.

In addition, several smaller scale reactors, in the W to kW size, have been designed and successfully operated for the purpose of raw gas upgrading. The R&D activities are supported by state-of-the-art analytical equipment. To increase the level of understanding of the process chemistry and to secure its balance, development of robust measurement methodologies and analysis techniques has enabled closure of the mass- and energy-balances in actual industrial gasification process with an extremely high precision both at the Chalmers unit and in the GoBiGas plant.

The focus of on-line of research has been on the underlying inorganic chemistry of the indirect process, involving the species potassium, sulphur, and calcium. These shown to have a large impact on the activity of the bed material for tar decomposition, which has been studied in Chalmers gasifier and later being implemented in the full scale GoBiGas plant. To utilize the chemical know-how, a second line of research involves the understanding

of the flow and mixing of the fuel and the bed material in the indirect system, as well as modelling these phenomena at different scales.

To address the utilization of the produced gas, a separate line of the research at Chalmers has been studying gas cleaning. A chemical looping reactor (CLR) was developed as means of reducing the tar content of the gas. Figure 6 shows a schematic of the CLR concept.

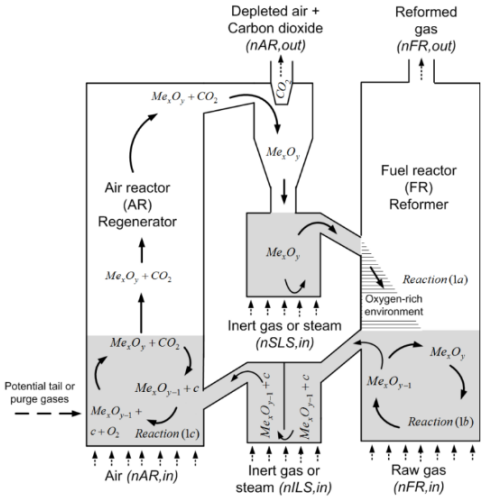

Figure 6. CLR concept for secondary upgrading of biomass producer gas

Chalmers has also in the past had activities in black liquor gasification in association with other organizations and is also engaged in modelling of gasification energy cycles as well as in catalysis research for gas cleaning and synthesis processes.

Since the commissioning start of the GoBiGas project, researchers at Chalmers have supported the commissioning and the operating staff with measurements and other activities to facilitate the plant start-up and have also been successful in resolving some of the critical issues encountered. Chalmers is also a partner in the BioProGReSs project, which had the main objectives to develop, implement and demonstrate new innovative syngas cleaning methods in both pilot and industrial-scale gasification facilities.

The importance of the support from Chalmers has also been widely acknowledged by the plant owner Göteborg Energi AB. Following the operational stop of the GoBiGas plant in 2018, Chalmers is reorienting its research towards thermal recycling through the gasification of waste materials.

Address

Chalmers University of Technology
Department of Space, Earth and Environment
SE-412 96 Gothenburg, Sweden

Contact: Prof. Henrik Thunman: henrik.thunman@chalmers.se

University of Gothenburg

The activities of the University of Gothenburg within the SFC program relates to inorganic chemistry, particles, and measurements techniques. Extensive work on measurement techniques was made within the CIGB node, principally for on-line quantification of alkali, tars and particulates tested and used at the Chalmers facilities but also in the GoBiGas plant.

Adress

University of Gothenburg
BOX 100
SE-405 30 Gothenburg

Contact: Prof. Jan Pettersson: janp@chem.gu.se

KTH Royal Institute of Technology

Gasification activities at KTH are mainly carried out at the Division of Process Technology of the School of Engineering Sciences in Chemistry, Biotechnology and Health at KTH and to some extent also at the Division of Processes (Energy and Furnace) of the School of Industrial Engineering and Management.

The Division of Process Technology has extensive experience in thermochemical conversion of solid fuels, starting with MSW pyrolysis in the early 1970's. A gasification research program has been in continuous operation since 1974. Early studies of waste, biomass and peat gasification (1975-85) were process-oriented and used to develop a pressurized oxygen-blown process known as MINO, a process subsequently evaluated in a pilot plant at TPS. Later, also CFB gasification systems (TPS and Kværner, today part of Valmet) were studied. The research today mainly concerns gasification of biomass, predominately chemical kinetics in fluidised bed gasification and gas cleaning. In the first two phases of the SFC program, this was strongly linked to the plans of E. ON and Andritz/Carbona to use this technology commercially. In the third phase of SFC, downstream gas cleaning has come into the focus to the extent that the node name was changed to Cleansyngas.

Examples of the research areas are the basic course of events in pyrolysis, gasification kinetics, tar analysis, thermal and catalytic tar decomposition, alkali analysis and gas cleaning.

One important part of the research has been the development of sampling methods and methods for analysis of tar. One of these being the so-called solid phase absorption (SPA) technique, i.e., the collection of a sample by adsorption and condensation at room temperature on an SPE (solid phase extraction) column. This method is suitable for intermittent trapping of tar compounds ranging from benzene to asphaltenes which are common in gasification product gases and very suitable for use both under laboratory, industrial and field conditions as the sample column can be stored and sent for analysis at a different site by normal mail service, whereas cold trapping is sometimes difficult under field conditions. This method has a very wide-spread use due to its simplicity relative to e.g., the Tar Protocol CEN Standard. There is also an on-going development to extend the sampling to also include heavy tars. Furthermore, a method for quantification of phenolic compounds in the tar has been developed. Finally, there is a development of on-line techniques for tar measurements based on photoionization, e.g., as part of an ERA-NET Bioenergy and BRISK projects. In addition to the techniques for tar measurement, on-line alkali measurement techniques are also being developed. These activities are now being developed further via a spin-off company, Verdant Chemical Technologies AB.

Experiments at are primarily conducted in a combination of an atmospheric fluidized bed gasifier and a pressurized bubbling fluidized bed, both 75 kW_{th} and being connected to a downstream filter and an electrically heated reformer, Figure 7. It enables both atmospheric and pressurized experiments can be performed in the filter and reformer. In 2006, the pressurized unit was also complemented by a small monolith slip-stream tar cracking reactor.

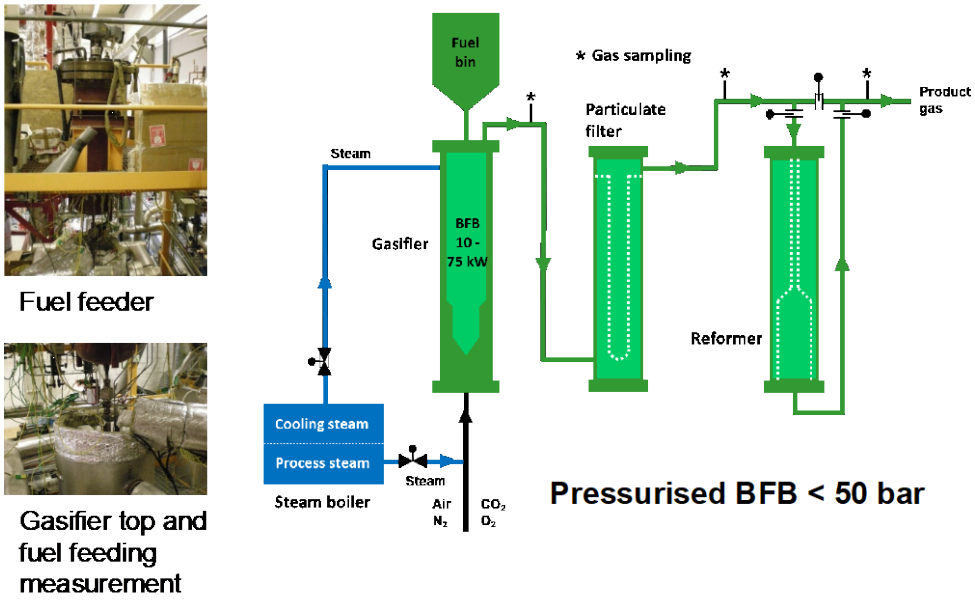

Figure 7. The 75 kW_{th} pressurized bubbling fluidized bed gasifier coupled to particulate filter catalytic tar reformer.

There is also a fluidized bed, 5 kW_{th} equipped with a filter and reformer in series shown in Figure 8.

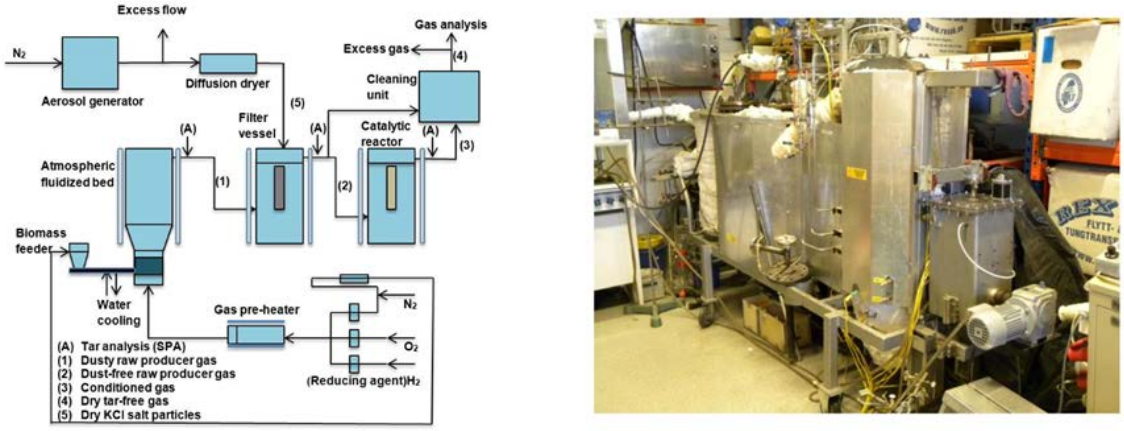

Figure 8. The 5 kW_{th} atmospheric bubbling fluidized bed gasifier coupled to particulate filter catalytic tar reformer.

In the area of pressurized fluidized bed gasification, the research has primarily focused on the use of limestone-based bed materials, such as dolomite, and how these can be optimized with respect to catalytic activity, anti-agglomeration effect and mechanical strength. Of particular significance are the results pointing at the possibility to select suitable bed materials based on relatively simple laboratory scale tests and characterisation. Also, ilmenite (iron titanate) bed material has been investigated.

In late 2014, a new mobile pressurized ATR reformer (30 bar, 10 Nm^3/hr) was constructed, Figure 9. The new reformer differs from the older one using a partial oxidation burner in addition to the possibility to use catalysts. This allows the study of both homogenous and the combination of homogeneous and heterogeneous reactions in a more realistic way. Since it is mobile it can be used at different gasification sites and have been tested at the Cortus Energy pilot plant.

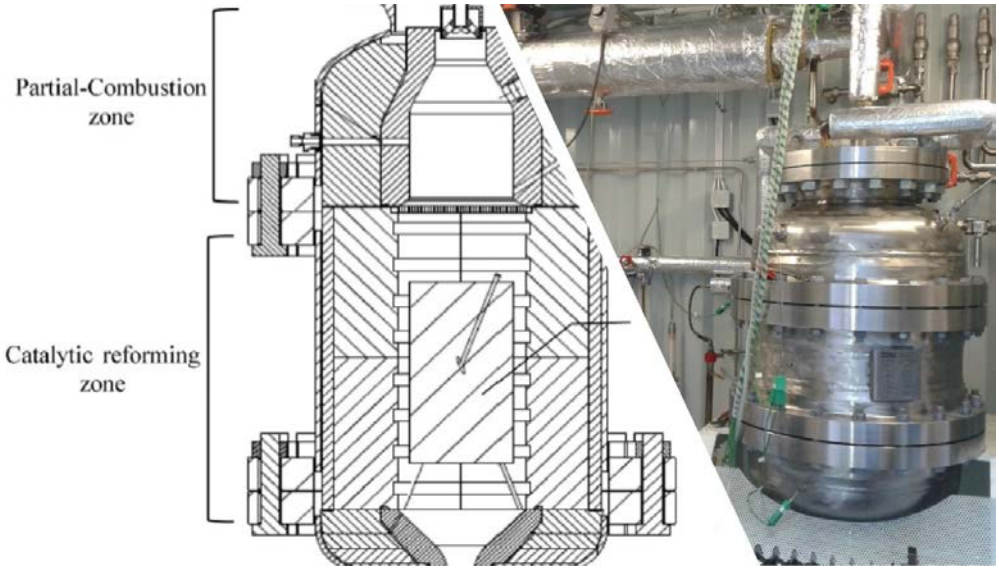

Figure 9. Pressurized autothermal reformer for dusty gas reforming

Activities in the SFC program on gas cleaning were focused on bed materials and catalytic cleaning from tar using mainly nickel-based catalysts. Extensive studies of the impact of contaminants such as alkali and sulphur on the catalyst activity were made in cooperation with Haldor Topsøe. Via cooperation with universities in Poland, Chemical Physics at Stockholm University and Materials Physics at KTH, work on such fundamental topics continues but also include development of new, non-nickel catalysts for tar removal.

Process Technology at KTH is also supporting Cortus Energy on various research issues such as modelling of a drum pyrolizer using basic data from e.g., TGA tests and a model developed at KTH. In the gas cleaning area, gas filtration and catalytic stabilization of pyrolysis gas have been addressed. R&D activities have also been established in cooperation with MEVA Energy on gas cleaning and fluidised beds.

Work on modelling of partial oxidation (POX) of dusty tarry gas in ATR and 2D imaging using techniques like laser induced incandescence (LII) and laser induced fluorescence (LIF) is carried out in collaboration with École Polytechnique de Montréal, Canada. A swirl burner is used for the POX studies and the experimental setup is shown in Figure 10.

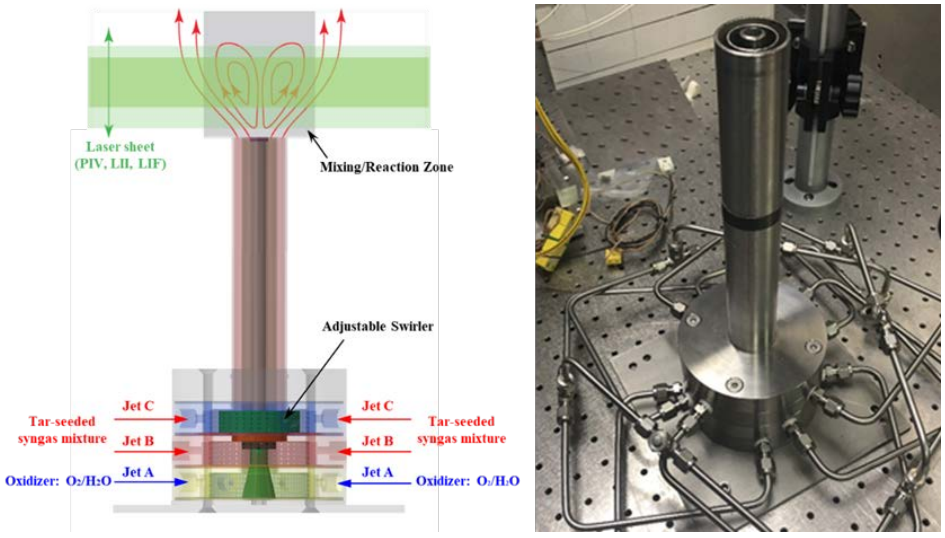

Figure 10. The POX swirl burner and imaging zone

The ability to do work under pressurised conditions, from laboratory scale and in larger scale is of interest for Phoenix Biopower AB that are developing an integrated fluidised bed gasification-gas turbine process at high pressures (>40 bar) for CHP applications.

On a more theoretical level, the Division of Processes at School of Industrial Engineering and Management, jointly with Process Technology is studying the chemistry of alkali in a gasification environment covering both gas phase and interactions with other solids. This work is carried out in cooperation with Umeå University within the SFC framework and is related to the pressurized gasification and gas cleaning systems as developed by Andritz/Carbona.

The same department studied high temperature regenerative pre-heaters for furnaces for several years. Their use in conjunction with biomass gasification, HTAG (High Temperature Air Gasification) technology, was developed up to 2011 when the technology rights were purchased by Boson Energy AB, a Swedish-Luxembourgian company which has ambitions to develop the technology for use in a CHP setting. Boson Energy is a partner in the third phase of SFC.

Future research will mainly focus on gas cleaning and conditioning to support the commercialization of emerging gasification technologies. The activities will, for example, focus on issues related to dry high temperature purification, using additives and advanced high temperature filters combined with catalytic tar conversion. Finally, research aimed at developing instruments for process monitoring and accurate measurements in relation to different processes for gasification as well as gas cleaning and conditioning, emphasizing development of standard instruments and methods, is planned.

Adress

KTH - Royal Institute of Technology
Process Technology
Teknikringen 42
SE-100 44 Stockholm

Contact: Prof. Klas Engvall: kengvall@kth.se

Linnaeus University

Linnæus University (LNU) was formed because of a merger between the universities of Växjö and Kalmar. At the Faculty of Technology, the R&D program "Wood Design and Technology" is directed towards forestry, logistics, industrial production economy for forestry and marketing of wood and wooden products, including also the thematic area "Wood and Energy Technologies" where the use of the forest and its residues as a source of energy is studied.

The university is a partner in the Cleansyngas node of SFC. Their gasification-related research covers mainly particulate characterization and aerosol sampling.

One development being studied is a novel aerosol-based method to be applied for online investigation of steam gasification kinetics of suspended biomass char particles and can in combination with thermogravimetric analysis, generate accurate data for gasification chemical kinetics at high temperature 800 to 1300 °C, which is not possible by means of traditional TGA.

A study was made to investigate the tar-removal capability of char particles finely dispersed on a high-temperature filter using the aerosol-based method developed by LNU. In this case, benzene was selected as the model tar compound, and the results indicate that both activated carbon and pine char reduced the benzene concentration. Also, understanding char gasification kinetics, combined with tar cracking capabilities, where effects of e.g., inorganics among other things are important issues.

Adress

Linnæus University
Universitetsplatsen 1
352 52 Växjö

Contact: Prof. Michael Strand: michael.strand@lnu.se

Luleå University of Technology

Luleå University of Technology (LTU) is the coordinator of the SFC and the owner of the LTU Green Fuels Plant. The activities at LTU within the SFC Bio4Gasification node are focused on entrained flow biomass gasification, including thermochemistry and associated modelling, gasifier process modelling and ash-related issues. The goal is to provide methods, models and knowledge about entrained flow gasification that can be used to design and optimize full size entrained flow gasifiers. The ambition is also to find ways to maximize the number of different biomass feedstocks that can be gasified.

The conversion of individual fuel particles is one key aspect and where research activities characterise the properties of fuel particles undergoing gasification from the initial particle and through the reactions to its extinction, and where the particle structure and morphology change during the reaction. Also, the kinetic impact of inorganic gasification catalysts (alkalis) and inhibitors (Si, Al) is studied. In cooperation with Umeå University, validation experiments are made by LTU regarding the theoretical modelling of the inorganic chemistry made at Umeå University.

Experiments are carried out in various experimental apparatus (see Figure 11) specialized for extracting various aspect of fuel conversion, such as a Single Particle Converter (SPC) in which single biomass particles with fuel particle sizes relevant for entrained flow gasifiers can be inserted and exposed to a hot reactive gas flow. By filming biomass particles during reactions, the change in temperature and size of particles during fuel conversion can be estimated. Additionally, a Flat Flame Pulverized Burner (FFPB) used for measuring how particle interactions affect ignition and burnout of particles as well as a Drop Tube Reactor (DTR) for parametric studies and kinetic studies.

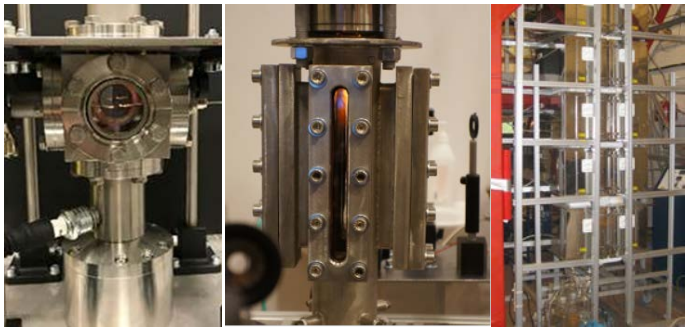

Figure 11. Various experimental apparatus. From left to right: single particle converter (SPC); flat flame pulverized burner (FFPB); and drop tube reactor (DTR).

In the flame situation, there is an interaction between a multitude of particles, and between particles and the surrounding gas, respectively. Methods to increase dispersion by acoustic forcing is one technical method being developed. The complexity of the reaction system also requires the development of specific predictive CFD models to predict the reactions and flows in the reactor. Recently, work on a model of syngas combustion in a gas turbine has been initiated. The purpose is both to investigate whether it is possible to combust raw syngas in existing gas turbines in combined cycle power stations and to integrate the resulting improved gas phase reaction model into an existing gasification model.

Since entrained flow gasifiers operate in a slagging mode the thermochemistry of the ash-forming components and how this influences other properties such as e.g., viscosity of the slag. Interactions between the slag with e.g., refractory materials in the gasifier are another aspect.

Previously, a small-scale BIG-GT CHP concept, consisting of a cyclone gasifier, was developed by LTU and ETC to be used as a combined gasifier and solid separator integrated with a combustor of a small, low inlet temperature gas turbine. A 500 kW pilot unit was built at RISE ETC and tested at both atmospheric and pressurized conditions, with gas cleaning retrofitted for MEVA Energy AB. However, the technology was bought and is further developed by the same company.

As one of the scientific partners, LTU participates in the Austrian COMET project "Waste2Value". The objective of this project is the development, engineering, commissioning, and operation of a steam blown dual fluidized bed (DFB) gasifier in pilot-scale (1 MW) for the purpose of long-term experiments of thermal residue gasification. The main aim of this project is shifting the possible feedstock range from woody biomass to more difficult feedstocks (biogenic residues, wastes from different sources, e.g., sewage sludge, as well as mixtures of those). The project leader is BEST Bioenergy and Sustainable Technologies Austria, and the project partners are TU Wien, LTU, Wien Energie, Heinzel Paper, SMS Group, Wiener Linien, Wiener Netze, and Österreichische Bundesforste. LTU contributes with expertise in the ash chemistry field, especially regarding ash-bed material interactions and phosphorus-recovery from sewage sludge in the DFB process.

In addition, and outside SFC, projects relating to gas cleaning and upgrading R&D and on system analysis are performed. System analysis projects focuses on techno-economic assessments and opportunities for integration of gasification technologies in existing industries, in paper and pulp industry via black liquor gasification but also in sawmills and steel and metal making.

Address

Luleå University of Technology
Universitetsområdet Porsön
SE-971 87, Luleå

Contact: Prof. Joakim Lundgren: joakim.lundgren@ltu.se

Lund University/LTH

Gasification research started at the Department of Chemical Engineering, LTH in 1975 with work focused on oil shale gasification. This resulted in the development, construction and operation of a laboratory-scale fluidized bed gasifier at atmospheric pressure. Gradually, the work focused more and more on biomass and peat fuels. In 1991, pressurized biomass gasification research was started as R&D support for the Värnamo plant, which was then in the planning phase. A biomass PICFB (Pressurized Internal Circulating Fluidized Bed) gasifier test rig was built, and the project group was involved in several EC-sponsored R&D projects. However, by the end of 2000, all the gasification activities at LTH were stopped.

However, more recently, some activities were restarted. Within the SFC framework, researchers at Lund are engaged on work on particulate measurements and characterization in cooperation with GU, RISE and LNU.

Address

Lund University/LTH
Faculty of Engineering
Box 118, 221 00 Lund

Contact: Prof. Per-Erik Bengtsson: per-erik.bengtsson@forbrf.lth.se

Mid-Sweden University

Within the Department of Natural Sciences, Engineering and Mathematics at Mid-Sweden University (MiUn), the research organization Fibre Science and Communication Network FSCN has a Bioenergy Gasification Group. The group has for almost a decade engaged in biomass gasification activities and is a participant in one of the nodes of the Swedish Gasification Research Centre. The activities are supported by local and regional organizations, which include forest industries, communities, and a regional environmental initiative, Biofuel Region North. Based on previous funding from the Swedish Energy Agency, EU regional support grants and from other local sources, a 150 kW_{th} indirect type, sand circulation pilot gasifier (Figure 12) for oxygen-free generation of synthesis gas was constructed in 2005-2006 at the Härnösand campus. Current research focuses on synthesis gas production from biomass for automotive fuel production and the development of technology for biomass to synthetic fuels (BTS), including DME, FT fuels, ethanol, synthetic natural gas (SNG) and hydrogen. In the recent years, the use of catalysts in the bed for decomposition of tars and other hydrocarbons has been studied. Apart from the experimental work, modelling activities are also part of the research program.

In 2017 MiUn and local partners initiated a project with a budget of 0.9 M€, of which 50 % was from the EC Regional Fund, aiming to increase the production of bio-methane for use as transport fuel. The project included work on AD biogas production but also the part of MiUn on the gasification of biomass to synthesis gas, and its conversion to methane by catalytic or biochemical methods.

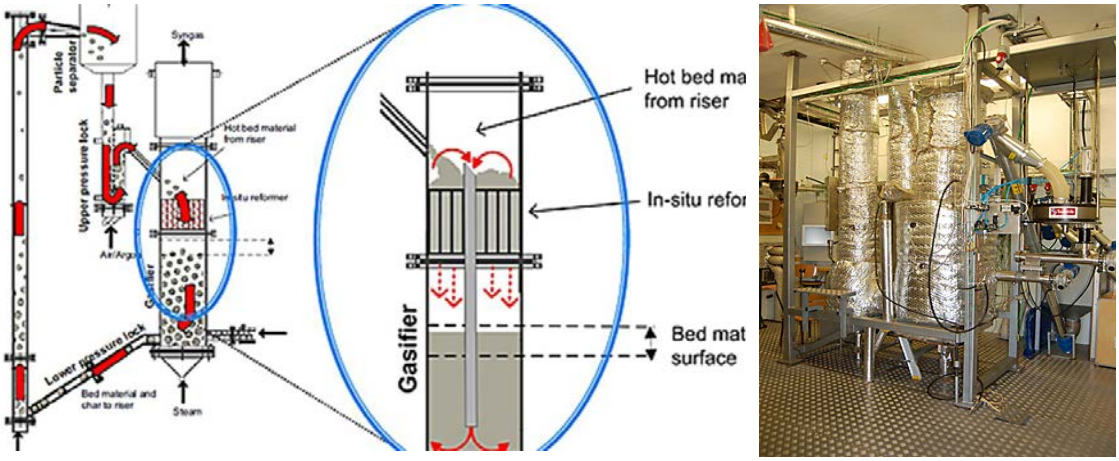

Figure 12. The CFB gasification unit at MiUn

Address

Mid-Sweden University
Campus Sundsvall
SE-851 70 Sundsvall

Contact: Dr Wennan Zhang: wennan.zhang@miun.se

RISE ETC

The Energy Technology Centre (ETC), a foundation based in Piteå, was formed in 1989. The activities at ETC were boosted in 1993 when Assi Domän Kraftliner (presently, Smurfit Kappa) made their old laboratory available to ETC and a close collaboration with the universities in Umeå (UmU)and Luleå (LTU) was initiated. ETC is a research organisation that provides both research work and professional services to the academia, public agencies, and industry. The main areas of research were thermochemical conversion of biomass and services provided are related to applications in combustion, gasification, and bio-refining processes. The site is located right next to Smurfit Kappa Kraftliner mill in Piteå, Sweden.

From the end of 2014, ETC became a part of the RISE framework (Research Institute of Sweden) as a separate non-profit legal entity within the RISE Bioeconomy Division as RISE ETC AB, and with the same activity profile as ETC had before. During the last decade the activities have expanded, the staff is over 20 persons at present, and new equipment has been installed.

The main areas of activity are:

- Sustainable hydrocarbon fuels (syngas from various residues, pyrolysis oil, co-refining biocrudes)
- Carbon free energy solutions (fossil free iron and steel, metallic energy carriers, northern solar PV)
- Computer based process optimization (ProcessAI, CFD simulations, non-intrusive diagnostics)
- High value-added materials (green carbon nanomaterials)
- Provision of client-oriented professional services for industry, public agencies and academia

The main gasification facilities of RISE ETC are shown in Figure 13. In addition, RISE ETC has other units for thermochemical and chemical treatment of biomass, as well as analytical and laboratory equipment as required for the research.

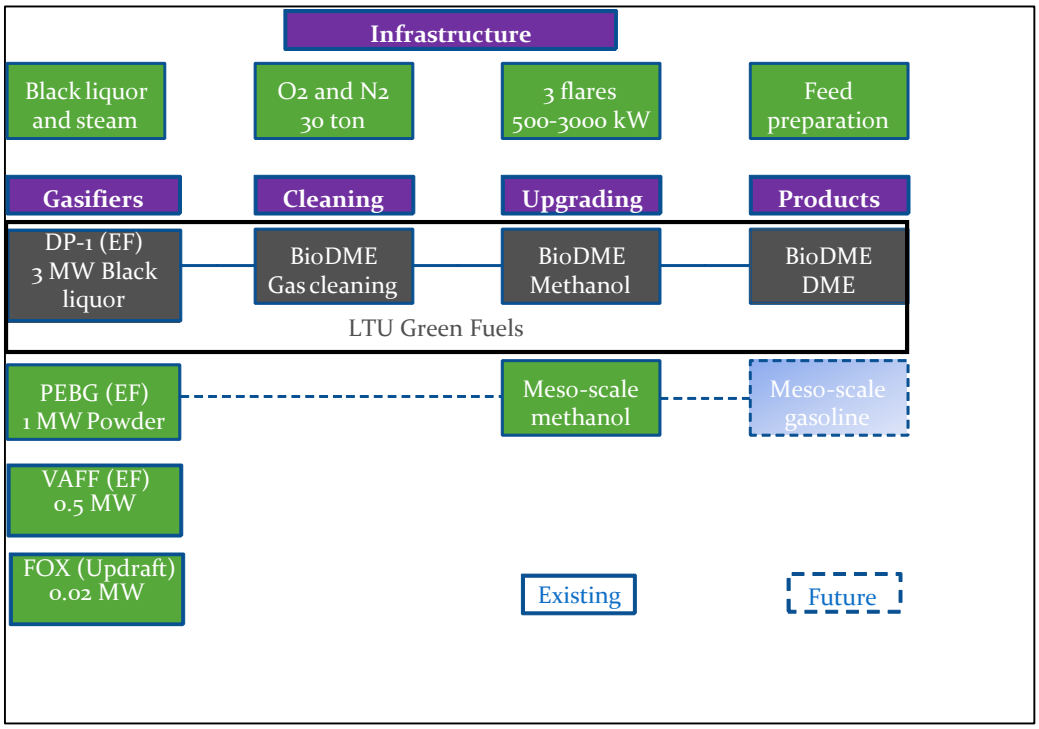

Figure 13. The gasification facilities at the RISE ETC site in Piteå

In the gasification area, RISE ETC is the host organization of the 3 MW_{th} pressurized black liquor demonstration/pilot plant DP1 and coordinated the Black Liquor Gasification R&D program associated with the Chemrec development activities until it ended in 2010.

In addition to the activities in black liquor gasification, solid biomass has also been addressed. The cyclone gasifier concept, on which work was initiated by LTU 1994, has been developed further since 2006 together with MEVA Energy AB, previously under the name "VIPP" Vortex Intensive Power Process. The 0.5 MW_{th} thermal cyclone gasifier that was already available was complemented with gas cleaning by cyclones, oil scrubber and a WESP (VIPP-ECP Evidential Cleaning Process) to allow the use of the gas in a 100 kW_e gas engine. The pilot plant has operated for more than 800 hours, and the results have been used for scale-up to the 1 MW_e demonstration at Hortlax. In 2017, following start of operation in the Hortlax plant, this plant was dismantled.

RISE ETC also studies entrained flow gasification of solid fuels. The VAFF unit of 0.5 MW_{th} was complemented by a unit with more of a process development purpose, PEBG (Pressurized Entrained flow Biomass Gasifier) in 2011. This unit, Figure 14, can operate at a pressure of up to 10 bar.

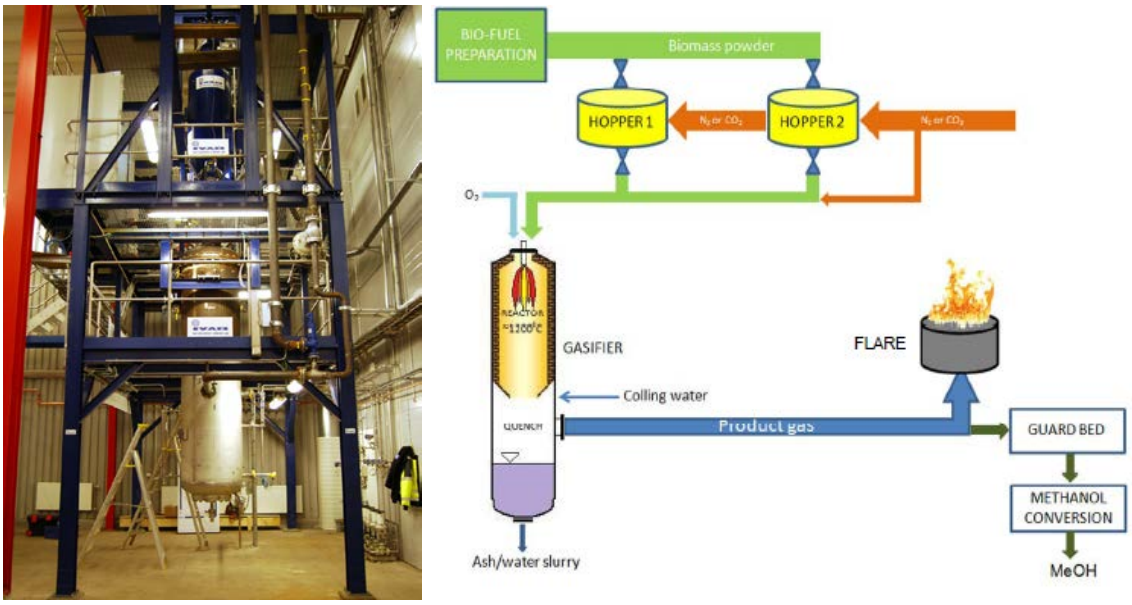

Figure 14. The 1 MW PEBG unit

The PEBG development is a cooperation between RISE ETC and a local engineering company IVAB for the purpose of generating synthesis gas for the manufacture of e.g., methanol. This unit has since its commissioning been used for fuel tests compromising wood pellets, hydrothermally treated wood and peat as well as pyrolysis oil and biorefinery lignin, the latter two fuels being part of the FP7 Suprabio project.

The tests were used to build thermodynamic models for the entrained flow gasification system and to experimentally study the dependence of operating conditions on soot formation and the distribution of inorganic elements between slag, fines and soot. The PEBG and VAFF units are used to test measurement techniques developed by other participants in the Bio4Gasification node of SFC.

In addition, in the area of process control and monitoring, RISE ETC has developed a number of laser-based measurement devices for the purpose of optical in situ measurements of soot particle concentration, particle size measurements, weighted temperature average, major gas component concentrations and alkali in the gas phase. These have initially been validated in laboratory scale equipment such as burners, flame furnaces etc., at LTU and then been tested at RISE ETC at full scale in the PEBG unit. The latest gasification unit to come on stream is an updraft fixed bed gasifer (FOX). In addition to the activities within SFC, RISE ETC also has projects covering gasification and gas cleaning.

In addition to RISE ETC, other departments within RISE also work together with the CIBG node, in particular to the theoretical and experimental studies of release of inorganic components in the ash during devolatilization and gasification and also regarding particle measurement techniques.

Address

RISE Energy Technology Centre (ETC)
Industrigatan 1,
941 38, Piteå
Contact: Dr Fredrik Weiland: fredrik.weiland@ri.se

Umeå University

Umeå University (UmU) is engaged in research in gasification and combustion, specializing mainly in the inorganic chemistry of ash constituents and its impact on bed materials and agglomeration, slagging and fouling properties. Through the Bio4Energy research environment, and in the gasification area within the Bio4Gasification node, it also works with LTU, MiUn and RISE ETC on biomass conversion technologies.

Since entrained flow gasifiers operate in a slagging mode the thermochemistry of the ash-forming components and how this influences other properties such as e.g., viscosity of the slag. Interactions between the slag with e.g., refractory materials in the gasifier are another aspect. The activities at UmU provide the theoretical basis for modelling e.g., slag deposition while many of the validation experiments are made by LTU or RISE ETC. As previously mentioned, collaboration with KTH on the chemistry of alkali in a gasification environment is ongoing.

Address

Umeå University
KBC-huset
901 87 Umeå

Contact: Prof. Markus Broström: markus.brostrom@umu.se

OTHER ACADEMIC ACTORS

Mälardalen University

School of Sustainable Development of Society and Technology program at Mälardalens University, campus Västerås, a research program, Mälardalen Energy & Resource Optimization (MERO). In this program, the group Process Development & Bioenergy, has some limited activity on black liquor gasification based on the fluidized bed process of ABB. In addition, there are activities relating to CFB gasification. These activities are both experimental, in a bench-scale CFB unit acquired, and theoretical in the form of system analyses of the use of CFB gasification systems integrated in conventional CHP plants to co-produce biofuels, bio-methane and power and heat in various configurations.

Address

Mälardalens University
Box 883
721 23 Västerås
Contact person: Prof. Jinyue Yan: jinyue.yan@mdh.se

COMPANY RESEARCH AND DEVELOPMENT

Cortus Energy AB

The developer Cortus Energy AB was founded in 2006 by Rolf Ljunggren, former CEO and currently vice President, for the purpose of developing and exploiting the WoodRoll® technology. Cortus 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 several 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.

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.

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.

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 14.

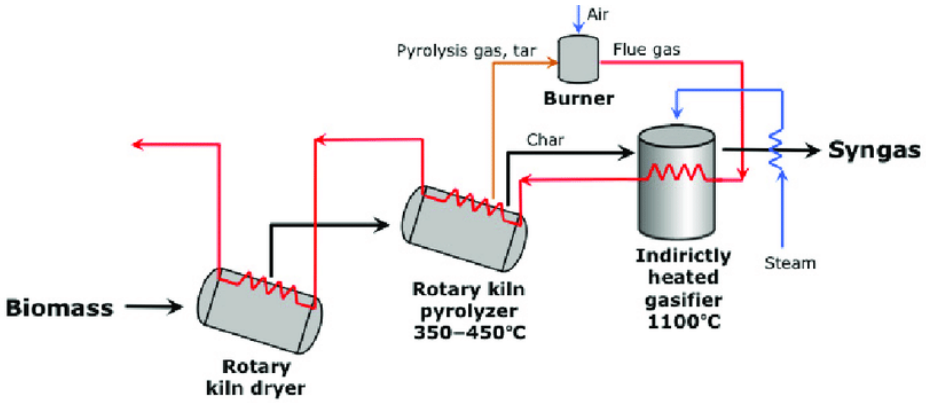

Figure 15. The WoodRoll® Technology

The biomass fuel is first dried using heat from combustion of part of the pyrolysis gas from the next pyrolyser step. In the pyrolyser, the fuel is decomposed thermally to pyrolysis gas and char. The char is injected as a powder into the gasifier by steam and the gasifier operates at very high temperature. The heat required for the gasification of the char is provided indirectly by burning the pyrolysis gas in recuperative burners, transferring heat by radiation to the gasification chamber. In this way, the char is gasified with steam only such as that the product gas is free from tar, low in methane and has no dilution by nitrogen, i.e., a medium calorific value gas product. The gasifier gas is then cooled to generate the steam required in the gasifier. The hot flue gases remaining after the combustion is routed to the pyrolyser for indirect heating of this unit.

The syngas has a typical composition of 55-60% hydrogen, 25-30% carbon monoxide, 1-2% methane 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 as well as the content of light hydrocarbons in the gas is low and other contaminants in the fuel have been reduced during the pyrolysis. 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. 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. The medium heating value gas is a better substitute fuel gas for fossil fuel than low calorific gas, as flame temperatures and other combustion properties are closer to the properties of

the common fossil fuels while the low hydrocarbon content also makes the gas suitable for syngas production.

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, see Figure 16. After its initial operation, this unit was moved and reassembled in Köping where it was taken into operation in February 2012. After testing with the three stages operating off-line, a fully integrated unit was constructed and was mechanically completed in early 2015.

Within a project involving KTH and Haldor 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.

Figure 16. Cortus 500 kW prototype gasifier at Köping; CFD and 3-D models, IRL.

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.

As a further development in the pilot unit, bio-methane (SNG) production was tested. The project started in 2009 at the coordinator Karlsruhe Institute of Technology (KIT), Germany, where a containerized SNG module was developed and tested at KIT, see Figure 28. Partners in this phase were KIT, KTH, Cortus and the Spanish utility company Gas Natural Fenosa. The container was 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 17. The DemoSNG pilot plant

Additional development activities include the Biogasxpose project and the BIO-CCHP project. The Biogasxpose project had 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 was made within projects for the Swedish Energy Agency biofuel program at the Köping pilot site. The scope of these includes both conventional catalytic conversion of syngas to bio-methane and bioconversion of the syngas.

The objective BIO-CCHP project, carried out in between the beginning of 2018 and the end of 2020 was 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, six different gasification systems were optimized for the coupling with a SOFC, broadening the range of biomass feedstock which can be employed. Also, a high temperature gas cleaning method was developed and optimized in tests at gasifier sites. A techno-economic analysis and an industrialization plan of BIO-CCHP were conducted.

Supporting test work was also carried out in the pilot plant, e.g., to produce a charcoal by-product that was used in 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 were explored. On the technical side, a modular approach was taken and the design for a 6 MW_{th} module was developed, see Figure 18.

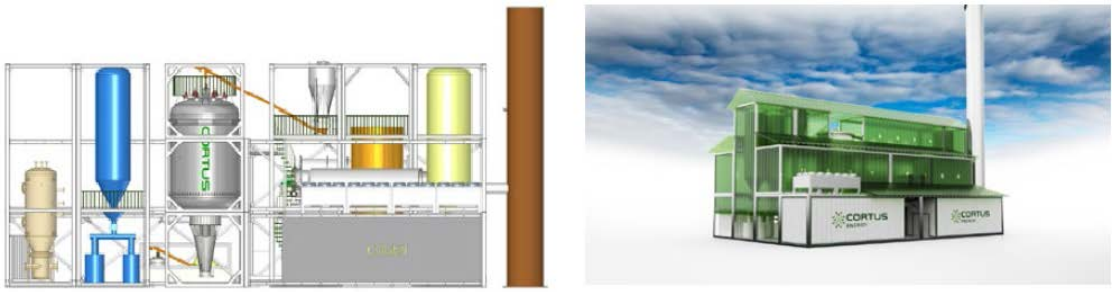

Figure 18. Cortus Wood Roll 6 MW_{th} CHP module

The project Probiostål with a budget of 3.8 million Euro 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 opportunities of substituting fossil fuels in steel making processes 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 the Swedish Energy Agency, where industry, institutes and academy together developed a complete engineering basis the plant at Höganäs.

In 2016, a 20-year fuel gas take-off agreement with Höganäs and Cortus Energy to the investment decision to build a 6 MW_{th} demonstration plant on an own-operate basis. The investment in the Höganäs plant is said to be of the magnitude of 10 million Euros. Financial support of 3.7 and 0.8 million Euros, respectively, was received from Klimatklivet ("The climate leap"), a central-government investment program for GHG reduction technologies administered by Swedish Environmental Protection Agency, and from the technical demonstration funding program of the Swedish Energy Agency. The balance of the investment is provided by Cortus via loans and emissions of shares on the market.

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 have been mechanically completed 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 cost increases. The ground-breaking ceremony for the plant was held in November 2017 and site installation work started in March 2018. In December 2018, the piping and IE&C installations were finalized, and the control system verified. In the end of 2019, Cortus Energy announced that the WoodRoll® plant in Höganäs was technically complete (see Figure 19), including third-party certificates and instruction manuals, as well as that the control system was fully implemented and quality assured. In March 2020, the plant produced the first renewable energy gas. The gas was identical to what was previously produced at the pilot plant in Köping, and fulfilled the delivery agreement with Höganäs AB.

The milestone to deliver renewable gas of approved quality without operational interruption for 168 hours (7 days) has however not yet been achieved. Currently, the plant experience problems related to particle build-up in the pyrolysis gas pipes. The pyrolysis process generates some finely ground char, which then accompanies the pyrolysis gas into the pipes. The finely ground char causes deposits in the pipes and complicates the combustion of pyrolysis gas. In December 2020, Cortus announced that more tests have been conducted and that the technical measures to overcome these problems are going forward as planned. Part of required new equipment is already ordered and under manufacturing. Preparations for the integrated and continuous operation after the reconstruction are ongoing and the aim is to begin these tests by the end of March 2021.

Figure 19. The WoodRoll® plant in Höganäs (Photo from August 2020).

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 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 MWe gas engine to produce of electricity for the grid. In 2019, Cortus submitted a notification to the BioMAT program for a 20-year subsidy for electricity supplies for the Mariposa project. In 2020, the grid owner Pacific Gas & Electric (PG&E) approved the Cortus and Mariposa project for the delivery of 2.7 MW of electricity. This means that Cortus can participate in upcoming auctions within the BioMAT program for contracts for 20 years of electricity supplies.

In early 2018, the French energy company, 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 Euros, is the first step of several for a complete Basic Engineering, estimated to 0.750 million Euros. In 2019, Engie placed an order for an Advanced Feasibility Study worth 135 000 Euros to jointly project a plant in Southern part of France as a basis for an investment decision, which was expected to be taken in 2020. At the time of this writing, no information on such a decision is publicly available.

Contact: info@cortus.se

Meva Energy AB

The originating company Meva AB was founded in 1939. The activities of Meva AB were 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 the MEVA technology (previously referred to as the VIPP systems) for biomass gasification technology.

The MEVA technology originates from the developments at Luleå University of Technology. A test unit was installed at RISE 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 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 RISE ETC had an input of 500 kW_{th} and included the gas cleaning process and an engine of 100 kW_e output. It was operated for development purposes on crushed wood pellet fuels for 800 hours in total; the longest uninterrupted operational time was 12 hours. Following the scale-up to the Hortlax plant, the pilot was no longer deemed necessary and was dismantled in 2017.

The gasifier is fed with pulverized fuel by means of the gasification air. The cyclone gasifier is operated between 800-900°C. The hot syngas exits the gasifier at the top and is cooled down to below 100 °C in a water quench. The cooled syngas is conditioned in a two-stage cleaning process: particles and tars are removed in a venture scrubber and the remaining aerosols and small droplets are removed in a wet electrostatic precipitator. 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 20 shows a schematic of the technology.

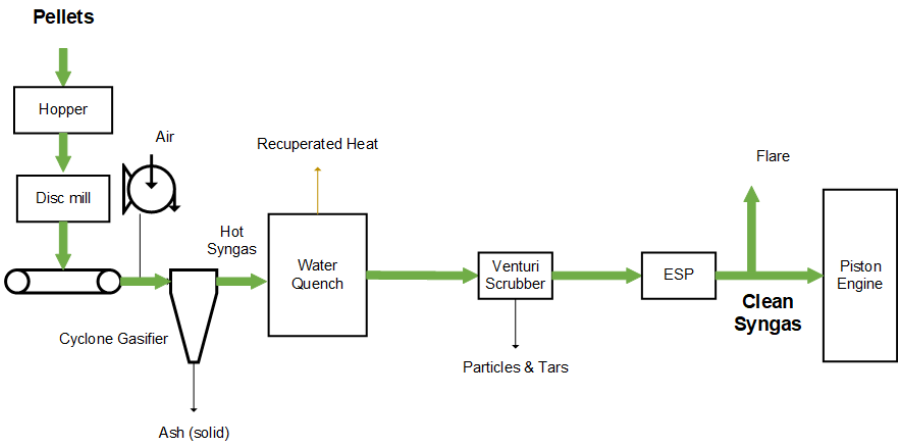

Figure 20. A schematic for MEVA Energy AB's technology

In 2011, a first prototype, scaled-up, plant of 5 MW_{th} feedstock input, 1.2 MW_e 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 feedstock 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 several constraints that originated from the need to stay within the physical 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 the SFC 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. Figure 21 shows a photo of the plant.

Figure 21. The Meva gasification plant in Hortlax.

The main market for this small-scale technology is energy plants and wood industries, e.g., sawmills and paper mills, where there is a continuous heat demand. The market is 1 -10 MW electric with 2-20 MW as thermal heat by-product.

In the end of 2019, Meva Energy announced the starting of a project titled BtoMI (Low value Biomass to high-quality Manufacturing Industry) with the main objective to optimize the combination of a (Meva) gasification and (Andritz-Enviroburners) burner system for industrial burner application. Optimizing the combination of the gasification and a burner system, means that the burner can be operated on a renewable gas with lower heating value and as an effect the gasification system can be simplified.

Within the BtoMI-project, Andritz-Enviroburners has adapted a burner configuration based on Meva's gas data and a complete containerized combustion chamber is installed at the Hortlax plant. The burner is a multi-fuel burner, meaning that it can operate on 100% syngas and 100% LPG, which is a requirement for installation in an industrial setting having full redundancy with existing solution.

Contact: info@mevaenergy.com

Phoenix BioPower

Phoenix Biopower is a company based in Stockholm working with developing its Biomass-fired TopCycle (BTC) technology, see Figure 22. 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.

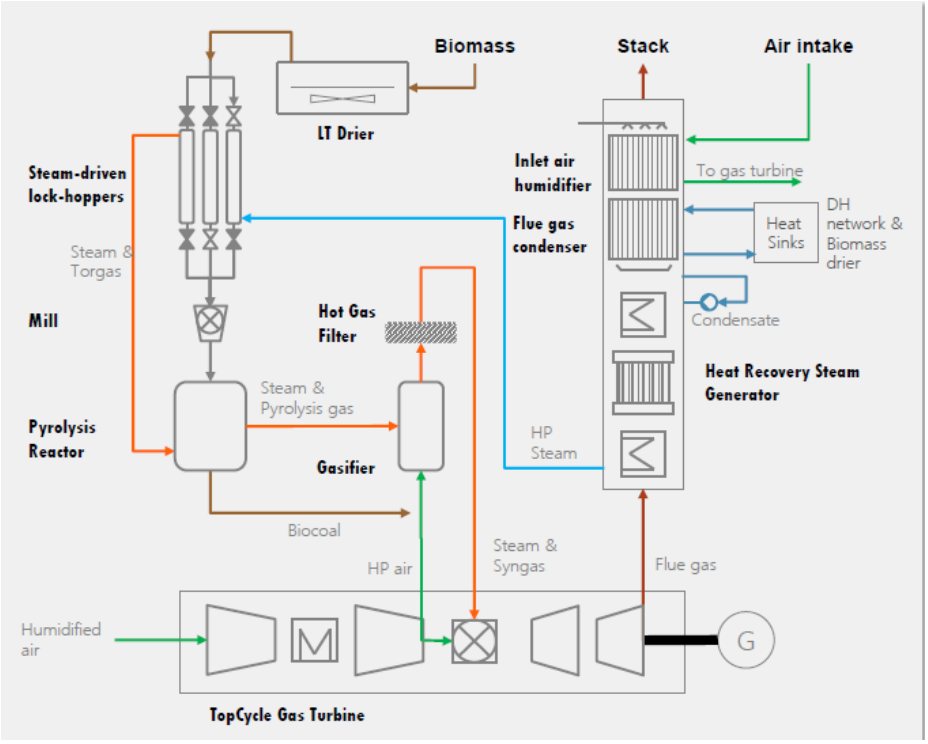

Figure 22. The Phoenix BTC concept

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.

Contact: info@phoenixbiopower.com

BioShare AB

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 to produce fuels. BioShare was recently granted funding from the Swedish Energy Agency for a demonstration project, in which a boiler at the Hedenverket CHP plant will be rebuilt for thermochemical co-production and demonstration of both pyrolysis and gasification. In the project, no end products will however be taken out of the system, but the volatile components will be returned to the boiler. The project will be carried out together with Karlstads Energi and Chalmers.

Contact: info@bioshare.se

ScanArc AB

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 several 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, see Figure 23, 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.

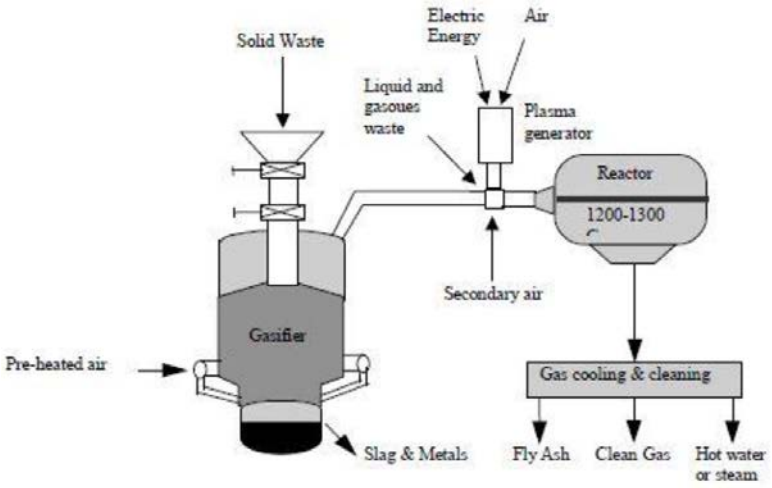

Figure 23. The ScanArc gasification process

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.

Contact: https://scanarc.se/contact/