IEA Bioenergy Task 33
Country Report Sweden 2018

Cover photo: The ATR test unit at KTH

IEA Bioenergy

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Content

Sammanfattning

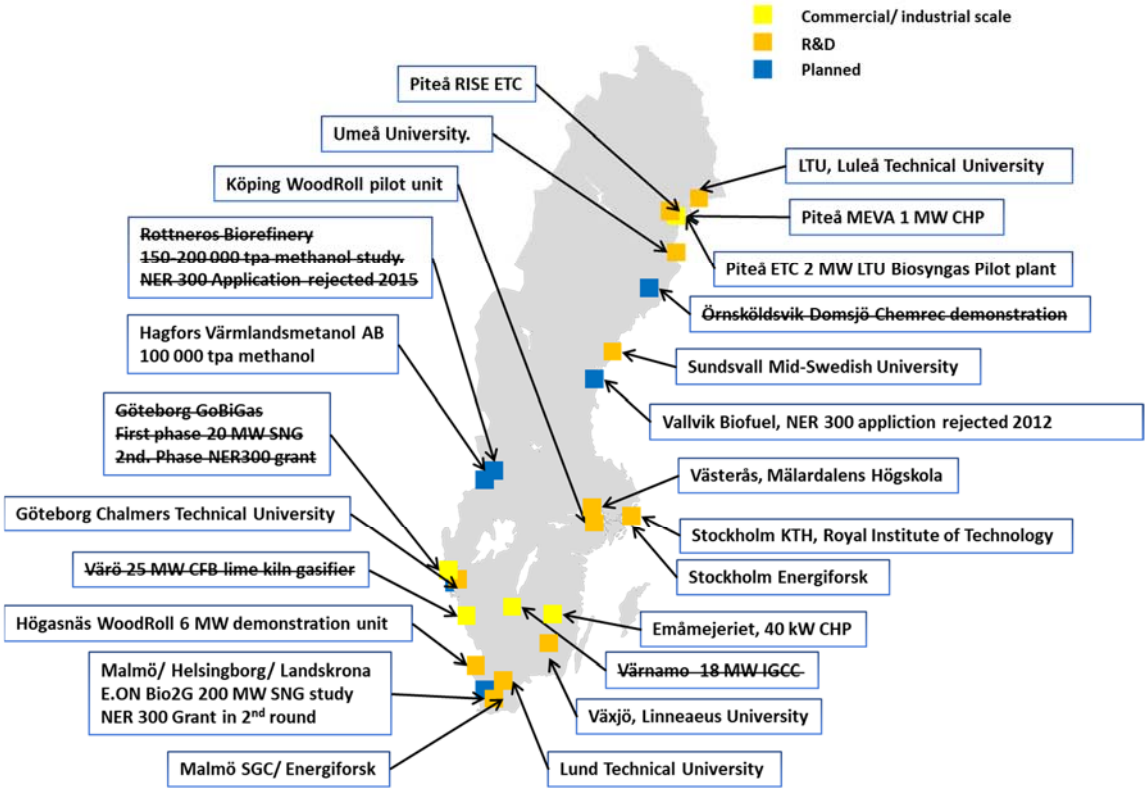
Föreliggande rapport innehåller en sammanfattning av svenska forsknings-, utvecklings- och demonstrationsaktiviteter inom området termisk förgasning av biobränsle under perioden 2016-2018.

Nedanstående kartskiss ger en överblick av olika forsknings- och industriella aktiviteter som pågått under senare år fram till 2018. Den huvudsakliga forksningen sker inom ramen för SFC, Svenskt Förgasningscentrum inom vilket en rad universitet samverkar under ledning av LTU.

Teknik för mindre förgasningsanlanläggningar utcklas av Cortus AB och Meva Energi AB, främst för att producera bränslegas och kraftvärme.

Det finns också en rad projekt som mer eller mindre aktivt planerar för biodrivmedelsanläggninagr, men den enda anläggningen i drift, GoBiGas, stängde 2018.

I rapporten beskrivs dessa aktiviteter närmare.



Summary

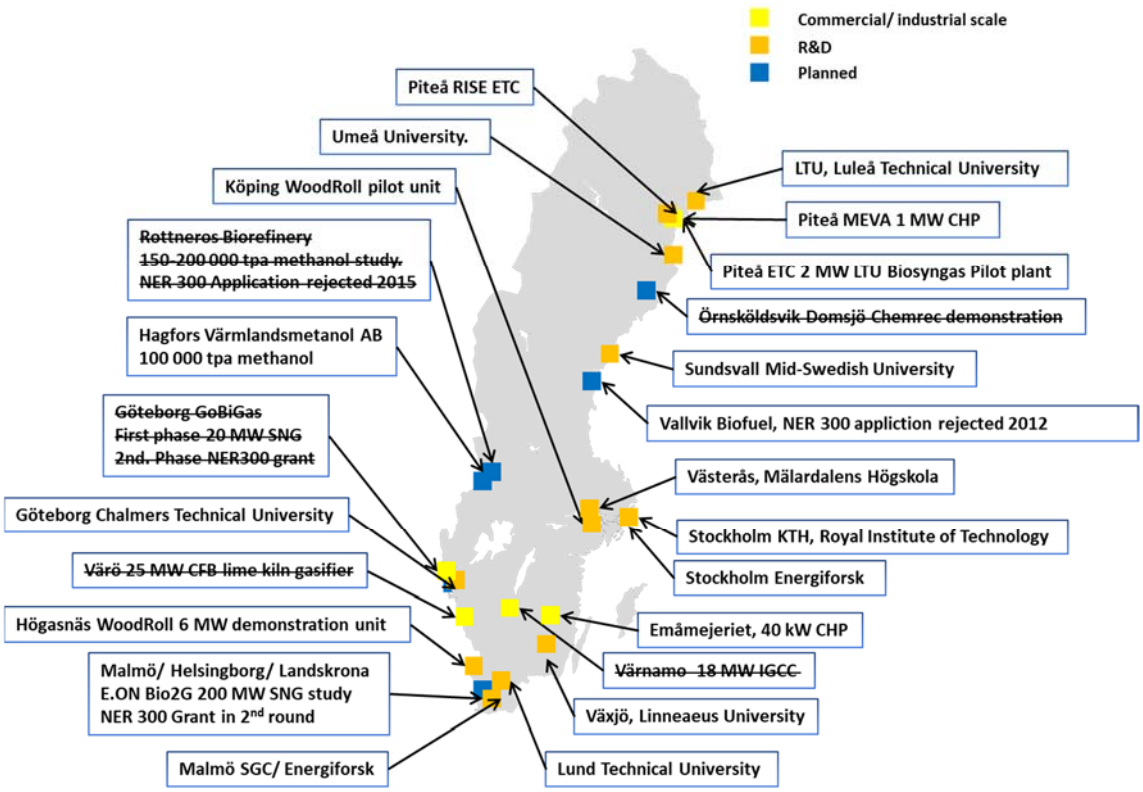
The report covers information on the activities in Sweden in the field of thermal gasification of biomass in 2016-2018.

The map below gives an overview of the current industrial and R&D&D activities in 2018. The main research activities are carried out within the framework of SFC, the Swedish Gasification Centre, in which several universities cooperate under the leadership of the Luleå technical University.

There is also a development of gasification technologies for fuel gas production and small-scale CHP within the companies Cortus AB and Meva Energy AB, respectively.

There are also a number of planned projects for the commercial production of biofuels at various stages, but the only operating plant for this purpose, the GoBiGas plant in Gothenburg, was closed in 2018 for economic reasons.

The report gives more details on these activities and projects.



1. GENERAL OVERVIEW

On-going industrial and academic activities on biomass gasification in recent years indicating the status as of 2018 are summarized in Figure 1.

The projects and research activities highlighted on the map have all been active in the period 2016-2018, i.e. the current IEA Biomass Agreement triennium period. These are described in the report.

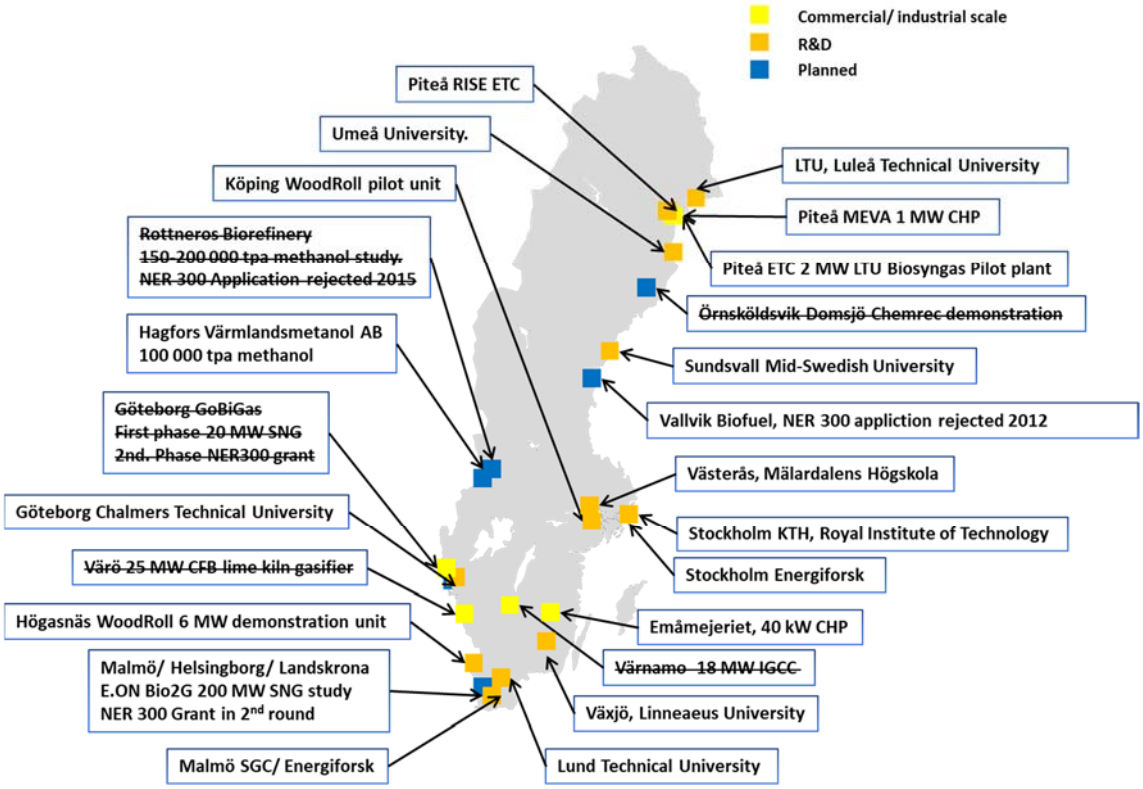


Figure 1 The biomass gasification map of Sweden

There are also some historical activities, indicated where for reference, previous country report.

2. BIOMASS GASIFICATION R&D FUNDING R&D

The main funding agency for R&D and demonstration activities in the biomass gasification area is Energimyndigheten, directly and indirectly. Other financing sources are Energiforsk, f3 and EC R&D programs.

2.1. ENERGIMYNDIGHETEN (www.energimyndighten.se)

The energy R&D is managed by Energimyndigheten (the Swedish Energy Agency). In the past, Swedish activities in the energy R&D field were based on topical programs. The programs were typically operated on a three-year cycle and under the control of a steering committee representing various stakeholders. Since 2012, a re-orientation of the R&D was made, and it is now broadly defined by the parliament by its Energy Research proposition for a four-year period.

In addition, the program has structured the applied research in six broader program or thematic areas;

- Energy system studies.
- The Transport system
- Bioenergy
- Buildings within energy system.
- Energy intense industry.
- Fuel systems targets research in the areas:
- Power generation and the power system
- Industry
- Business development and commercialisation
- International cooperation
- A sustainable society

Each thematic area has several sub-areas with research programs covering different topics. Biomass gasification research and development for both power generation and biofuels is included in the Bioenergy area but with some activities in the Transport thematic areas regarding the use of the end products.

It has up to 2016 supported the LTU-Biosyngas Centre which is now idling, see Section 3.2

It supports the Swedish Gasification Centre, SFC, in its third phase 2017-21 with a third of its total budget of 24 M€, see Section 3.1

The f3 system analysis program, see Section 2.2.2, has also received support for a third phase in 2018-21, the budget provided by the agency is 2.2 MEuro budget and further supplemented by the f3 stakeholders.

There is also a Biofuels program running in 2017-2021 with annual calls for proposals that covers all forms of bio-chemical, chemical and thermochemical conversion technologies with a total budget of 18 M€ from the agency and supplemented by contractor and third-party funding. This program includes some on-going projects involving Chalmers, KTH, LTU and companies like Cortus, see below in the report.

Energimyndigheten also have had a joint program with SGC on “Energetic Gases” and has on-going joint programs on a 50/50 contribution basis with Energiforsk, into which SGC has merged, that can involve gasification-related activities, the “SEBRA” and “Biofuel for Sweden 2030” programs, see Section 2.2.1.

In 2018 a program was initiated, “Sustainable Bio-Fuels in Aviation”, with a budget of 10 MEuro for the period 2018-2020 to be supplemented by project collateral funding. The scope of the program is to support R&D for the development of sustainable aviation fuels and to establish “innovation clusters”, i.e. a stakeholder grouping that covers the entire value chain from feedstock to user-ready fuel, whereby the transition from R&D to implementation can be facilitated. The first call for proposal, where the agency provided 4 MEuro out of the above budget resulted in that eleven projects were awarded, out of which three had a clear gasification-related approach, involving LTU, Cortus and BioShare AB, see Sections 3.2, 5.1.4 and 5.3.3, respectively.

Energimyndigheten is also the agency in charge of the energy-related funding provided to identified “Strategic Areas of Research” of which one is energy-related. The funding is provided to

the universities as direct support to select strong “research environments”. In the context of the gasification R&D, three such programs are related to academia engaged in SFC and used as academic co-lateral financing, see below. The first phase was 2012-2015 meant that the research environment received financing of 5 M€ per year to support the overall activities, including the gasification activities. After an evaluation in 2015, the three research environments below received financing at the same level, or in some cases more, for the period of 2016-2020.

Bio4Energy (bio4energy.se)
(Umeå University / Luleå Technical University / SLU Swedish Agricultural University)

- Biorefining of woody biomass.

Chalmers Energy Initiative (www.chalmers.se)
(Chalmers Technical University, SP Technical Research Institute of Sweden, Inventia).

- Energy Combinates, electricity propulsion systems and hybrid vehicles, large-scale renewable electricity generation and grid integration, technology impact assessment. Since 2016, the activity has been integrated into “Energy in a Circular Economy “ platform at Chalmers.

STandUP (www.standupforenergy.se)
(Uppsala University / Luleå Technical University / SLU Swedish Agricultural University, KTH, Royal Institute of Technology).

- Mainly electrical grid and vehicle technology, but also RE power generation.

Energimyndigheten also supports demonstration projects via a separate budget. The phase 1 of the GoBiGas project received 222 MSEK (22MEuro) in funding in 2009, and also the Domsjö project was eligible for 500 MSEK (50 MEuro) in funding had the project come to a final investment decision.

2.2. OTHER GASIFICATION-RELATED FUNDING ORGANIZATIONS

2.2.1. Energiforsk *fka* SGC (www.energiforsk.se)

Svenskt Gastekniskt Centrum, SGC (Swedish Gas Centre) was in the beginning of 2015 merged with Värmeforsk (Thermal Engineering Research Foundation) and Elforsk (Power Utility Research Organization merged to Energiforsk. Energiforsk is a non-profit company owned by industrial associations representing the stakeholders in the power, gas and heat utility sectors in Sweden.

The former SGC part of Energiforsk follows R&D on energy gases, mainly on natural gas and biogas, but also in recent years increasingly in the field of thermal gasification of biomass. This is coordinated by means of the program “Energetic gas technologies”. This program had a budget of 8 MEuro for the period 2013-2017 of which 60 % came from Energimyndigheten and 40 % from the industrial stakeholders in SGC. SGC was also known for organising the “International Gasification Seminar” annually since 2007 with the last seminars held in Gothenburg in 2013 and in Malmö in 2014 and in 2016. The “Energetic gas technologies” program was concluded in 2017 and has not been supplemented with any program with strong gasification relevance.

Nevertheless, there are two programs funded on a 50/50 basis by Energiforsk and Energimyndigheten with some gasification-related content within the framework of Energiforsk.

The “SEBRA” program is running in its second phase 2016-19 and relates to R&D applied on CHP systems and has a budget of 6 MEuro. The program activities mostly cover conventional CHP

installations for waste and biomass operated by utilities and industry but have had a few gasification-related activities in the first phase 2012-2016.

Biofuel for Sweden 2030 is an on-going program in 2017-2020 with a total budget 0.6 M€ relating to the production of biofuels and covers activities on feedstock, production, energy efficiency, societal impacts of domestic production of biofuels, and allocation of biofuels to different transport sectors.

2.2.2. Swedish Knowledge Centre for Renewable Transportation Fuels f3

(www.f3centre.se)

The Swedish Knowledge Centre for Renewable Transportation Fuels (f3) was established as a nationwide knowledge platform for cooperation and research related to systems aspects of the entire renewable fuels value chain. The mission of f3 is to contribute with scientifically-founded decision support for policy makers, government, industry and other organizations, on environmentally, economically, and socially sustainable renewable transportation fuels, f3 engages in five different project areas relating to the entire value chain, see Figure 2:

- Comprehensive technological, economic and/or environmental system studies
- Stakeholder, policy and strategy studies
- Comparative system studies of alternative process chains
- Studies on process integration and efficiency improvement potentials
- Syntheses of current knowledge status for specific areas or surrounding conditions of the value chain

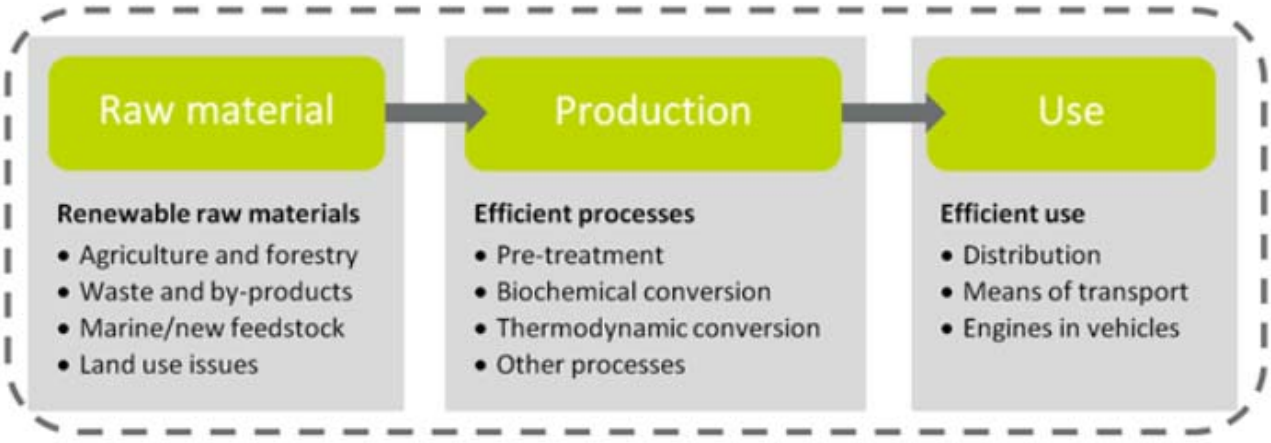


Figure 2 The f3 definition of the value chain being studied

F3 is composed of 16 partners representing both academia, institutes, regional bodies as well as various industries engaged in fuel production, vehicle manufacturers and transports.

For 2014-17, f3 had a total budget of 6.5 MEuro, of which a part was a joint program of 4.4 MEuro, “Renewable transport fuels and systems”, of which 50 % is provided by Energimyndigheten under the thematic area Transports and the remaining part from the partners.

A new program phase, 2018-2021 was initiated in 2018. The overall gross budget planned is 4.4 MEuro for the project activities, of which 2.2 MEuro is provided by Energimyndigheten and supplemented by the f3 partners to a total of 3.3 M€ and a 25 % share of collateral funding from the project participants or from third parties.

In addition to the main objectives, f3 also receives funding from Vinnova (Sweden's innovation agency) as a Swedish advocacy platform towards Horizon 2020.

The activities of f3 does not include gasification per se, but gasification is included as a system element as one conversion pathway from biomass to biofuel. Nevertheless, funding has been provided for e.g. systems and feasibility studies of the use of gasification of black liquor and other feedstocks gasification to produce biofuels and on gas cleaning technologies from a system perspective, etc.

2.2.3. EU funding programs

NER300 (ec.europa.eu/clima/policies/lowcarbon/ner300_en)
NER 300 is so called because it is funded from the sale of 300 million emission allowances from the New Entrants' Reserve (NER) set up for the third phase of the EU emissions trading system (EU ETS). The aim of NER 300 was to establish a demonstration programme to support the best possible CCS (pre-combustion, post-combustion, oxyfuel, and industrial applications) and RES (bioenergy, concentrated solar power, photovoltaics, geothermal, wind, ocean, hydropower, and smart grids) projects and involving all Member States. In two calls in 2012 and 2014, 39 projects in total were selected and receiving support amounting to 2.1 billion Euro. However, this far only 6 projects are operational or in construction due to changing boundary conditions such as e.g. energy prices in general and other circumstances, such that support funding was only payable once the plant was operated and hence not assisting in de-risking the design and construction phase cash flow. Both the GoBiGas project, see Section 5.1.2, and E.ONs Bio2G project, see Section 5.2.1, received grants.

Surplus funds from the first call has now been transferred to the EIB InnovFin Energy Demonstration program, while the surplus from phase 2will be transferred to the ETS Investment Fund that will replace the NER 300 program after 2020.

Horizon 2020 (ec.europa.eu/programmes/horizon2020/en/)
Horizon 2020 is the biggest EU Research and Innovation programme ever with nearly 80 billion Euro of funding available over 7 years (2014 to 2020. It has calls of relevance for biomass gasification in the areas of production of renewable electric power and advanced biofuels, respectively. The Sustainable energy part of the H2020 program, which is managed by DG Research and Innovation has 5.9 billion Euro in its budget.

Although there have been applications by various Swedish R&D performers and entities, these have not met with success, and there is no on-going H2020 project in the biomass gasification area with Swedish participants.

However, Cortus, see Section 5.1.4, was awarded a Seal of Excellence (SoE) based on an application to the H2020 SME (small and Medium Size Enterprises) Instrument. The SoE is a sort of consolation for applicants who met the stringent evaluation criteria to be eligible for funding but fell outside the overall budgetary limitations. The SoE is also an entry to EU regional funding and other funding programs.

BRISK-Biofuels Research Infrastructure for Sharing Knowledge (www.brisk2eu.com**)**
BRISK-Biofuels Research Infrastructure for Sharing Knowledge aims to develop a European research infrastructure for thermochemical biomass conversion and to support R&D on innovative processes to convert sustainable feedstocks into liquid, gaseous or solid fuels. The specific aim of

BRISK is to overcome fragmentation in R&D facilities for thermochemical technologies, by enabling researchers to have access to high-level experimental facilities and services across Europe. The BRISK network will encourage and facilitate cooperative research in the specialized laboratories of project partners. One feature of the BRISK project is that the experimental facilities are open to researchers outside the project via a Transnational Access modality. Joint Research Activities are designed to improve the services offered by BRISK participant's infrastructure. Topics like fuel characterization, improved measurement methods, and enhanced catalytic conversion processes are intimately linked to these facilities. As a third item, networking activities are a part of the project in order to promote research infrastructures in thermochemical conversion. This is accomplished e.g. by so-called TOTeM's – Topic Oriented Technical Meetings.

BRISK (www.briskeu.com) was an € 11M four-year initiative operative in 2011-2015 with € 9M funded under EC coordinated by KTH Stockholm, and also includes ETC at Piteå as well as partners from Austria, Denmark, Finland, Germany, Greece, Italy, Netherlands, Norway, Poland, Spain, Sweden, Switzerland, Turkey and the UK.

A second phase, Brisk 2, was initiated in 2017 and to 2022 with more or less ta similar scope as Brisk 1, and with an EC contribution of 9.9 MEuro.

ERA-NET (www.eranetbioenergy.net)
As part of FP6, the EC launched a new form of cooperation for coordination activities. To decrease the fragmentation of research funding allocated by the member states themselves, the EC supported coordination activities carried out by national research funding agencies in the member states through joint programs and calls for proposals.

ERA-NET Bioenergy brings together national ministries and funding agencies that support bioenergy R&D. The participants can coordinate national research efforts and thus achieve higher quality results, as well as a more efficient use of their limited financial resources. Via joint calls, innovative, transnational research, development and innovation (R&D&I) projects on Technology Readiness Levels (TRL) 2-5 are funded via joint calls. As of 2014, this program has been changed to be completely funded by the participating member states.

Currently there are eight ERA-NET Bioenergy partners: Austria, Germany, the Netherlands, Poland, Sweden (represented by the Energy Agency), Switzerland and the United Kingdom. There are also nine observers. ERA-NET Bioenergy has so far implemented 12 joint calls and resulting in 52 international R&D projects.

The BESTF (Bioenergy Sustaining the Future) network of national/regional ministries and funding agencies from Denmark, Finland, Germany, Spain, Portugal, Sweden (represented by the Energy Agency), Switzerland and the United Kingdom) exists since 2012 and provides funding to collaborative bioenergy projects that will result in demonstration at a pre-commercial stage (TRL 6-8). So far, the BESTF network has launched three calls and supported eight demonstration projects.

In order to widen the scope of the BESTF joint Calls to support initiatives at Technology Readiness Levels 2-8, a cooperation with ERA-NET Bioenergy was set up via BESTF3. The combined ERA-NETs and networks provide added value compared to national funding, bringing a greater opportunity for coordination and knowledge sharing. It is envisaged that, with the joined forces of BESTF and ERA-NET Bioenergy, there will be four calls under the duration of BESTF3 (2016 2020).

There have been two projects funded that are in the gasification field and have Swedish participation:

- BioProGReSs, Biomass Product Gas Reforming Solutions. BESTF3, October 2014-December 2017. The project was strongly linked to activities relating to the GoBiGas project, see Section 5.1.2, and hence was coordinated by Göteborg Energi AB and also involving Chalmers, Section 4.1, and Renewable Energy Technology International AB and Technische Universität Berlin
- BIO-CCHP - Advanced biomass CCHP based on gasification, SOFC and cooling machines. ERA_NET Bioenergy, 2018-2020. Coordinated by Graz University of Technology and also involving a number of gasification technology providers, Including Cortus AB, see Section 5.1.4.

LIFE (ec.europa.eu/environment/life/about/)
The LIFE programme is the EU's funding instrument for the environment and climate action. The general objective of LIFE is to contribute to the implementation, updating and development of EU environmental and climate policy and legislation by co-financing projects with European added value.

The European Commission (DG Environment and DG Climate Action) manages the LIFE programme. The Commission has delegated the implementation of many components of the LIFE programme to the Executive Agency for Small and Medium-sized Enterprises (EASME). External selection, monitoring and communication teams provide assistance to the Commission and EASME. LIFE began in 1992 and to date there have been four complete phases of the programme (LIFE I, II and III as well as LIFE+) that have co-financed some 3954 projects across the EU, contributing approximately €3.1 billion to the protection of the environment.

The LIFE work programme for 2014-2017 had a budget for funding projects of 1.1 billion Euro and 0.36 billion Euro under the subprograms for Environment (87 topics) and Climate Action, respectively. The LIFE multiannual work programme for 2018-2020 has a budget of 1.2 billion Euro and 0.41 billion Euro for work on nature conservation and environmental protection (42 topics) and for climate action, respectively.

With regard to LIFE projects in the period involving gasification, the project Biogasxpose focusing on bio-methane production involves Cortus. see Section 5.1.4.

KIC InnoEnergy (www.innoenergy.com)
KIC InnoEnergy, a company incorporated under EU law, combines research with education and innovation in order to accelerate technology transfer and create a sustainable energy system for Europe. KIC InnoEnergy (Knowledge & Innovation Community) is composed of 35 European partners from companies, universities, research institutions, and business schools. It is funded by the EU via the European Institute of Innovation and Technology. InnoEnergy work in three essential areas of the innovation chain:

- Education and capacity building to develop the workforce to demands of sustainability and the needs of industry.
- Innovation Projects to bring together ideas, inventors and industry to create commercially attractive technologies.
- Business Creation Services to support entrepreneurs and start-ups with innovative offerings in the energy ecosystem.

KIC Innoenergy are involved in Swedish gasification activities via Innovation Projects involving Cortus Energy, Section 5.1.4, and MEVA, Section 5.1.5 and via Business Creation Services as a financier and stakeholder in Phoenix Biopower, see Section 5.3.1

3. Gasification research programs

3.1. SFC, SWEDISH GASIFICATION CENTRE

(www.ltu.se/centres/Svenskt-forgasningscentrum-SFC)

The Swedish Gasification Centre was formed in 2011 as an academic research organization (Centre of Excellence). The formation of the centre was a way of overcoming fragmentation of the research and to closely connect the research to industrial needs. The initial budget was approximately 6 million Euros for a two-year start-up period during 2011-2012, followed by an annual budget of 6 million Euros/year for the second phase 2013-2017 and third phase 2018-2021, respectively, and a possible follow-up if favourably evaluated.

In total, 19 companies, 8 universities and 1 research institute are engaged. The funding is provided in equal shares by the Swedish Energy Agency as part of the Bioenergy thematic area, industrial partners and the universities engaged. There are 25-30 senior researchers engaged. In addition, the centre organizes the research work and supervision of 30-35 PhD students.

The organization of the centre is depicted 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) at Luleå University of Technology, indirect gasification at Chalmers (CIGB Centre of Indirect gasification of Biomass) and gas cleaning at KTH Royal Institute of Technology (Cleansyngas). For governance reasons, the structure was changed from a coordinated activity in the first phase to a structure where the nodes, including their industrial partners, have autonomous responsibility within the framework agreement, and where the steering group and advisory board is responsible for defined joint activities and general supervision that the framework procedures are followed.

Even if the nodes are autonomous and follow the activity plan agreed with its industrial partners via node steering groups, there are a number of horizontal activities. These include the annual program conference, summer schools for the students engaged in the node activities, 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 institutes involved are RISE, the Research Institutes of Sweden (RISE ETC and RISE Bioeconomy). Industries include power and energy companies such as E.ON, Fortum, Göteborg Energi and Pite Energi, bioenergy companies such as Bioenergigruppen I Växjö, Hulteberg Chemistry and Engineering, other industrial companies such as Akademiska Hus, Centriair, Tenmat, Stena Recycling and Verdent Chemical Technologies as well as gasifier developers such as Boson Energy, Cortus, MEVA, Phoenix Biopower, Scanarc and Valmet, etc.

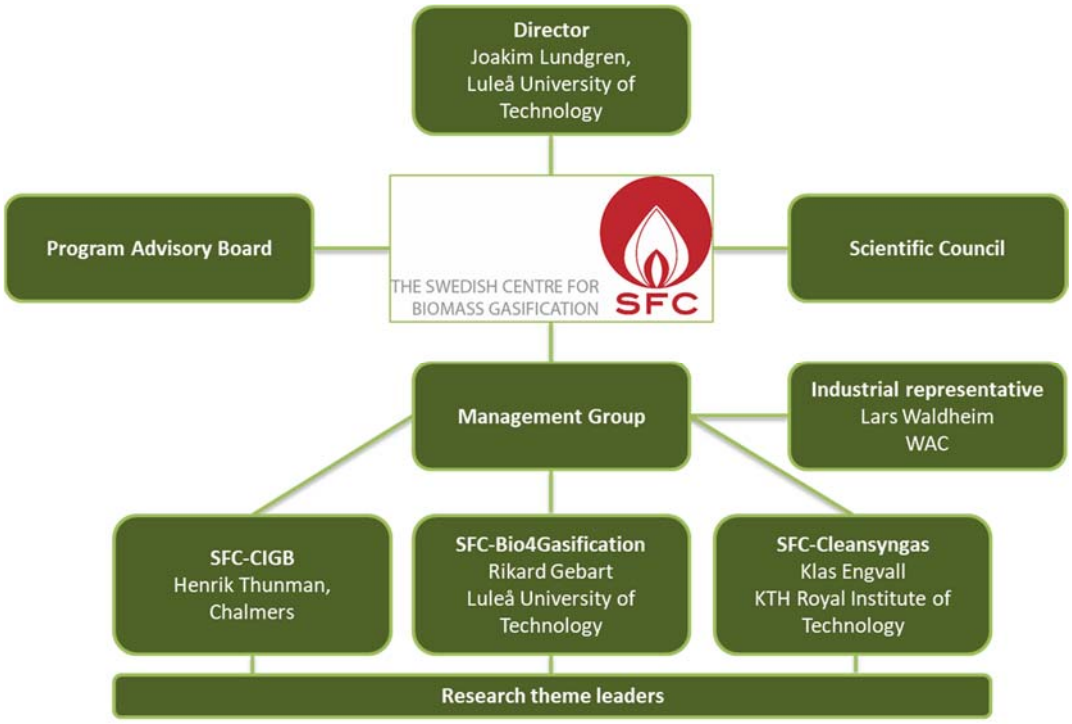


Figure 3 Organization of SFC in Phase 3, 2017-2021

The technical program is presented in Figure 4.

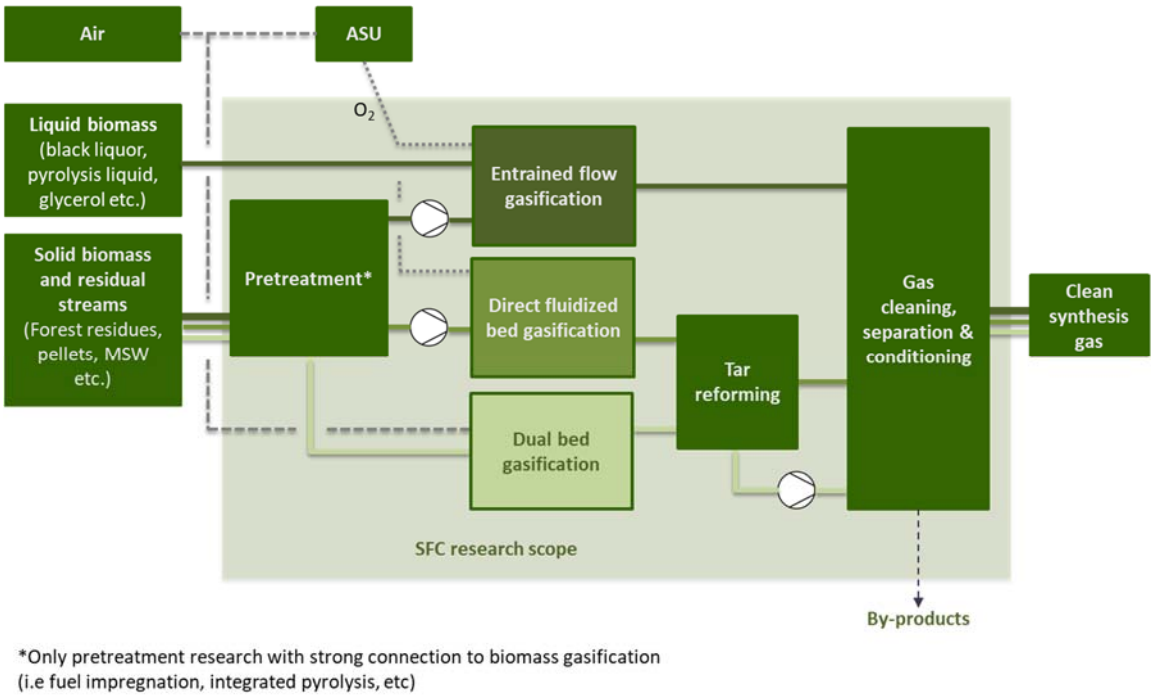


Figure 4 The technical structure of SFC

The delimitations of the program activities are shown as the shaded area, i.e. the centre focuses

on the gasification and 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 centre focuses on the gasification and 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 technical activities and resources of the universities involved are further described for each university in Section 4.

3.2. LTU BIOSYNGAS CENTRE (www.ltu.se/org/tvm/Avdelningar/LTU-Green-Fuels)

As a consequence of the decision by Domsjö to not go ahead with the black liquor gasification demonstration project and when the Bio-DME project ended in 2013, Chemrec could no longer finance the activities in its pilot plant, a 3 MW_{th} black liquor gasifier constructed by the company, and in the 4 ton per day Bio-DME/Bio-Methanol facility constructed as part of the FP7 Bio-DME project. Figure 5. Shows the plant which is co-located with RISE ETC, which is described in more detail in Section 5.1.3, adjacent to the Smurfit Kappa mill in Piteå.

To avoid that the infrastructure was demolished, and in order to secure a continued use of the pilot plant infrastructure and the various developments on gasification, gas cleaning and chemical syntheses in the pilot plant, and also to allow production of a fuel quality DME for vehicle fleet tests performed by Volvo, a research program was initiated under the name LTU Biosyngas Centre. LTU took the role as a principal and coordinator for this research program and also bought the physical assets of the pilot plant and access to the embedded IPR.

LTU Biosyngas Center is an open research centre with an ambition to have academic and industrial partners to use the facility for research at pilot scale or in side-streams. The goal is to gradually build a project portfolio to be less dependent on Swedish national funding.

Figure 5 The Chemrec/LTU Green Fuels plant (foreground), the Smurfit Kappa mill, Piteå

The LTU Green Fuels process and some operating data is shown in Figure 6.

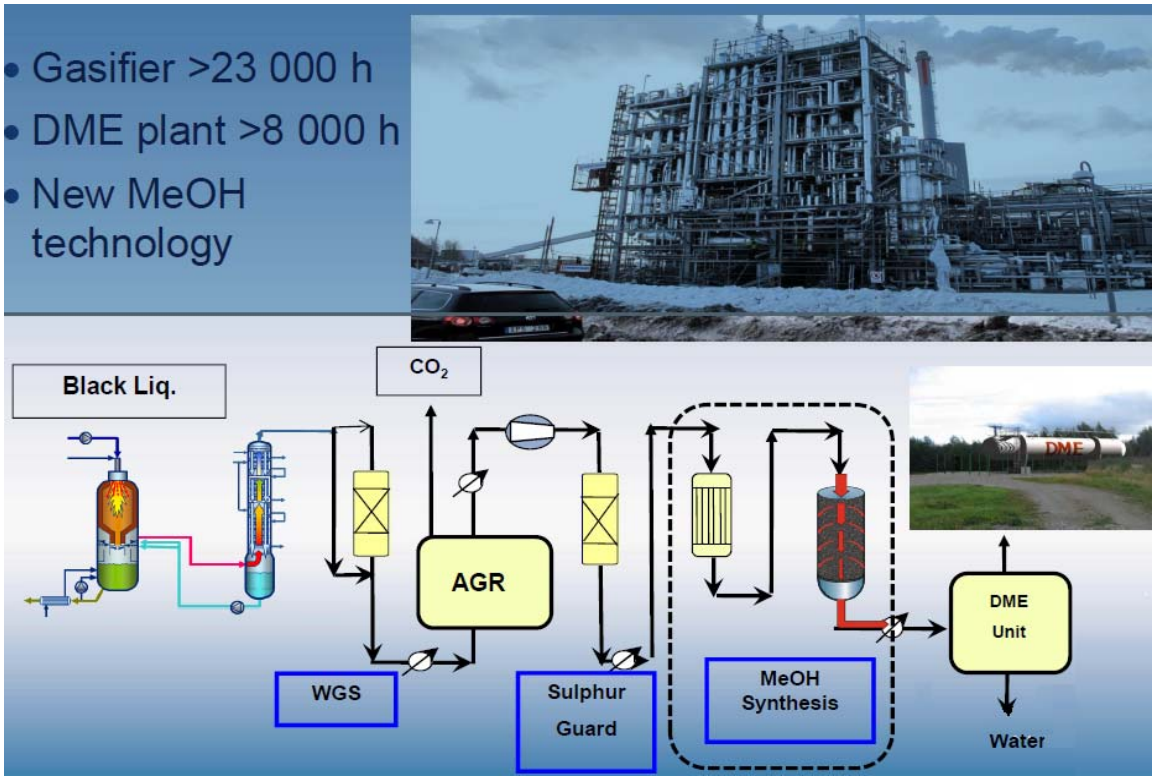


Figure 6 LTU GreenFuels plant process and data

The total budget for the program was 16 MEuro for the period December 2013 - May 2016. The Swedish Energy Agency contributed 11 MEuro, of SEK 2.5 million and the initial 14 research partners the Norrbotten County Board provided the balance of funding. The partners include Chemrec, Haldor Topsøe, Smurfit Kappa, Sveaskog, Holmen, Södra, Biogreen, Volvo, Preem, Flogas, Perstorp, ETC, Aga and LTU Green Fuels. Figure 6 describes the LTU Green Fuels and some data on the accumulated operating hours.

The theme of the research up to 2016 was to broaden the raw material base, to improve the efficiency of sub-processes and to reduce production costs. The subprojects involved the gasification of pyrolysis oil and wood powder, gas purification, catalytic conversion of synthesis gas, materials for hot alkaline environments and field trials with the products from the plant, Bio-DME as a diesel fuel and substitute for LPG as well as the use of bio-methanol for chemical and fuel purposes. The DME produced has been used for vehicle fleet test by Volvo trucks. Some 800 tons of DME have been produced and Volvo have accumulated some 1 400 000 km in these fleet tests.

This program was successfully concluded in 2016. Following its conclusion, attempts to secure additional projects via e.g. H2020 funding has been pursued but this far have not been successful.

4. R&D Institutes and Centers

4.1. CHALMERS TECHNICAL UNIVERSITY (www.chalmers.se)

Chalmers has a long history and tradition in CFB combustion systems. 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 and recirculating char and cold sand back from this unit. As a result, a 2-4 MW_{th} gasifier unit, connected to Chalmers 12 MW_{th} CFB heating boiler, was constructed and started-up in 2008, Figure 7. The unit was funded by STEM and the Göteborg Energi Research Foundation and is an R&D support to the Göteborg Energi GoBiGas project, Section 5.1.2. Some of the activities of Chalmers in conjunction to the GoBiGas project are described under this heading.

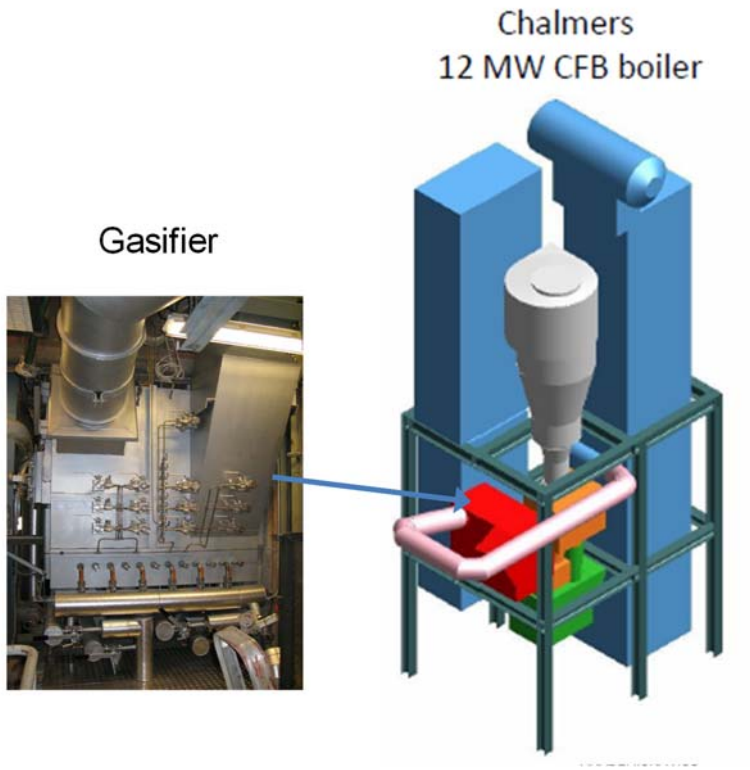


Figure 7 The Chalmers 4 MW gasifier connected to the 12 MW CFB boiler

From a relatively small start, the activities have expanded such that now over twenty researchers are directly engaged. The gasifier 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. 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 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.

Gas cleaning is also being addressed as a line of research. A chemical looping reactor is being developed as a means of reducing the tar content of the gas, Figure 8. Using a mixture of ilmenite (FeTiO3) and silica sand, tar reduction of over 50 % has been achieved. The use of activated carbon for removal of BTX in the synthesis gas and the potential recovery of BTX as a product has been studied.

The optimisation of and scale-up of the GoBiGas system, including estimates of CAPEX and OPEX for such second-generation systems have been a topic of another project.

The main financing has been through the SFC program and Göteborg Energi but funding has also been obtained from the Biofuels program and BESTF3.

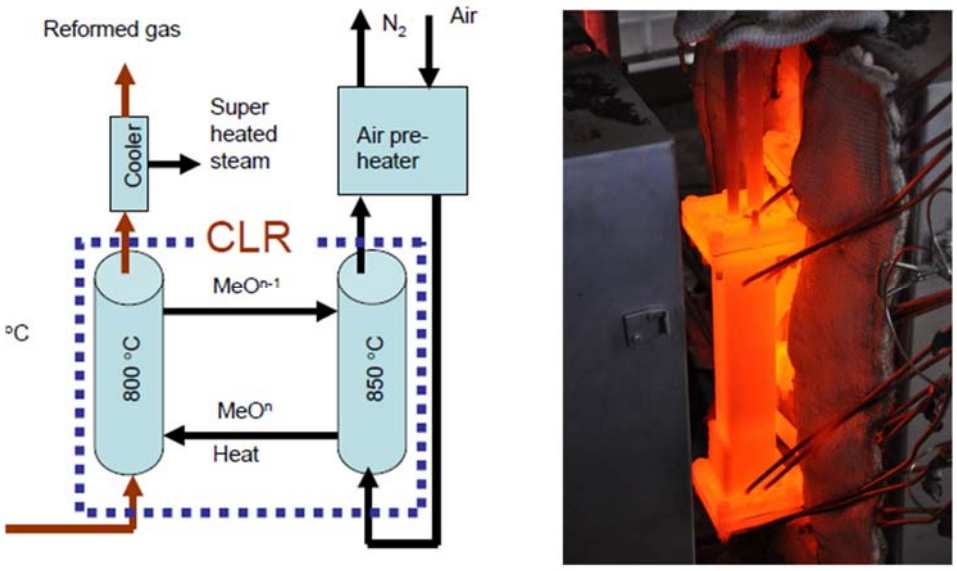


Figure 8 The Chemical Looping reformer system

Chalmers have also in the past had activities in the area of 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. It is also the coordinator for the f3-center for biofuel-related system studies, See Section 2.2.2.

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 issues encountered[1]. Chalmers is also a partner in the BioProGReSs project, see xxx. The importance of the support from Chalmers has also been also been widely acknowledged by the plant owner Göteborg Energi AB.

Following the closure of the GoBIGas plant in 2018, Chalmers is reorienting its research towards the gasification of waste materials.

4.2. GÖTEBORGS UNIVERSITET (GU) (www.gu.se)

The activities of the Gothenburg University within the SFC program relates to inorganic chemistry, particles and measurements techniques. Extensive work on measurement techniques has been 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.

4.3. KTH (ROYAL INSTITUTE OF TECHNOLOGY) (www.kth.se)

Gasification activities 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.

Division of Process Technology
The Division of Process Technology of the School of Engineering Sciences in Chemistry, Biotechnology and Health at KTH 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 issues 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 Carbona to use this technology commercially.

In the third phase of SFC, since 2018, 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 also 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

[1] GoBiGas demonstration –a vital step for a large-scale transition from fossil fuels to advanced biofuels and electrofuels. Chalmers 2018.

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 and neutral compounds in the tar has been developed. Finally, there is a development of on-line techniques for tar measurements based on photo-ionization, 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 150 kW_{th} and being connected to a downstream filter and an electrically heated reformer, Figure 9. 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.

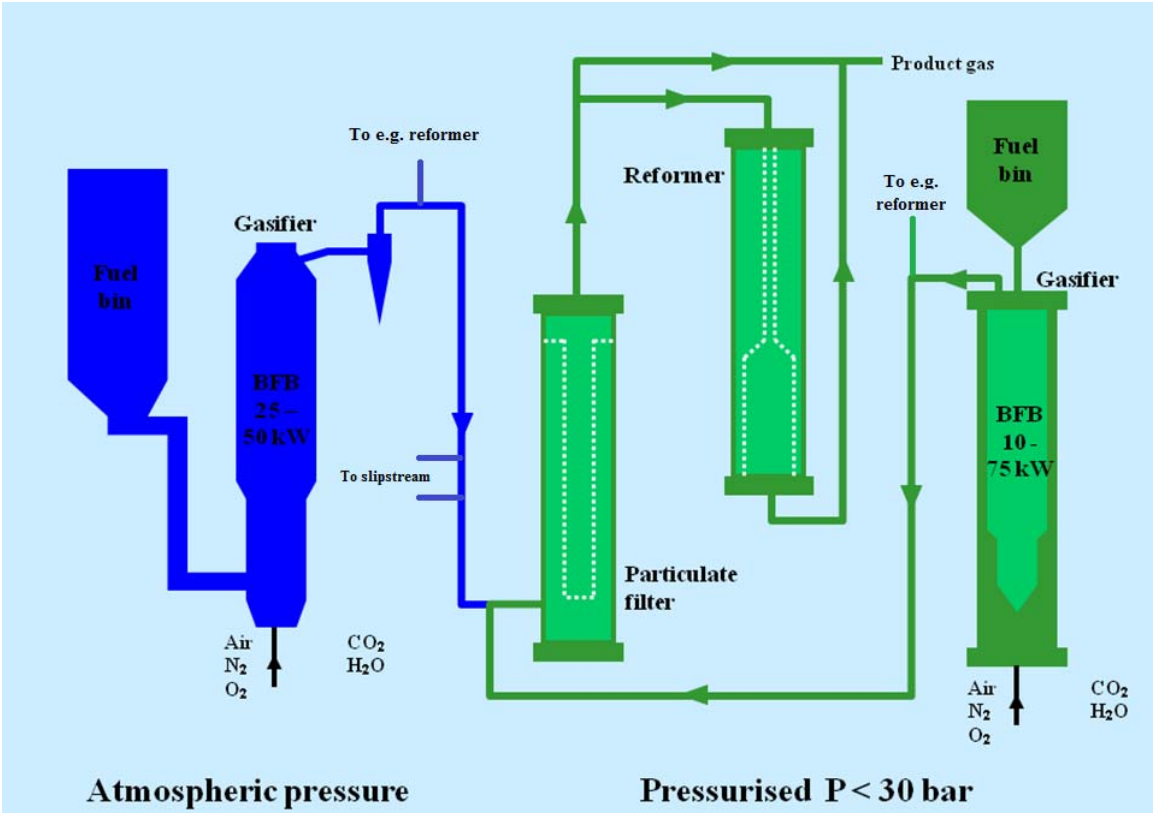


Figure 9 KTH's atmospheric and pressurized fluid beds, 150 kW_{th} with gas cleaning

There is also an isothermal fluidized bed, 50 kW_{th} equipped with a filter and reformer in series shown in Figure 10.

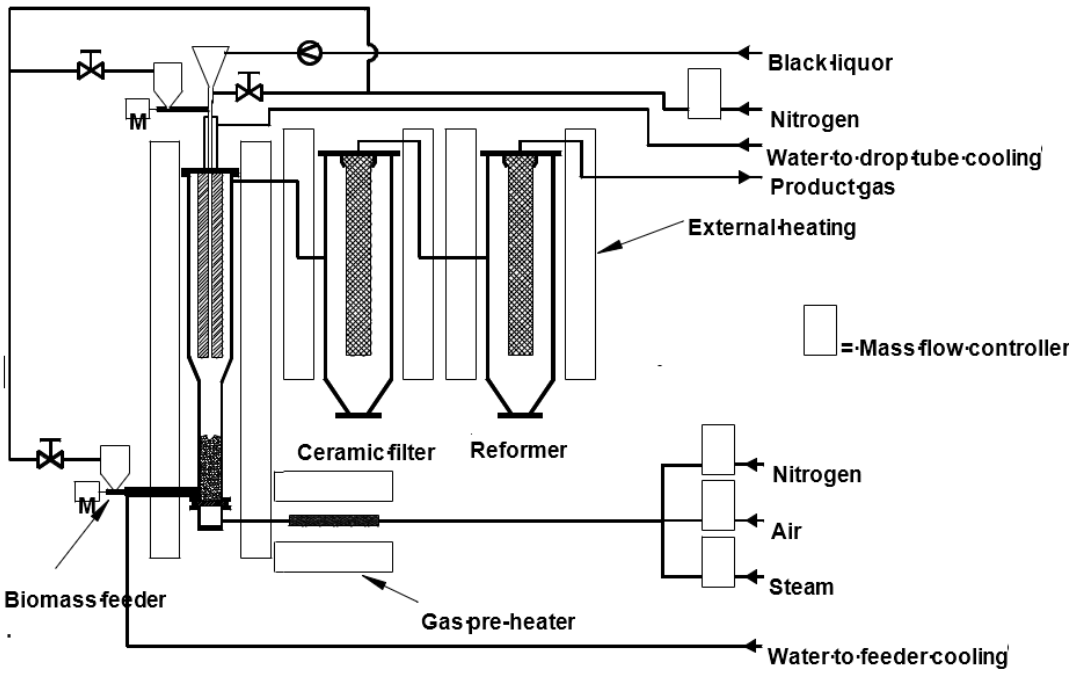


Figure 10 Isothermal fluidized bed reactor, 50 kW_{th}

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 dolomite bed materials on the basis of relatively simple laboratory scale tests and characterisation. Also, ilmenite (iron titanate) bed material has been investigated.

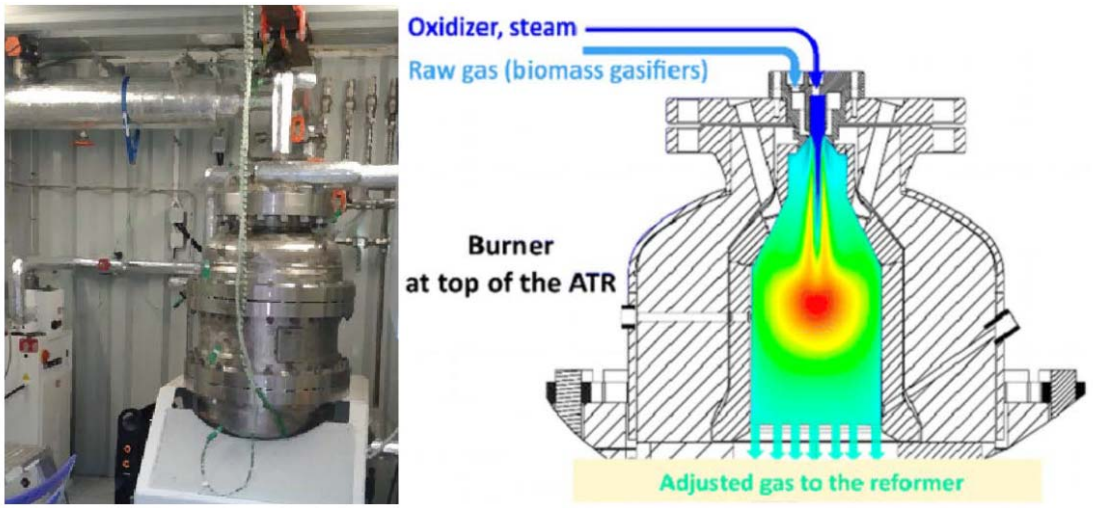


Figure 11 The ATR unit (left), a schematic cross-section of the POX burner (right).

In late 2014, a new mobile pressurized ATR reformer (30 bar, 10 Nm^3/hr) was constructed, Figure 11. The new reformer differs from the older one by the use of 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.

Activities in the phase II of the SFC program on gas cleaning were focused on bed materials and catalytic cleaning from tar using mainly nickel catalysts. Extensive studies of the impact of contaminants such as alkali and sulphur on the catalyst activity have been made in cooperation with Haldor Topsøe and Carbona. Via cooperation with universities in Poland and Canada work on such fundamental topics continues but will also include development of new, non-nickel catalysts for tar removal.

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

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

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.

On a more theoretical level, the department of Energy and Furnace Technology is studying the chemistry of alkali in a gasification environment covering both gas phase and interactions with other solids. This work is in cooperation with Umeå University within the SFC framework and is related to the pressurized gasification and gas cleaning systems as developed by Carbona.

The same department has studied high temperature regenerative pre-heaters for furnaces for a number of 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.

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4.4. LINNÆUS UNIVERSITY (LNU) (www.lnu.se)

Linnæus University (LNU) was formed as a result 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.

It is a participant in the CleanSyngas node of SFC, the Swedish Gasification Centre. 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 important issues.

4.5. LULEÅ TECHNICAL UNIVERSITY OF TECHNOLOGY (LTU) (www.ltu.se)

Formally, LTU is the coordinator of the Swedish Gasification Centre, see Section 3.1, and was also coordinating the LTU Biosyngas program, see Section 3.2 including the ownership of the LTU Green Fuels Plant.

Within gasification R&D, Luleå University of Technology (LTU) also has strong links to Umeå University (UmU), see Section 4.10 and to RISE ETC (see Section 4.9) and collaborates with ETC on some black liquor gasification activities.

The activities at LTU within the SFC Bio4Gasification node are focused on entrained flow biomass gasification, are focused on 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 characterises 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 course of the reaction. Also, the kinetic impact of inorganic gasification catalysts (alkalis) and inhibitors (Si, Al) is studied. In cooperation with UmU, validation experiments are made by LTU regarding the theoretical modelling of the inorganic chemistry made at UmU

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 is 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. However, the technology was bought and is further developed by MEVA Innovation AB, see Section xxx.

In addition, and outside SFC, projects relating to gas cleaning and upgrading R&D and on system analysis are performed within the f3, Biofuels, and Sustainable Bio-Fuels for Aviation programs. System analysis projects focuses on the impact on techno-economic assessments and integration of gasification technologies in industry, in particular in paper and pulp industry via black liquor gasification but also in sawmill, mining and steel industries.

4.6. LUND UNIVERSITY (LTH) (www.lth.se)

Gasification research started at the Department of Chemical Engineering II, 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 have been restarted. Within the SFC framework, researchers at Lund are engaged on work on particulate measurements and characterization in cooperation with in particular GU, RISE and LNU.

4.7. MITTUNIVERSITETET MIUN (www.miun.se)

Within the Department of Natural Sciences, Engineering and Mathematics at MittUniversitetet (Mid-Swedish University), the research organization Fiber 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 Energimyndigheten, 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.

Figure 12 The MiUN 150 kW gasifier

In 2017 MiUN and local partners initiated a project with a budget of 0.9 MEuro, of which 50 % is from the EC Regional Fund, aiming to increase the production of bio-methane for use as transport fuel. The project includes 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.

4.8. MÄLARDALENS HÖGSKOLA (www.mdh.se)

School of Sustainable Development of Society and Technology program at Mälardalens Högskola, 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.

4.9. RISE ETC (www.sp.se/en/units/risebio/etc/Sidor/default.aspx)

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 Energy Technology Center 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 have amalgated into 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.

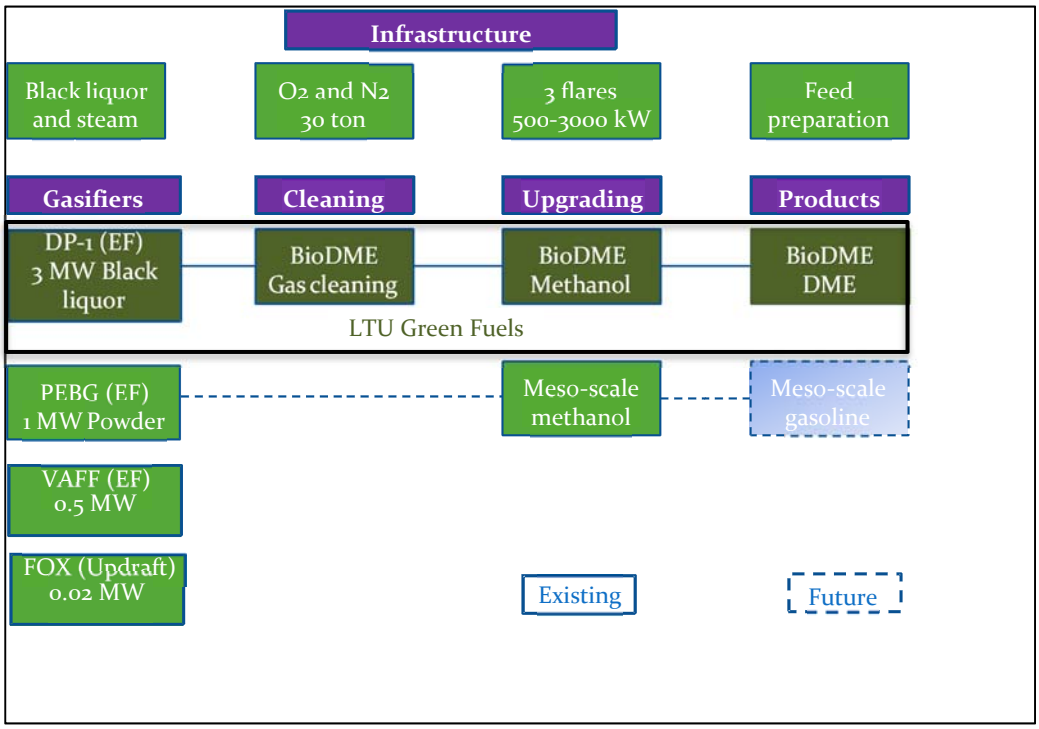

Figure 13 The gasification facilities at the RISE ETC site in Piteå

In the gasification area, 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. The DP1 unit is described further in conjunction with the description of LTU Biosyngas activities, see Sections 3.2 and 5.1.3.

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 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, see Section 5.1.5. In 2017, following start of operation in the Hortlax plant, this plant was dismantled.

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.

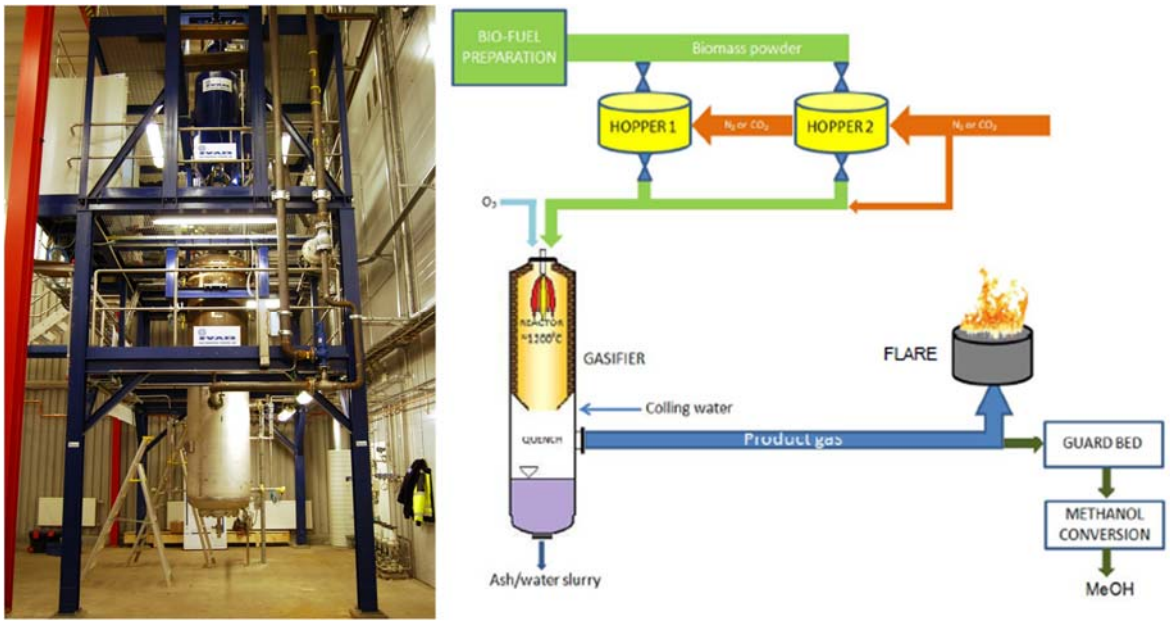

Figure 14 The 1 MW PEBG unit

The PEBG development is a cooperation between 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 have been 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 FOX, funded by Bio4Energy project, see Section 2.1 and RISE itself.

In addition to the activities within SFC, RISE ETC also has projects covering gasification and gas cleaning within the Biofuels program.

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.

4.10. UMEÅ UNIVERSITY (www.umu.se)

Umeå University 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 in particular within the Bio4Gasification node, it also works with LTU MiUn and ETC on biomass production and 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 is 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.

5. Industrial developments 2016-2018

There have been some few gasification plants in operation in Sweden in the period 2016-2018, and also one plant is in the later stages of commissioning. Yet a few projects are in planning.

Over time there has been a number of gasification plants in operation in Sweden. One of the first was the pressurised oxygen-blown 2 MW_{th} MINO pilot plant at Studsvik where the aim of the program between 1980 and 1986 was to develop what would today be called a biofuel process, but in the wake of the oil crisis in the 1970's the products were referred to as indigenous fuels or alternative fuels. Furthermore, there were originally three so-called lime kiln gasifiers installed in Sweden in the late 1980's by Foster Wheeler (today Sumitomo SHI Foster Wheeler), at Norrsundet and Karlsborg mills, and by Götaverken (today Valmet) at the Värö mill. The first two were in operation for some years into this century while the Värö gasifier continued operation until 2014, i.e. an impressive 25 years of service. The reasons were age but also major modernisation of the Värö site including the lime kiln and an investment in a pellet plant using saw dust from the co-located saw mill, whereby undersize fines could fuel the lime kiln.

There was also the pioneering Bioflow Värnamo plant that was built in the beginning of the 1990's to develop pressurized air-blown biomass gasification integrated with a gas turbine combined cycle. After the program ended at the turn of the century, the revived interest for biofuels led to two serous initiatives under the name VVBGC to re-purpose the plant for development of oxygen-blown gasification to produce synthesis gas. Finally, in 2011, for lack of financial closure the plans were stopped but the mothballed plant is still there.

The developer TPS was also active and via licensing provided technology to two plants outside of Swede, Greve-in Chianti in Italy and the Arbre plant at Eggborough, UK, and where the technology has been taken up in two plants in recent years by the French contractor LLT.

More details on these plants can be found in previous triennial Country Reports on the Task 33 web page.

5.1. PLANTS IN OPERATION OR UNDER CONSTRUCTION

5.1.1. 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 15, 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}.

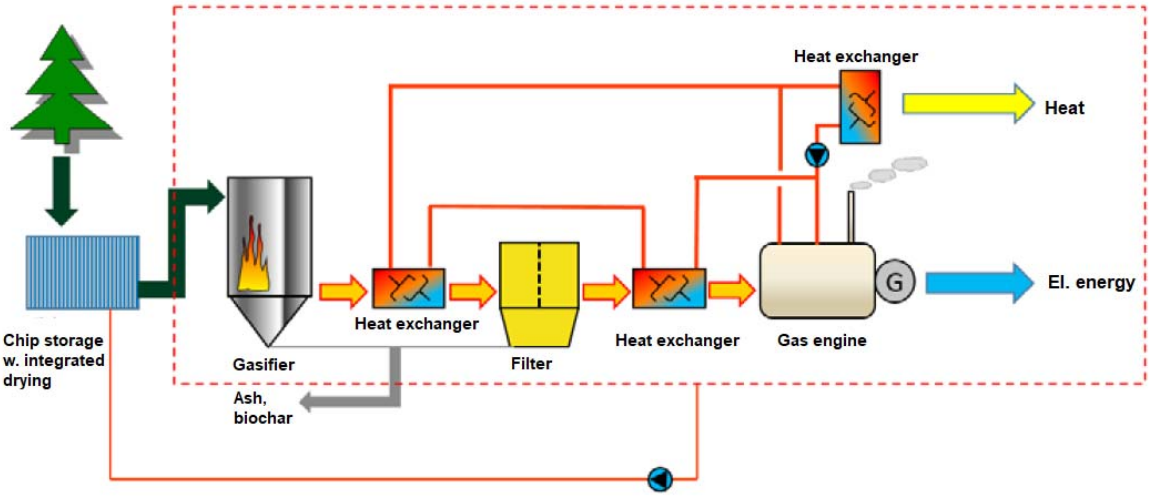

Figure 15 The gasification system at Emåmejeriet

The plant uses whole-tree wood chips from thinnings 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 1.

Table 1 The gas composition of the Emåmejeriet plant

CO Vol. %	H_2 Vol. %	CO_2 Vol. %	CH_4 Vol. %	N_2 Vol. %	Gas LCV
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.

5.1.2. 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 cited report[1] made by Chalmers and the Final Report prepared by Göteborg Energi[2].

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, Figure 16.

[2] The GoBiGas Project. Demonstration of the Production of Biomethane from Biomass via Gasification. Anton Larsson, Ingemar Gunnasrsson, Freddy Tengberg. Göteborg Energi AB 2018.

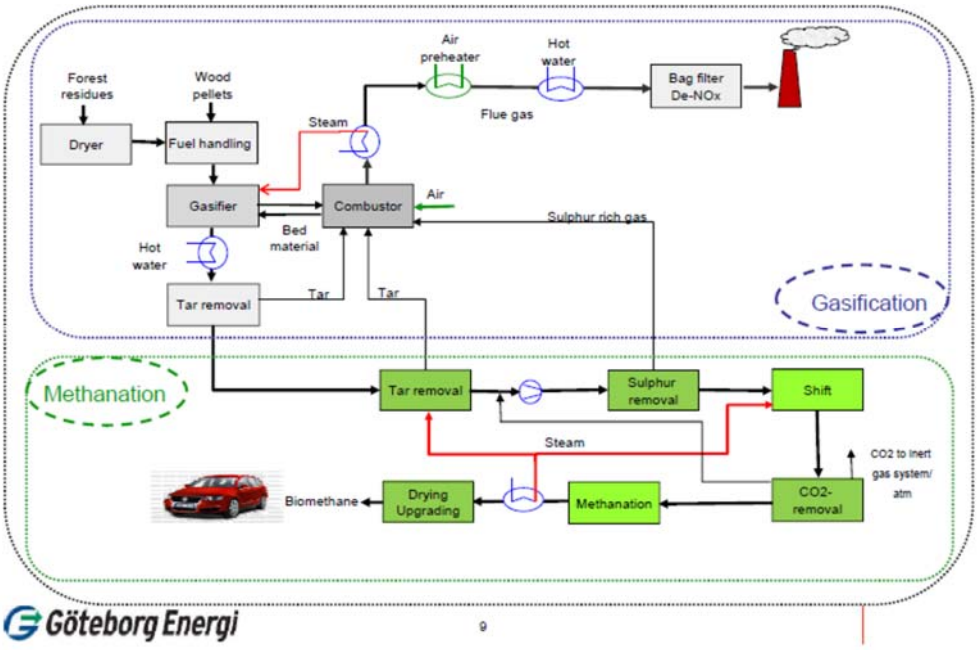

Figure 16 The GoBiGas technical concept

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 CO2 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 totalled 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, Figure 17. 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 17 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 Figure 18.

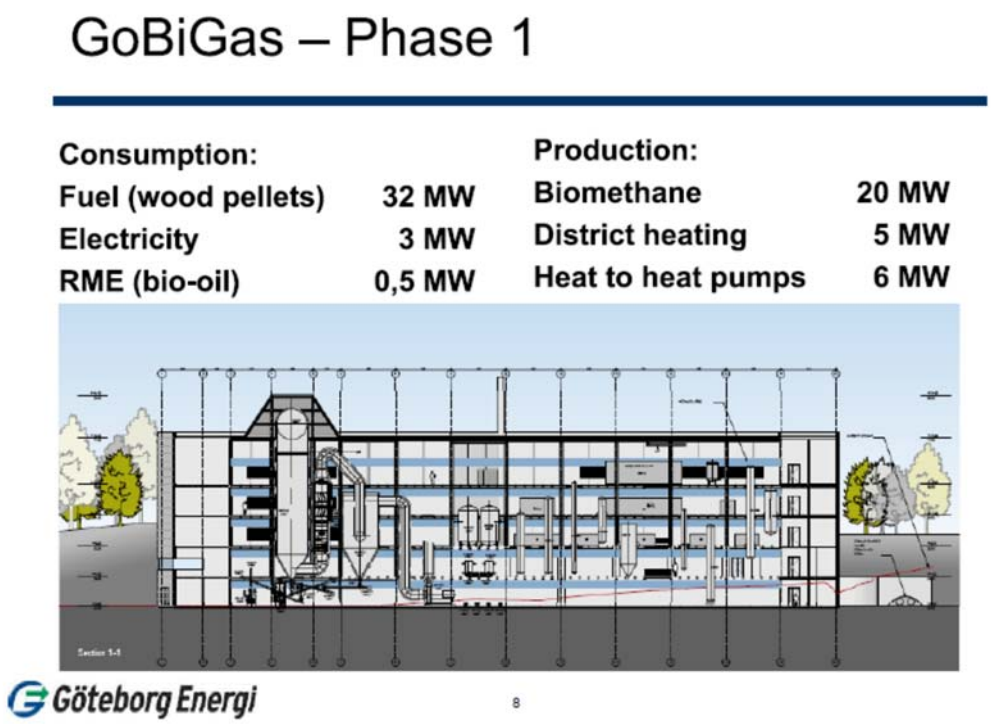

Figure 18 Main data for the GoBiGas phase 1 project.

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 Figure 19. 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.

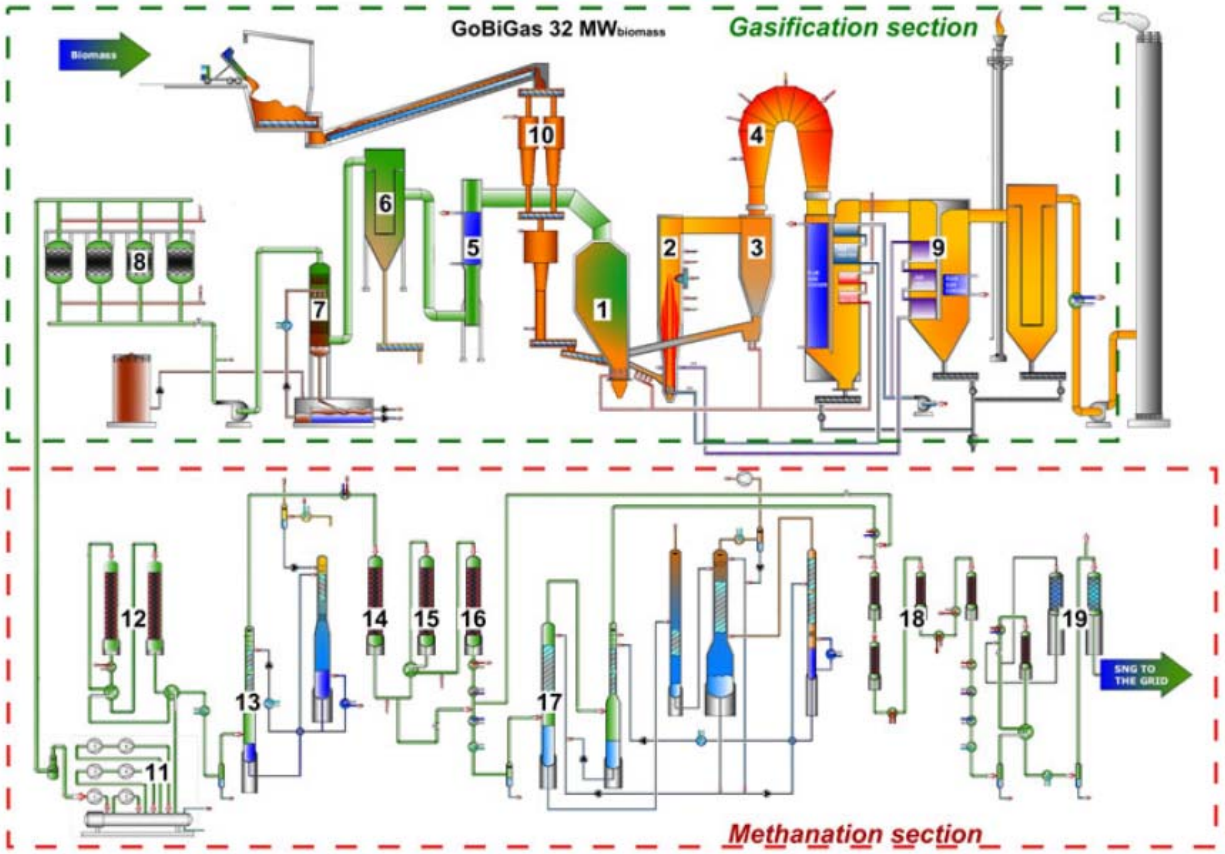

Figure 1. Process schematic of the Gothenburg Biomass Gasification (GoBiGas) biomass to biomethane plant: 1, gasifier; 2, combustion chamber; 3, cyclone; 4, post-combustion chamber; 5, raw gas cooler; 6, raw gas filter; 7, rapeseed methyl ester scrubber; 8, carbon beds; 9, flue gas train; 10, fuel feeding 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 19 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 20.

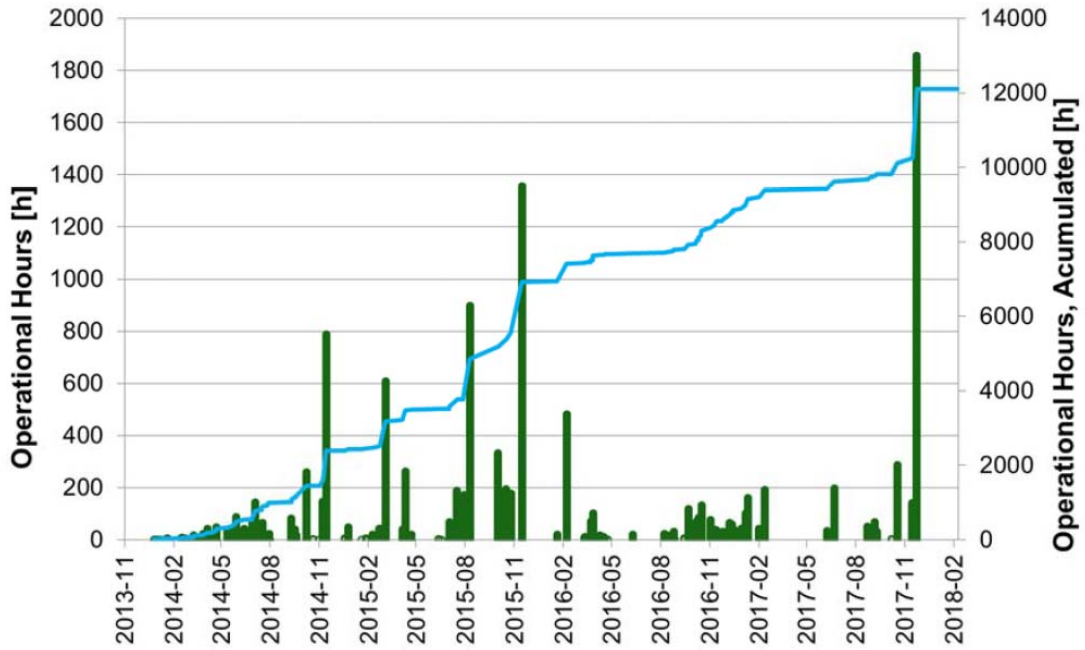

Figure 20 **Operational history for the gasification section of GoBiGas[2] each bar represents a continuous run. The line represents the accumulated number of operational hours**

In Figure 21, 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 problems 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.

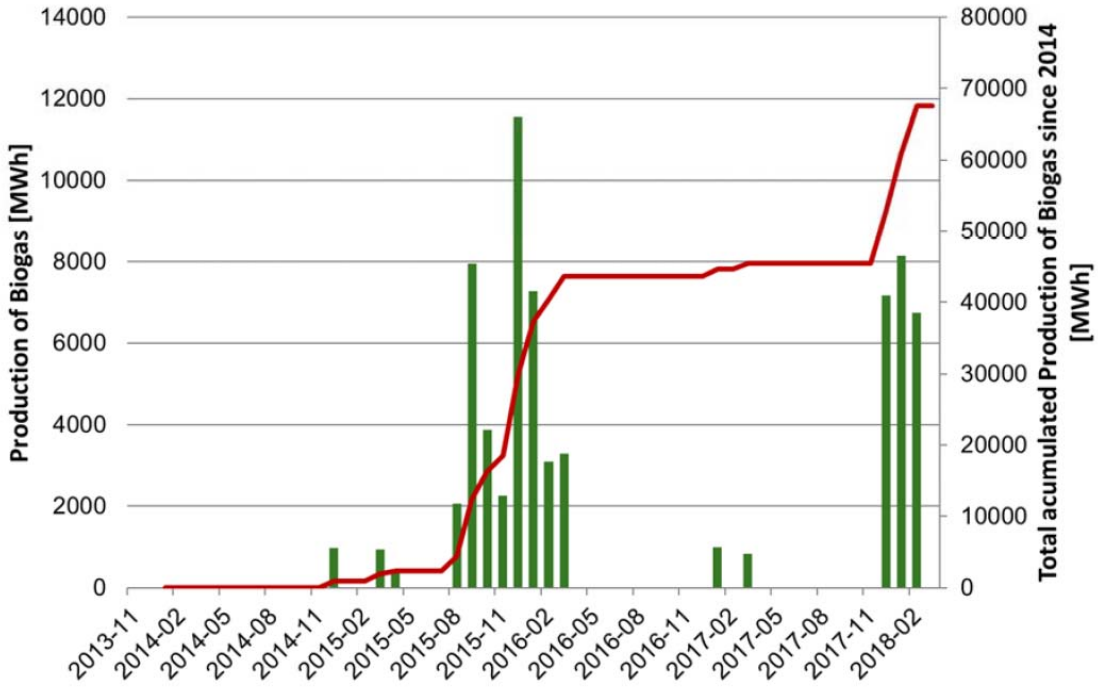

Figure 21 **Operational history of the bio-methane production of GoBiGas[2] each bar represents a continuous run. The line represents the accumulated number of operational hours**

The period August 2015 to first quarter of 2016 was characterised 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.

Table 2 and Table 3 gives more specific data on the operational results and on the gas quality.

Table 2 An overview of the operational data and performance for the fuels used[2]

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 3 An overview of the gasifier product gas for various fuels used[2]

	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, and several “lessons-learned” and a to-do for future modifications are included in the reports[1, 2].

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 been 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. The final report summarizes the R&D activities2 and gives references to the publications made in these projects.

5.1.3. 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 (Figure 22). The liquor is decomposed in the reaction zone into melt droplets consisting of sodium compounds, and a combustible gas containing H_2 and CO.

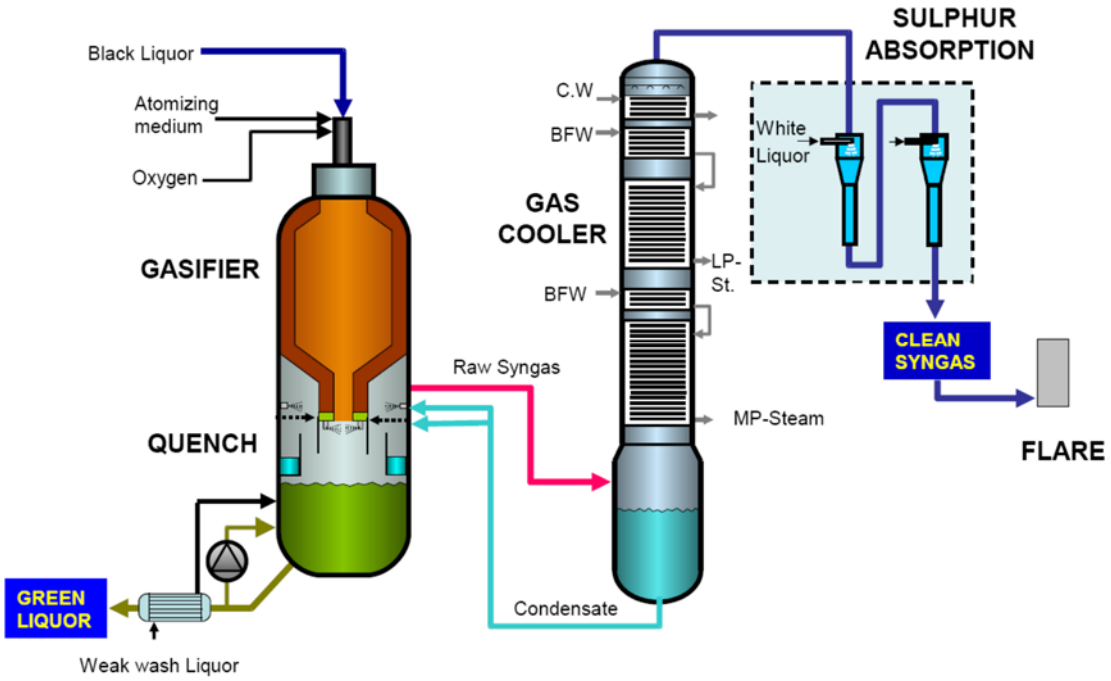

Figure 22 CHEMREC™ black liquor gasifier

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 H2S 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 tons dry substance per day capacity (Figure 23) 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 23 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 is shown in Figure 24. The flow sheet is shown in Figure 25. As can be seen from Figure 25, 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 24 The Bio-DME plant and some plant data.

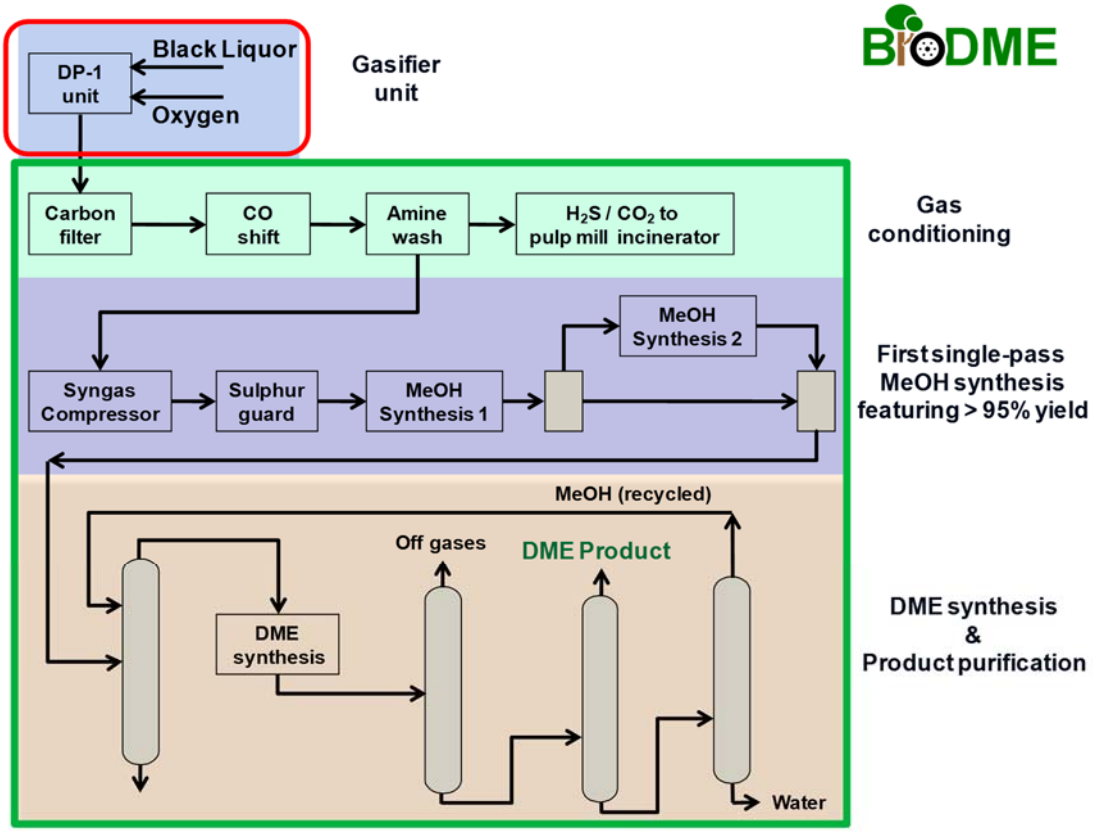

Figure 25 Schematic of ¨DP1 and Bio-DME unit.

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 as described in Section 3.2,

5.1.4. 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 26.

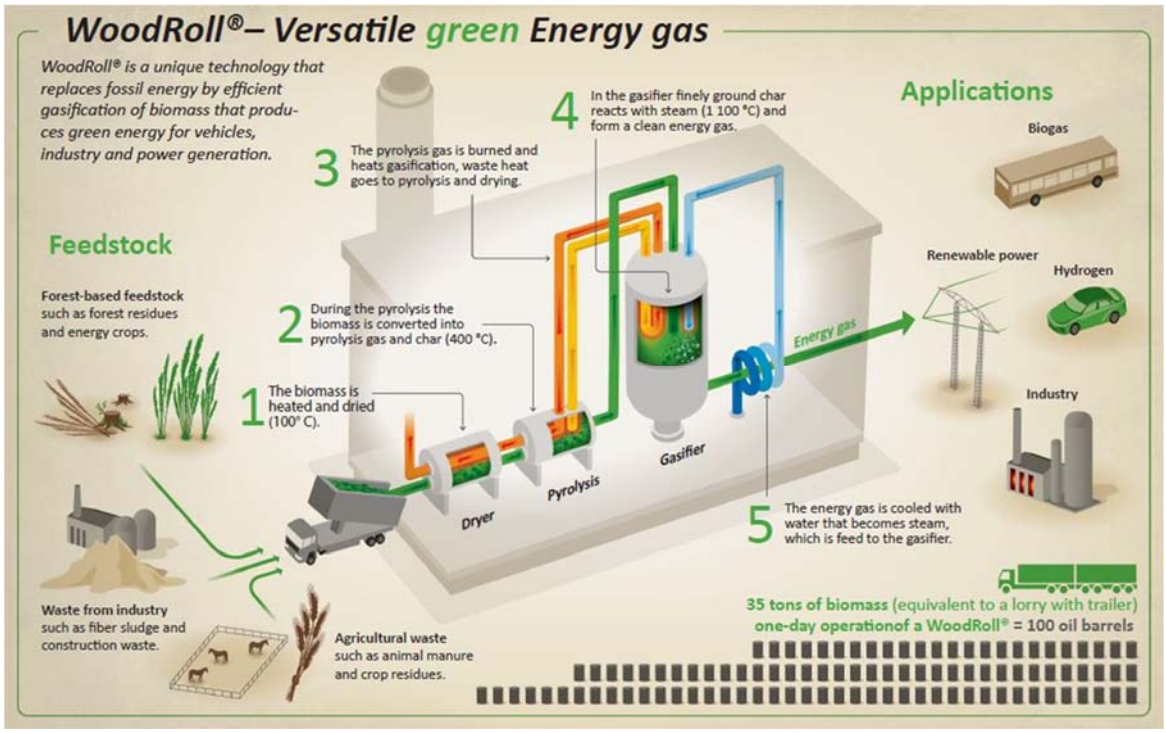

Figure 26 The WoodRoll Technology

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 26. 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 27. 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 27 Cortus 500 kW prototype gasifier at Köping; CFD and 3-D models, IRL.

Within a project financed by Energiforsk, see Section 2.2.1, 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, see Section 2.1.

As a further development in the pilot unit, bio-methane (*aka* SNG) production was tested. This is a project cooperation within KIC Innoenergy, see Section 2.2.3, 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, see Figure 28. Partners in this phase are KIT, KTH, see Section 4.3, 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 28 The DemoSNG pilot plant

Additional development activities include the Biogasxpose project and the BIO-CCHP project. The Biogasxpose project is funded by Life, see Section 2.2.3, 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, See Section 2.1, 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, see Section 2.2.3, 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 Figure 29.

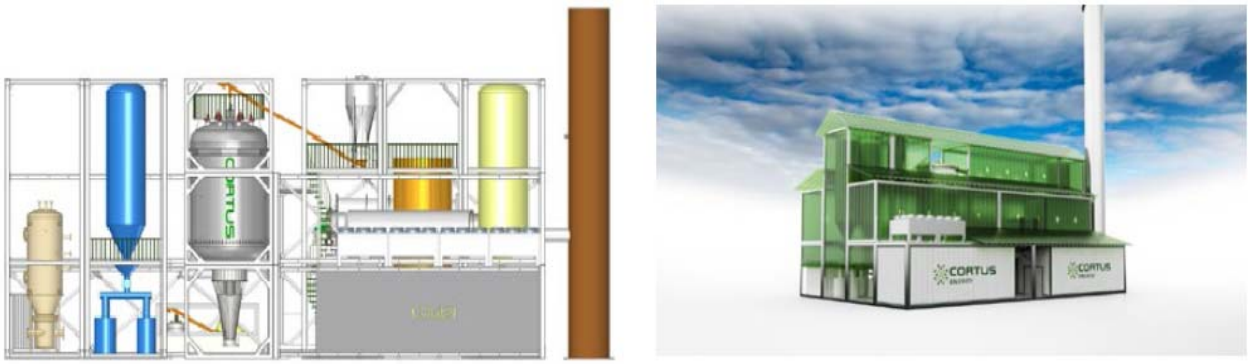

Figure 29 Cortus Wood Roll 6 MW thermal CHP module

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, see Figure 30. 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.

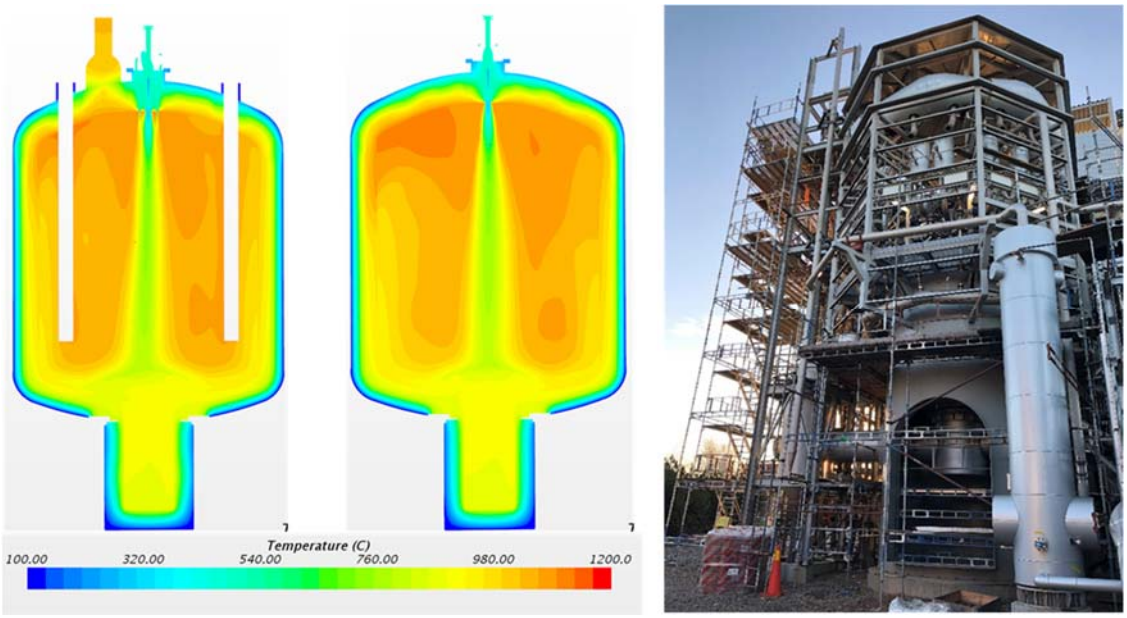

Figure 30 Cortus 6 MW gasifier in Höganäs; CFD and IRL.

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), see Section 2.1. 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, see Section 4.3, 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 31, a recent photo of the plant is shown.

Figure 31 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.

5.1.5. 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, see Section 4.5. 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, see Section 2.2.3, 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), Figure 32, 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.

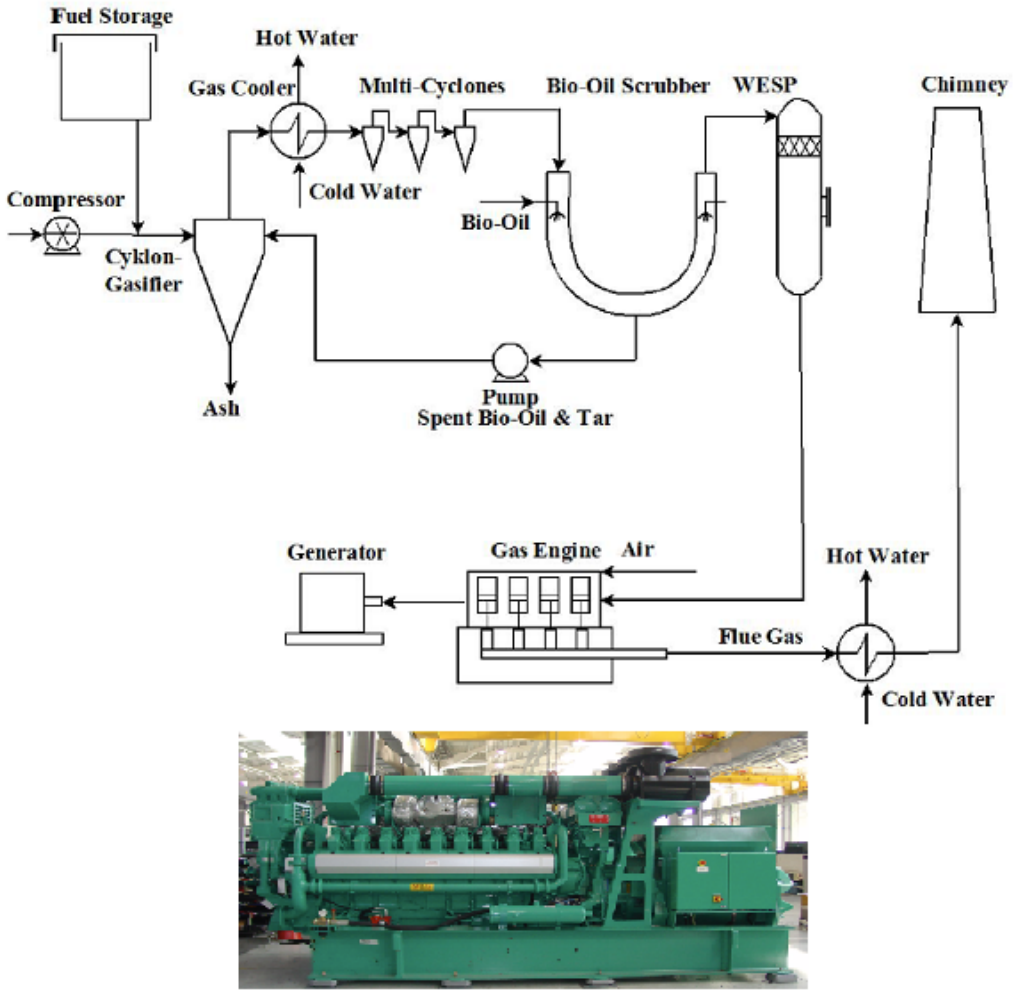

Figure 32 The VIPP system of MEVA and the Cummins V18 engine.

In 2011, a first prototype, scaled-up, plant of 5 MW_{th} fuel 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 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.

5.2. PLANNED DEVELOPMENTS

5.2.1. 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 33. 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.

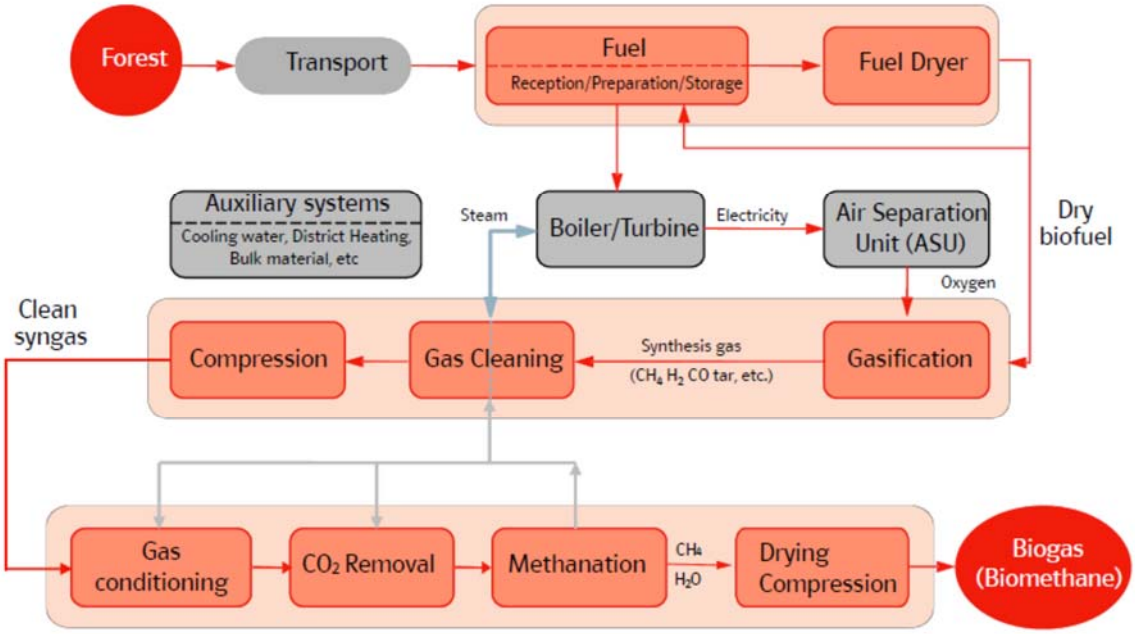

Figure 33 Bio2G technical concept.

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.

5.2.2. 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 m³ 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 34.

Figure 34 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.

5.3. OTHER DEVELOPERS

5.3.1. Phoenix BioPower (www.phoenixbiopower.com)

Phoenix Biopower is a company based in Stockholm and is a company in the Innoenergy Business Service program, see Section 2.2.3. 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 Figure 35.

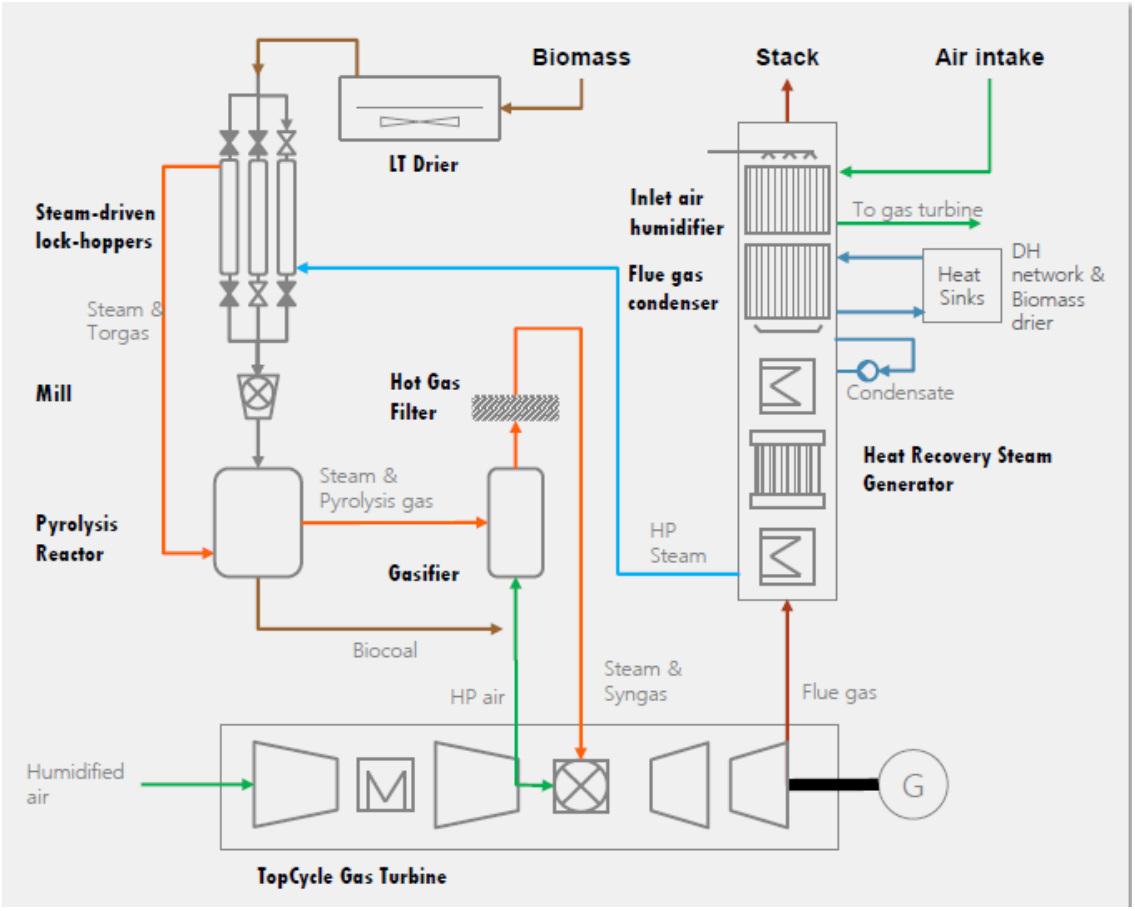

Figure 35 The Phoenix BTC concept

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.

5.3.2. 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, see **Figure 36**.

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

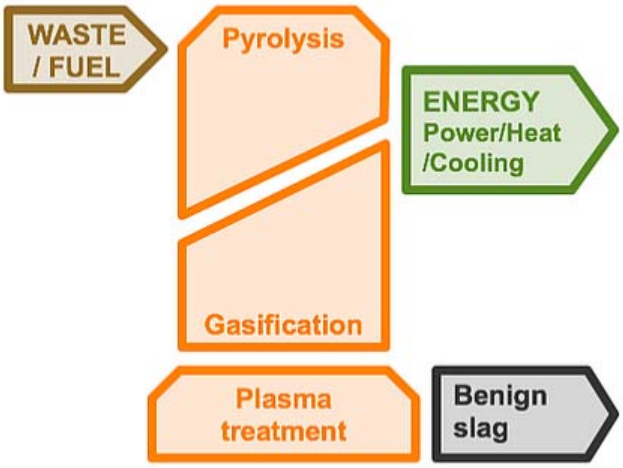

Figure 36 The Boson ATT process schematic

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.

5.3.3. 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 Agency, see Section 2.1, the production of FT fuel integrated with the Heden CHP plant in Karlstad, Sweden, is studied.

5.3.4. 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, see Figure 37, 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.

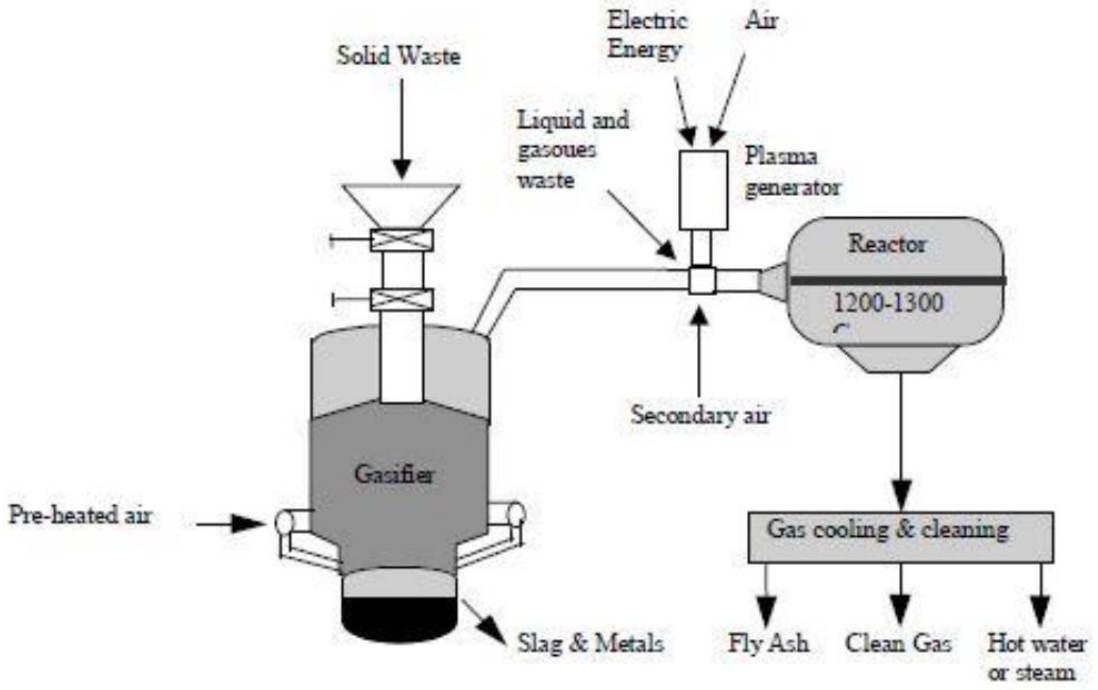

Figure 37 The Scanarc gasification process

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.

Further Information

IEA Bioenergy Website
www.ieabioenergy.com

Contact us:
www.ieabioenergy.com/contact-us/