CHALMERS
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Energy-Related Cooperation Projects between Chalmers and Swedish West Coast Process Industries

A Compilation of Ongoing and Recently Finalized Activities

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ENERGY
A CHALMERS AREA OF ADVANCE

Executive Summary

This report deals with R&D cooperation between Chalmers University of Technology and the process industry on the Swedish West Coast, in many cases also in cooperation with research institutes and regional organisations. This extensive cooperation is, at least in some respects, unique in an international perspective.

In order to limit the size of the report, only the process industries with significant cooperation with Chalmers have been included. This cooperation has mainly dealt with activities directed towards energy efficiency and conversion as well as CO_2 emissions reduction. However, other areas, such as material science and cooperation with equipment manufacturers, have also been the object of cooperation. These areas are not included in this report.

As shown below, the cooperation has included/includes most of the strategic areas which are currently being discussed for industrial development and for the role of industry in contributing to sustainable development.

The cooperation has been performed through many different projects and constellations. In this report, 22 projects are presented and discussed. They represent the core part of the cooperation.

The main aims of this report are to:

- increase awareness among all stakeholders on the Swedish West Coast about the projects, major actors in different projects as well as major findings so far
- increase the awareness within Chalmers about magnitude and breadth of activities (e. g. for identifying new opportunities for multi-disciplinary research)
- increase the awareness externally, nationally and internationally, in order to promote increased R&D and industrial cooperation as well as national and international (e. g. EU) funding of unique demonstration projects
- identify opportunities for synergy effects and common conclusions between the different projects
- provide a platform for discussions on further cooperation areas and forms for such cooperation

The projects included are all projects in direct cooperation with and fully or to a large extent partly funded by the process industries on the Swedish West Coast.

A short description of the 22 projects is presented below:

Cooperation with the Stenungsund Chemical Cluster

- Assessing opportunities to integrate biomass gasification-based processes in the production of chemicals at Perstorp, Stenungsund
- Methodology and case study for LCA assessment of ethylene production via fermentation
- Methodology development and case study of energy integration opportunities in complex industrial clusters (total site integration)
- Routes for collaboration between the forest and chemical industries for establishing biorefinery concepts
- Hinders and opportunities for vision-driven multi-partner collaboration: Case study of the Swedish petro-chemical industry's work with the Sustainable Chemistry 2030 vision.

Projects together with Göteborg Energi

In addition to the project below, there is a long tradition of cooperation between Chalmers and Göteborg Energi (in several earlier projects, therefore not included here) and as a part of the Swedish Gasification Centre (also not included here, as that is part of a larger national centre). For a description of the Chalmers and Göteborg Energi activities in this Centre, please see the Centre's web-site www.ltu.se/centres/Svenskt-forgasningscentrum-SFC

- Use of process integration methods and tools to identify synergy effects between different sub-processes required for production of synthetic natural gas (SNG) from gasified biomass

Projects together with PREEM

- Energy efficiency measures in existing equipment and in integrated biorefinery-oil refinery processes
- Technologies and systems for post-combustion CCS in oil refineries
- Chemical treatment of biomass-based diesel
- Use of biomass in petrol and diesel production for GHG emissions reduction
- Influence of operational and control aspects on opportunities for implementing process integration measures in practice
- Types of algae suitable for biorefinery concepts emissions
- Control issues related to industrial energy efficiency projects.

Projects together with Södra

- Exploring the optimal design for a partially/totally converted kraft pulp mill into dissolving pulp mill in terms of being energy efficient and consequently cost-effective.

Projects together with the Regional Industries on the Swedish West Coast

- Factors influencing optimal location of large biomass gasification plants
- Rational use of excess heat internally or externally
- System and sustainability consequences of industrial excess heat usage
- The importance of business and market models for cluster cooperation
- Coordination and synthesis of technical, economic and environmental aspects of using industrial excess heat in the West Swedish region
- Regional opportunities for CCS
- Analysis of pathways to meet EU, national and regional targets for CO_2 emissions, energy efficiency and penetration of renewable energy in the Kattegatt-Skagerrak region (KASK).

Projects Directed towards EU Cooperation

- R4R – Chemical Regions for Resource Efficiency

Some very important challenges for industry, related to the energy system and addressed in the various cooperation projects, are:

- to become more energy-efficient
- to develop more sustainable processes and products
- to better understand future opportunities for cluster formations

- to understand and introduce new business and market models in order to achieve new developments in industry
- to develop a good cooperation internationally for information exchange, participation in demonstration and R&D projects

The following main aspects have been included in the projects:

- Energy Efficiency in industry
- Development towards more sustainable processes and products through biorefinery concepts
  - Biomass gasification
  - Fermentation
  - Biomass Conversion through Chemical Treatment
  - Algae production and Usage
- CCS in industries on the Swedish West Coast
- Regional Cooperation related to Industrial Excess Heat
- Organisational Aspects of Clusters
- Projects for Improving Participation in EU Projects

This cooperation includes most of the areas being discussed nationally and internationally regarding measures for a sustainable future in the industrial sector. This makes the cooperation an important part of the Swedish West Coast ambitions to create a more sustainable society. Given the variety of areas in energy efficiency, biobased economy, organizational, economic and CO_2 emissions mitigation aspects, this cooperation is broader than the other clusters discussed in Chapter 1. It constitutes therefore a unique cooperation between university, industry and research institutes in this broad area.

The results of working together include a knowledge improvement for all parties involved, an increase in R&D activities in the international forefront in this area and highly improved bases for strategic decision making for the industries involved.

In the cooperation so far, however, only parts of these large areas have been studied .A continuation of the cooperation, building on the well-established network, could become beneficial for all stakeholders involved and be a way to help create a more sustainable society.

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Chapter 1: Introduction

1.1 Background and aims

This report deals with R&D cooperation between Chalmers University of Technology and process industry on the Swedish West Coast, in many cases also together with research institutes and regional organisations. This large cooperation is, at least in some respects, unique in an international perspective.

In order to limit the size of the report, only the process industries with significant cooperation with Chalmers have been included. This cooperation has mainly dealt with activities directed towards energy and CO_2 emissions reduction. However, other areas, such as material science, have also been the object of cooperation, although at a lower level. Such areas are not included in this report.

The main background for this cooperation is twofold: (i) the strategies and visions of industry and organisations on the Swedish West Coast to become considerably more sustainable and (ii) the large R&D activities in these areas. The results of working together include a knowledge improvement for all parties involved, an increase in R&D activities in the international forefront in this area and highly improved bases for strategic decision making for the industries involved.

The main areas of cooperation have been energy efficiency in industry, innovative industrial technologies and processes, integrated biorefinery concepts, future opportunities for industrial carbon capture and storage (CCS), new biobased products, new market and business models, influence of future energy market scenarios and policy instruments, cluster opportunities and LCA-based evaluations and comparisons. This means that the cooperation has included most of the strategic areas which are currently being discussed for industrial development, from both an economical as well as an environmental perspective.

The cooperation has been performed through many different projects and constellations. In this report, 22 projects are presented and discussed. They represent the core part of the cooperation.

The main aims of this report are to:

- increase the awareness among all stakeholders on the Swedish West Coast about the projects, major actors in different projects as well as major findings so far
- increase the awareness within Chalmers about magnitude and breadth of activities (e. g. for identifying new opportunities for multi-disciplinary research)
- increase the awareness externally, nationally and internationally, in order to promote increased R&D and industrial cooperation as well as national and international (e. g. EU) funding of unique demonstration projects
- identify opportunities for synergy effects and common conclusions between the different projects
- form a basis for discussions on further cooperation areas and forms for such cooperation

The projects included are all projects in direct cooperation with and fully or partly funded by the process industries on the Swedish West Coast. In several cases this cooperation also involves research institutes and additional funding from national and/or regional funding organisations. In addition, many R&D activities at Chalmers deal with areas of interest for this industry but are not direct cooperation projects. These activities are not included in this report as projects. All projects discussed were recently finished or are ongoing. Projects that were completed more than 3 years ago are not included.

The main stakeholders involved in some or many of the projects in this report are: Perstorp, Borealis, AGA, Akzo-Nobel, Ineos, PREEM, Göteborg Energi and Södra. Göteborg Energi is not a process industry. However, the GoBiGas project can be seen as a process industrial plant. Therefore, recent direct cooperation projects connected to this plant, as well as other cooperation projects with process industries, in which Göteborg Energi is participating, are included. In some projects, industries outside the West Coast have also been/are involved. The research institutes involved are SP and IVL. Gothenburg University, as well as other Swedish universities, have been involved in a few projects. Major funding organisations, in addition to Chalmers and the industries involved, have been/are the Swedish Energy Agency, VINNOVA, Västra Götalandsregionen (VGR) and Business Region Gothenburg (BRG). In several projects, CIT (Chalmers Industriteknik) has been an important supporting organization to Chalmers (especially CIT, Industrial Energy). Within Chalmers, many projects have been funded in part by the Energy Area of Advance.

In the main part of this report, Chapter 2, the projects are briefly described with respect to main actors, level of funding and funding origin, area of cooperation, aims and major final or preliminary findings. They are divided into the following categories:

- Cooperation with industries in the Stenungsund chemical cluster
- Cooperation mainly with one company
- Regional cooperation with all or many of the main industrial actors (in some projects also including actors outside the West Coast region)
- Projects aiming at EU Cooperation

Thereafter, in Chapter 3, a synthesis is presented, in which an overview of activities and main findings for each R&D area are presented. Thereafter a discussion and summary follows, Chapter 4.

1.2 Energy-related Industrial R&D Cluster Organisations in Sweden

Some of the major R&D cluster organisations are:

- The West Swedish Chemical Cluster
- The West Swedish Cluster for a Biobased Society
- Processum
- Paper Province

The Processum cluster has a close cooperation with Bio4Energy with activities at Luleå, Umeå and SLU universities. The West Swedish Chemical Cluster as well as the West Swedish Cluster for a Biobased Society have a close cooperation with the Chalmers Energy Area of Advance.

Processum

SP Processum AB started in 2003 and has developed from a technology park in Örnsköldsvik to a leading biorefinery initiative, both nationally and internationally. The major parts of the activities concern support and initiatives regarding research and development in the areas of biotechnology, energy technology, inorganic chemistry, organic chemistry and raw materials with a focus on sustainability.

SP Processum, together with other biorefinery initiatives along the coast of the northern part of Sweden, and together with the regional universities, form an important hub for development of new products, energy solutions and fuels based on wood raw material.

Paper Province

The Paper Province is a cluster organisation for the pulp and paper industry in Värmland, North Dalsland and Örebro counties. The activities are concentrated around marketing, competence and project development as well as regional growth. Ninety companies are members. Karlstad and Örebro universities are the leading R&D organisations in Paper Province.

The West Swedish Cluster for a Biobased Society

This cluster is one of five clusters under development in the western part of Sweden. Leading representatives from the city including politicians, academia and industry have jointly identified the five strongest clusters in the region. The clusters each have a long tradition, and they are all facing some exciting challenges. The five clusters include Urban futures, The marine environment and the maritime sector, Transport solutions, Green chemistry and bio-based products and Life science.

The intention is for these clusters to develop cross-boundary collaborations, something Gothenburg and West Sweden have become very good at over the years. The region is characterized by openness to the surrounding world, both nationally and internationally. It is also known for the closeness between academia, the public sector, and business and industry.

The West Swedish Chemical Cluster

The purpose of the West Swedish Chemical Cluster is to develop and strengthen cooperation between actors from industry, academia/institutes and the public sector, by identifying innovation and development projects in prioritised areas. The cluster's strength lies in the cross connection of actors from the chemical, energy, recycling and forest industries.

The overall objective of the cluster is to contribute to sustainable growth and fossil-fuel independence for Västra Götaland by 2030. Another important objective is to strengthen the competitiveness of the regional companies and to attract new establishments and investments in the region.

The Chemical Cluster offers access to networks of actors from industry, academia, research institutes and the public sector. The cluster also offers the opportunity to highlight and pursue issues that are important to the cluster's actors, as well as to initiate and participate in strategic joint projects. The main activities of the Cluster include networking activities; seminars, workshops, conferences and dialogue meetings.

The cluster pursues issues and development projects linked to the following four focus areas:

- Renewable raw materials for chemical and material products as well as transport fuels
- Resource and energy efficiency
- Recycling
- Development and management of core competence

The Cluster is hosted by BRG (Business Region Göteborg). The Cluster members are: AGA, AkzoNobel, Bilfinger, Business Region Göteborg, Business Sweden, Borealis, Chalmers, COWI, Göteborg Energi, Hogia, Ineos, IVL (Swedish Environmental Research Institute), Lysekils kommun, Perstorp, Preem, SP Sveriges Tekniska Forskningsinstitut, Renova, Stena, Stenungsunds kommun, Swedegas, Swerea, Södra and Västra Götalandsregionen.

Chapter 2: Recently Finished and Ongoing Cooperation Projects with the Process Industry on the Swedish West Coast

In this chapter all projects are described briefly. In the appendix all projects are described in more detail.

2.1 Cooperation with the Stenungsund Cluster

Project S1

Project title:
Assessing Integration of Biomass Gasification-Based Production of Chemicals — Case Study of an Oxo Synthesis Plant

Area:
Assessing opportunities to integrate biomass gasification-based processes in the production of chemicals at Perstorp, Stenungsund

Collaboration partners:
Chalmers and Perstorp Oxo, Stenungsund

Project S2

Project title:
Environmental Assessment of Emerging Routes to Biomass Based Chemicals – The Case of Ethylene

Area:
Methodology and case study for LCA assessment of ethylene production via fermentation

Collaboration partners:
Chalmers and Borealis

Project S3

Project title:
Methodology development for efficient integration of energy-intensive climate-friendly processes in industrial clusters

Area:
Methodology development and case study of energy integration opportunities in complex industrial clusters

Collaboration partners:
Chalmers and the five industries in the Stenungsund industrial cluster

Project S4

Project title:
Skogskemi

Area:
Routes for collaboration between the forest and chemical industries for establishing biorefinery concepts

Collaboration partners:
SP Processum was the project leader. Chalmers and 18 other organisations participated

Project S5

Project title:
Collaborative Chemistry Cluster Case study

Area:
Hinders and opportunities for vision-driven multi-partner collaboration: Case study of the Swedish petro-chemical industry's work with the Sustainable Chemistry 2030 vision.

Collaboration partners:
Chalmers, Gothenburg University, SP together with the chemical cluster in Stenungsund.

2.2 Projects together with Göteborg Energi

The direct cooperation between Chalmers and Göteborg Energi (in several earlier projects, therefore not included here) and as a part of the Swedish Gasification Centre (also not included here, as that is part of a larger national centre) has been done mainly through the Energy Technology Division at Chalmers (Henrik Thunman leading researcher), partly based on the unique indirect pilot gasifier at Chalmers, but also with Heat and Power Technology (process integration aspects, Project G1). This cooperation has contributed significantly to a fully operational GoBiGas 1 plant for SNG production. For a description of the Chalmers and Göteborg Energi activities in this centre, please see the GoBiGas web-site www.gobigas.se

Project G1

Project title:
Production of synthetic natural gas from gasified biomass - Process integration aspects

Area:
Use of process integration methods and tools to identify synergy effects between different sub-processes required for production of synthetic natural gas (SNG) from gasified biomass

Collaboration partners:
Chalmers and Göteborg Energi (GoBiGas Project)

2.3 Projects together with PREEM

Chalmers has an ongoing cooperation with PREEM, in which PREEM provides full financing or co-financing of projects. The projects below constitute the basis of this cooperation. In Phase 1, which finished formally on 2013-12-31 (but several projects finished during 2014), the projects were combined into "clusters", as shown below.

Project P1

Cluster 1:
Process integration of new processes in the design and operation stages

Area:
Energy efficiency measures in existing equipment and in integrated biorefinery-oil refinery processes

Collaboration partners:
Chalmers and PREEM

Project P2

Cluster 2:
CCS in oil refineries-technologies and system solutions

Area:
Technologies and systems for post-combustion CCS in oil refineries

Collaboration partners:
Chalmers and PREEM

Project P3

Cluster 3:
Isomerisation for improved properties in cold climate and thermic decarboxilysation for lower hydrogen consumption

Area:
Chemical treatment of biomass based diesel

Collaboration partners:
Chalmers and PREEM

Project P4

Cluster 4:
Biorefinery Concepts in Oil Refineries

Area:
Use of biomass in petrol and diesel production for GHG Mitigation

Collaboration partners:
Chalmers and PREEM

Project P5

Project title:
Analysis of differences between theoretical and practically achievable potentials for heat integration

Area:
Via case studies identify how achievable process integration opportunities are influenced by operational and control aspects

Collaboration partners:
Chalmers and PREEM

Project P6

Project title:
Alternative biomass types as feedstocks in biorefinery concepts

Area:
Types of algae suitable for biorefinery concepts

Collaboration partners:
Chalmers and PREEM

Project P7

Project title:
Methods and tools for evaluation of dynamic aspects when designing more efficient industrial energy systems, MoveDynE

Area:
Control issues related to industrial energy efficiency projects.

Collaboration partners:
Chalmers and PREEM

2.4 Projects together with Södra

Project Sö1

Project title:
Strategic energy efficiency and development towards biorefineries in the pulp and paper industry

Area:
Explore the optimal design for a partially/totally converted kraft pulp mill into dissolving pulp mill in terms of being energy efficient and consequently cost-effective.

Collaboration partners:
Chalmers and Södra

2.5 Projects together with the Regional Industries on the Swedish West Coast

Project R1

Project title:
Advantages of regional industrial cluster formations for integration of biomass gasification systems

Area:
Factors influencing optimal location of large biomass gasification plants

Collaboration partners:
Chalmers and IVL, Perstorp Oxo, Göteborg Energi, EoN, PREEM, Swedish Energy Agency

Project R2

Project title:
Sustainable use of industrial excess heat − competition between internal heat recovery and export to a district heating system

Area:
Rational use of excess heat internally or externally

Collaboration partners:
Chalmers with SP and IVL plus 11 regional industries

Project R3

Project title:
Use of New Industrial Excess Heat in the West Swedish District Heating Systems, including economic, sustainability and policy instruments aspects

Area:
System and sustainability consequences of industrial excess heat usage

Collaboration partners:
Chalmers and IVL with 11 regional industries

Project R4

Project title:
The influence of type of market model on Opportunities for delivering industrial heat to district heating systems

Area:
The importance of business and market models for cluster cooperation

Collaboration partners:
SP and 11 regional industries (this project has been included due to the close cooperation with Projects R2 and R3)

Project R4

Project title:
Scientific Coordination of Projects R2, R3 and R4

Area:
Coordination and synthesis of technical, economic and environmental aspects of using industrial excess heat in the West Swedish region

Collaboration partners:
Chalmers, SP and IVL with 11 regional industries

Project R6

Project title:
Carbon Capture and Storage in the Skagerrak/Kattegat region

Area:
Regional opportunities for CCS

Collaboration partners:
Chalmers with Gothenburg University, Tel-Tek (Norway), Preem Lysekil (refinery), Preem Göteborg (refinery), Esso Slangentangen (refinery), Borealis Stenungsund (ethylene cracker), Yara Porsgrunn (ammonia plant).

Project R7

Project title:
Sustainable use of energy carriers in the KASK region

Area:
Analysis of pathways to meet EU, national and regional targets for CO_2 emissions, energy efficiency and penetration of renewable energy in the Kattegatt-Skagerrak region (KASK).

Collaboration partners:
Chalmers/Energy Technology, Chalmers/Heat and Power Technology, CIT-IE, PROFU, Tel-Tek (Norway)

2.6 Projects Directed towards EU Cooperation

Project E1

Project title:
R4R – Chemical Regions for Resource Efficiency
Region Västra Götaland Stenungsund, Sweden

Area:
Exchange of knowledge and best practices in the area of resource efficiency by enhanced triple helix collaboration within and between some of the most process intensive European regions

Collaboration:
SP Project Leader. Other organisations Chalmers, BRG, Borealis, Perstorp.

Chapter 3: Challenges and Opportunities for Future Developments Addressed in the Cooperation

3.1 Introduction

Some very important challenges for industry, related to the energy system and addressed in the cooperation, are:

- to become more energy-efficient
- to develop more sustainable processes and products
- to better understand future opportunities for cluster formations
- to understand and introduce new business and market models in order to achieve new developments in industry
- to develop a good cooperation internationally for information exchange, participation in demonstration and R&D projects

In this chapter, these aspects are discussed and findings so far are highlighted. Synergy effects are also discussed.

3.2 Energy Efficiency in industry

This aspect has been dealt with especially in the following projects: S3, P1, P5, and R2. Please note that most of the biorefinery based projects (see below) also include significant focus on process integration and energy efficiency aspects.

In these projects, pinch analysis or total site analysis (which is based on pinch analysis) have been used. These methods have shown to be very suitable in real case studies for identifying energy efficiency opportunities and to discuss with industry about practical opportunities for implementation. With these methods, it is possible to identify opportunities as a function of the complexity of measures and of opportunities for implementation in practice. In the main projects listed above, the results have been presented in this way. The general experience seems to be that theoretical energy efficiency opportunities are very significant and that there are interesting opportunities also in practice. Another experience is that this kind of cooperation highlights opportunities, partly already identified by industry, but puts them into a system perspective, as well as “challenges” industry to evaluate also other opportunities.

Project S3 investigated opportunities within the whole industrial cluster in Stenungsund. The results showed that cluster cooperation regarding the energy system shows a considerably higher potential for energy efficiency than the sum of measures for the individual industrial plants. The theoretical saving potential is very high: in theory the cluster could operate without firing purchased fuels in utility boilers. Detailed discussions with plant energy experts indicate that approximately half of this potential could be achieved in reality.

In these projects, method developments and applications through case studies have led to a considerably increased knowledge about energy saving potentials in these industries. The potentials are higher than anticipated but practical constraints and consequences must be studied further.

Hence, a new area of research has recently started together with PREEM, partly in the form of a new internal collaboration between the Industrial Energy Systems and Technologies and Automatic control, Automation and Mechatronics divisions at Chalmers and Industrial Energy, CIT. The objective of the collaboration is to investigate "real" practical opportunities for energy saving, taking obstacles and consequences in the operational phase into account, but without being traditionally "too" conservative about realizable theoretically identified opportunities. No results from this work have as yet been reported.

3.3 Development towards more sustainable processes and products through biorefinery concepts

All industries involved in the cooperation have a more or less formalized strategy of becoming more sustainable in the future. Different biorefinery concepts have been identified as one important avenue to achieve this. Biorefinery concepts included in the cooperation are:

- Biomass gasification
- Fermentation of lignocellulosic biomass
- Biomass Conversion through Chemical Treatment
- Algae production and usage

Biomass gasification

Biomass gasification is dealt with in projects S1, S2, S4, G1, P1, P4, P6 and R1. The type of biomass intended to be used in all these projects is, explicitly stated or implicitly intended, lignocellulosic biomass. The quality of the biomass varies between pellets, wood chips, (normally GROT-based) and GROT, from regional sources or imported (not always specified). The end products studied are methanol, SNG, FT-diesel, hydrogen or olefins. In the oil refinery sector (PREEM), FT-diesel or hydrogen have been the two interesting ones to study. For Perstorp methanol (as transportation fuel or as a base for chemicals) and for Borealis olefins (via methanol) have been the most interesting end products to study. For the Stenungsund industries in general, replacing part of the cracker syngas by syngas from biomass is interesting, where e. g. methanol as an intermediate or end product can be used. Finally, for Göteborg Energi, SNG (as transportation fuel or to be distributed to e. g. Stenungsund) has been the main route.

In the Skogskemi project, replacing part of the Stenungsund cracker syngas by biomass gasification for methanol or olefin production has been studied. Also methanol import to Stenungsund from chemical pulp and paper mills (where small amounts of methanol is a by-product) has been included.

In Project R1, a comparison between three different locations, PREEM Lysekil, Stenungsund and Gothenburg, for a gasification plant has been carried out, in which each location is connected to one specific product, FT-diesel, methanol and SNG, respectively.

The direct cooperation between Chalmers and Göteborg Energi (in several earlier projects, therefore not included here) as a part of the Swedish Gasification Centre and in Project G1) has been done mainly through the Energy Technology Division at Chalmers (Henrik Thunman leading researcher), partly based on the unique indirect pilot gasifier at Chalmers,

but also with Heat and Power Technology (process integration aspects, Project G1). This cooperation has contributed significantly to a fully operational GoBiGas 1 plant for SNG production.

Results regarding biomass gasification in Stenungsund have shown that methanol seems to be a good candidate as end or intermediate product, e. g. replacing part of the existing cracker. The amount of excess heat would then increase, and novel opportunities for excess heat usage should be investigated. To achieve a good economic performance, future high levels of CO_2 charge will be necessary.

For gasification in PREEM Lysekil, FT-diesel or hydrogen are interesting end product candidates.The end product to prefer depends on future assumptions for input data .Higher levels of CO2 charge are needed to justify investments economically.

SNG production in Gothenburg can be of interest if future CO_2 charges are high.

Fermentation

Studies of biomass fermentation have been done in Projects S2 and S4. These projects have been carried out in cooperation with the Stenungsund industries. The main route has been lignocellulosic fermentation to ethanol as an intermediate for olefins production. Two main aspects have been studied, different fermentation routes (technologies and process integration) and LCA aspects of olefin production via ethanol. In addition, evaluations of routes where biomass-based ethanol is imported and used in e. g. Borealis have been included..

The results show that ethanol can be an interesting intermediate for olefin production technically, but that high future CO_2 charges are needed in order to make it economically interesting. Furthermore, the sustainability aspects are significantly influenced by the assessment of time lags for biomass CO_2 (wood routes), and of emissions from indirect land use change.

Biomass Conversion through Chemical Treatment

This area is connected to the studies in Project Sö1, in which conversion in a pulp mill to dissolving pulp has been evaluated. The results have shown that the possible decrease in production capacity is a major obstacle and that large equipment investments in some cases can be necessary.

Algae production and Usage

This area has been studied in Projects P1 and P6. So far, only small studies have been carried out in this area. Together with PREEM, some specifications for micro and macro algae have been done, in order to identify the opportunities to use one or the other type for diesel and/or biogas production. However, a large project has recently been started, for aims and details see Project P6. Hence, no real results about opportunities to use algae in the West Swedish Region have as yet been reported.

3.4 CCS in industries on the Swedish West Coast

CCS has been studied in Projects P2, P4, R6, R7 and (partly) R1.

Together with PREEM and the Stenungsund industries, opportunities for CCS as a means for CO_2 mitigation have been studied regarding technology, process integration, system aspects, distribution and storage. Both technical and economic aspects have been included. The main type of CCS studied has been post combustion with chilled ammonia or MEA. CCS with fossil-based CO_2 as well as in combination with possible future biomass-based emissions have been studied. In addition, assessment of the technical and economic parameters of the complete CCS chain and, in particular, identification of possible storage locations have been studied.

In general, in order to achieve economically favourable conditions for CCS, the future CO_2 charge must be high. This has been confirmed by the projects reported here. However, according to future scenarios by international organisations, such high CO_2 charges can be a reality in some scenarios already by 2035-2040.

3.5 Regional Cooperation related to Industrial Excess Heat

This aspect has been studied in the project package Nos.R2, R3, R4, R5.

The main parts in this package have been:

- What parameters govern the optimal mix between internal recovery of excess heat or export to a district heating system?
- Under what future conditions is it economically advantageous and sustainable to cooperate between industry and district heating systems through a long pipe line and what role will policy instruments play?
- How shall market and business models be introduced in order to create economically advantageous situations for all stakeholders and at the same time contribute to creation of a sustainable system for society?

The results of this work will be available in early 2015.

3.6 Organisational Aspects of Clusters

Two projects are presently carried out in this area, Projects S5 and R4 (being carried out by SP only, but in such close cooperation with R2 andR3, that it is included in this report) Although no direct results are available yet, experiences from these projects as well as from several other ones show that these aspects are of crucial importance for a good cluster cooperation. More knowledge in this area is therefore needed.

3.7 Projects for Improving Participation in EU Projects

Project E1 deals with this area. EU is becoming more and more important platform for research and development for Swedish academics and industries. There are also an increasing number of large calls, in which a cooperation between industry and academia is mandatory. A closer cooperation for identifying and initiating participation in EU projects could therefore mean a win-win situation.

Chapter 4: Discussion and Summary

In this compilation, the energy-related cooperation with process industry on the Swedish West Coast is included. Other important cooperation in the material area, together with equipment manufacturers, etc should also be compiled. Regarding material research, e. g. together with the large Swedish cooperation project the Wallenberg Centre, there are no large cooperation projects with the process industry but many activities together with other companies in the region. Regarding equipment manufacturers, VALMET should be specifically mentioned. Chalmers has cooperation with VALMET in at least two areas, indirect gasification (mainly through the Energy Technology Division) and evaporation and biomass cracking (mainly involving the Industrial Energy Systems and Technologies Division).

Chalmers has a broad and close cooperation with the process industry on the Swedish West Coast, in many cases together with SP or IVL and in a few cases also with Gothenburg University. This cooperation includes most of the areas being discussed nationally and internationally regarding measures for a sustainable future in the industrial sector. This makes the cooperation an important part of the Swedish West Coast ambitions to create a more sustainable society. Given the variety of areas in energy efficiency, biobased economy, organizational, economic and CO_2 mitigation aspects, this cooperation is broader than the other clusters discussed in Chapter 1. It constitutes therefore a unique cooperation between university, industry and research institutes in this broad area.

This large cooperation has been developed over several years (although only projects having finished three years ago or later have been included). This development has been facilitated by the network in the West Swedish Chemical Cluster mentioned in Chapter 1), in which BRG, Business Region Gothenburg, has played a major role. The support from and cooperation with Västra Götalandsregionen has also been of high importance for this development. Probably the most important reason, however, is the enthusiasm key personnel in the process industries have shown and the network between industry, Chalmers, research institutes and regional organisations that has been established. Finally, the role of the Swedish Energy Agency, having been the largest financing organization, has been of utmost importance.

Several projects have heavily relied on earlier projects or projects having been performed in parallel. This means that many projects had not been possible to perform within the given time-frames and budgets without the knowledge from other projects. The development of this large cooperation has therefore created many synergy effects and cross-fertilization of benefit for both industry and academy. Just to mention two examples: The project package R2, R3 and R4 would not have been possible without Projects S3 and P1, the large cooperation project S4 would have been very difficult to perform without Projects R1, S3 and S1.

The activities and the results could serve as a model for other regions in Sweden and internationally. They should therefore be presented at appropriate conferences, meetings, etc. and opportunities for identifying e. g. EU-funded demonstration plants, based on the results, should be investigated further.

In the cooperation so far, however, only parts of these large areas have been studied .A continuation of the cooperation, building on the well-established network, could become beneficial for all stakeholders involved and be a way to help create a more sustainable society.

Appendix: Recently Finished and Ongoing Cooperation Projects with Process Industry on the Swedish West Coast

A.1 Cooperation with the Stenungsund Cluster

Project S1

Project title:
Assessing Integration of Biomass Gasification-Based Production of Chemicals — Case Study of an Oxo Synthesis Plant

Area:
Assessing opportunities to integrate biomass gasification-based processes in the production of chemicals at Perstorp, Stenungsund

Collaboration:
Chalmers and Perstorp Oxo, Stenungsund

Main researchers:
Maria Arvidsson, Chalmers
Simon Harvey, Chalmers
Matteo Morandin, Chalmers

Approximate size of project: 6.5 MSEK

Contents:
The work has been conducted in the form of a case study involving a conventional oxo synthesis plant processing syngas derived from partial oxidation of natural gas (NG), and olefins into various specialty chemicals. The following options were investigated: (*i*) retaining the existing syngas production unit and fully substituting the natural gas feedstock by either importing or producing biomass-derived synthetic NG (bio-SNG) on-site; (*ii*) scrapping the existing syngas generator and directly producing biomass-derived syngas fulfilling the specifications for downstream oxo synthesis.

Examples of Results:
The route via bio-SNG with LP steam export shows the highest GHG emission reduction potential. The direct biosyngas route achieves higher economic performance. Future scenario calculations at different CO2 charge levels indicate that the biomass route will not be economic unless other policy instruments are introduced.

Project S2

Project title:
Environmental Assessment of Emerging Routes to Biomass Based Chemicals – The Case of Ethylene

Area:
Methodology and case study for LCA assessment of ethylene production via fermentation

Collaboration:
Chalmers and Borealis

Approximate funding: not available

Time: not available

Main researchers:
Christin Liptow, ESA, Chalmers
Mathias Janssen, ESA, Chalmers
Ann-Marie Tillman, ESA, Chalmers

Contents:
The aim of this thesis was to provide guidance for the development and production of biomass based ethylene, using life cycle assessment tools. This is achieved this by (1) identifying environmental hot spots throughout the product life cycle; (2) by comparing the environmental impact of sugarcane, wood fermentation, and wood gasification routes for production of ethylene. The production routes are compared with each other, as well as with a fossil alternative. In addition, the thesis contributed to the methodological development of LCA to better fit the assessment of emerging routes to biomass based products (1) by determining methodological challenges linked to the assessment of products (e.g. biomass based chemicals) produced via emerging technologies; and (2) by identifying application and methodological challenges related to the climate impact assessment of land use and of time lags between CO2 release and uptake from biomass.

Examples of Results:
From a global warming perspective, all three biomass routes can outperform the fossil alternative. However, this finding is significantly influenced by the assessment of time lags for biomass CO_2 (wood routes), and of emissions from indirect land use change (sugarcane route). Both factors can significantly increase the global warming potential of the biomass routes, making them comparable to the fossil alternative related decreases in carbon stocks. Consideration needs to given on how to use wood based ethylene to best mitigate potential effects of time lags between CO_2 uptake and release from biomass. The climate impact assessment of land use and time lags in CO_2 release and uptake was found to encounter a number of methodological and practical issues, which need to be addressed.

Project S3

Project title:
Methodology development for efficient integration of energy-intensive climate-friendly processes in industrial clusters

Area:
Methodology development and case study of energy integration opportunities in complex industrial clusters

Collaboration:
Chalmers and the five industries in the Stenungsund industrial cluster

Approximate funding:
The Energy Systems Program, Swedish Energy Agency 1 140 000 SEK
The Swedish Energy Agency, industrial program 1 275 826 SEK
The industrial companies in Stenungsund 828 000 SEK
Total: 3.2 Million SEK

Time:
Start date: 2010-09-01, End date: 2014-03-31

Main researchers:
- Roman Hackl, PhD student (Chalmers, Division of Heat and Power Technology)
- Simon Harvey, Professor (Chalmers, Division of Heat and Power Technology)
- Eva Andersson (CIT Industriell Energi)

Contents:
The project's aim was to develop the "Total site" analysis method (TSA) for analysing opportunities for implementation of common energy efficiency measures and advanced biorefinery concepts in industrial clusters. Selected cases were evaluated with respect to techno-economic performance as well as associated potentials for reduction of CO_2 emissions using energy market scenarios. The project was conducted as a case study linked to the chemical cluster in Stenungsund.
This work presents a framework methodology that can provide guidance to the process industry in order to manage this transformation in an efficient way. Process integration tools are used to identify common measures to improve energy efficiency at a site-wide scale. This targeting procedure is followed by a detailed procedure for design and evaluation of practical energy efficiency measures.
The results from this project can be used to evaluate the advantages for co-localisation of other processes at an existing cluster.

Examples of Results:
The methodology developed can be used to identify favourable ways to integrate biomass based processes that can replace fossil with biogenic feedstocks and utilise existing infrastructure. For the case study in Stenungsund, the results show that cluster cooperation regarding the energy system shows a considerably higher potential for energy efficiency than the sum of measures for the individual industrial plants. The theoretical saving potential is very high: in theory the cluster could operate without firing purchased fuels in utility boilers (such utility boilers currently supply approx.. 125 MW of utility heat to the cluster site). Detailed discussions with plant energy experts indicate that approximately half of this potential could be achieved in reality.

Project S4

Project title:
Skogskemi

Area:
Routes for collaboration between the forest and chemical industries for establishing biorefinery concepts

Collaboration:
SP, Processum was the project leader. Chalmers and 18 other organisations participated

Approximate funding:
10 Million SEK from Vinnova
10 Million SEK from participating industries/organisations

Time:
September 2012 - October 2014

Main researchers:
Project leaders were Claes Engström, SP Processum, Jonas Joelsson, SP Processum and Lena Heuts, CIT
Main researchers at Chalmers and CIT: Matteo Morandin, Eva Andersson, Carl Johan Franzén, Johan O. Westman

Contents:
The aim of the Skogskemi innovation development project has been to lay the foundation for a sustainable and competitive production of forest-based bulk chemicals through the cooperation between the forest industry and the chemical industry. Two large Swedish clusters participated in Skogskemi: The chemistry cluster in Stenungsund and the biorefinery cluster of Processum. Three value chains with potential to be scaled up to demonstrators in Sweden were selected: Butanol, Methanol and Olefins. Large market volumes providing for bulk production potential and the ability of the chemicals to fit into existing infrastructure – so called drop-in chemicals – were important selection criteria. The project has performed detailed technical studies of the three value chains and preliminary front-end engineering designs (pre-FEED) have been delivered. The project has also delivered extensive knowledge regarding two technology platforms for the conversion of Swedish lignocellulosic feedstock: a sugar platform with production of ethanol and a gasification platform with production of methanol. Ethanol and methanol are important intermediates in the butanol and olefins value chains.

A dedicated systems analysis sub-project has contributed with environmental assessments in the form of life cycle assessment (LCA) for the full chain from forest to chemical products. Innovation system analysis and policy analysis have provided insights into potential risks and barriers in the process of developing new biorefinery industries and a review of the present policy landscape have been performed. Finally, the project has provided for a discussion platform - a forum for forest industry, chemical industry and other stakeholders in the bioeconomy, realized in the form of a number of seminars. A total of approximately 300 participants from a large number of companies attended the five events.

Examples of Results:

One of the main project conclusions was that the technologies for production of butanol and olefins from ethanol and methanol are mature, and the construction of such plants could start today. The step from forest feedstock to methanol and ethanol still carries uncertainties with respect to upscaling of

the processes. Large-scale demonstration projects are, however, under way, which is likely to reduce uncertainties in the near future.

The economic assessments show that some of the projects appear feasible if the product is to be sold on the transportation fuel market with the current tax exemption policy, while production for the chemicals markets is less promising. Although there are important synergies between renewable transportation fuels and renewable chemicals markets, it is apparent that use of the studied chemicals for non-fuel purposes will be difficult to realize unless this is given similar conditions as their use for biofuel purposes. A rough estimate is that a long-term, stable green premium on forest methanol and ethanol as well as the value chain end products in the vicinity of 20-50% would create sufficient impetus to start realizing investments. The LCA results show a significantly lower contribution to global warming with forest-based chemicals than with fossil-based chemicals. For other environmental impact categories the picture is more diverse.

Apart from the more technical and economic results of the extensive work done in Skogskemi, some very important but more intangible results are worth mentioning: personal trust has been built and new collaboration and networks have been set up. An important example is the representation of the chemical industry and the forest industry in the Bioinnovation Strategic Innovation Area.

Wood is the feedstock for a range of products today, and there are several pathways to new forest-based products. This project has focused on specific value chains for bulk production of drop-in chemicals and their feasibility. Based on the project results, three broad conclusions are delivered on what would be needed to realize the studied value chains:

- A policy for deployment of new technology is needed
- Policies should be designed for long-term stability
- New value chains may require new business models

Project S5

Project title:
Collaborative Chemistry Cluster Case study

Area:
Collaboration: Chalmers, Gothenburg University, SP & chemical cluster in Stenungsund

Approximate funding:
Swedish Energy Agency
The Stenungsund Cluster

Time:
2012-01-01–2015-06-30

Main researchers:
Maria Thomtén and Johanna Mossberg, SP, Coordinators
Main researchers at Chalmers: Simon Harvey and Roman Hackl

Contents:
The chemical companies in Stenungsund (AGA, Akzo Nobel, Borealis, Ineos and Perstorp) have formulated a common vision for Sustainable Chemistry 2030 (Vision Hållbar Kemi 2030). Under the vision the companies seeks to cooperate to achieve energy-efficient production, reduce greenhouse gas emissions and increase the use of renewable raw materials in order to develop more sustainable products.

In the ”4C - Collaborative Chemistry Cluster Case study” researchers from Chalmers, University of Gothenburg and SP Technical Research Institute of Sweden studied the interaction and collaboration within the realms of Vision Hållbar Kemi 2030.

The project built upon ”collaborative learning”, where participating researchers contributed knowledge even during the project. The intention was that companies, through the project, would acquire increased understanding about how both the possible technical options and guidance in organizational and structural barriers affect the ability to achieve the Vision by 2030.

During the work, the researchers, through a number of workshops and seminars, shared their findings and analyses with the collaborative enterprises and other stakeholders involved in the process - in order to contribute to the knowledge of vision-driven multi-party collaboration.

Examples of Results:
J. Jönsson, R. Hackl, S. Harvey, Ch. Jensen, A. Sandoff. (2012). From fossil to biogenic feedstock – exploring different technology pathways for a Swedish chemical cluster. ECEEE Industrial Summer Study Conference, Arnhem, The Netherlands, 11-14 September 2012, Paper ID 2-141-12

J.Mossberg, R.Hackl, S.Harvey, C.Jensen, A.Sandoff, G.Schaad, A.Furberg, M.Haggärde. (2014). Bridging barriers for multi-party investments in energy efficiency – A real options based approach for common utility systems design and evaluation. ECEEE Industrial Summer Study Conference, Arnhem, The Netherlands, 2-5 June 2014, Paper ID 4-017-14

A.2 Projects together with Göteborg Energi

Project G1

Project title:
Production of synthetic natural gas from gasified biomass - Process integration aspects

Time:
2007-10-01– 2013-08-30

Area:
Use of process integration methods and tools to identify synergy effects between different sub-processes required for production of synthetic natural gas (SNG) from gasified biomass

Collaboration:
Göteborg Energi (GoBiGas Project)

Approximate funding:
The Swedish Energy Agency: 1 826 490 SEK (40.0%)
Göteborg Energi AB: 2 440 234 SEK (53.4%)
E.ON Sverige AB: 300 000 SEK (6.6%)

Main researchers:
Stefan Heyne, Simon Harvey, Henrik Thunman, Martin Seemann, Chalmers and Ingemar Gunnarsson, Göteborg Energi

Contents:
The main goal was to quantify SNG production costs that can be achieved in a process that is fully optimized using process integration methods. Different process schemes were assessed using process simulation tools and process integration methods.
Another goal was to quantify CO_2 emissions reduction consequences associated with production and use of SNG produced from gasified biomass.

Examples of Results:
The project indicated that if process integration methods are applied systematically to the design of a Bio-SNG process, it is possible to achieve an overall process efficiency from wet biomass at (50 wt-% moisture) to Bio-SNG of approximately 70 % (LHV basis). A conservative estimate indicated production costs in the range 103–112 $€_{2010}/MWh_{SNG}$ and a CO_2 emission reduction potential of up to 205 kt CO_2/year for a plant with a gasifier sized for 100 $MW_{th,LHV}$ input. The variation of process performance for different choices of sub-processes for the major conversion steps – drying, gasification, gas cleaning, methanation, and gas upgrade – was analyzed using performance indicators evaluating the thermodynamic, economic and carbon footprint both on an isolated process level as well on an energy system level. By systematically synthesizing the overall process using process integration tools both the internal energy recovery as well as the cogeneration of power and heat could be maximized.

A.3 Projects together with PREEM

Chalmers has an ongoing cooperation with PREEM, with PREEM financing or co-financing projects. The projects below constitute this cooperation. In Phase 1, finishing formally 2013-12-31 (but several projects finished during 2014), the projects were combined into "clusters", as is shown below.

Project P1

Project title (Cluster 1):
Process integration of new processes in the design and operation stages

Area:
Energy efficiency measures in existing equipment and in integrated biorefinery-oil refinery processes

Collaboration:
Chalmers and PREEM

Approximate funding:
PREEM 2.4 Million SEK
Swedish Energy Agency 1.6 Million SEK

Time:
2010-10-11–2013-12-31

Main researchers:
Thore Berntsson, Chalmers
Matteo Morandin, Chalmers
Jean-Florian Brau, Chalmers
Per-Åke Franck, CIT
Anders Åsblad, CIT
Eva Andersson, CIT
Viktor Andersson, Chalmers
Eva Albers, Chalmers

Contents:

This project investigated opportunities for heat recovery, energy efficiency and reduction of CO_2 emissions in an oil refinery. The project considered strategic investment opportunities and included considerations related to operability and practical implementability of the suggested measures. The following sub-projects were included: (1) inventory of energy usage and existing heat recovery measures within the plant and opportunities for increased heat recovery considering safety, operability and availability aspects; (2) heat integration and energy system consequences of integration of a biomass gasification unit for production of hydrogen; (3) opportunities for production of biogas from algae integrated with the refinery. For all sub-projects, PREEM's refinery in Lysekil was used as a Case Study.

Examples of Results:

To quantify the importance of practical parameters, the process integration results in the existing equipment were reported on three different levels:

A. No restrictions on heat exchanging between different streams, i e all streams in all areas can be used for heat exchanging (an unrealistic alternative but showing the theoretically maximum possible potential).
B. All streams within each area/department can be used for heat exchanging, but no heat transfer between areas/departments.
C. Only streams in heat exchangers, which today are connected to utility streams (steam, air, water) are considered for heat exchanging.

The estimated potential for energy saving was approximately 210 MW, 125 MW and 27 MW, respectively, compared to the initial level of utility usage (450 MW).

With the aid of process integration tools promising integration and heat recovery opportunities were reported with hydrogen, HP steam and electricity outputs. Results highlight the potential for improvement of process performances by performing biomass drying with low quality refinery excess heat instead of biorefinery excess heat. This integration allows the export of additional HP steam to the refinery or electricity generation through an integrated steam cycle, which increase the efficiency of the biorefinery.

The algae part of the cluster was a small part in the end of the product and no explicit results were reported.

Project P2

Project title (Cluster 2):
CCS in oil refineries-technologies and system solutions

Area:
Technologies and systems for post-combustion CCS in oil refineries

Collaboration:
Chalmers and PREEM

Approximate funding:
PREEM 1.9 Million SEK
Swedish Energy Agency 1.3 Million SEK

Time:
2010-11-10–2013-12-31

Main researchers:
Filip Johnsson, Thore Berntsson, Fredrik Normann, Viktor Andersson, Stefanìa Òsk Gardarsdòttir (all from Chalmers)

Contents:

This project investigated post-combustion CO_2-capture with focus on the chilled-ammonia process. The project has produced data and models for process integration of the ammonia process. The results show a potential for ammonia to substantially lower the energy requirement of CO_2 capture, compared to amines. However, the energy requirement of the ammonia process is highly dependent on operating conditions, with slip of ammonia as the single largest explanation. Oil refineries have favorable conditions for post-combustion absorption of CO_2 with ammonia as 1) they often has access to low temperature cooling water, 2) there is experience of operation of similar processes, and 3) they consist of processes with high CO_2 concentrations. Future work should focus on the most suitable sub-process within a refinery, which will be a good demonstration project for efficient carbon capture. In discussions with Preem it has been concluded that the hydrogen production is especially interesting.

Examples of Results:

A model for calculation of absorber behavior below 20C has been established and the importance of changing the desorber temperature, considering use of excess heat for heating, has been quantified. Opportunities for CCS in the five chimneys at PREEM showed that four of them could be good candidates. With the combined knowledge of absorber and desorber behavior, the process simulation results, combined with the process integration results from Cluster 1, showed that reducing the absorber temperature could lead to higher CO2 capture using only excess heat. However, the effect was smaller than expected due to the higher desorption heat needed at lower temperatures, which was identified in the project.

Project P3

Project title (Cluster 3):
Isomerisation for improved properties in cold climate and thermic decarboxilysation for lower hydrogen consumption

Area:
Chemical treatment of biomass based diesel

Collaboration:
Chalmers and PREEM

Approximate funding:
PREEM 2.8 Million SEK
Swedish Energy Agency 1.2 Million SEK

Time:
2011-01-01 – 2013-12-30

Main researchers:
Börje Gevert, Chalmers
Shanmugam Palanisamy, Chalmers

Contents:
In this project the focus has been to use vegetable oils (i.e. FAME; Fatty Acid Methyl Ester) as raw material for producing biofuels. The first generation biofuels were produced via transesterification, which provides a fuel with relatively high oxygen content. To produce a biofuel that potentially can replace conventional diesel, there is a need for a process that eliminates the oxygen in the fuel. One such method is hydrotreatment (or hydroprocessing), as in the refining process is done after transesterification to get a diesel-like fuel. The project has focused on methods to use bio-based fat-rich feedstocks for production of biodiesel with improved cold properties. Another focus has been to minimize the need for hydrogen in the process. In order to reduce the hydrogen consumption a combination of thermal and catalytic hydroprocessing of FAME and/or rapeseed oil has been used.

Examples of Results:
The results showed that non-cartalytic cracking of FAME can be facilitated by preheating and that hydrogen treatment of resin acid creates promising properties for mixing with diesel fuel.

Project P4

Project title (Cluster 4):
Biorefinery Concepts in Oil Refineries

Area:
Use of biomass in petrol and diesel production for GHG Mitigation

Collaboration:
Chalmers and PREEM

Approximate funding:
PREEM 2.4 Million SEK
Swedish Energy Agency 1.6 Million SEK

Time:
2010-11-10–2013-12-31

Main researchers:
Thore Berntsson, Chalmers
Daniella Johansson, Chalmers
Per-Åke Franck, CIT

Contents:
In this project, opportunities for economically and environmentally interesting solutions for increased use of biomass in a refinery have been studied. It has been partly performed as a part of the big project Pathways to a European Sustainable Energy System. Different opportunities for CCS via post-combustion and for introduction of biomass as raw material have been studied. The CCS systems have been based on MEA as working fluid and in the biomass systems Fischer-Tropsch diesel or hydrogen have been produced via gasification. Opportunities for process integration have a strong influence on the economic and environmental characteristics of these processes

Examples of Results:
The main results consisted in the development of models for simulation of complex biorefinery concepts and integration opportunities for them as well as a detailed economic and CO_2 emission comparison between the alternatives, using the ENPAC tool. A comparison between CCS and FT-diesel showed that the result depends heavily on possible future levels of CO_2 emission costs and that CCS is advantageous only at very high such costs.

Project P5

Project title:
Analysis of differences between theoretical and practically achievable potentials for heat integration

Area:
Via case studies identify how achievable process integration opportunities are influenced by operational and control aspects

Collaboration:
PREEM and Chalmers

Time:
2014-01-01 – 2016-12-31

Approximate funding:
3.4 Million kronor

Main researchers:
Simon Harvey, Chalmers
Elin Svensson, Chalmers
Sofie Marton, Chalmers

Contents:
Increase knowledge about the role control, operational and risk aspects play for achievable levels of process integration as opposed to theoretical levels

Examples of results:
None so far

Project P6

Project title:
Alternative biomass types as feedstocks in biorefinery concepts

Area:
Types of algae suitable in biorefinery concepts

Collaboration:
PREEM

Approximate funding:
4.15 Million kronor
Time:
2014-01-01 – 2016-12-31

Main researchers:
Eva Albers, Viktor Andersson, Chalmers

Contents:
Evaluation and identification of opportunities for cultivation of different types of algae for use in biorefinery concepts. For the most interesting ones, technical and process integration aspects will be studied, including energy balances and CO2 emissions.

Examples of Results:
None so far

Project P7

Project title:
Methods and tools for evaluation of dynamic aspects when designing more efficient industrial energy systems, MoveDynE

Area: Control issues related to industrial energy efficiency projects

Collaboration:
PREEM

Approximate funding:
PREEM 2.3 Million kronor
Vinnova 2.3 Million kronor

Time:
2014-09-01 – 2017-08-31

Main researchers:
Karin Eriksson, Industriell Energi, Chalmers Industry Technology,
Torsten Wik, Chalmers
Elin Svensson, Chalmers

Contents: The aim of this ongoing project is to develop methods and software tools that can be used in combination with existing tools for analysis of industrial energy systems in order to investigate stationary and dynamic control aspects of such systems. It is anticipated that such a combination will provide new insights and lead to innovative process design configurations that would not have been identified otherwise.

Examples of Results:
None so far

A.4 Projects together with Södra

Project Sö1

Project title:
Strategic energy efficiency and development towards biorefineries in the pulp and paper industry

Area:
Explore the optimal design for a partially/totally converted kraft pulp mill into dissolving pulp mill in terms of being energy efficient and consequently cost-effective.

Collaboration:
Chalmers and Södra

Approximate funding: 3 MSEK

Time: not available

Main researchers:
Valeria Lundberg, VoM, Chalmers
Elin Svensson, VoM, Chalmers
Thore Berntsson, VoM, Chalmers

Contents:
The opportunities for integration between different parts of a pulp mill when it produces dissolving pulp, including new equipment for e. g. hemicellulose precipitation and treatment, have been studied in detail. The possible bottlenecks in the recovery cycle have been identified and the production capacity versus different levels of equipment upgrading has been studied.

Examples of Results:
The present situation for the existing equipment, especially, cooking plant, recovery boiler and evaporation plant, regarding opportunities for capacity increase with no or small investments is crucial for the economy for producing dissolving pulp. Lignin precipitation for debottlenecking the recovery boiler can be one economically interesting measure. The cooking plant can in some circumstances need to be upgraded up to 70 % in order not to decrease production capacity with dissolving pulp.

A.5 Projects together with the Regional Industries on the Swedish West Coast

Project R1

Project title:
Advantages of regional industrial cluster formations for integration of biomass gasification systems

Area:
Factors influencing optimal location of large biomass gasification plants

Collaboration:
Chalmers and IVL, Perstorp Oxo, Göteborg Energi, EoN, PREEM, Swedish Energy Agency

Approximate funding: 6.5 MSEK

Time: 2009 – 2015/09

Main researchers:
- Kristina Holmgren, Industrial PhD student (Department of Energy and Environment, Division of Heat and Power Technology and IVL Swedish Environmental Research Institute)
- Thore Berntsson, Professor (Department of Energy and Environment, Division of Heat and Power Technology)
- Tomas Rydberg IVL Swedish Environmental Research Institute)
- Eva Andersson (CIT Industriell Energi)

Contents:
The objective is to identify possibilities to increase resource efficiency by industrial cluster formations in the integration of biomass gasification systems. Scenario analysis for possible development routes will be made using the Västra Götaland region as a case study. As part of the study possible development routes (technology, investments in new production units, products etc.) will be identified and scientific models will be used to describe process integration in existing industries and to determine costs and CO_2 emissions for the development routes at different future price and policy instrument scenarios.

The results will show differences in technology, CO_2 emission reductions, energy efficiency and economy. The results will also include identification of crucial parameters for potential cluster formation for integration of biomass gasification systems. The parameters can be used in order to evaluate the potential of other European regions.

Examples of Results:
With production of SNG, the highest conversion efficiencies can be achieved. In principle, the CO_2 mitigation level is highly influenced of what the biomass-based product replaces, with coal having the highest influence, followed by oil and natural gas. In all cases, CCS can improve this substantially. Production of methanol for the transportation sector of olefins for production of biomass-based materials results in approximately the same level of CO_2 mitigation. Dry biomass results in higher overall efficiencies and opportunities for power production, but wet biomass can be dried by internal excess heat and thereby improve the energy balance in a situation where excess heat cannot be used otherwise. Overall CO_2 and economic comparisons between the different development routes are yet to be finalized.

Project R2

Project title:
Sustainable use of industrial excess heat-competition between internal heat recovery and export to a district heating system

Area:
Rational use of excess heat internally or externally

Collaboration:
Chalmers with SP and IVL plus 11 regional industries

Approximate funding:
Regional industries 2.0 MSEK
Västra Götalandsregionen 0.4 MSEK
Swedish Energy Agency 1.3 MSEK

Time:
2013-09-01–2014-12-31 (continuation in a Phase 2 planned between 2015-01-01 and 2015-06-30)

Main researchers:

Lina Eriksson, SP (and industrial PhD student at Chalmers)
Simon Harvey, Chalmers
Matteo Morandin, Chalmers
Rickard Fornell, SP

Contents:
In Stenungsund or PREEM, the possible amount of excess heat depends on:

- the projected situation 2030 regarding energy efficiency, capacity and degree of biomass used
- degree of integration between the industries in Stenungsund
- the incoming and the return temperature of the district heating water

At given values of these parameters, possible amounts of available excess heat are calculated as well as assess the investment cost when all or a part of this is utilized. In addition, the optimal share of heat from each of the cluster industries in the Stenungsund case is calculated. In the project total site analyses are carried out and results from other projects, e.g. S3 and P1, are incorporated.

Examples of Results:
The possible total excess heat amounts available are more than 160 MW, but decreases if with increasing internal use (0, 20 and 50 MW of internal heat recovery have been used in the study). The investment cost for a water system, collecting heat from the individual industries and delivering it to a district heating pipe line, has been calculated as a function of the size of the excess heat.

Project R3

Project title:
Use of New Industrial Excess Heat in the West Swedish District Heating Systems, including economic, sustainability and policy instruments aspects

Area:
System and sustainability consequences of industrial excess heat usage

Collaboration:
Chalmers and IVL with 11 regional industries

Approximate funding:
Regional industries 760 kSEK
Västra Götalandsregionen 250 kSEK
Swedish Energy Agency 500 kSEK

Time:
2013-09-01-2014-12-31

Main researchers:
Akram Sandvall, Chalmers
Erik Ahlgren, Chalmers
Jenny Arnell, IVL,
Tomas Ekvall, IVL

Contents:
The need for new excess heat in the district heating system in West Sweden in the future depends on:

- Availability of excess heat from other sources in the region
- Assessment of the total need in the district heating system
- Assessment via the MARKAL tool on mix of old and possibly other new heat production systems

Assessments of these parameters have been done. With given values of these, the optimal mix of production technologies and excess heat deliveries have been calculated at different values of energy prices, policy instruments, investment costs and annuity factors.

Furthermore, main sustainability parameters have been defined and the influence of different types of policy instruments has been investigated.

Examples of Results:
An important general result is that the economic benefits of utilizing heat from Stenungsund to Gothenburg are too small for justifying an investment, even at possible future positive economic input parameters for such an investment. The main parameters influencing the economy are the pipe line cost, the cost of biomass and, partly, other energy prices, the annuity factor.

One main parameter influencing the carbon footprint of investing in a pipe line is the future CO2 emissions from the marginal electricity production system in the North European power system. 14 important sustainability aspects have been identified.

The economy is highly influenced by the development of policy instruments levels and types of instruments.

Project R4

Project title:
The influence of type of market model on Opportunities for industrial heat to district heating systems

Area:
The importance of business and market models for cluster cooperation

Collaboration:
SP and 11 regional industries (this project has been included due to the close cooperation with Projects R2 and R3)

Approximate funding:
Regional industries 400 kSEK
Västra Götalandsregionen 280 kSEK
Swedish Energy Agency 570 kSEK

Time:
2013-0901–2015-02-28

Main researchers:
Magnus Brolin, SP

Contents:
The aim of this project is to analyze the impact of different market designs on the economic incentives and risks for suppliers of industrial excess heat. This includes identifying new market roles such as operators of internal heat supply systems within industry clusters, or jointly owned enterprises operating district heating connections between cities and areas. Focus in this project is on the role of the suppliers of industrial excess heat, but in order to fully understand the role of excess heat in the system and the interaction with other actors on the regional heating market, a more holistic view is required. Hence, the project also includes analyzes related to other actors within the system.

Examples of Results:
None so far

Project R5

Project title:
Scientific Coordination of Projects R2, R3 and R4

Area:
Coordination and synthesis of technical, economic and environmental aspects of using industrial excess heat in the West Swedish region

Collaboration:
Chalmers, SP and IVL with 11 regional industries

Approximate funding:
330 kSEK from the Chalmers Energy Area of Advance

Time:
2013-09-01–2015-03-30

Main researcher:
Thore Berntsson

Contents:
In the three research projects, the following main aspects are dealt with:
R2: Possible amounts and temperature levels of excess heat from the Stenungsund industrial cluster or PREEM, depending on future decisions on improved energy efficiency
R3: Technoeconomic opportunities for use of excess heat in the Swedish West Coast district heating systems at different future scenarios and comparison with competing technologies, as well as sustainability aspects of a pipeline between Stenungsund and Gothenburg and influence, in principle, of different future policy instruments
R4: Influence on distribution of costs and profits with a pipeline of different future business and market models
In order to draw conclusions from this project package, a coordination regarding parameter levels, scenarios for energy costs and policy instruments, scenarios for future amounts of district heating, etc, was considered necessary. In addition, a synthesis report also including a summary of the package was included

Examples of Results:
- The possible amounts of excess heat from Stenungsund are high but dependent on the future level of energy efficiency measures (20 and 50 MW were investigated) and degree of future biomass use (not investigated in detail in this phase of R1).
- The economic opportunities depend to a high extent on the future development of energy prices and policy instruments, investigated via two main future energy market scenarios, but the profit is between 0 and 150 MEuros in the time period 2020-2050. This profit is calculated as the difference of using a pipeline and of not using it under the assumption that a relatively large part of today's excess heat usage in the district heating network will disappear in the future. Otherwise this profit would be very low or negative
- Some major uncertain parameters, influencing the economic performance to a high extent, are pipeline cost, energy (especially biomass) price development and future policy instruments
- The total influence on GHG emissions depend to a high extent on the future build margin power production technology in the grid. If this technology is coal power condensing plants, there would in most cases be no benefits with a pipeline, but if this technology is natural gas combined cycle or even lower-emitting technology, a pipeline would contribute to a global emission reduction
- Business and market models influence the economic viability of such projects significantly

Project R6

Project title:
Carbon Capture and Storage in the Skagerrak/Kattegat region

Area:
Regional opportunities for CCS

Collaboration:
Chalmers with Gothenburg University, Tel-Tek (Norway), Preem Lysekil, refinery, Preem Göteborg, refinery, Esso Slangentangen, refinery, Borealis Stenungsund, ethylene cracker, Yara Porsgrunn, ammonia plant

Main researchers:
A large group from the participating organisations.

Approximate size of project:
Funding by industries, Swedish Energy Agency-INTERREG and Gassnova/CLIMIT. Main funding:

- Swedish Energy Agency-INTERREG 11 Million Norwegian kronor
- Gassnova/CLIMIT 8 Million Norwegian kronor (partly associated project)

Contents:
This project explored the feasibility of establishing a Carbon Capture and Storage (CCS) infrastructure in the Skagerrak/Kattegat region of southern Scandinavia. This involves assessment of the technical and economic parameters of the complete CCS chain and, in particular, identification of possible storage locations.

Examples of Results:

1. One of the main problems relates to the time-consuming procedures required to implement appropriate legal frameworks and to obtain permits to establish a CCS network, as well as agreements for the transportation of CO2 across national borders.
2. Qualification of the Gassum formation as a candidate CO2 storage site in the Skagerrak/Kattegat region requires further investigation. The responsible national authority should initiate the relevant work and include this site as part of the mapping of CO2 storage sites on the Norwegian continental shelf. Until this is accomplished, there will be little motivation for industries to proceed with work on the upstream part of the CO2 chain.
3. There is a lack of economic incentives for building the CCS network. Even with a future CO2 emission cost of 45 €/tCO2 there is a gap of 10–20 €/tCO2 to be covered to meet the cost of the least expensive capture system described in the present study. This gap is even larger if the transport and storage infrastructure is constructed and operated for a network of less than full capacity, as will undoubtedly be the case for the establishment of the transport and storage infrastructure over time.

Project R7

Project title:

Sustainable use of energy carriers in the KASK region

Area:
Analysis of pathways to meet EU, national and regional targets for CO_2 emissions, energy efficiency and penetration of renewable energy in the Kattegatt-Skagerrak region (KASK).

Collaboration:

Chalmers/Energy Technology, Chalmers/Heat and Power Technology, CIT-IE, PROFU, Tel-Tek (Norway),

Main researchers:

A large group from the participating organisations.

Approximate size of project:

Project period: 2013-01-01 through 2014-12-31
Funding: Activities in Norway and Sweden were funded separately. The funding level for the Swedish and Norwegian activities were 4.3 MSEK and 4 MNOK, respectively.
Breakdown of funding for the Swedish activities: Västra Götalandsregionen (23%), EU INTERREG Iva (44%), Chalmers internal funding (12%), Göteborg Energi (12%), Preem (5%), Elforsk (5%).

Contents:

The aim of this project was to investigate possible pathways towards a sustainable energy system in the Västra Götaland (VGR) and Halland counties which belong to the Kattegat Skagerrak (KASK) region. The work took into consideration local, regional, national and EU based targets and plans for improved energy efficiency, increased deployment of renewables and reduction of production-based CO_2-emissions. A special focus was placed on energy efficiency savings potential in the building sector and in the energy intensive industry in the region as well as on large-scale deployment of renewables in the electricity generation sector which is a fully integrated part of the European electricity sector.

Examples of key results and conclusions:

1. The combined energy savings potential for the Preem refinery in Lysekil and the chemical cluster in Stenungsund is approximately 500 GWh/yr of fuel in the short term (2020) increasing to 1,300 GWh/yr in 2030, corresponding to potential CO_2 emissions reduction of 120 and 330 kton/yr respectively. However, to meet significant CO_2 emission reduction requirements in the long-term, the industries in the region must aim for radical change. Such changes could include a switch to biomass feedstock, adopting new process technology and implementation of ambitious programs to maximize process energy efficiency and CCS.
2. The energy savings potential in the building stock in the region was modelled. Applying a package of Energy Conservation Measures (ECMs), up to 16 TWh/yr, mostly heat, could be saved. The single most efficient measure would be to install ventilation systems with heat recovery. Considering only those measures where the cost of the measure is lower than the cost of the saved energy, i.e. a techno-economic potential, up to almost 6 TWh/yr could be saved in the regions building stock of the region.
3. There is a large potential for renewable energy in the KASK-SE region. Under the assumption that the region maintains a strong forest industry and there is a positive economic development globally, up to 6 TWh/yr of additional biomass could be produced within the region. Likewise, under the existing subsidy regime, consumer based solar PV installations could reach production levels up to 2.5 TWh/yr of electricity. Utility-scale PV installations could

raise this potential substantially but this would require subsidy schemes dedicated for this purpose. Furthermore, the study showed that there is a large potential for cost-efficient onshore wind power in the KASK-SE region. Up to 10 GW wind power capacity could be installed at electricity prices between 65 to 70 € per MWh, generating between 20 and 25 TWh annually. The analysis also suggests that continued expansion of wind power within the region should focus on onshore sites due to the considerably higher cost of offshore wind power, at least under the existing financial support schemes.

A.6 Projects Directed towards EU Cooperation

Project E1

Project title:
R4R – Chemical Regions for Resource Efficiency
Region Västra Götaland Stenungsund, Sweden

Area:
Exchange of knowledge and best practices in the area of resource efficiency by enhanced triple helix collaboration within and between some of the most process intensive European regions

Collaboration:
SP Project Leader. Other organisations Chalmers, BRG, Borealis,

Approximate funding:
(For the whole project, not only Västra Götaland)
EU FP7: 2 579 711 EUR
Total: 2 740 397 EUR (funding for partners in Västra Götaland: 555 155 EUR, 20% of total funding)

Time:
Start date: 2012-12-01, End date: 2015-10-31

Main researchers:
- Anna Sager, SP Technical Research Institute of Sweden
- Anna Widerberg, SP Technical Research Institute of Sweden
- Hans Larsson, Business Region Göteborg AB
- Simon Harvey, Chalmers University of Technology
- Eva Andersson, Chalmers University of Technology
- Lars Josefsson, Business Region Göteborg (West Sweden cluster coordinator)

Contents:
Societal challenges, RTD and innovation offer opportunities to rejuvenate and transform the resource intensive chemical and process industries into eco-efficient high-tech solution providers, by switching to bio-based feedstock, improving efficiency of processes, by recycling waste materials and by looking at industry as an integrated system (industrial symbiosis). Objective of the Chemicals Regions for Resource Efficiency project (R4R) is to overcome European fragmentation of ambitious and innovative regions, to improve triple helix collaboration within and between some of the most process intensive European regions by

1) analyzing and benchmarking successful regional technology innovation systems (TIS) within six complementary regions that target three specific technology domains (alternative feedstock, resource efficient processes and recycling);
2) based on this analyses improving synergies between regions through aligned regional, national and European Joint Action Plans and innovation roadmaps;
3) promoting internationalization, with a strong focus on SMEs, through an international cluster platform on resource efficient regions, embedded in the SusChem ETP;
4) disseminating a toolset and experience on technology innovation system analyses (TIS), to European regions in cluster platform.

Accelerating innovation in this domain promises enormous impact in resource efficiency by 2030 i.e. a major CO2- footprint reduction of up to 50%, meaning reducing 0.5 GtCO2e annually, a potential 10-

fold increase in (bio)renewable raw materials as feedstock (e.g. incl. end of life recyclables), a 30% reduction in primary energy consumption and a 20% reduction in raw materials net use (e.g. mineral, chemical, bio-based feedstock) and secondary (e.g. water and other auxiliary materials) materials, by increasing chemical and physical transformation yields. R4R targets increased global competitiveness and new high-quality jobs through a sustainable European process industry.

Examples of Results:
Main result so far is the IS3 EU H2020 application. The application was submitted in September 2014. Unfortunately the application was not funded. Hereafter follows a summary of the proposal:

The IS3-project aimed at demonstrating and accelerating the possibilities towards dramatic resource efficiency gains through multi-stakeholder Industrial Symbiosis (IS) within large multi-sectorial industrial parks and clusters, including massive resource and energy intensive process industries such as chemicals, steel, aluminium, agro-food and cement producers. The project aimed at bringing together 6 regional multi-sectorial resource and energy intensive industrial parks and clusters in different European countries that share the objective and commitment to leverage on large resource (energy and materials) waste and side-streams. To achieve these resource efficiency gains, IS3 aimed to showcase 4 techno-economic and 3 non-technical innovative IS demonstrations, and tackle key techno-economic, financial, organizational and social bottlenecks associated with them. Through these cases, the partners could jointly experiment, develop, fine-tune and demonstrate an improved and innovative IS identification and incubation process and toolbox, targeted at overcoming the key bottlenecks of multi stakeholder IS. Finally, the project aimed at setting the base for a regional and cross-border European "industrial resource and knowledge base" to identify novel waste-to-resource opportunities, and ignite a large number of regional and inter-regional IS business cases, including novel opportunities for SMEs to develop new businesses that leverage on the valorization of industrial side streams. The IS3 project was estimated, via the above work, to lead to energy efficiency gains of more than 550 GWh/year and a reduction of more than 192 kTon/year of CO_2 eq.