Research projects 2008–2017

Environmental Technology Research Funded by Swedish Research Council Formas

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Environmental technology projects are well represented in the research that Formas supports. Examples of these projects can be studies to develop new smart windows, new efficient energy technologies and improved systems for recycling, as well as governing policies for environmental technologies.

Environmental technology and cleantech innovations have had, and will come to have, an increasingly important global role in reducing environmental burdens and contributing to sustainable development. Sweden therefore needs a strong and internationally competitive environmental technology sector.

Formas defines environmental technology in broad terms: *"Environmental technology includes such products, systems, processes and services that provide distinct environmental advantages in relation to existing or alternative solutions when viewed from a lifecycle perspective."*

Research and development plays an important role. Trees and other plants, as well as their waste products, must be utilised more efficiently than they are today, for example in biorefineries – for the development of green materials and bioenergy. New technologies and new systems are needed for purifying water and sewage, decontaminating land, managing waste and recycling. There is an obvious potential for more efficient energy use within the built environment and agricultural sciences. New environmental technology initiatives are often characterised by a holistic approach, with a focus on system innovations and system solutions with major environmental relevance. The highest priority is placed on lifecycle considerations.

To apply a holistic approach also necessitates social science research, for example concerning needs, governance and regulatory policies.

This catalogue presents a selection of 160 environmental technology projects within the different research and responsibility areas of Formas. We hope that the projects can provide inspiration for new research, new systems, methods, policies, products and processes.

We also hope that the catalogue will encourage the formation of new contacts and networks.

We wish you an enjoyable read!

Conny Rolén
Senior Research Officer

Ingrid Petersson
Director General

External view

In 2015 two very important steps were taken towards transitioning to a sustainable society. The Paris Agreement highlighted how we can reduce climate emissions globally and concomitantly reduce the global rise in temperature to 1.5 to 2 degrees Celsius. In addition the UN 2030 Agenda for Sustainable Development was adopted, which highlights seventeen areas where ambitious goals must be fulfilled if we are to achieve a sustainable society.

The failings of linear economy models have become increasingly obvious and last year the EU adopted a circular economy model as its guiding principle. This means that we must utilise raw materials in a more efficient manner, use more renewable raw materials, design products that are more durable and can be recycled, build cities in a more sustainable way, process waste as part of a circulation cycle, transport people and goods using renewable energy and, most difficult of all, we must change our consumer habits.

Sweden aims to be part of the vanguard in all of these areas and this has led to the establishment and growth of companies that can deliver solutions to these challenges for an international market.

When I now look at the diversity of environmental technology projects that have been funded by Formas over the past decade I am struck by how many of these projects can contribute to solving the challenges described above and that also are aligned with the Swedish goverments areas for collaboration programs introduced in the spring of 2016. It should be emphasised, however, that I do not have the possibility to judge all of the effects many of the projects have had and will have, as some of these are still ongoing.

Examples of important areas included in the environmental technology projects funded by Formas are recycling and recovery of biological resources. In linear production strategies the products and the waste from production have previously been treated as waste. But to reach the long term goals we must find sustainable solutions for the recovery of plastics, textiles, solar cells, mining residues, sludge, batteries, used cars etc. The Formas projects provide good advice about what some of the solutions could be, but the projects also provide information about which solutions are not likely to work well.

A major challenge in fulfilling our climate commitments is the replacement of fossil raw materials as the source materials for product and fuel production. All forest source materials are not currently utilized to their full potential. The projects funded by Formas demonstrate a great wealth of inventiveness to enable better use of wood as a source material.

Östen Ekengren
Executive Vice president
IVL Swedish Environmental Research Institute

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Introduction

Just over half of the funding awarded by Formas is allocated to support projects in the annual open call within the three responsibility areas of Formas; Environment, Agricultural Sciences and Building and Planning. The remaining research funding is allocated to targeted initiatives, which are calls announced within defined topic areas for which there is an urgent need for research and knowledge. Environmental technology projects exist within all of the responsibility areas of Formas.

Environmental technology in different Formas programmes and collaborations

In 2007 Formas and Vinnova, Sweden´s Innovation Agency were commissioned by the Swedish Government to jointly develop a research strategy for the environmental technology area. Based on this research strategy Formas then introduced an Environmental Technology Program for the period 2007–2012. This program comprised four calls in collaboration with Vinnova and the Swedish Energy Agency, all with co-financing from the commercial sector. In total this program comprised around SEK 210 million, with half of the funding awarded co-financed by the commercial sector.

Over the period 2010–2014 Formas also participated in an ERA-Net (EU collaboration) for environmental technologies and environmental innovations, EcoInnovera. In this collaboration 25 organisations, research funding bodies and research administrators from 20 EU countries participated. Formas participated in the two calls launched by Eco-Innovera.

Another program with a major environmental technology content was the program that was run in collaboration with the Swedish construction industry's innovations centre, BIC (a forerunner to the Swedish Centre for Innovation and Quality in the Built Environment, IQ Samhällsbyggnad). Formas and BIC jointly announced a large number of both national and international calls.

A number of the strong research environments that have received funding from Formas in recent years have also had an environmental technology focus.

This catalogue presents summaries of projects that have received funding within these various programs and collaborations. The other projects have presented awarded funding through the Formas open call. In total 160 projects are presented.

Formas also collaborates within the environmental technology area by having the task of providing state funding for research in collaboration with other various research organisations. Such financing for example is allocated to IVL, the Swedish Environmental Research Institute and the Swedish Institute of Agricultural and Environmental Engineering, JTI.

This catalogue is subdivided into the following sections: Natural Resources in the Circulation Cycle, Biological Resources, Energy, New and Advanced Materials, Sustainable Building and Planning– Technologies and Processes, and Environmental Protection Technologies.

Natural Resources in the Circulation Cycle

These projects examine the recycling of materials – plastics, metals, rare earth elements, cotton, sewage, agricultural waste and other organic waste.

Eco-efficient recycling of plastics

The aim of the project was to identify and propose resource and eco-efficient solutions for improving the level of recycling of plastics from highly qualitative products, such as cars and electronic products, as well as to identify obstacles preventing the efficient recovery of materials. 21 companies and organisations from different parts of the value chain were involved.

Plastic waste from cars and electronic products was collected and analysed. The bumpers from different makes of cars were treated in a material recovery process. The properties of the material were then analysed and compared with new raw materials. Material from electronic waste was crushed and different types of mixtures were analysed and compared with new raw materials.

There is the potential to recover more plastic from recycled vehicles and electronic products. Recovered plastics from car bumpers can be used in the production of new vehicles, but primarily for parts that are exposed to lower loads. The development of a simple pre-sorting of electronic plastics provides the opportunity to produce 80 percent pure plastic fractions in the recovery process.

By identifying waste streams for construction plastics, as well as potential markets and products, the material flow of recovered materials back to the market can be improved.

Project title
Sustainable recycling of plastics – closing the lifecycle of polymeric materials in engineering applications

Project number
2008-2153
Environmental Technologies Program

Project duration
2009–2011

Funding awarded
SEK 4 152 000

Project leader
Sigbritt Karlsson
KTH
sigbritt@kth.se

Recycling photovoltaic cell waste

Electricity production using photovoltaic cells is one of several alternatives in a future energy mix. There are several different types of potential photovoltaic systems, with varying development potential and efficiency. One variant that has been shown to be efficient and flexible is thin film solar panels, which among other things include what are known as CIGS-cells. These are highly efficient but are costly to produce, as they contain expensive and rare metals such as indium and gallium. In addition, almost 50 percent of the expensive CIGS-material is lost during the manufacturing process.

The researchers have developed and patented a method for recycling highly pure selenium (>99.999 percent) from the manufacturing waste. They have also demonstrated how other pure metals can be recycled using

Project title
Recycling of production residue from photovoltaic cell manufacturing

Project number
2008-2162
Environmental Technologies Program

Project duration
2009–2011

Funding awarded
SEK 1 536 000

Project leader
Christian Ekberg
Chalmers
che@chalmers.se

Doctoral student Anna Gustafsson.
Photograph: Christian Ekberg

electrochemical or fluid extraction methods. The processes developed have been tested in laboratory and pilot scale.

The next step in the work is to install the recycling process directly at the manufacturing unit for maximal efficiency and recycling of materials in the process. In a future project a natural continuation will be to investigate the recycling of decommissioned or obsolete photovoltaic cells.

Project title
Biogas production from distiller´s waste and Quality and function of anaerobic digestion residue – impact of process temperature and type of input material Digested mash as an agricultural fertilizer

Project number
2008-2174
Environmental Technologies Program
2009–2049

Project duration
2009–2011
2009–2014

Funding awarded
SEK 1 558 000
SEK 435 000

Project leader
Anna Schnürer
SLU
anna.schnurer@slu.se

Optimisation of industrial biogas production

In Sweden biogas is produced from different types of organic waste. Biogas is produced via a complex microbiological decomposition process that leaves a nutrition-rich digested mass (sometimes referred to as bio-fertilizer) that can be used as an agricultural fertilizer. To achieve profitability in biogas production facilities a stable process that gives high production of biogas of good quality is required. It is also important that the decomposed mass has a high plant nutritional value and contains low amounts of contaminants. The researchers have examined industrial biogas production in two different projects.

In one project, which was carried out in collaboration with Tekniska Verken AB, the goal was to optimise biogas production from distillery waste, a by-product from the production of ethanol. Distillery waste produces a lot of biogas, but the gas that is formed contains high concentrations of hydrogen sulphide. Different operational strategies were examined to reduce the activity of hydrogen sulphide producing bacteria. Biogas reactors were studied in laboratory and industrial scales, using chemical and microbiological analyses. Distillery waste functioned well as a substrate, but it was difficult to steer the process towards reduced hydrogen sulphide production. Mixing with other materials, as well as the addition of micronutrients and ferric chloride was necessary to achieve stable and efficient operation and to reduce the problem of hydrogen sulphide formation.

Biogas reactor in the laboratory at Tekniska Verken AB.
Photograph: Jan Moestedt

The second project investigated the importance of the digester operating temperature on the chemical composition of the digested mass, with a focus on different phenols. Phenols are naturally occurring in certain materials but can also be formed in the biogas production process. These can inhibit the microbial systems in the soil when the decomposed mass is used as a fertilizer, but can also inhibit the microorganisms in the biogas production process. The results have demonstrated that operating temperatures above 50 °C result in no detectable turnover of phenols. At lower operating temperatures decomposition occurs very rapidly and the resulting decomposed mass therefore has low phenol concentrations.

Polyethylene from renewable raw materials

Is it better for the environment to produce the most common plastic, polyethylene, from the biomass instead of from oil? The researchers investigated sugar cane from Brazil and wood from Sweden using fermentation to produce ethanol (from sugar cane or wood) or pre-gassing (of wood) followed by methanol synthesis. The process steps that impact the environment most were identified in order to indicate the important needs for technological developments. The project developed methods, in the first instance lifecycle analyses, to assess climate effects of using the biomass. Representatives of TetraPak, Trioplast, Borealis and Stena Metall were associated with the project.

From a climate point of view the production of polyethylene from the biomass was shown to be better than the fossil-based alternative. However, there is great uncertainty in the assessments, partly in evaluating the effects of changes in land use and partly in evaluating how carbon dioxide is taken up and released at various time points when forests are grown and felled. In terms of other environmental effects, such as acidification and eutrophication, the biobased process pathways need to be improved. The production of enzymes was shown to be crucial for the process pathways in which forestry raw materials were fermented into ethanol. The environmental impact of enzyme production or dosing needs to be substantially reduced. (A similar project, 2014-181, can be found in the Biological Resources chapter.)

Project title
Conventional plastics from renewable raw materials – A sustainable alternative?

Project number
2009-670

Project duration
2010–2012

Funding awarded
SEK 2 456 000

Project leader
Anne-Marie Tillman
Chalmers
anne-marie.tillman@chalmers.se

Project title
Removal and recovery of metals from municipal solid waste incineration ash and slag

Project number
2010-1572

Project duration
2011–2013

Funding awarded
SEK 5 757 000

Project leader
Britt-Marie Steenari
Chalmers
bms@chalmers.se

Recycling of metals from ash and slag

Sweden has a well-developed district heating network and a great need for heating. We have therefore been able to make use of the majority of the energy content in household waste. But ash from waste is a controversial material, especially fly ash, as this contains a number of metals in relatively soluble forms. Such ash must be transported to special disposal sites, at high cost. Taking into account the fact that fly ash contains around 0.5 percent copper and higher percentages of zinc, disposal of this material means loss of valuable metals. This is one of the motivating factors behind the project; the other is the detoxification of the ash by removal of the hazardous metals.

The researchers have worked to optimise leaching the metals out from the ash and separation of the metals using chemical extraction techniques so that the metals can be reused. They have also investigated how the metals are bound chemically in the ash in order to understand how the leaching process works. They are also working with electrolytic separation of the metals from the leaching fluids.

Fly ash from different facilities varies in how easily the metals can be leached out from it, but the researchers have now developed a method that works for different types of ash. The method has been demonstrated to make it possible to recover 70–90 percent of the copper and 75–80 percent of the zinc from the ash, at the same time as most of the lead and cadmium is also removed.

Project title
Economic and environmental performance of metal recovery from disconnected city power grids

Project number
2010-2261
Environmental Technologies Program

Project duration
2011–2013

Funding awarded
SEK 2 999 000

Project leader
Joakim Krook
Linköping University
joakim.krook@liu.se

Recycling of metals from urban power grids

Underground electricity cables comprise one of the largest stores of copper in the built environment. Even if the majority of the power grid system is still in use, there are large parts that have been decommissioned and left in the ground. The rate of decommissioning is likely to increase in the future, as many of the networks are old and need to be replaced. The infrastructure owners lack clear driving forces and therefore the methods, routines and assisting tools to be able to plan, organise and carry out the recycling of the decommissioned electricity network. Even for the landowners and government agencies

this has until now be a non-issue and guidelines for how these hidden and forgotten resources should be handled is therefore lacking in contracts and legislation.

In this project a mapping has been performed of the electricity grid in Linköping to identify the existing preconditions, driving forces and obstacles to increased recycling. Within the project a new technique has also been tested, Kabel-X, which is based in principle on drawing out the metal cores of the cables instead of digging them up. The project has been carried out in close collaboration with the infrastructure owner (Tekniska Verken in Linköping), recycling company (Stena Recycling) and the technology company (TSD Technical support). The researchers are continuing work on a broad front in new projects studying the issues of when, where, how and by whom the recycling of the infrastructure system can be performed in a profitable and environmentally justifiable manner.

Doctoral student Björn Wallsten.
Photograph: Peter Modin

Recycling of powders from fluorescent tubes and low energy lightbulbs

Rare earth metals play a crucial role in technology development. Due to the high demand, attention has been turned towards the possibilities of recovering these metals from end-of-life products. The focus in this project was to evaluate the advantages and disadvantages of hydrometallurgic processes in the recovery of rare earth metals from used low energy lightbulbs that contain fluorescent powders with rare earth metals, and also small amounts of mercury. Mercury is one of the reasons that this waste is difficult to handle. The metal is toxic and is difficult to separate from the rest of the fractions.

Real waste samples from Nordic Recycling AB have been studied. The leaching of metals from the solid material has been performed using various solutions (water, acid and alkali solutions). Separation of rare earth metals from potassium nitrate solutions has been performed using commercial extraction processes. The project has shown that the separation and recovery of rare earth metals and the separation of mercury can be carried out in an efficient and environmentally friendly way. Vinnova has granted funding to scale up the system to an industrial pilot facility.

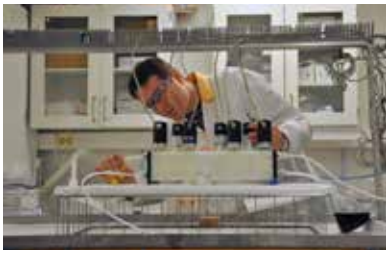
Project title
Sustainable processes development for recycling of fluorescent phosphorous powders – rare earths and mercury separation

Project number
2010-2266
Environmental Technologies Program

Project duration
2011–2012

Funding awarded
SEK 3 539 000

Project leader
Teodora Retegan
Chalmers
tretegan@chalmers.se



Doctoral student Cristian Tunsu.
Photograph: Martina Petranikova

Project title
Ammonia treatment of sewage sludge for production of hygienically safe bio fertiliser

Project number
2010-2292
Environmental Technologies Program

Project duration
2011–2013

Funding awarded
SEK 983 000

Project leader
Björn Vinnerås
SLU
bjorn.vinneras@slu.se

Mixing of urea in sewage sludge prior to the pilot scale study.
Photograph: Annika Nordin

Ammonia hygienisation of sewage sludge

The project has developed ammonia hygienisation as a method for the hygienisation of sewage sludge. The method is intended to be used as a post-treatment, following decomposition, and can be dimensioned according to the need to process a certain amount of sludge that is to be recycled as fertilizer. The project has been carried out in collaboration with Uppsala Vatten and Kemira, and LRF Mälardalen has participated as part of the reference group.

The project initially developed a lab-scale method to treat sewage sludge with the addition of urea (urine-based) for the effective reduction of disease-causing microorganisms. Pilot studies were then carried out using 60 tonnes of sludge and the addition of 1.6 percent urea at the Hovgården treatment facility in Uppsala. After three months of covered overwinter storage the sludge was hygienised and safe to use as a fertilizer. Hygienisation is scale-independent, and after use of ammonia for hygienisation the sludge is a complete fertilizer.

Subsequent research has shown that it is possible to perform a more rapid treatment over two weeks by combining composting with subsequent ammonia treatment. The results of the project offer purification treatment facilities a cheaper hygienisation technique for sludge compared to conventional heat treatment, and the hygienisation can be performed based on the need for hygienisated sludge.

Project title
Laser induced breakdown spectroscopy in combination with automatic image analysis as a tool for fast sorting of mixed metallic flows

Project number
2011-549

Project duration
2011–2017

Funding awarded
SEK 4 720 000

Project leader
Jonas Gurell
Swerea KIMAB
jonas.gurell@swerea.se

Rapid sorting of mixed waste streams

Annually 1,500 million tonnes of steel are produced for infrastructure, consumer goods and other products. This annual production equates to five times the weight of the global human population, and is expected to almost double by 2050. Recycling of steel waste is important. The lifetime of a steel product is 25–30 years. This means that the 1,500 million tonnes of steel we produce in 2015 will be scrap by 2040. This material must be managed and the industries and societies that best succeed in doing this will gain great environmental and financial benefits.

This project develops techniques for the chemical analysis of recyclable steel scrap with the aim of making this a more attractive raw material. Rapid analysis will allow the waste material to be used as a source material, which will

reduce the demand for virgin source material. A prototype has been developed based on laser technology. By illuminating the scrap with a laser pulse the chemical content can be determined within a fraction of a second at a distance of one metre. By positioning the instrument above a conveyor belt the composition of the scrap can be analysed and information can therefore be provided that increases the value of the material. The prototype has been evaluated by both the recycling and steel industries. Work is currently ongoing to achieve permanent industrial implementation. This work is being carried out by Swerea KIMAB in collaboration with Stena Recycling and Outokumpu Stainless. The project has also led to a collaboration with Acreo Swedish ICT in Sweden, Fraunhofer Institute for Laser Technology in Germany and Centro Sviluppo Materiali in Italy.

Field trial of the instrument (the green box) that has been developed in the project.
Photograph: Jonas Gurell

Resource streams in the circulation cycle

A major challenge for cities is how to improve efficiency in resource management and use of waste products. A circulation cycle for biological resources within waste and sewage management has great potential, but knowledge about these systems is still limited to small-scale pilot and demonstration projects. This project will identify the obstacles to creating a circulation cycle for biological waste and sewage and will recommend measures to overcome these obstacles. A planning tool will be developed during a later stage of the project in collaboration with colleagues at Chalmers, SLU, Eawag in Switzerland and possibly with Maseno University in Kenya.

Increased resource efficiency and recycling processes within urban areas necessitates change in order to involve the users, develop technologies and manage organisational issues. Research must therefore take the entire sociotechnological system into account. The researchers have used case studies of the existing circulation cycle system to identify the driving forces and the obstacles preventing a more circulation cycle-adapted system. These cases will be compared with international trends to be able to provide recommendations and guidance for those seeking to scale up circulation cycle solutions.

Project title
Closing the loops on resource flows – a starting point for sustainable peri-urban water and waste management

Project number
2011-1259

Project duration
2012–2015

Funding awarded
SEK 2 531 000

Project leader
Jennifer McConville
Chalmers
jenmcc@chalmers.se

Project title
Yesterday´s agricultural waste is the functional material of tomorrow

Project number
2013-844

Project duration
2014–2016

Funding awarded
SEK 3 113 000

Project leader
Ulrica Edlund
KTH
edlund@kth.se

Agricultural waste becomes valuable material

Can the farm waste of yesterday become the valuable and renewable material of tomorrow? Rapeseed straw is a by-product left over from the harvest of rapeseed to extract rapeseed oil. This straw is currently to a large extent ploughed back into the field again, as it is not suitable as bedding material. As rapeseed oil is used as a source material for biodiesel the land area used for growing rapeseed has steadily increased.

Rapeseed straw is a renewable, cheap and readily accessible material, but despite this it has not yet been utilised commercially. The researchers are working to convert the hemicellulose in rapeseed straw into functional material, for example into plastic film for packaging purposes. They are developing methods for hydrothermic extraction of the different carbohydrates and are mapping the chemical composition of the rapeseed straw components. The extracted fractions are rich in hemicellulose molecules, the chemical properties of which are analysed to understand how temperature and other parameters during the extraction affect the structure, lignin content and ability to function as source materials. In the next step the hemicellulose molecules are used for the production of plastic films. In time the straw extracts and similar raw materials could contribute to replacing oil-based plastics with renewable and biodegradable material. (A similar project, 2009-1527, can be found in the Biological Resources chapter.)

Elisabet Brännvall, Antonia Svärd and Ulrica Edlund – with rapeseed straw, a polysaccharide-rich powder extracted from the straw, as well as a piece of plastic created using rapeseed powder as a source material.
Photograph: Daniel Tavast

Project title
Increased reactivity and applications for recycled cotton textiles by electrochemical oxidation techniques

Project number
2013-1680

Project duration
2014–2017

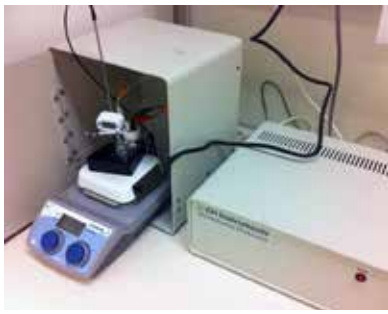
Funding awarded
SEK 3 459 000

Project leader
Hanna de la Motte
SP-Technical Research Institute of Sweden
hanna.delamotte@sp.se

Recycling cotton fabric

The major environmental impact that our clothes and textiles represent has gained increased attention. The combination of the amount of clothing that is thrown away each year and the environmental problems associated with textile production constitute an enormous waste of resources. At the same time the population is increasing and also the use of new textiles. This project focusses on the electrochemical oxidation of cellulose in used cotton fibres in order to increase their reactivity and facilitate the use of recycling or further production of new material.

Preliminary results have demonstrated successful oxidation with the method, which is interesting as it is driven by electrical energy instead of the addition of chemicals. Through oxidation the cotton fibres gain improved fibrillation and cross-binding properties, as well as increased solubility. These are valuable properties for the recycling system and can give longer lifecycles. The project will also examine whether ionic solutions can function as electrolytes for the electrochemical oxidation of cellulose. Ionic solutions do not only have electrolytic properties but may also solubilize cellulose. These two properties mean that it should be possible to oxidise cellulose homogeneously, which can give both more efficient chemistry and newly regenerated material from used cotton.



An electrochemical workstation with cellulose oxidation ongoing.
Photograph: Hanna de la Motte

Fly larvae raised on organic waste become source material for feed production

Project title
Safe Protein from Unused Waste (SPROUT)

Project number
2013-2020
EcoInnovera

Project duration
2013–2014

Funding awarded
SEK 2 700 000

Project leader
Björn Vinnerås
SLU
bjorn.vinneras@slu.se

This project has developed fly larvae composting for the treatment of organic waste and the production of a protein-rich animal feed and a concentrated ecological fertilizer from the resulting waste products. It is part of the EcoInnovera program and is a collaboration between SLU and two Swiss organisations, the Eawag research institute, and the food company Pacovis.

In an initial treatment stage the waste is decomposed and the fly larvae concomitantly become biomass. One tonne of waste can be converted into around 400 kg compost and between 100 and 150 kg of maggots. Per kilogram of dry matter the maggots comprise 40 percent raw protein and 30 percent fat. This makes them an excellent source material for feed production, where they replace fish and soya proteins. This handling system offers a new value chain for waste management as safe feedstuff can be produced without the requirement for growing the source ingredients. This means that the results can be important for a sustainable society.

At the conclusion of the project a pilot facility for the treatment of organic household waste will be developed with a capacity to treat 2–3 tonnes of waste a day. This is the equivalent of waste from a community of around 10,000 inhabitants. The main research questions of the project, in addition to process technology development, are handling of the flies, eggs and maggots while at the same time maintaining the hygienic quality of the system.

Prepuppae – the final larval stage before it leaves the material to find a dry, dark place to pupate.
Photograph: Sara Eriksson

Biological Resources

These projects deal with how renewable raw materials such as lipids, fatty acids, cellulose and lignin from oil crops, fungi, timber and algae can be used to produce such products as biofuels, chemicals, packaging materials, glue, paints, plastics and detergents. Biorefining processes play a key role.

Production of biobased lubricants

Biobased oils can be a sustainable alternative to petroleum in many instances. They have similar chemical structures and properties to mineral oils and can be used in many applications where we are currently entirely dependent on mineral oils. Lubricants are one such application, where the global market amounts to 50 million tonnes.

Special wax esters have qualities and properties that make them suitable as "green" lubricants. This project has worked with the identification of the relevant enzymes necessary for the manufacture of different wax esters with high yields. More recent research has demonstrated that large scale production of these wax esters is possible from oil crops, but the current legislation governing genetically modified organisms (GMO) makes practical application in plants difficult. In contrast there are yeast strains that are excellently suited to the production of oil-based lubricants.

Until now this type of lubricant has had a limited impact in the petroleum market. The major bottleneck has been the cost. It has been estimated that a biobased alternative to mineral oils can only be competitive when oil prices are in excess of 60 dollars a barrel. As special qualities can be achieved in biological systems, lubricants with unique properties can be developed, even if the price level is higher.

Project title
Production of biobased lubricants Characterisation and LCA evaluation

Project number
2008-162
Environmental Technologies Program

Project duration
2008–2010

Funding awarded
SEK 3 359 000

Project leader
Leif Bülow
Lund University
leif.bulow@tbiokem.lth.se

Cellulose – a sustainable source in biocomposite materials

Today's technologically driven society places ever increasing demands on the production of materials with specifically designed properties and for more materials to be produced from renewable sources. Cellulose is one of the most common naturally occurring polymers. It has very good properties, comes from renewable sources and is available in virtually unlimited amounts. All around the world there is currently intensive research and development taking place to enable cellulose fibres to be used as a replacement for carbon and glass fibres as a reinforcing material in composites. A cellulose-reinforced product could be much lighter than an equivalent product strengthened with conventional fibres.

For cellulose to be able to be used in composite material its surface must be modified, as it is difficult to mix

Project title
Cellulose as a sustainable source in biocomposite materials

Project number
2008-725

Project duration
2008–2011

Funding awarded
SEK 2 400 000

Project leader
Eva Malmström
KTH
mavem@kth.se

Cellulose substrate in the form of a normal filter paper, upper image showing a small amount of hydrophobic polymer on the surface, lower image with a large amount of polymer.
Photograph: Anna Carlmark Malk and Linn Carlsson

cellulose, which is very hydrophilic, with matrix materials that are often hydrophobic. If the cellulose can instead be modified, for example by grafting polymer (seeding) to its surface a bespoke bonding can be achieved. This project has investigated the modification of different cellulose surfaces by the grafting of polymers. A similar approach can also be applied to provide cellulose-based materials with specific functions. This makes it possible to produce functional materials, for example, by attaching a polymer that reacts to the characteristics of its surroundings.

Project title
Environmentally friendly plasticizers from renewable raw material

Project number
2008-2176
Environmental Technologies Program

Project duration
2009–2011

Funding awarded
SEK 2 645 000

Project leader
Anna Jansson
SP-Technical Research Institute of Sweden
anna.jansson@sp.se

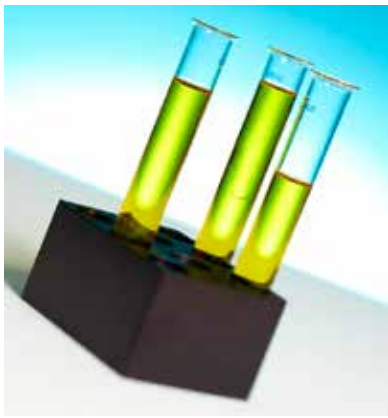
Environmentally friendly plasticizers from renewable raw material

The demand is great for environmentally and cost efficient plasticizers, among other things for PVC. Using oils from plants contributes to the development of a bioeconomy. In a previous project epoxidized soybean oil was shown to function as a plasticizer for PVC and the researchers therefore want to investigate if other plant oils, such as linseed oil, rapeseed oil and thistle oil, can also function as a source material for new environmentally friendly plasticizers to replace the controversial phthalates. Raw materials from forestry, tall oil and lignin, have also been examined.

The plant oils contain triglycerides that have been chemically modified so that they are miscible with PVC and can function as plasticizers in flexible products such as floor coverings. The plasticizers have then been mixed with PVC and test sample materials have been manufactured. The mechanical properties and durability of the materials have been tested. Important properties are flexibility, that the plasticizer remains in the material and does not migrate out, and that the samples do not become discoloured during manufacture or subsequent aging. Several of the oils functioned well as plasticizers. The major advantages were that the oils did not migrate

Test samples made using the different modified plant oils.
Photograph: Anna Bondeson

out when exposed to high temperatures and that the samples retained their mechanical properties. The major drawback was discolouration of the oils, which resulted in yellowing of the samples. Stabilisers need to be examined to counteract the discolouring deterioration of PVC and the plasticizers need to be purified more. Biological source materials are not as "pure" and controlled as oils derived from modern refineries.



Test tubes containing plant oils.
Photograph: Per Aronsson

Natural resources from the Baltic Sea

Is it sustainable to initiate projects in a Swedish coastal area that utilize marine biomass, such as algae, mussels and reeds to produce for example biogas? This is something the researchers want to find out. They have studied different process pathways, such as extraction of algae from the beaches in Trelleborg and the harvest of reeds in the Kalmar region. The process pathways have then been evaluated with respect to the amount of energy that goes into the pathway and what is produced at the end, for example in the form of biogas. They have also investigated the socioeconomic dimensions and the value that the harvesting of the biomass contributes, such as the uptake of nitrogen and phosphor, to determine if such projects are sustainable from a purely economic angle. The results demonstrate that the extraction of algae from the Swedish south coast for example can be profitable socioeconomically and that there is great support within the local community. The working methods of the researchers can be utilized in future projects in other regions or countries where use of the marine biomass as a resource is desired. Concepts from this project have given rise to the Seafarm research environment (project number 2013-92).

Project title
Sustainable use of Baltic Sea natural resources based on ecological engineering

Project number
2009-468

Project duration
2010–2012

Funding awarded
SEK 3 204 000

Project leader
Fredrik Gröndahl
KTH
fgro@kth.se

Large amounts of filamentous red algae from the south coast of Skåne have been collected for use in biogas production.
Photograph: Fredrik Gröndahl

Project title
Developing sustainable and energy efficient alternatives to petroleum-based production of energy and materials

Project number
2009-1315
Targeted call

Project duration
2009–2014

Funding awarded
SEK 20 000 000

Project leader
Sten Stymne
SLU
sten.stymne@slu.se

To direct the storage of sugar to be converted into oil instead of starch the researchers have studied how oat plants, the only cereal seed type with oil in its endosperm, does this. Åsa Grimberg is leading the research.
Photograph: Åsa Grimberg (left) and Anders Carlsson (right)

Energy efficient alternatives to fossil fuel

The scientists involved in this project have used molecular genetic techniques to optimise the qualities of plant oils for different industrial purposes directly in the plant and in this way have made this more economically viable for the chemical industry to use. By introducing three genes the levels of industrially valuable erucic acid have been increased in Crambe abyssinica seeds. By transferring genes from the dessert-growing jojoba plant the researchers have also been able to get Crambe abyssinica to produce wax esters, or more specifically an oil similar to sperm whale oil, which there is great demand for as a lubricant.

Although only 10 percent of fossil oil is used by the chemical industry this is still a large amount, around 400 million tonnes. For plant oils to be able to replace fossil oils in the chemical industry to any significant extent production levels must be increased substantially. This is not possible with the few oil-producing plant types we have today. The project has therefore also worked with the creation of new oil-producing plants by steering the storage of sugar from photosynthesis to be converted into oil instead of starch. To achieve this the researchers have used gene technology to change the activities of transcription factors, the controlling genes that activate the genes that produce enzymes. The plants that are primarily intended to be transformed into oil-producing plants are wheat, sugar beet and maize, but the energy crop willow is also included.

Project title
High-value compounds from agricultural and forestry waste by sustainable methods – An interdisciplinary approach for bioresource utilization

Project number
2009-1527
Targeted call

Project duration
2009–2012

Funding awarded
SEK 19 500 000

Project leader
Charlotta Turner
Lund University
charlotta.turner@chem.lu.se

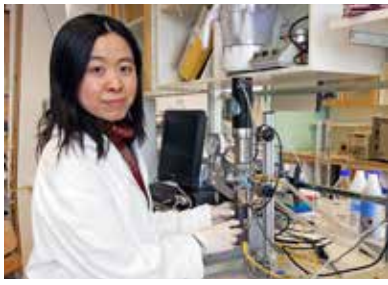
High-value compounds from agriculture and forestry waste products

This project examines how the value of national agriculture and forestry waste products can be increased and how the use of these can made more efficient. From waste products, such as birch bark, onion skins, pressed carrot and fruit pulps, substances that are important to the health, food and cosmetic industry sectors are extracted in more environmentally friendly and more economically efficient ways than those used today. After processing the waste products can still be used as previously, for soil enrichment, biogas production, animal feed or combustion.

The researchers have focussed primarily on the extraction of antioxidants and lipid-soluble vitamins from the waste products. They are developing green processes that use only pressurized hot water and carbon dioxide as solutions, with thermostable sugar digesting enzymes to increase the yields of the antioxidants. Environmental sustainability is assessed using lifecycle analyses and analyses of commercial economic profitability are carried out in close collaboration with the industrial representatives involved in the project.

Rapid, automated processes where enzymes can be reused, organic solvents can be avoided entirely and energy consumption is small have been developed for the extraction of carotene from carrot waste, betulin from birch bark and antioxidants from onion waste and apple press pulp cakes. Find out more by visiting: www.suretech.lu.se

Apples contain beneficial antioxidants, and most of these are in the peel.
Photograph: Charlotta Turner



Doctoral student Jiayin Liu investigates if antioxidants can be extracted from onions.
Photograph: Charlotta Turner

BIOIMPROVE – Improved biomass and bioprocessing properties of wood

This project develops biotechnology methods that can be used in forestry to increase the utility of the timber in the production of biofuels, green chemicals and other materials. The scientists have a vision of culturing rapidly growing species, such as hybrid aspen and sallow, in plantations where the trees are specifically designed for use in different applications using genetic modification, among other things. The applications are part of a biorefinery concept that includes the production of chemicals, materials and different forms of energy. These "by-products" may be crucial to adding value to Swedish forestry raw materials and this may increase the profitability of the pulp and paper industry.

Several new genes have been identified that regulate the biomass production in timber by affecting the cellulose, hemicellulose and lignin in the wood. The utility of the wood for the production of green chemicals is affected by its permeability for thermochemical and biotechnology treatments. One of the most important chemical properties that determines permeability is the amount of

Project title
BIOIMPROVE – Improved biomass and bioprocessing properties of wood

Project number
2009-1698
Targeted call

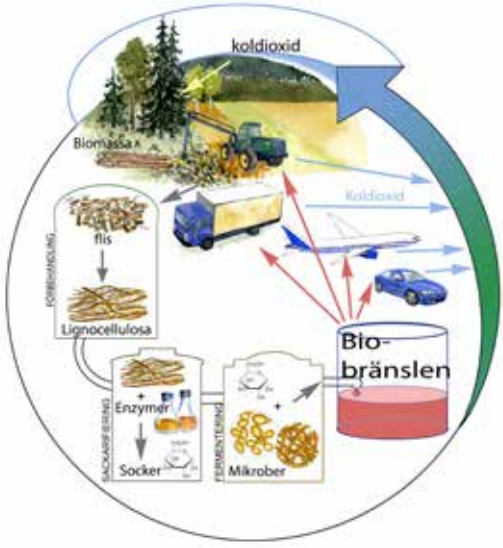
Project duration
2009–2013

Funding awarded
SEK 25 000 000

Project leader
Hannele Tuominen
Umeå University
hannele.tuominen@umu.se

The project included trials of transgenic plants, among other things in greenhouses under controlled conditions. Project leader Hannele Tuominen on the far left.
Photograph: Hannele Tuominen

lignin in the wood. The results have made it possible to produce transgenic aspen strains, which are now being tested in field trials. This will provide decisive information about some of the factors that determine the quantitative and qualitative properties of wood and these can then be used as tools for the production of forestry biomass in the future.



Lignocellulose from wood can be used for the production of biofuels and green chemicals, such as ethanol. To do this in an economically profitable way the researchers are attempting to improve tree growth and modify the chemical composition of forested wood so that it is more suitable for these applications.
Illustration: Gun Lövdahl

Project title
Assessment of glycerol as an environmentally friendly low friction lubricant produced from renewable resources– a pilot study

Project number
2009-2050

Project duration
2009

Funding awarded
SEK 557 000

Project leader
Roland Larsson
Luleå University of Technology
roland.larsson@ltu.se

Glycerol as an environmentally friendly lubricant

Glycerol is a by-product of biodiesel production. If biodiesel is produced in large quantities there will be a large excess of glycerol. The researchers investigated if glycerol could be used as a base for an entirely new type of green, non-toxic, water-soluble, biodegradable and cost effective lubricant. The lubricant consists of glycerol and additives that also have a natural source. It has been tested in model tests where friction and wear have been measured under controlled conditions. The results have demonstrated that the glycerol-based lubricant has equally good performance as lubricants based on rapeseed oil. Lantmännen has since helped with field tests of a prototype chainsaw lubricant. The prototype was seen to function well and gave longer operational time in forestry harvesting than equivalent rapeseed oil-based chainsaw lubricant.

To be able to use lubricant of this type is of great benefit for the environment, especially as nature is exposed to lub-

ricant contamination, such as is exemplified by chainsaw lubricants. Another important effect is that biodiesel production will become more economically viable, as the value of the by-product can be increased significantly by manufacturing lubricant from glycerol instead of disposing of it. Subsequent research has shown that it is possible to improve the performance of the lubricant and that there are many more application areas in addition to chainsaw lubrication. (A similar project, 2010-1565, can be found in the following section.)

The research group with Roland Larsson on the extreme left.
Photograph: Ted Karlsson

Low quality forage for biogas

This project investigated if dairy farms that began to collaborate in biogas production and simultaneously changed their feeding and forage crop growing strategies lowered their environmental impact. The strategy that was investigated was to use the first harvest, which often had the highest quality, for fodder and to use the regrowth harvest for biogas. The researchers analysed two scenarios that described the production at the farms, before and after the introduction of the alternative forage growth and feeding strategy, and biogas production, where the biogas was used for heating.

The study showed that the environmental advantages can be great, even when the heat that is generated is not sold, but are even greater when the heat can be sold. Climate impact was reduced by 40–60 percent, depending on if the heat was sold or not, when the biogas that was produced replaced fossil fuel energy. The economic results were poorer for the forage growth scenario than for the basic scenario. The costs for the biogas facility and forage harvest increased at the same time as the revenue from cereal crops decreased. The farms needed to buy less concentrated feed and less commercial fertilizer. But these expenditure reductions and the revenue from the biogas did not compensate for the increased costs. To use biogas energy so that it replaces fossil fuel energy is essential to fully realise the major environmental potential of the concept.

Project title
High quality forage for dairy cows and low quality forage biogas

Project number
2009-2052

Project duration
2009

Funding awarded
SEK 1 320 000

Project leader
Ingrid Strid
SLU
ingrid.strid@slu.se

Biogas facility.
Photograph: Sofia Bureborn

Project title
Soil carbon – an opportunity to improve the greenhouse gas balance of bioenergy production

Project number
2009-2056

Project duration
2009

Funding awarded
SEK 995 000

Project leader
Cecilia Sundberg
SLU
cecilia.sundberg@slu.se

Soil carbon – for improved greenhouse gas balance

The most important sources of greenhouse gases in biomass production are the use of fossil fuels in the production chain, the production of fertilizers and the diffuse emission of greenhouse gases from the soil. Changes in carbon storage in the soil play a major role in greenhouse gas emission from bioenergy production. Lifecycle analyses have until now not taken this into account, as there has been a lack of knowledge about the carbon balance in the soil. In the production of forestry for energy, as well as in biogas production where the decomposed waste is returned to the land as fertilizer, the soil carbon levels can increase. By taking soil carbon into account in lifecycle analyses this project contributes to obtaining a more accurate picture.

The accumulation of soil carbon necessitates uptake of carbon dioxide from the atmosphere. This has been calculated using a soil carbon model for growth of forestry for energy and biogas systems.

In addition, a method was developed to demonstrate the change on the effects of greenhouse gases over time. This demonstrated that when forestry is grown for energy on pasture land the increase in soil carbon and carbon in the vegetation is often so great that it counterbalances the greenhouse gas emissions that occur during the growth and fertilizing of the energy forest. When it is also taken into consideration that willow can replace fossil fuels the reduction in greenhouse gas emissions becomes very large. When biogas is produced and the decomposed waste is returned to the soil the amount of soil carbon increases and greenhouse gas emissions decrease.

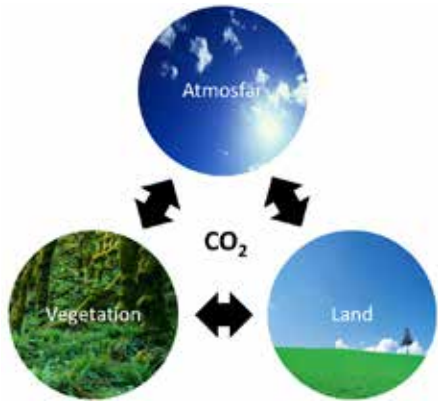


Illustration: Torun Hammar

Glycerol as a starting material for organic synthesis

Glycerol is a renewable source material that is formed as a by-product of biodiesel production. To increase the value and sustainability of this process it is important to find new areas of use for glycerol. At the same time many of our daily goods are currently made from fossil-based sources. The researchers want to determine if glycerol can be used to replace a number of the component elements that are currently derived from mineral oils to construct molecules that can be used to manufacture materials such as plastics, paints and pharmaceuticals.

Glycerol is transformed into new molecules using metal-catalysed reactions that target the hydroxyl-group in glycerol, and where the only by-product is water. The researchers have investigated the possibility of coupling glycerol to other renewable molecules derived from biomass, for example to the aromatic groups of lignin. They have demonstrated that glycerol can be converted into amino alcohols, starting materials used in the pharmaceutical industry. A simple glycerol derivative has also been studied in reactions with ketones, with promising results.

Glycerol is only one of many biomolecules that contain a hydroxyl group. The long-term objective of this project is to develop general methods to increase the value of renewable biomolecules and to prepare these for the process industries; a step forward on the path to reducing the dependency of society on mineral oils.

Project title
Glycerol as a sustainable starting material for organic synthesis

Project number
2010-1565

Project duration
2011–2013

Funding awarded
SEK 4 262 000

Project leader
Nina Kann
Chalmers
kann@chalmers.se

Doctoral student Anna Said. The steel smith in the lab.
Photograph: Nina Kann

Transforming lignin into fine chemicals

Lignin is one of the most common renewable source materials from forestry. There is major potential to use lignin to produce more than fuel for the pulp and paper industry. For example polymeric lignin can be used as a starting material for the production of both bulk and fine chemicals by catalytic depolymerisation. The catalytic degradation of lignin generates a mixture of different molecules that contain different functional groups, including aldehydes, ketones and alcohols. These can be used for further processing using chemical synthesis or biocatalysis, such as in this project that aims to develop

Project title
One-pot biocatalysis for direct multistep valorisation of lignin

Project number
2011-1052

Project duration
2012–2015

Funding awarded
SEK 4 880 000

Project leader
Magnus Carlquist
Lund University
magnus.carlquist@tmb.lth.se

microbial methods to convert the molecules in depolymerised lignin into more valuable fine chemicals and pharmaceuticals.

Genetic methods have been used to design and construct microorganisms so that these can transform lignin monomers into target compounds. The microorganisms have been characterised in detail and implemented in a suitable bioprocess. In contrast to the traditional characterisation of bioprocesses that are based on measuring average values from cell populations, the scientists have used a single cell analysis approach. This allows the analysis of populations at a more detailed level and enables more rapid selection of more efficient strains.

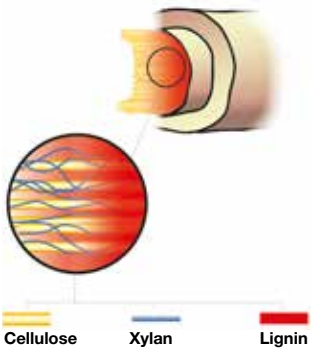
Project title
Modification of lignin composition for sustainable utilization of woody biomass

Project number
2011-1312

Project duration
2010–2012

Funding awarded
SEK 3 223 000

Project leader
Hannele Tuominen
Umeå University
hannele.tuominen@plantphys.umu.se



Product development of woody biomass is affected by its chemical composition of cellulose, hemicellulose and lignin. The sugar polymers of cellulose and hemicellulose contribute to the yield in traditional mass extraction, whereas lignin does not.
Illustration: Mattias Petterson

Woody biomass – modification of lignin composition

The researchers have developed new methods to modify the quantity or composition of lignin using transgenic technologies, or molecular forestry renewal, to reduce the negative effects of lignin. They have identified an entirely new way to regulate lignin composition by modifying the activity of a new protein in mouse-ear cress *(Arabidopsis thaliana)*. They have used transgenic technologies to modify protein activity in an equivalent manner in a hybrid aspen tree model *(Populus tremula x tremuloides)*. These new genetically modified varieties have been tested in field trials. The researchers have also studied variations in lignin concentrations and lignin composition in naturally occurring populations of aspen, and how these variations interacts at the DNA level in order to identify genetic variants and new genes that regulate lignin chemistry.

The project has contributed to the development of molecular tools to modify lignin composition in Nordic tree varieties so that the wood is better adapted to the production of biofuels and green chemicals.

Biocatalysis gives new products from forestry

All forest source materials are not currently utilized to their full potential. In this project some of the components that are poorly utilized, such as hemicellulose, are extracted from industrial forestry waste streams. Using biocatalysis the scientists have refined the hemicellulose to provide added value. Naturally occurring enzymes are the most important tools. New enzyme technologies have been developed to modify the hemicellulose in specific and environmentally friendly ways so that it acquires new refined properties. Using specific enzymes the researchers have been able to couple new chemical groups, for example, and to achieve improved properties suitable for use in cleaning fluids. They can also alter the solubility properties to improve gelling capabilities and the formation of films, which is of interest in the development of new, environmentally friendly packaging.

The choice of enzyme for a specific biocatalysed reaction is extremely important. The researchers have in part developed methods to find new enzymes from natural environments that can be used, and have in part developed methods to genetically modify the molecular structure of the enzymes. With altered structures the enzymes can be used in new reactions. This project has contributed to the development of biotechnology processes for the biorefineries of the future, where all components of plant source material will be used industrially.

Project title
Enzymatic hemicellulose biorefining and functionalisation

Project number
2011-1620

Project duration
2012–2014

Funding awarded
SEK 2 577 000

Project leader
Henrik Stålbrand
Lund University
henrik.stalbrand@biochemistry.lu.se

Improved collaboration in the wood value chain

The wood value chain is comprised of stakeholders from different operational areas. This imposes high demands on communication and information exchange. WoodApps is an EU project that aims to develop a pilot version of an IT supporting platform, with functions to enable collaborations and make collaborations and business activities more efficient between the various stakeholders throughout the value chain. The challenge lies in creating user-friendly solutions and mobile applications for classifying source materials, products and services that offer multiple functions, while at the same time providing the space to define individual company profiles and wishes.

Project title
Improvement in collaboration along the wood value chain through knowledge-based methods and mobile applications

Project number
2011-1864
ERA Wood Wisdom

Project duration
2011–2013

Funding awarded
SEK 1 335 000

Project leader
Lotta Woxblom
SLU
lotta.woxblom@slu.se

Study visit to a forestry company in Germany – an intended user of the platform that has been developed in the project.
Photograph: HCN /SST in Wismar

Qualitative interviews have been carried out to map the value chain and the information needs of the different stakeholders. The respondents perceive that there is an information gap in the wood value chain. The many stakeholders in the chain and the often manual methods applied for collection of data mean that information can be lost on the way to the end user. Technology development and access to electronic data collection and communication tools vary between countries. Based on these results a concept and demo version of a platform have been developed. To ensure the ease of use of the platform the companies linked to the project will test and assess the functions, which can then be further developed as required.

Wood-based materials and fuels

Project title
Wood-based materials and fuels

Project number
2011-1917

Project duration
2011–2013

Funding awarded
SEK 4 977 000

Project leader
Monica Ek
KTH
monicaek@kth.se

The need for purified cellulose mass from wood is increasing, among other things due to the increased production of high-value cellulose-based products such as cellulose acetate (for the growing LCD market), plastics, coverings and sealants. Other examples are mixed cellulose esters (coverings, varnishes, ink) and cellulose ethers for food and pharmaceutical industry applications.

This project introduces new concepts for the manufacture of purified cellulose mass, as well as other wood components, hemicellulose and other particularly attractive substances that can be extracted and used within biorefinery operations. An initial process is based on the pre-hydrolysis of wood. A second process is intended to lead to the production of both purified cellulose and hemicellulose with high molecular weights. A supplementary eco-friendly bleaching process is also included. The various separated products are used for the production of different chemicals and materials, for example wood-derived glues, film and biocomposites based on the highly purified cellulose in combination with suberin from bark.

Photograph: Birgitta Johansson

Multifunctional fatty acids from forestry

This project has nine partners, both academic and industrial, from different parts of Europe. In total 20 scientists have been involved in the project. The scientists want to use chemicals from forestry source materials and find applications where these chemicals can be used as building blocks in glues, paints and plastics instead of the chemicals that are based on fossil fuel sources. One of these source materials is fatty acids, which form the basis of this project. The scientists take small chemical building blocks and design these so that they can build larger structures. The research has now come close to the point where it can be profitable to construct biorefineries for the extraction of the named source substances.

Project title
A novel lipid platform to sustainable biobased products from low-value forestry streams through multi-functional fatty acids

Project number
2011-1924

Project duration
2012–2014

Funding awarded
SEK 2 160 000

Project leader
Anders Larsson
SP-Technical Research Institute of Sweden
anders.larsson@sp.se

Enzyme technology for production of chemicals and fuels

The researchers in this project use enzymes, the catalysts in living cells, to convert biological resources into diverse products. These enzymes are most often derived from microorganisms and they are used as catalysts in different types of reactors. The product area where results are most advanced is in the production of detergents, which are intended as ingredients in washing powders, washing up liquids, shampoos, pharmaceuticals etc. These new detergents contain a water-soluble component that consists of a starch component and a fat soluble component that is derived from vegetable oil. The researchers have succeeded in using enzymes as catalysts to obtain detergents that were previously impossible to produce and that are more gentle but also more efficient than previous products.

In a similar way they are also working to produce biodiesel from fats and oils. They allow the oil to react with ethanol in the presence of an enzyme in solution in a small amount of water. The process produces very pure biodiesel. To make the process more efficient they have developed a methodology where they use particles to generate emulsions with very small droplets, without the need to use a lot of energy. This is an important step on the pathway to achieving a rapid and cost-efficient process.

Project title
Enzyme technology for sustainable production of chemicals and fuels

Project number
2012-820

Project duration
2013–2015

Funding awarded
SEK 4 827 000

Project leader
Patrick Adlercreutz
Lund University
patrick.adlercreutz@biotek.lu.se

Biodiesel emulsion. Conversion of a vegetable oil into biodiesel can be performed using an enzyme as a catalyst in an emulsion. Relatively large particles help to generate an emulsion with very small droplets, which makes the process very rapid and efficient.

Project title
Recombinant polysaccharide synthases – future enzyme factories for sugar-based polymers

Project number
2012-915

Project duration
2012

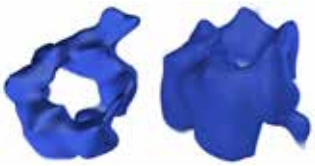
Funding awarded
SEK 4 397 000

Project leader
Christina Divne
KTH
divne@biotech.kth.se

Future enzyme factories for sugar-based polymers

Cellulose from prokaryotes (organisms without a cell nucleus) have high biocompatibility and a wide number of areas of use, for example in the production of paper-based products, electronics, acoustic membranes and biomedicine applications, including dialysis membranes, wound healing, tissue regeneration following burn injury, tissue regrowth in vivo, the formation of artificial blood vessels and as templates casts for the generation of tissue in situ, internally or externally on the body. The knowledge of how the cellulose-synthesising enzymes of bacteria function can also facilitate the development of personalized medicines as a method in the struggle to combat bacterial infections.

The long-term objective of the researchers is to describe and understand the mechanisms that regulate the formation of polysaccharides, primarily cellulose, in bacteria and plants. The most time consuming aspects are to express and purify the enzymes. The possibilities of determining the crystal structures of the enzymes and producing modified variants are also being investigated, partly to study enzyme activity and partly to influence this, for example to achieve higher activity or altered product composition.



3D reconstruction from electron microscopy data for a cellulose-producing enzyme complex. The complex viewed from above (on the left) and from the side (on the right).
Illustration: Maarten Schledorn

Project title
Bioprospecting GH5 enzymes for applications in biomass processing

Project number
2012-1513

Project duration
2013–2016

Funding awarded
SEK 4 706 000

Project leader
Henrik Aspeborg
KTH
henrik.aspeborg@biotech.kth.se

GH5 enzymes for applications in biomass processing

Enzymes are valuable biotechnology tools and the use of enzymes in industrial processes provides many economic and environmental advantages. One possible scenario for enzymes identified and characterised in this project is that they shall be able to be used as selective tools to convert biomass into specific products in the biorefineries of the future. For example, certain enzymes could be used to make the bioethanol of the next generation more commercially viable by making the enzymatic digestion of plant biomass more efficient.

The scientists are examining how different GH5 enzymes from plants and microorganisms work. The GH5 family is interesting to study as within this family there are enzymes that have many different activities, and a

lot of these activities are relevant to the decomposition of plant biomass. It is hoped that new enzymes with interesting properties can be identified that can then be used in biotechnology processes to convert biomass, for example for biofuel production or for the manufacture of green materials and chemicals. The biochemical and catalytic properties of the target enzymes are being examined. In addition the project is investigating which tissues the genes for GH5 enzymes from plants are expressed in and attempting to elucidate the 3D structures for some of the previously unknown target enzymes.

High value products in biorefineries

This project is investigating how a biorefinery should be built to introduce products that have medium and high economic value. The researchers will develop new products that can be used to replace chemicals and materials that are currently based on fossil sources.

A value development chain will be developed for the production of products with increasing economic value. Each link in the chain involves a broad technology platform. Biorefining begins at one end with the use of separation technologies to extract components from food and agricultural waste, while at the other end advanced biotechnology and polymer technology methods are used to produce fine chemicals and materials.

Project title
Introduction of high value products into the biorefinery

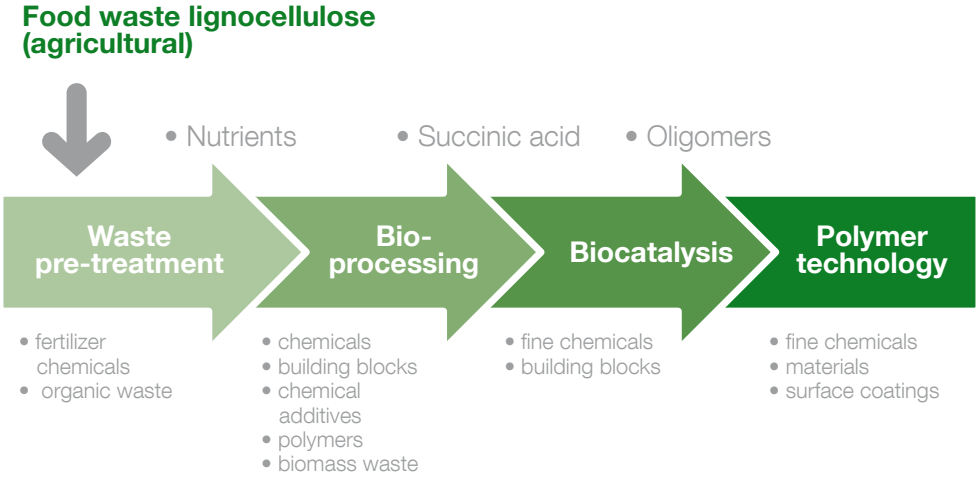
Project number
2013-70
Strong research environment

Project duration
2013–2017

Funding awarded
SEK 23 931 000

Project leader
Gen Larsson
KTH
gen@kth.se

Value development chain for the production of products with increasing economic value.



Fractionation of the waste is currently ongoing and it has been possible to culture the target microorganisms directly on the material with high cell productivity. A new method has been developed to produce specific building blocks for polymerisation with high yields. The foundations have also been laid for the production of short polymers that, due to their properties, will form the basis for a multitude of new materials.

Project title
Upgrading of renewable domestic raw materials to value-added bulk and fine chemicals for a bio-economy: technology development, systems integration and environmental impact assessment

Project number
2013-78
Strong research environment

Project duration
2013–2018

Funding awarded
SEK 24 975 000

Project leader
Lisbeth Olsson
Chalmers
lisbeth.olsson@chalmers.se

BIOBUF

Renewable raw materials become valuable chemicals

In a new biorefinery concept the researchers want to use microorganisms and enzymes to produce chemicals from renewable source materials. System studies will ensure that the biorefining is technologically viable and will identify the technology development that is essential to achieve an environmentally and economically sustainable concept. To achieve this processes will be modelled on an industrial scale and it will be possible to investigate the potential for integration of these processes with existing industry.

The researchers will use forestry waste and will evaluate the use of microalgaes as biological raw materials. In addition to producing biomass, algae can be used to produce high value products and to bind nutrients that can cause problems of eutrophication in the oceans.

In a biorefinery genetically modified yeast strains will manufacture adipic acid from the sugar in the biomass. Adipic acid is the starting material for the manufacture of nylon, but is also used as a plasticiser, lubricant and food additive. The lignin part of the raw material will be used to produce aromatic chemicals. By-product streams that are generated will be decomposed anaerobically for the production of biogas and treatment in bioelectrochemical systems for the recovery of nutrient substances.

Converting hemicellulose into fatty acids for biofuels and animal feed

The researchers aim to develop new microbial processes for the production of biodiesel from plant biomass, combined with production of high value fish feed for fish farming. There are yeasts in nature that if allowed to grow on sugar under limited nitrogen conditions accumulate different types of fatty acids. The ability of these microorganisms to accumulate lipids can be utilised to develop biological processes to convert the cellulose and hemicellulose in plants into the renewable fuel biodiesel. This project will identify the best possible conversion processes for both a straw source from agriculture and from forestry raw materials.

Approximately one year after the start of the project it has been shown that the researchers, using different types of oil-accumulating yeast strains, can transform plant biomass into lipids with relatively good yields and that after extraction these lipids can be further processed into biodiesel. Processes are also currently being developed so that the remains of the yeast generated can be used to make high value fish feed. This project will contribute to Sweden being able to replace some of the fossil fuel that we use today with renewable fuel and will also allow the concomitant production of a fish feed that to a certain extent will be able to replace the fish bone meal that is often used today. For more information visit: www.slu.se/lipodrive

Project title
Microbial hemicellulose to high value fatty acid conversion for sustainable biofuel and animal feed production from lignocellulose

Project number
2013-80
Strong research environment

Project duration
2013–2017

Funding awarded
SEK 12 093 000

Project leader
Mats Sandgren
SLU
mats.sandgren@slu.se

Culturing the yeast that Mats Sandgren's project uses to obtain lipids.
Photograph: Cajsa Lithell

New soil production methods

One of the major challenges in farming today is to produce sufficient food for the expanding population. As the amount of agricultural land is limited, and reclamation of natural ecosystems for crop growing has serious environmental consequences, crop production must be improved using the existing land available concomitant with a reduction in the addition of fertilizers and pesticides by utilising the soil more efficiently. Scientists believe that crop yields can be improved for all soils by 10–25 percent and that environmental impacts can also be reduced. Growth of the root systems of plants and their ability to take up water and nutrients will be promoted by improving the structure of the subsoil, partly through the deeper placement of mineral nutrients.

Project title
Future crop production relies on new management strategies for soils

Project number
2013-82
Strong research environment

Project duration
2013–2017

Funding awarded
SEK 23 280 000

Project leader
Holger Kirchmann
SLU
holger.kirchmann@slu.se

The research group testing new ways to produce soil, with Holger Kirchmann on the far left.
Photograph: Jenny Svennås Gillner

To create a more root-friendly soil structure under agricultural soil the ground will be deep ploughed and organic material introduced into the soil. Mineral nutrients will be placed more deeply in the agricultural soil (10, 15 and 20 cm), depending on the root development of the different crop varieties. Carbon filters to bind phosphor and pesticide contaminants in the run-off water will be placed in ditches to reduce the environmental burden on lakes and watercourses. Field trials in 2014 demonstrated that deeper placement of mineral nutrients increased yields by up to 19 percent.

Project title
Seaweeds for a biobased society? Farming, biorefining and energy production (SEAFARM)

Project number
2013-92
Strong research environment

Project duration
2013–2017

Funding awarded
SEK 24 716 000

Project leader
Fredrik Gröndahl
KTH
fgro@kth.se

Seaweeds for a biobased society

This project aims to farm sugar kelp (seaweed) on the west coast of Sweden to produce biomass that can be used as source materials for food and fodder production, and as chemicals for the manufacture of new biological materials, such as plastics, as well as energy production. This will take place in biorefineries. The project will also determine if this is sustainable or not and will discover if a new industry can be established along the Swedish west coast.

The project is subdivided into five focus areas:
1) Development of methods for algae farming at sea.
2) Storage and pre-treatment of the algae biomass.
3) Biorefinery development for the project, examining the opportunities for extracting food, fodder and chemicals for new materials, such as polymers for plastics.
4) Production of biogas from the waste products of the biorefining processes, as well as the possibilities to use waste material as an agricultural fertilizer, and
5) Evaluation of the entire process chain from a sustainability criteria perspective.

After eighteen months of the five year project the researchers have established two farming facilities and have learned how to grow kelp on ropes. Within the biorefinery part of the project new interesting materials have been developed and a deeper understanding has been gained of what the biomass contains. If this project is successful it will have laid the foundations for the establishment of a new industry on the Swedish west coast, a commercial activity that could generate economic development for coastal communities away from the major cities. For more information visit: www.seafarm.se

SEAFARM scientist Gunnar Cervin holding the first seaweed (sugar kelp) farmed in Sweden. The experimental farming facility for the project can be seen in the background.
Photograph: Henrik Pavia

Green chemicals from marine microalgae

The scientists will study how a microscopic species of marine algae, *Chlorella*, can be used to generate a starch-enriched biomass that can function as a basis for the biobased production of chemicals. The project is a collaboration between Chalmers, SP-Technical Research Institute of Sweden and the University of Gothenburg. It will be investigated how the selected Chlorella strains can utilise nutrients from industrial waste streams, such as from process water and flue gases, to obtain efficient production of starch-enriched biomass.

The researchers will identify the effects of culturing conditions on productivity by mapping the composition of cell material from well-defined cultures, the metabolite levels in the cells and how efficient nutrition and lighting conditions can be utilised. The effects that are identified can then be characterised in conjunction with culturing parameters. Algae-derived biomass with high starch content will be processed in a downstream fermentation stage to release the sugars that are used in the production of chemicals. Algaes are currently an underutilised resource that can contribute renewable source materials for the production of green chemicals and can therefore be part of the transition process from fossil sources to renewable resources.

Project title
Marine microalgae enriched in carbohydrates for concomitant nutrient recycling and green chemicals production

Project number
2013-865

Project duration
2014–2016

Funding awarded
SEK 5 177 000

Project leader
Eva Albers
Chalmers
albers@chalmers.se

Researchers culturing the algae variety Chlorella to provide biomass for the production of chemicals.

New analysis methods for biorefineries

The biorefineries of the future will be extremely important in creating a bioeconomy. One of the challenges in developing new sustainable processes is the amount of chemical contaminants that are generated in the processes, by-product streams and waste products. A number of these contaminants are a hindrance, for example in the fermentation of sugar into ethanol. Other contaminants are however of value and should be separated before the biomass is used for the productions of biofuels.

One limitation in the development of biorefineries is the demand for advanced chemical analyses. This project focuses on the development of advanced two-dimensional chromatography methods for the separation of complex samples from the forestry and biofuel

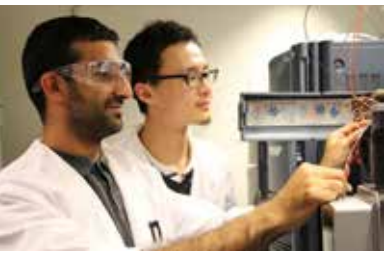
Project title
Advanced chemical analysis of complex biorefinery samples: Two-dimensional high-diffusion fluid chromatography

Project number
2013-971

Project duration
2014–2016

Funding awarded
SEK 3 699 000

Project leader
Charlotta Turner
Lund University
charlotta.turner@chem.lu.se



Doctoral students Said Al-Hamimi (left) and Mingzhe Sun (right), who are working on the project.
Photograph: Charlotta Turner

industries, in particular lignin hydrolysate. The chromatography methods will be significantly more efficient than they are today, with a higher peak capacity. The project will lead to a rapid method for the separation of hydrolyzed lignin using supercritical carbon dioxide chromatography. The result will be more rapid "greener" chemical analysis methods that will be of major importance in the development of more sustainable processes and biorefineries.

Project title
New value chain around polyols from renewable resources for a biobased chemical industry

Project number
2013-1061

Project duration
2014–2016

Funding awarded
SEK 3 279 000

Project leader
Sang-Hyun Pyo
Lund University
sang-hyun.pyo@biotek.lu.se

Sustainable production of polyols for the chemical industry

An alternative eco-friendly method has been investigated for the production of polyols (alcohols with multiple hydroxyl groups) from renewable resources.
The polyols produced are converted to their corresponding carboxylic acids and cyclic carbonates, which are monomers that can be used to produce compounds such as polycarbonates and polyurethanes. The anticipated results are a new production process and a new value chain, in addition to information about enzyme systems, functional chemicals and polymers.

Conventional methods based on fossil resources often require the use of environmentally hazardous chemicals that require very careful handling and complete removal from the end product.
This project aims to solve this problem. A new green and sustainable pathway from natural resources for the manufacture of polyols will revolutionise the chemical and polymer industries, as well as the biomaterials industry.

Oxidation of polyols to their corresponding carboxylic acids using microorganisms.
Photograph: Mahmoud Sayed

Bioscreen – textiles woven from biobased sunscreen material

This project has worked with developing sunscreens (textiles and blinds) made from biobased materials. Sunscreens can be used indoors or outdoors. They are generally made of a woven fabric strengthened by a surface coating. The fabric and surface coating are often comprised of different oil-based products, such as polyesters, acrylate and/or PVC. Biobased polymers and surface coatings are becoming increasingly accessible, but up until now these have been used to a limited extent for these types of textile applications.

PLA is one example of a biobased thermoplastic polymer that is produced from the bacterial fermentation of starch-rich plant crops, for example maize or sugar. In Bioscreen research is being carried out to develop new biobased material, optimise the properties of the material and adapt production processes to be able to manufacture entirely biobased sunscreen textiles. In addition to the requirements for the appearance of the products there are also high demands for qualities such as product strength, flexibility and stability when exposed to UV-light, heat, fire and chemicals. An advantage of a biobased sunscreen is that this will give a much lower net emission of CO^2 compared to an oil-based equivalent. It will also be easier to recycle. Bioscreen is a collaboration between Belgian and Swedish companies and research institutes within the EcoInnovera platform.

Project title
Sunscreens and blinds from biobased materials for indoor and outdoor use, Bioscreen

Project number
2013-2019
EcoInnovera

Project duration
2013–2014

Funding awarded
SEK 2 392 000

Project leader
Daniel Wendels
Swerea IVF
daniel.wendels@swerea.se

Daniel Wendels assesses the properties of the material.
Photograph: Swerea IVF

Bio-oils for fuel

The production of fuels from biomass via the production of bio-oils has been identified as having potential economic advantages in comparison to other processes. The much higher oxygen content in bio-oils is one of the greatest differences in comparison to crude oil. This makes bio-oils unsuitable as fuels without some form of refining, such as hydrodeoxygenation (HDO). HDO is a process that uses hydrogen to remove oxygen from the bio-oil to give a product more similar to crude oil.

One problem is the toxicity of the catalyst in this process and this project will examine the underlying mechanisms of this toxicity. The project will begin by

Project title
Alternative fuel production using bio-oils from the forest sector -Fundamental studies of catalyst deactivation

Project number
2014-164

Project duration
2014–2016

Funding awarded
SEK 3 780 000

Project leader
Louise Olsson
Chalmers
louise.olsson@chalmers.se

Reactor for the hydro-deoxygenation of bio-oils.
Photograph: Houman Ojagh

manufacturing different catalysts, for example nickel sulphide and molybdenum sulphide. Experiments will be performed under realistic HDO conditions in liquid-phase at high pressures and temperatures. The products will be analysed using gas chromatography and infrared spectroscopy. The toxicity levels on the catalysts will be detected. Models will also be developed to describe de-activation.

Project title
Bioethanol, bioethylene och biopolyethylene

Project number
2014-181

Project duration
2014–2016

Funding awarded
SEK 4 052 000

Project leader
Gen Larsson
KTH
gen@kth.se

Biobased polyethylene – how will Swedish production be established?

Biobased "green" polyethylene will be in high market demand in order to reduce the amount of plastics manufactured from fossil-based sources. This project will determine and eliminate the factors hindering the establishment of polyethylene production in Sweden using green ethanol as a source material. The project is based on increasing the production of green ethanol by re-circulating the streams in an ethanol production facility and using these streams to produce ethanol using a new microorganism.

As there is currently no production in Sweden the researchers want to determine where and how such production could be established. They also want to examine functional governance policies that can increase the risks for the companies involved in the value development chain from green ethanol, via green ethylene, to green polyethylene, as well as the products and end users.

Project title
Research and develop a novel steam catalytic pyrolysis of lignin for producing promising bioliquid

Project number
2014-205

Project duration
2014–2016

Funding awarded
SEK 4 249 000

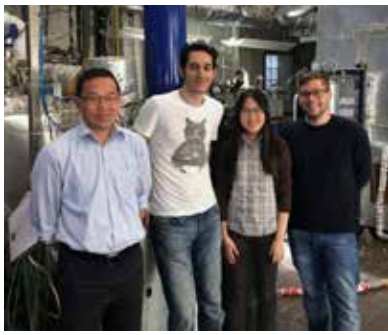
Project leader
Yang Weihong
KTH
weihong@kth.se

Pyrolysis of lignin for the production of biofuels

This project will develop a new method for the production of renewable fuels and chemicals. A process environment has been developed in a previous project, but the focus now will be on the catalyst material, which is a key component for the process to work.

Renewable resources, such as forestry waste, contain cellulose and lignin. These are chains of ring-formed, linked units, each of which is similar to the components of crude oil (aromatic hydrocarbons). The differences

are that the units in cellulose and lignin contain oxygen atoms, something that drastically reduces the possibilities of directly manufacturing a good liquid fuel. But with new catalyst material it is now possible to cleave out the oxygen without destroying the fundamental ring structures. Hydrogen normally needs to be added to capture the oxygen atoms, but in this project the scientists will attempt to replace the expensive hydrogen with steam. In addition they will attempt to develop a new catalyst material adapted for use in a steam atmosphere and with lignin as the source material. If the project succeeds in finding a suitable catalyst material the lignin that is a waste product will be able to be converted into renewable fuel with high efficiency. Potentially this could provide major environmental advantages and a substantial boost for the industry.



Project team with project leader Yang Weihong on the far left
Photograph: Alfred Halvarsson

Algae purify water and produce biomass

This project will investigate how carbon dioxide, nutrients and contaminants in flue gases, sewage and waste streams from industry can be recycled using photosynthesising microorganisms, such as algae and cyanobacteria. Flue gases and sewage function as "food" for microorganisms. The biomass that algae and cyanobacteria produce can then be used for biorefining to produce biofuels such as biodiesel, ethanol and biogas, but can also be used to energy-enrich products such as animal feed and bio-fertilizers.

In this way problematic waste streams, carbon dioxide and sewage can be used for algae farming and the waste can be converted into algae biomass. After harvesting of the algae, substances such as fats, starches and cellulose can be extracted. The fats can become biodiesel. Starches and cellulose can be broken down into sugars, which in turn can be converted into bioethanol. Alternatively the algae biomass can be used for the production of fish feed and biogas. This project is of great benefit to society, as it aims to purify water and at the same time generate products with additional value.

Project title
Why waste the waste? Characterization of Swedish microorganisms growing on sewage for the generation of biomass and high value products

Project number
2014-1504

Project duration
2015–2017

Funding awarded
SEK 5 147 000

Project leader
Christiane Funk
Umeå University
christiane.funk@chem.umu.se

Christiane Funk growing algae.
Photograph: Thomas Kieselbach

Energy

These projects concern biogas and other biofuels, geothermal heating, fuel cells, batteries and how carbon dioxide can be converted into various fuels using hydrogen gas. Some of the social science projects also address policies for governing technology dissemination and the management of local energy systems.

Biofuels – synergies in production

The production of first generation biofuels was based on well-established techniques for the production of bio-ethanol, biodiesel and biogas. These are also relatively easy to use in existing vehicle and infrastructure technology systems. This has made it possible to increase their use. But biofuels are controversial, due to their alleged poor environmental and energy performance. Sometimes this can be explained by the analyses having focused on the conversion of the source materials into fuel without fully considering the by-products.

By developing efficient use of the by-products, energy and infrastructure through synergies between the various biofuel production systems, and also including other industrial activities, the environmental and economic performance of biofuels can be improved. This project has contributed to the development of knowledge to make such synergies possible. More than 60 potential production synergies were identified in the initial phase of the project, together with the project's industrial partners. These synergies were then categorised into a model. The industrial partners were Ageratec AB, Lantmännen Agroetanol AB, Svensk Biogas AB and Tekniska Verken AB.

Phase two addressed how to enable the potential synergies. The results have shown that pure by-product exchange is easy to evaluate for individual companies, but production synergies that involve a common infrastructure are more difficult to achieve.

Project title
Synergies for improved environmental performance of first generation biofuels for transportation

Project number
2008-126
Environmental Technologies Program

Project duration
2008–2010

Funding awarded
SEK 3 289 000

Project leader
Mats Eklund
Linköping University
mats.eklund@liu.se

Michael Martin and Mats Eklund in a biogas reactor that is not yet in operation.
Photograph: Tommy Hvitfeldt

Changes in viscosity in biogas reactors

Increased biogas production by the addition of new substrate to digestion chambers often means that the viscosity of the process liquid changes, resulting in poor stirring, foaming and breakdown of the agitator. Dimensioning for viscosity in biogas reactors is mainly based on the amount of dry matter. But the rheology (how the material behaves in solutions) in biogas reactors is also thought to be linked to the extracellular polymeric substances (EPS) that are secreted by bacteria. This project has studied the flow, viscosity and EPS content in laboratory and full-scale reactors to examine all of the conditions that exist in Swedish biogas facilities.

Project title
Effect of extracellular polymeric substances (EPS) on change in viscosity of completely stirred tank reactors for biogas production related to substrate mix and microflora

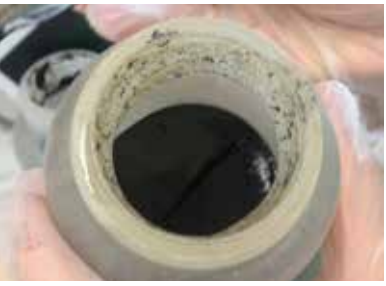
Project number
2008-139
Environmental Technologies Program

Project duration
2008–2010

Funding awarded
SEK 1 404 000

Project leader
Bo H. Svensson
Linköping University
bo.svensson@liu.se

Annika Björn analysing digestion fluid from a biogas reactor using a rotational viscosity rheometer.
Photograph: Monika Westman Svenselius



Extraction of sludge from a biogas reactor.
Photograph: Annnika Björn

The studies confirmed that the rheology does vary according to substrate, process conditions and the amount of EPS. For processes that use sewage sludge the expected relationship between dry matter content and viscosity was observed, but this was not the case for co-digester reactors. For these the viscosity varied significantly, even if the dry matter content was the same. The dry matter content can therefore not be used as a basis for dimensioning calculations for these reactors, which can explain why breakdown of agitators has occurred in these types of reactors. Greater attention should therefore be paid to the rheology in biogas reactors to ensure long-term operation and profitability. Changes in rheology may indicate processing problems and can therefore be used in process monitoring.

This project was a collaboration between Linköping University and Scandinavian Biogas Fuels AB.

Project title
Third generation biogas from carbon dioxide and wind power-based hydrogen

Project number
2008–2164
Environmental Technologies Program
2010–937

Project duration
2009–2010
2011–2012

Funding awarded
SEK 1 350 000
SEK 1 486 000

Project leader
Per Alvfors
KTH
alvfors@kth.se

Carbon dioxide and hydrogen provide third generation biogas

The researchers wanted to verify the possibilities of converting carbon dioxide into methane by allowing carbon dioxide to react with hydrogen via a reaction known as the Sabatier reaction: $CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$. Electricity from wind power can be used to generate hydrogen via the electrolysis of water. The reaction of this hydrogen with carbon dioxide produces methane that can then be used as a vehicle fuel. The hydrogen was produced in the project in collaboration with the wind power company Agrivind AB. It is of particular interest to be able to convert the carbon dioxide from the gas produced in a bioreactor when food waste is used as the substrate for the digester, as this gas already consists of around 60 percent methane, with the remainder being carbon dioxide. The process technology to upgrade this digester gas to pure methane should be relatively simple.

The researchers have attempted to do this, in part using a "synthetic" biogas, or in other words a gas that they have artificially mixed together using bottled gas, and in part using real biogas from a digester, in a chemical reactor in the presence of various catalysts to promote the reaction. Promoting the reaction can mean that the majority of the carbon dioxide can be converted or that the reaction can proceed even at low reactor temperature and pressure. Conversion of carbon dioxide to methane in a biogas reactor has been shown to work well and it is not necessary to use particularly high pressure or temperature to achieve almost complete conversion to methane.

Electricity from wind power can be used to generate hydrogen via the electrolysis of water. The reaction of this hydrogen with carbon dioxide produces methane that can then be used as a vehicle fuel.
Photograph: Thinkstock

Thermophilic bacteria give more efficient ethanol production

The researchers have worked jointly with an Icelandic company to examine whether heat tolerant bacteria (thermophiles) can be used to produce the biofuel ethanol from renewable resources. Two main types of bacteria were examined: thermophilic anaerobes that require an oxygen-free environment (including *Thermoanaerobacterium* and *Caldocellulosiruptor*), and thermophilic facultative anaerobes that can live both with and without oxygen (including Geobacillus). Both types produce ethanol in the absence of oxygen, but the levels vary. DNA analysis revealed that Caldocellulosiruptor and *Geobacillus* have genes for the most interesting enzymes (with respect to the biomass preferred for use), but produce less ethanol. *Thermoanerobacterium* gave a good ethanol yield.

Attempts to genetically modify the bacteria demonstrated that it was difficult to find tools effective for *Caldocellulosiruptor*, but *Thermoanaerobacterium* possesses a natural mechanism that makes it easier to add and remove genes. Genetic tools have also subsequently been developed for *Geobacillus*. Based on the overall results, variants of *Thermoanaerobacterium* and *Geobacillus* are considered to be of interest for ethanol production using thermophiles. This research has also provided improved knowledge about the development of extreme microorganisms for biorefinery applications.

Project title
Metabolic engineering of thermophiles for high biomass utilization and improvements in ethanol production

Project number
2008-2196
Environmental Technologies Program

Project duration
2009–2011

Funding awarded
SEK 2 814 000

Project leader
Eva Nordberg Karlsson
Lund University
eva.nordberg_karlsson@biotek.lu.se

Thermophilic bacteria can be found in warm water pools in Iceland.
Photograph: Eva Nordberg Karlsson

Eva Nordberg Karlsson
Photograph: K Zubaida G Ara

Project title
Sustainable fuel production via solar water splitting and CO_2 conversion

Project number
2009-779

Project duration
2010–2012

Funding awarded
SEK 4 074 000

Project leader
Igor Zoric
Chalmers
igor.zoric@chalmers.se

Harvesting solar energy to produce sustainable fuel

The objective of the project was to capture solar energy and store this in the form of hydrogen or methanol (energy carriers) produced using a photoelectrochemical cell to split water or convert water and carbon dioxide. The ferric oxide hematite (Fe_2O_3) is a promising photoanode material, but unfortunately its energy conversion efficiency levels are low. The most important reasons for this are the large differences in spectra for light absorption and conductance spectra in the charge carriers.

This project investigated the possibilities of improving the optoelectronic properties of hematite using gold nanoparticles and surface plasmon films. In thin hematite films light capture and charge separation was improved using surface plasmon coatings and gold nanodiscs. The scientists also elucidated mechanisms involved in the plasmon-assisted electrolysis of water. This method also has major potential for many other applications, such as in photovoltaic cells.

Project title
A co-axial ground heat exchanger for low pumping power needs and combined heat and temperature sink storage simulation and laboratory test, and evaluation in system applications

Project number
2009-1963
Environmental Technologies Program

Project duration
2010–2012

Funding awarded
SEK 2 620 000

Project leader
Folke Björk
KTH
folke.bjork@byv.kth.se

Regulating geothermal heat storage

The KTH Department of Energy Technology and Division of Building Technology have many years of experience in the subjects of energy in buildings and heating pump technology. For the past six years much time has been spent performing field measurements in borehole systems and in the further development of more accurate models for the dimensioning of borehole systems. Doctoral student Patricia Monzó has worked on the project, developing numerical models that give a detailed image of the heat transfer processes in the ground in multiple borehole systems with more realistic boundary conditions in borehole walls than is common for such simulations. This has resulted in new functions that will give better predictability than the current commercially available programs. The results of the project will be applied to the design of advanced methods for regulating geothermal heat storage. The scientists will be able to verify the methods when they carry out detailed monitoring of the ground temperatures and other parameters in the new large geothermal borehole facility completed by Akademiska hus in 2015 in the Frescati area of Stockholm.

Patricia Monzo is studying geothermal heating.
Photograph: Monika Ignatowicz

Policies to encourage green technology use

This project examined how public policy can be developed to stimulate innovation and encourage more green technology use within industry and the energy sector. Above all the preconditions for a fit-for-purpose technology policy in the cases of wind power and transition in the pulp and paper industries were examined. This project contributes knowledge of how environmental policies should be supplemented with an active technology policy and also highlights the importance of this not being solely a matter of focussing on support for research and development but also on the learning effects in the production of new technologies.

The empirical aspects of the project have highlighted the importance of learning about the technologies, or in other words the fact that new technology cannot be developed by research and development (R&D) alone, but must be verified, scaled up and expanded in production. One of the studies has shown that innovation in the wind power sector is stimulated when the public funding for R&D is supplemented by production funding for wind power. The research focusing on wind power concomitantly illuminates the difficulties in measuring technology learning in a reliable manner. Another study examined how traditional environmental policies (for example individual limit values for emissions) can stimulate innovation in the area of the environment when these are implemented in a manner directed toward this purpose.

Project title
Clean Technology, innovation and the role of public policy: conceptual issues and case studies

Project number
2009-2045
Environmental Technologies Program

Project duration
2010–2012

Funding awarded
SEK 450 000

Project leader
Patrik Söderholm
Luleå University of Technology
patrik.soderholm@ltu.se

Photograph: Thinkstock

Integrated local energy systems assessments

The researchers wanted to investigate how long-term sustainability is affected by increased integration of district heating and the other energy systems, as well as the utilization of industrial waste heat in district heating systems. They also wanted to develop a framework for integrated assessments of these issues based on local energy systems. They therefore sought answers to questions such as: How should district heating sustainability be assessed? What potentials are there for reducing the costs and carbon dioxide emissions from district heating-driven

Project title
Integrated local energy systems assessments

Project number
2009-2053
Environmental Technologies Program

Project duration
2010–2014

Funding awarded
SEK 2 855 000

Project leader
Erik Ahlgren
Chalmers
ahleri@chalmers.se

Photograph: Birgitta Johansson

absorption cooling instead of electrically powered compression cooling? What are the consequences for carbon dioxide emissions and system economics of large-scale waste heat utilization?

The research was based on an investigation of the interdependencies between the technological, environmental and economic aspects. The central tool used was energy system models.

The study demonstrated that increased cooling needs can be met by district heating-driven absorption cooling with low, or even negative, net emission of carbon dioxide, as long as there is good accessibility to industrial waste heat in the heating/cooling system, or if new biofuel-based power plant heating capacity is installed. The use of industrial waste heat contributes to reduced use of both biomass and fossil-based fuel, as well as to a reduction in the carbon dioxide emission from the district heating system, but the amount of electricity generated is also reduced.

Project title
Characterisation of metabolic repressors in the yeast Pichia stipitis for improved bioethanol production

Project number
2010-651

Project duration
2011–2014

Funding awarded
SEK 4 920 000

Project leader
Tomas Linder
SLU
tomas.linder@slu.se

More efficient ethanol production from yeast

The yeast *Pichia stipitis* constitutes a promising system for the production of bioethanol from the plant tissue-derived lignocellulose that humans cannot digest. In contrast to common baker's yeast, P. stipitis has the valuable ability to ferment a number of the different sugars that lignocellulose contains. The project focussed on identifying genes that inhibit the activities of other genes, otherwise known as repressors. By inactivating these repressors P. stipitis can produce ethanol more efficiently.

It would also be advantageous if P. stipitis could assimilate several different types of sugars simultaneously. In naturally occurring strains of P. stipitis higher levels of glucose inhibits the consumption of other sugars, such as the pentoses. Another obstacle to efficient ethanol production is that P. stipitis only ferments sugars if oxygen levels are low – as opposed to baker's yeast that ferments sugars regardless of the oxygen levels. If the repressors that inhibit the switch from respiration to fermentation can be identified it would be possible to create a strain of P. stipitis that could ferment sugars continuously.

A colony of Pichia stipitis yeast growing on agar media. The colony is around 5 mm in diameter. Photograph: Tomas Linder

Dry rot fungus provides knowledge about wood degradation

Fungi that degrade wood can be used in the future to produce second generation biofuels, the generation of biofuels derived from wood sources that do not compete with food production. Strong scientific and economic powers are working to improve our apparent paucity of knowledge about how wood rots. The dry rot fungus is feared by every home-owner. In the worst cases the entire house may have to be demolished if the damage to the timber is too great. In an initial study the genome of the dry rot fungus was sequenced and found to contain around 13,000 genes. This work was carried out partly by a smaller group at SLU, and partly by an international consortium of scientists, including researchers in Norway, the USA and France. The genomic sequence, together with studies of which genes are active when the dry rot fungus degrades wood, indicate that the dry rot fungus has a very efficient arsenal of enzymes that work together in these processes.

The researchers have studied why it is that the dry rot fungus is only found in buildings. They have also examined why the fungus is so efficient at degrading wood. Comparisons have been made with related fungi found in nature. The dry rot fungus has been demonstrated to be weak in comparison, as it lacks many genes that have functionality when fungi are stressed by their environment or by competition from other microorganisms. The research is continuing through a privately funded project to study the enzymes the fungus uses to degrade wood.

Project title
Genomics of Serpula lacrymans, the dry rot fungus, as a model species for wood degradation with possible applications in biofuel development

Project number
2010-1354

Project duration
2011–2013

Funding awarded
SEK 3 087 000

Project leader
Nils Högberg
SLU
nils.hogberg@mykopat.slu.se

Optimisation of solar-powered thermally driven heat pumps

ClimateWell is developing the next generation of solar-powered heating and cooling systems. The objective of this project was to contribute knowledge of how small absorption components should be designed and function to be able to be integrated into conventional solar traps. Such solar traps would be able to deliver both heating and cooling directly from the trap itself. This seemingly small development step will have enormous importance for solar-powered heating/cooling systems in the future. The number of components will be drastically reduced, as well as the costs and system complexity, which are the greatest current obstacles to these systems.

Project title
Optimisation of reversible solar thermally driven heat pumps

Project number
2010-2277
Environmental Technologies Program

Project duration
2011–2013

Funding awarded
SEK 2 040 000

Project leader
Björn Karlsson
Mälardalen University
bjorn.karlsson@mdh.se

Project title
Next generation batteries: sodium

Project number
2011-405

Project duration
2012–2014

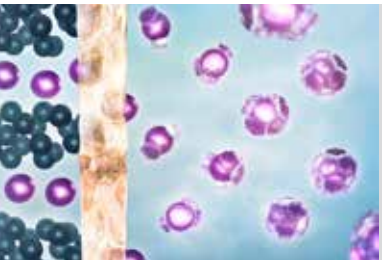
Funding awarded
SEK 2 394 000

Project leader
Patrik Johansson
Chalmers
patrik.johansson@chalmers.se

Sodium in next generation batteries

Today lithium batteries are universally used in our smartphones, laptops and tablets. The next step is that batteries will be needed to an even greater extent in different types of electric vehicles – cars, buses and trucks. But lithium can only be readily mined at a few sites worldwide. Batteries already accounted for 22 percent of total lithium use by 2013, and use is increasing by around 15 percent each year. It is therefore necessary to search for alternative or supplementary technology. Sodium batteries are one conceptually promising technology. Sodium is 30-times less expensive than lithium and is a thousand-fold more abundant in the Earth's crust.

Research to study sodium batteries is a rapidly growing research field. This research group at Chalmers is developing sodium batteries based on the insight that a technology is always ultimately limited by access to the material. Two doctoral students, with collaborative partners in Barcelona and Melbourne, have chosen to study the stability of polymer-based and ionic hydrogen-based electrolytes and to examine how quickly these can conduct charge, which is important for battery charging times. The group at Chalmers is also testing a range of promising material in electrochemical cells to assess battery performance.



Sodium ions (purple) are released from a carbon-based electrode into solution, but first pass through a type of membrane – essential to obtain sustainable batteries.
Illustration: Alexander Ternstrand, Mindboom

Project title
Integrated storage and pre-treatment (ISP) – a novel low input approach for sustainable biofuel production

Project number
2011-625

Project duration
2011

Funding awarded
SEK 2 212 000

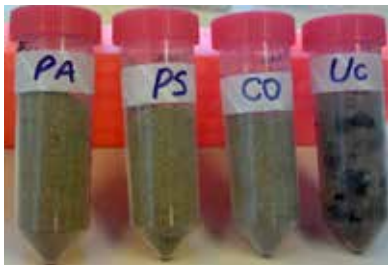
Project leader
Volkmar Passoth
SLU
volkmar.passoth@slu.se

More efficient biofuel production using yeast in storage

Lignocellulose, for example from forestry biomass or straw, is very resistant to digestion. An efficient conversion of lignocellulose, for example into bioethanol or biogas, requires expensive and energy consuming pre-treatment. This project has developed a new technique: integrated storage and pre-treatment. The researchers have added yeast that prevents mould outbreaks during storage and opens up the structure of the lignocellulose. This reduces the need for subsequent pre-treatment.

The biomass that is produced is stored after it is harvested, but in regions with pronounced seasonal variations, such as in Sweden, the biomass needs to be dried to prevent the growth of detrimental microbes such as moulds. The drying processes can require a lot of energy

due to high moisture content. The scientists have simulated integrated storage and pre-treatment in the laboratory, and have produced ethanol and/or biogas. In general it can be said that integrated storage and pre-treatment results in higher efficiency of biofuel production, especially when wheat straw is used as a substrate. The research group is working together with scientists in Austria and Norway, and are participating in larger research programs, such as MicroDrive and LipoDrive, which are examining sustainable biofuel production.



Storage trials with and without the addition of yeast. With no yeast added (sample Uc) there was strong mould growth.
Photograph: Muhammad Rizwan Tabassum

Ecopreneurship and small scale energy technology

This project was based on the insight that energy systems need to be converted to reduce emissions of carbon dioxide, achieve more robustness, obtain better energy efficiency and have more actors involved. The aim of the project was to study how such conversion can be achieved using ecologically sustainable entrepreneurship, known as ecopreneurship. This has been carried out in part through an archive study of the energy and environmental policies of the 1980s where an ecopreneur was the focus of the analysis, and in part a study has been carried out in New Zealand and Sweden to interview thirty ecopreneurs and to study their companies.

There are currently few, but extremely passionate, ecopreneurs who are an important aspect in transitioning society towards sustainability. Norms and regulations do not fully support this form of entrepreneurship. The ideals in terms of entrepreneurship are still based on the industrial model norms. The historical analysis of the situation in the 1980s has provided insights into how a commitment to transition, which at that time was supported by society to a greater extent, encountered obstacles in the form of strong industrial model structures. Technology and policies need to be jointly understood if change is to be achieved.

Project title
Ecopreneurship and small scale energy technology Historical and contemporary comparisons between WELGAS, EgenEL and Powerhouse Ltd.

Project number
2011-708

Project duration
2012–2013

Funding awarded
SEK 2 230 000

Project leader
Martin Hultman
Umeå University
martin.hultman@umu.se

Permaculture farm Rainbow Valley in New Zealand.
Photograph: Martin Hultman

Project title
Electrochemical and photochemical reduction of CO_2 to hydrocarbon fuels on nanostructured model electrodes

Project number
2011-959

Project duration
2011–2014

Funding awarded
SEK 3 587 000

Project leader
Björn Wickman
Chalmers
bjorn.wickman@chalmers.se

Measurement cell for the electrochemical reduction of carbon dioxide and analysis of the products.
Photograph: Björn Wickman

Reduction of carbon dioxide to hydrocarbon fuels

The scientists wanted to be able to recycle carbon dioxide to manufacture renewable and sustainable fuels. A functional and practical method of reducing carbon dioxide would make carbon dioxide a resource instead of just a waste product. If this reduction could also be achieved using energy in the form of electricity the process could be a method of storing excess capacity, for example from wind or solar power. When carbon dioxide is converted using water and energy a wide range of different hydrocarbons can be produced, such as methane and methanol. These hydrocarbons can then be used directly as fuel, or can be further refined into other fuels, or used as building blocks in the chemical industry.

Using model systems, well characterised electrodes and catalyst materials, the progression of the reactions was investigated, as well as the ways that production efficiency could be improved and how the hydrocarbon produced could be controlled. Theoretical studies and analyses were carried out in order to propose new materials. Gold is a promising material as a catalyst for the first step in an electrochemical carbon dioxide reduction. It has also been shown that the efficiency of production for the process, or in other words reducing the amount of electrical energy consumed, can be achieved by changing the orientation of the atoms on the gold surface and how these are coordinated with each other.

Project title
Providing renewable energy technologies for productive use for rural electrification (RETs-PURE)

Project number
2011-1354

Project duration
2012–2015

Funding awarded
SEK 6 078 000

Project leader
Sverker Molander
Chalmers
sverker.molander@chalmers.se

Renewable energy for rural electrification

This project investigated the possibilities and the factors preventing increased accessibility and use of electricity in East Africa. The focus was electrification based on often abundant renewable energy sources, such as small scale hydroelectric facilities. The project was interested in locally driven development processes where sustainable rural electrification was linked to the incipient commercial development of small companies. This is the type of productive use of electricity that can generate development and economic growth.

The researchers have carried out case studies in person in Tanzania, based on interviews, to identify different stakeholders and their interactions at different stages of the electrification process. They have also worked with system dynamic modelling to study the interactions between the different factors that affect the links between local commercial development and electrification. To date the results indicate that the local preconditions are extremely important for a successful energy project. The interplay between technology and institutions has begun to be understood at different levels in the society, as well as how power relations – not least between men and women – can impact the electrification process. The study has also pointed out the associations between electrification and the environment.

African electrification in Bulongwa – the researchers and local church and medical facility representatives.
Photograph: Gabriel Gustafsson

EASY – Energy-Aware feeding SYstems

As one aspect of developing sustainable production systems this project has focussed on the principles and analysis methods for reducing energy use in material handling systems. Lean-production attempts to minimize waste, but unfortunately the Just-in-Time principle within Lean-production can result in more and smaller batch deliveries and transport, which can then be a waste of resources from an energy point of view. The hypothesis is that it should be possible to reduce the energy used in material handling systems without loss of efficiency or increased production costs.

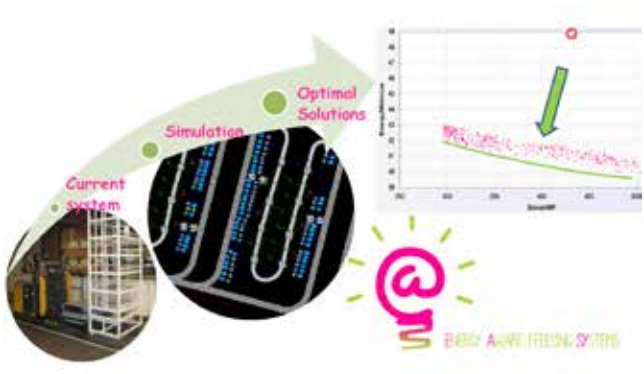
Project title
EASY Energy-Aware feeding SYstems

Project number
2011-2157
EcoInnovera

Project duration
2012–2016

Funding awarded
SEK 1 568 000

Project leader
Matias Urenda Moris
University of Skövde
matias.urenda.moris@his.se



Simulation is used to develop system solutions that minimize energy use in material handling systems.
Illustration: Matias Urenda Moris

The project is an EcoInnovera project with participants from France, Spain and Sweden. The researchers have used mathematical programming, optimisations and simulations, including multiple target optimisations that give the decision-makers the opportunities to evaluate a number of different combinations and find the optimal compromises for conflicting objectives. The initial results demonstrate a 20 percent reduction in energy use. This reduction is achieved by more efficient governance of material handling systems, where parameters such as order of delivery, time of delivery, point of sale and order quantity are adapted to optimise the system.

Project title
Alkaline membranes for sustainable fuel cell technology

Project number
2012-382

Project duration
2013–2015

Funding awarded
SEK 3 807 000

Project leader
Patric Jannasch
Lund University
patric.jannasch@chem.lu.se

Alkaline membranes for sustainable fuel cells

Polymer fuel cells are electrochemical systems for the efficient and green conversion of the chemical energy bound in hydrogen gas into electricity – without the emission of greenhouse gases or particle contaminants into air. The fuel cells of today will soon be used in larger scale. These are based on the use of thin plastic films (membranes) that can conduct protons, but are also entirely dependent on platinum metal to achieve the efficiency that is required, for example in cars. Large scale use of platinum fuel cells can lead to depletion of the global resources. In this project new types of membrane have been studied to enable the production of a new type of alkaline fuel cell that can use base metals such as nickel and several different types of fuel.

For this to be possible in practice however the development of new membrane materials with the correct property profiles of high ionic transfer and stability is necessary. By producing polymers with different positively charged groups, characterising the structures of these at the nanometre level and measuring ionic transfer and chemical-mechanical stability the researchers have created special molecular structures that combine the various essential properties required. They are now in the process of evaluating the selected optimized membranes in alkaline fuel cells in collaboration with industry.

Efficient binding of methane from protein-rich material

Protein-rich material, such as slaughterhouse waste, food waste and pig manure are interesting materials for biogas production as they provide a lot of gas and a nitrogen-rich by-product that is an attractive biofertilizer. Unfortunately there is also a risk of problems in using these materials, as the ammonia that is released during the protein degradation process inhibits certain methane-producing organisms. Previous research has shown that the microbial system that is the basis for methane production can adapt to high concentrations of ammonia and that the syntrofaaceta toxiderande bacteria (SAOB) is of particular interest in this context. These organisms "jump in" instead of the methane-producing organisms that are inhibited by ammonia. We know relatively little about how the biogas process should be run to ensure that SAOB thrives and can perform its work. The researchers have isolated a few different SAOB strains and have determined the conditions under which these grow best. This knowledge was used in this project to adapt operation of the biogas process so that these organisms could grow and contribute to a more stable and efficient process when levels of ammonia are high. The results to date have demonstrated that temperature is an important operating parameter that can be used to regulate growth. Trace elements, ammonia concentrations and residence time in the reactor are other parameters that have been shown to be of importance for efficient methane production.

Project title
Managing microbial communities towards more efficient biogas production

Project number
2012-807

Project duration
2013–2014

Funding awarded
SEK 3 304 000

Project leader
Anna Schnürer
SLU
anna.schnurer@slu.se

Biogas facility in Norrköping.
Photograph: Anna Schnürer

Lithium-Sulphur batteries – a sustainable technology for large scale storage

A key factor in establishing a sustainable energy system is better, cheaper and more environmentally friendly batteries that can store sufficient amounts of energy to allow, for example, plug-in electric cars to travel reasonable distances and for back-up stations for major electricity grids to become a reality.

This project has focussed on one of the most promising technological solutions: lithium-sulphur batteries (LiS). One LiS-battery theoretically has ten-times the energy storage capacity that today's lithium-iodide batteries have.

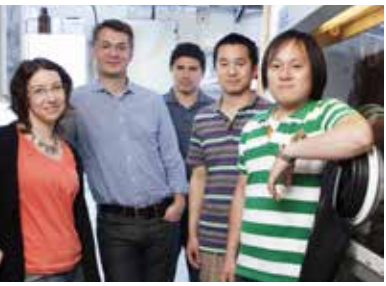
Project title
Li-Sulphur batteries – a sustainable technology for large scale storage applications

Project number
2012-1576

Project duration
2012–2015

Funding awarded
SEK 2 754 000

Project leader
Aleksandar Matic
Chalmers
matic@chalmers.se



The group researching lithium-sulphur batteries.
Photograph: Henrik Sandsjö

In addition to high energy storage capacity, the lithium-sulphur technology has the advantage of sulphur being a much more abundant basic element that has little environmental impact. Despite the principle for the technology having been known for a couple of decades very little practical advances have been achieved.

The reason for this is that sulphur is not as stable as the conventional electrolytes in use today. The researchers have focussed on developing new electrolytes based on thermally and chemically stable ionic solutions encapsulated in polymer membranes.

Project title
Fundamental experiments and modelling of hydrogenation of tall oil for biofuel production

Project number
2012-1584

Project duration
2013–2015

Funding awarded
SEK 3 030 000

Project leader
Louise Olsson
Chalmers
louise.olsson@chalmers.se

Biofuel production from pine resin

One way to reduce global warming is to use biofuels, preferably second generation biofuels that do not compete with food resources. For that reason pine resin is an excellent source material. To use pine resin as a fuel the oxygen content must be reduced, which is achieved by hydrogenation. A great amount of heat is generated in this reaction, which can deactivate the catalysts. The goal of this project was to investigate the thermal deactivation of the catalyst in the hydrogenation reaction.

The project synthesized catalysts that were then thoroughly characterised before and after undergoing different ageing processes. The researchers have synthesized a wide range of catalysts, for example nickel, molybdenum, cobalt, nickel/molybdenum and cobalt/molybdenum. These materials have been synthesized in both their pure forms and as sulphides. As it is crucial for the reaction that the catalyst is reduced in order to be active, the researchers have studied various reduction conditions. They have also built a liquid phase reactor to measure catalyst activity.

Photograph: Birgitta Johansson

Commercializing the bioeconomy

This project is examining the importance of pilot and demonstration facilities for the development of advanced biorefineries. Primarily this project will improve our knowledge of the societal benefits of such demonstration plants, among other things in reducing the technological, institutional and market-related uncertainties that prevent large scale commercialization of the technologies, but also in providing positive dissemination of current knowledge. The researchers also want to gain more knowledge of how the institutional structures related to these types of demonstration plants, such as public funding, can be more efficiently structured.

Important methods for the project are case studies of important pilot and demonstration installations in Sweden, for example the ethanol pilot plant in Örnsköldsvik and the BioDME pilot in Piteå. These are supplemented with equivalent initiatives in other countries. Other aspects examined by the project are based on secondary data, such as patent applications. The project will improve the possibilities of structuring and supporting technology development using pilot facilities in an efficient manner. This knowledge is important, partly for the stakeholders participating in the technology development processes and partly for those who shape the innovation policies, such as funding support.

Project title
Commercializing the bioeconomy: Pilot and demonstration plants in innovation policy and management

Project number
2013-100
Strong environment

Project duration
2013–2017

Funding awarded
SEK 16 005 000

Project leader
Patrik Söderholm
Luleå University of Technology
patrik.soderholm@ltu.se

Pilot facility in Piteå for the production of BioDME.
Photograph: Luleå University of Technology

Project title
High-velocity vacuum drying of forest industry sludge materials

Project number
2014-182

Project duration
2014–2016

Funding awarded
SEK 3 571 000

Project leader
Sylvia Larsson
SLU
sylvia.larsson@slu.se

New drying technique for forest industry sludge

Economically and environmentally sustainable drying methods are needed to realise the potential of forest industry sludge as a raw material resource. This project will thoroughly study and develop the technical potential of a drying method for industrial applications and will also investigate the possibilities of optimization for specific sludge types and individual process conditions. The process is based on cyclone technology in which a vacuum is generated using high-velocity air currents, but low value heating, to create a rapid drying process. The project has been preceded by pilot-scale studies, in collaboration with forestry industry partners, which have demonstrated promising results for several types of sludge.

This project provides the possibilities to adjust the processes using laboratory-scale trials and to use these results to understand how the technology can be developed. Parallel pilot-scale studies are also ongoing within the project where the new knowledge generated is implemented directly. If this drying technique succeeds in gaining acceptance it will be possible to utilize the by-products of large scale industry for fuel and other material purposes more efficiently.

Processing biosludge. The researchers must be very careful because of the risk of Legionella bacteria.
Photograph: Gunnar Kalén

Drying equipment in pilot scale (on the right).
Photograph: Gunnar Kalén

Combustion of oxygen from metal oxides

Oxygen is added in the form of air in all types of combustion. Air is comprised of 80 percent nitrogen, which is a problem if it is intended to store carbon dioxide from the combustion. The solution is to add oxygen in the form of a solid metal oxide, known as an oxygen carrier, which only releases the amount of oxygen required at the site it is needed, so that pure carbon dioxide is produced. But the majority of fuels contain ashes that can deactivate the oxygen carrier. The metal oxide in the oxygen carrier is also expensive.

The researchers want to find a cheap raw material that can be used as the oxygen carrier, for example waste from the steel industry, or by other manner reactivate the oxygen carrier so that it can be reused. They will investigate which components in the ash react with the oxygen carrier under combustion conditions and will also attempt to "wash" away the ash components so that they can reuse the oxygen carrier. The use of oxygen carriers in combustion will make the combustion itself more efficient, reduce the amount of NOx and hydrocarbon emissions and will enable the capture and storage of carbon dioxide.

Project title
Metal oxides for biofuel conversion

Project number
2014-918

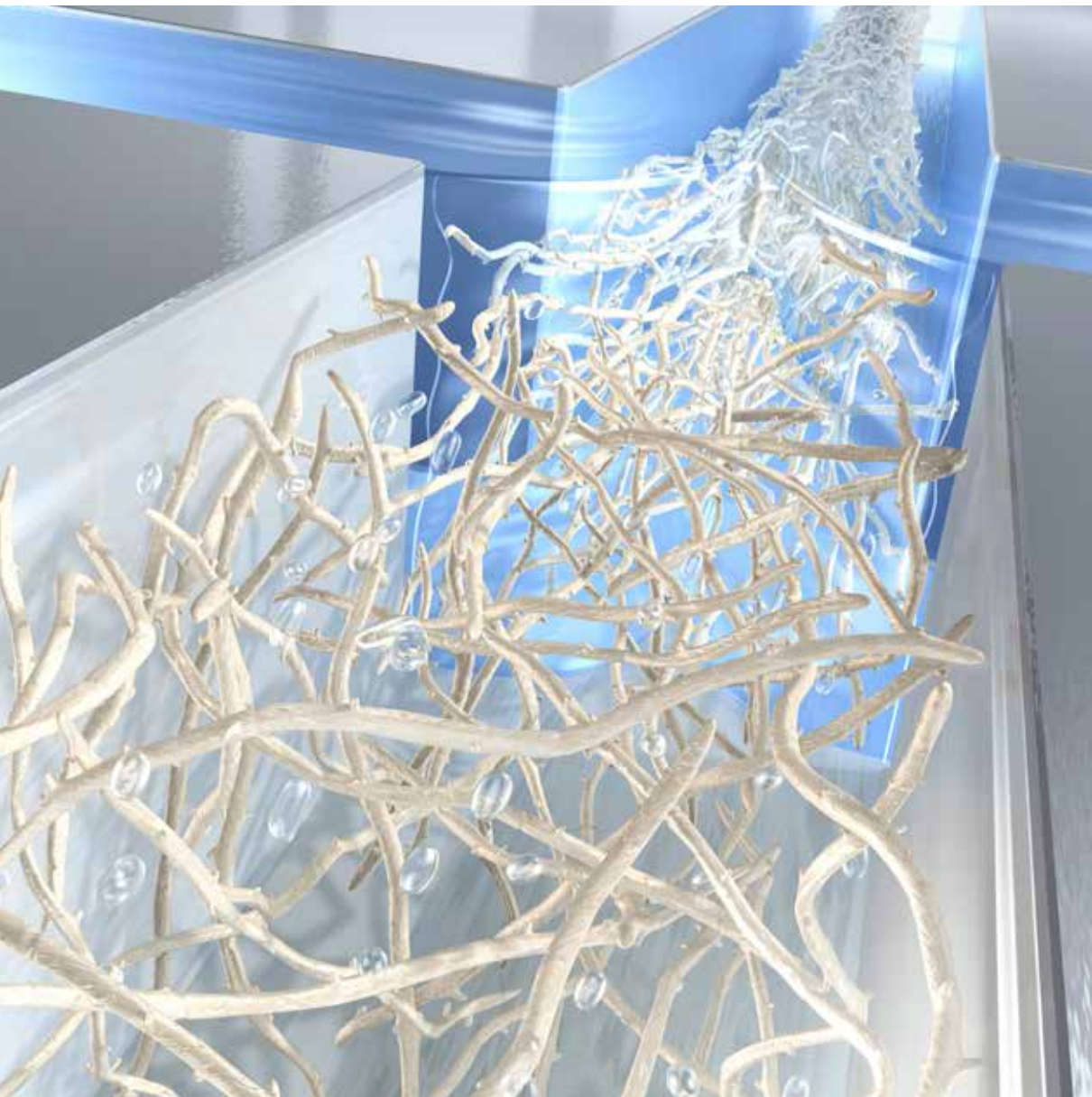
Project duration
2015–2017

Funding awarded
SEK 6 183 000

Project leader
Henrik Leion
Chalmers
leion@chalmers.se

New and Advanced Materials

Among other things these projects investigate new cellulose-based materials for different application areas, foams, methods for preventing biofouling, hydrogen storage materials, composite bridges, thermoelectric textiles, bioactive silk for wound healing and membranes for purifying biogas and desalinating seawater.



Hemicellulose for new materials

Forests are attracting increased interest as a source of raw materials for the production of chemicals where the wood source material is fractionated to generate renewable, degradable and cheap source materials. The medium and high molecular source materials that in addition to cellulose can be derived from wood comprise for the most part hemicelluloses. These are released during pulp processing into the process wastewater streams. In two research projects the process water containing hemicellulose (hydrolysate) has been collected, refined and used in the design of new materials.

A pre-hydrolysis process for spruce and birch was developed and demonstrated in pilot scale. The hydrolysate was converted into barrier formulations that were used to generate films and coatings for paper and plastics in laboratory and pilot scales. The films produced function exceptionally well as oxygen barriers. These projects have improved our knowledge of the function, applications and properties of different formulations and of the process parameters important for hydrolysate quality. The results provide good guidance to move towards an industrial process. The projects were run in collaboration with industry (Södra Cell AB, Tetra Pak), academia (KTH) and institutions (Innventia AB).

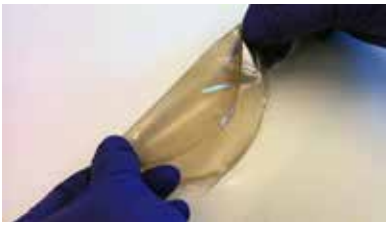
Project title
Wood hydrolysates from pulping as a renewable resource for functional polymeric products

Project number
2008-129
2009-2009
Environmental Technologies Program

Project duration
2008–2009
2010–2012

Funding awarded
SEK 1 505 000
SEK 4 466 000

Project leader
Ann-Christine Albertsson
KTH
aila@polymer.kth.se



Film made from forestry source materials.
Photograph: Ulrica Edlund

Food and plastic foams from cereal polymers

Foaming is an important process in the production of different types of food, such as bread and snacks. The same applies to materials used in shock absorption, absorption in general and in packaging. These projects have examined cereal proteins with the intention of producing new foam materials and new food products, including gluten-free bread. Biopolymers from grain seeds, proteins and starches are of particular interest as these are an environmentally friendly alternative to oil-based materials and because they are easily accessible in large quantities at low cost.

To generate a solid foam the smelt or dough must have the correct characteristics in terms of fluidity, surface tension and gas diffusion. The resistance in the dough must allow bubble formation during the proving process, but must be sufficiently great to prevent the bubbles from

Project title
Cereal protein foams

Project number
2008-149
Environmental Technologies Program
2010-1076

Project duration
2008–2010
2010–2013

Funding awarded
SEK 1 814 000
SEK 3 870 000

Project leader
Mats Stading
SP Food and Bioscience
mats.stading@sp.se

Maize protein being extruded (on the left).
Photograph: Mats Stading

Development and analysis of starch/protein foam, or in other words bread.
Photograph: Dick Gillberg

bursting. The foam material is created by first melting under high pressure and then pressing out the material from an extruder to be shaped into the correct form. These projects have determined the properties required for creating foams and have developed the correct mixtures of biopolymers for both plastics and bread. The results have been used, among other things, to make better gluten-free bread jointly with a small bakery. New bread based on African, naturally gluten-free grain types has been developed and is now available on supermarket shelves.

Project title
Minimal use of anti-growth substances by optimization of release from new microcapsule-containing coatings

Project number
2008-2160
Environmental Technologies Program

Project duration
2009–2011

Funding awarded
SEK 3 307 000

Project leader
Magnus Nydén
Chalmers
mnyden@chalmers.se

Microcapsules in anti-growth substances

The goal of this project was to develop microcapsules as micro-carriers of substances to prevent the growth of moulds and algae in house paints. The hypothesis was that these carriers would have the potential for long-term release of anti-growth substances and in this way the paints would be protected against the growth of mould for a longer time. The carriers also effectively protect the paint itself from the substances as the substances are encapsulated. This maintains the mechanical properties of the paint, for example hardness and porosity. The plan was to load microcapsules with anti-growth substances, mix these with house paints and then test for the growth of mould and algae under relevant weather conditions.

The researchers have developed the microcapsules for the purposes of the project. It was realised fairly early on that the conventional manufacturing methods would not be sufficient for controlled release from the capsules in the paint. This resulted in an early project reprioritization. The researchers have provided new knowledge about the production of microcapsules. There is currently no company in the world that has microcapsules on the

Microcapsule

market for these purposes, despite the intention having existed for more than two decades. This project has been run as a joint collaboration with Chalmers Innovation where Capeco AB was the end user with the intention of taking the research results to market.

Heading towards eco-efficient surface protection

Increased environmental awareness has created a need for eco-efficient surface protection with prolonged durability. Previous environmentally hazardous surface protectants, such as in paints, are now prohibited and house exteriors are currently painted with paints that can only protect the surface from growth of microorganisms for a few years before the exterior must be washed, painted or reconstructed, the costs of which are unacceptable for the house owner and the environment. These projects intend to fulfil the scientific, industrial and environmental demands for sustainable eco-efficient surface protection.

The researchers have demonstrated that protectants, biocides, can be placed inside and released from microcapsules to extend the durability of the surface protectant. They have designed cost-effective microcapsules with controllable permeability for biocides from the product family known as isotiazolinones and have formulated a release system using isotiazolinone microcapsules in water-based paints for house exteriors. The research group is now ready to take the next step in implementing a release system using microcapsules.

Project title
Eco-efficient surface protection: To prolong material durability through controlled release of actives from microparticles. To explore aspects that govern release from microparticles

Project number
2009-668
2010-1609

Project duration
2010–2014
2011–2014

Funding awarded
SEK 3 512 000
SEK 2 351 000

Project leader
Lars Nordstierna
Chalmers
lars.nordstierna@chalmers.se

Controlled release of a biocide from microcapsules prolongs the lifetime of a pained surface.
Illustration: Jonatan Bergek

New polymers protect against biological growth

This project has developed an entirely new method to protect underwater surfaces against biological growth (biofouling) such as the growth of bacteria, barnacles and mussels. The researchers were inspired by the way nature protects surfaces from fouling. For example, a shark uses energy from the food it eats to produce biocides that it releases through its skin. The skin of the shark also contains microscopic plates that inhibit fouling, as the shark uses its energy to constantly move these plates around.

Project title
New sustainable hydrophilic polymer materials for antifouling coatings

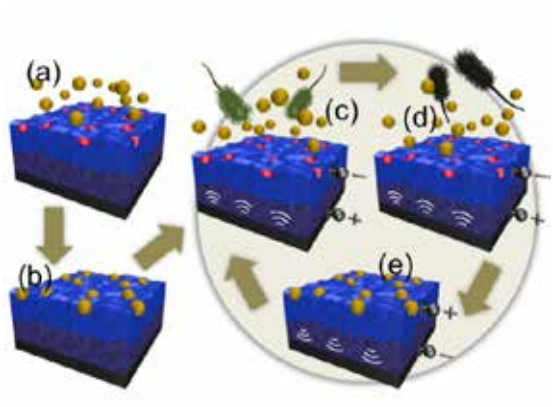
Project number
2009-1482

Project duration
2010–2012

Funding awarded
SEK 3 760 000

Project leader
Magnus Nydén
Chalmers
mnyden@chalmers.se

The aim of this project was to develop a surface that, via energy stimulus, can extract copper from seawater and release this when required. Copper is an efficient biocide that protects against biofouling. The project also developed smart polymers that can bind copper from seawater and then create a flow of copper in and out of the surface without the need to add energy. This project has already resulted in a material with an extremely great ability to efficiently and selectively bind copper from seawater. The results have led to two patent applications. If this surface material can be developed further, so that the release of copper from the surface can also be controlled, this could generate the new boat paint products that industry and private boat owners have wanted for a long time.



Antifouling technique:
a) Uptake of copper from seawater onto the surface.
b) Intrinsic binding of copper.
c) Release of copper through the addition of energy.
d) Bacteria die in the presence of high copper concentrations on the surface.
e) Copper is taken up by providing additional energy.

Project title
Nanostructured polymer materials for efficient and robust water desalination membranes

Project number
2009-235

Project duration
2010–2012

Funding awarded
SEK 2 589 000

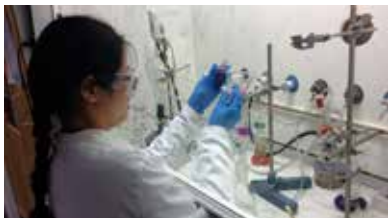
Project leader
Patric Jannasch
Lund University
patric.jannasch@polymat.lth.se

Desalination using polymer membranes

Water is our most important nutrient. In large areas of the world it is a constant struggle to obtain water. This project worked to develop new types of plastic films (membranes) that when pressurised allow water to permeate but not salts. In this way seawater can be desalinated and drinking water can be produced by "reverse osmosis". Reverse osmosis techniques are being intensely developed and the capacity globally to produce drinking water using reverse osmosis will increase immensely. One serious obstacle to the future development of this method however is the poor characteristics of the membranes.

This project has worked to develop knowledge of how new membranes can be produced and tailored to provide improved efficiency and durability so that costs can be reduced. Long chains of molecules (polymers) are

produced that have salts bound within their structures. When these membranes come into contact with water the salts form nanometre-sized channels where water is transported. By controlling how the ionic groups are placed within the molecular structure it will be possible to regulate the size of the water channels that are formed and how much water and salt can pass through. In the final phase of the project the selected optimized membranes will be evaluated for desalination using reverse osmosis under realistic conditions.



Chemical synthesis of material for new membranes.
Photograph: Patric Jannasch

Hydrogen storage materials for vehicles

Project title
Hydrogen storage materials for environmentally friendly application

Project number
2009-844

Project duration
2010–2012

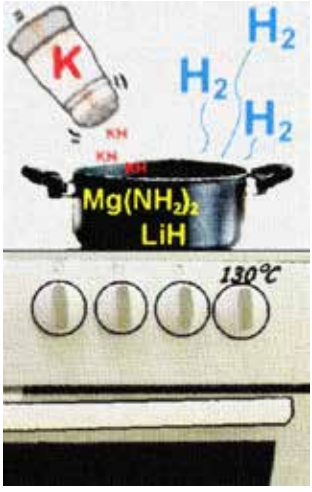
Funding awarded
SEK 2 025 000

Project leader
Rajeev Ahuja
Uppsala University
rajeev@fysik.uu.se

Vehicles can be powered either by providing a continuous supply of energy or by storing energy aboard the vehicle. Hydrogen gas would be the perfect synthetic fuel, as it is light, abundant and the product of its oxidation (water) is eco-friendly. But storage is a problem. The researchers aim is to find a safe, economic and clean solution for the transport sector to be able to store hydrogen. They have performed theoretical studies of hydrogen storage materials to identify and improve the most important properties. Based on this knowledge they will then discover better materials.

They want to provide fundamental knowledge by performing proof-of-principle calculations and are seeking answers to the following questions:

1) What are the most advantageous sites for hydrogen in material structures?
2) Is hydrogen bound as atoms or molecules? What types of hydrogen binding occur – ionic, covalent, metallic or weak van der Waals?
3) What role does the morphology and defects in the surface have on the adsorption and desorption of hydrogen?
4) In what ways can it be advantageous to store hydrogen in nanostructured and porous material?
5) How do catalysts contribute to improving the thermodynamics of hydrogen adsorption and desorption?



The researchers are working with additives for hydrogen storage materials.
Illustration: Rajeev Ahuja

Project title
Selective reflectors based on natural and artificial quasi-regular chiral structures for energy-related issues

Project number
2009-1425

Project duration
2010–2013

Funding awarded
SEK 3 550 000

Project leader
Sergiy Valyukh
Linköping University
sergiy.valyukh@liu.se

Photograph: Shutterstock

Selective reflectors for energy applications

Achieving desired reflection and transmission in specific spectral areas (selectivity) is a problem. For several applications in the energy sector this problem has been solved using surface coatings. In recent years there have been important advances in polymer science, particularly within the areas of polymer science and liquid crystal polymers. This has made it possible to seriously consider selective reflectors based on rotated (chiral) structures as an attractive alternative to surface coatings. The spectral characteristics of these types of reflectors can be much closer to the ideal case and they can be more cost-effective.

Polymers with chiral structures are already available for mass production. This project has worked to develop new, highly efficient optical units that can lead to energy saving technologies for buildings and greenhouses and to concentrate solar energy on the surface of photovoltaic cell panels. The results will have practical and theoretical consequences and can play a crucial role in energy production and energy saving. Optical studies of insects as a spin-off from this project will provide valuable information for biologists and will hopefully highlight the role that chirality plays in nature from an energy perspective.

Project title
Fundamentals of new materials for energy applications; towards batteries, fuel cells, hydrogen storage and carbon capture

Project number
2009-1435

Project duration
2009–2012

Funding awarded
SEK 16 500 000

Project leader
Aleksandar Matic
Chalmers
matic@chalmers.se

Materials for batteries, fuel cells, hydrogen storage and carbon dioxide capture

To meet the environmental and climate challenges facing society today we need new methods and materials that utilize sustainable sources of energy, such as solar, wind and water, more efficiently. We also need new ways to store and transfer energy. In this project the researchers worked to develop new materials to facilitate new technologies such as lithium batteries, low temperature fuel cells, hydrogen storage material and carbon dioxide capture. They studied the fundamental processes of material function, such as ion transfer, to be able to propose new material concepts. They also examined how materials behave directly in applications to be able to understand the stability and degradation processes that limit the lifetime and utility of the materials. Within this project new

electrolyte materials have been developed, based on polymers, polymer composites and ionic fluids. The scientists have worked collaboratively in EU projects such as APPLES, STORAGE and DECODE.

CarboMat – consortium for advanced carbohydrate materials

Carbohydrates from plant cell walls are an underutilized natural resource with significant potential to meet the needs of society for renewable materials. Cellulose, the structurally most important polysaccharide in plant cell walls, is the most common biopolymer on Earth. In nature cellulose is linked to a number of other cell wall polysaccharides and forms unique composite materials, the properties of which are exceptionally well adapted to performing specific functions. These complex biomaterials are created by photosynthesis and they are biodegradable.

The CarboMat scientists use cell walls as a source of inspiration to design new biocomposites. Using enzyme techniques the sugar-based polymers such as cellulose are cleaved and reconstructed to create new materials with significantly improved strength and function. With their sights set on future societally beneficial products, the researchers are focussing on concepts for new materials. They are working on a number of focus areas, including new cellulose-based biomedical materials for wound healing and tissue regeneration and improved filters for water purification.

Project title
CarboMat – The KTH advanced carbohydrate materials consortium

Project number
2009-1687
Targeted call – Sustainable development

Project duration
2009–2013

Funding awarded
SEK 25 000 000

Project leader
Vincent Bulone
KTH
bulone@kth.se

Recyclable materials with novel functions

Carbohydrates in plant cell walls, together with lignin and structural proteins, build a complex network that fulfils the mechanical demands of the plant during its lifetime. The properties of these carbohydrates are already utilized today in products such as paper, textiles, fibres and construction materials. Cell walls can also be utilized for the production of liquid biofuels through the use of fermentation, a process which must however be improved by increasing the breakdown of the plant cell walls.

Project title
Engineering of plant biomass for the production of novel functional and recyclable natural materials

Project number
2010-1808

Project duration
2011–2013

Funding awarded
SEK 4 173 000

Project leader
Vincent Bulone
KTH
bulone@kth.se

Altering the composition and architecture of plant cell walls for material development and improved production of biofuels is to date something that has not been exploited to any large extent.

The researchers have modified the natural composition of plant cell walls by altering the biochemical carbohydrate synthesis pathways, an area that has great relevance for a wide spectrum of applications.

This project contributes to the fundamental understanding of carbohydrate biosynthesis in plant cell walls. The researchers have created cell walls with modified composition, architecture, physical and mechanical properties. These cell walls have enormous potential for biotechnology applications within a number of industries, such as the pulp and paper industry, as well as the material, pharmaceutical and textile industries.

Project title
Biopolymers from wastewater resources

Project number
2009-2042
Environmental Technologies Program

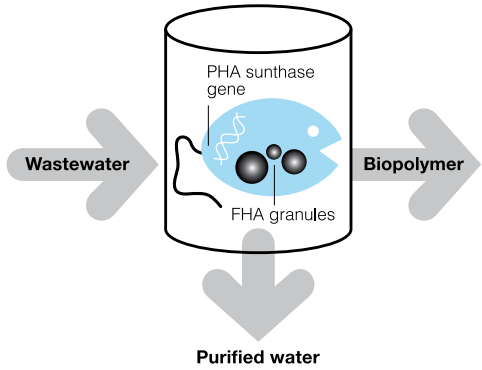
Project duration
2010-2012

Funding awarded
SEK 2 865 000

Project leader
Frans H.J. Maurer
Lund University
frans.maurer@polymat.lth.se

Biopolymers from wastewater resources

This project deals with the use of municipal and industrial wastewater to produce source materials for the production of valuable plastics by allowing bacteria to function as small bioreactors and at the same time produce purified water. This has been achieved in pilot scale by the project's collaborative partner AnoxKaldnes in Lund. The concept is based on the ability of bacteria to store polyhydroxyalkanoates (PHA) as an intercellular carbon and energy source. The researchers control, regulate and modify the structures of biodegradable PHA and improve its thermal stability to provide the potential to within the near future replace important synthetic bulk polymers that are currently produced using fossil fuels.



A characteristic for PHA is that its molecular size decreases at temperatures close to the process temperatures for extrusion and moulding. Reduction of the molecular mass can be reduced by using chain extenders, which have been studied in this project. To further influence the properties of PHA a method has been introduced that uses small quantities of nanosized graphene oxide particles. In general the physical characteristics of polymer composites are dependent on boundary layer tension, particle size and shape, and above all else the degree of dispersion. Interesting novel combinations of properties have been achieved that widen the application areas for the PHA produced from wastewater streams.

Long-term performance of composite bridges

Both new and existing bridges must be sustainable. More stringent safety requirements are imposed by current regulations. Use of fibre reinforced polymer (FRP) materials together with adhesive bonding techniques has attracted much attention in recent years. The outstanding properties of FRP materials, such as high strength, high modulus of elasticity, light weight and corrosion resistance have made these suitable for use in upgrading existing bridges and constructing new ones The use of high-performance, durable, lightweight composites provides longer lifetimes and less maintenance and construction disruption, which results in a cost reduction for society.

As FRP materials are relatively new there is a lack of reliable information about the performance of these materials in different climate conditions. The aim of this project was to investigate the durability of glass and carbon fibre material and how the bonds between these materials and steel perform. Numerical modelling was used to simulate long-term effects. The modelling results are being verified in trials. The results to date have demonstrated that the materials in the absence of salt show negligible reduction in strength. However, in the presence of salt solutions the FRP materials exhibit various degrees of reduction in strength and this must be documented in construction.

Project title
Effective construction and upgrading of steel and steel-FRP composite bridges – with the emphasis on long-term performance

Project number
2011-415

Project duration
2012–2015

Funding awarded
SEK 4 760 000

Project leader
Reza Haghani
Chalmers
reza.haghani@chalmers.se

Project title
Environmentally friendly plasticized PVC by means of nanotechnology

Project number
2011-657

Project duration
2011–2015

Funding awarded
SEK 6 000 000

Project leader
Ignacy Jakubowicz
SP-Technical Research Institute of Sweden
ignacy.jakubowicz@sp.se

PVC plasticized with nanoclays

The aim of this project was to develop a new technique for plasticizing PVC to significantly reduce the environmental impact of this material by drastically reducing, or even preventing, the emission of additives. This would be achieved through the development of specially designed nanosized filler material consisting of ultra-thin clay flakes that concomitantly function as a flame retardant. That this technique functions for polymers in general has been demonstrated in a number of research studies, but the chemical structure of PVC makes things more complicated.

The researchers have used mineral filler of the phyllosilicate type. The technique is based on using specific organic molecules to cleave the clay particles into their smallest component parts, flakes that can be as thin as a nanometre. The work consists of identifying suitable molecules and methods for organically modifying the clay particles. Another important aspect of the work is to optimize the material composition and develop processing methods that will result in the best nanocomposite characteristics. Apart from preventing the plasticizers and other additives from migrating out from the material, the nanoclay also has other advantages, for example providing the plastics with improved mechanical properties. The technique will also lead to a significant reduction in the use of flame retardant chemicals.

Jenny Johansson working with an extruder in the laboratory.
Photograph: Sten-Åke Johansson, SP

Project title
Ultra-insulating and flameretardant-free foams based on wheat gluten

Project number
2011-1436

Project duration
2012–2014

Funding awarded
SEK 3 720 000

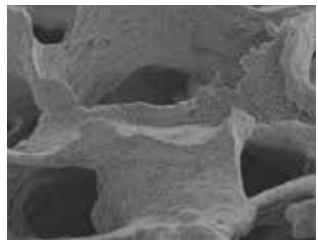
Project leader
Mikael Hedenqvist
KTH
mikaelhe@kth.se

Ultra-insulating and flame-retardant-free foams from wheat gluten

The starting point for this project was to examine if it was possible to produce a good flame-retardant insulating material from a biobased by-product, in this case wheat gluten. The source material is cheap and Sweden produces its own. If the project would succeed in its entirety it would enable oil-based plastic foam to be phased out. It would also be possible to avoid the use of conventional flame-retardants.

The foam is created by freeze-drying. The protein is mixed, among other things with water. When the mixture

freezes small ice crystals are formed and when the water is vaporised pores are created in the protein matrix. What remains is a foam with primarily open pores. To make the foam fire-resistant the researchers have chosen to mix the protein solution with silanes. A glass network is then formed that improves flame-retardant properties.
The gluten foam has been demonstrated to have good insulating qualities – not quite as good as contemporary polystyrene and polyurethane foams, which have a larger number of pores, but on par with cellulose-based eco-fibre, glass fibre and mineral wools, and better than wood wools. The foam has excellent frame-retardant properties due to the glass network that is formed from the silanes added to the gluten solution before freeze-drying, or in other words before the formation of the foam structure.

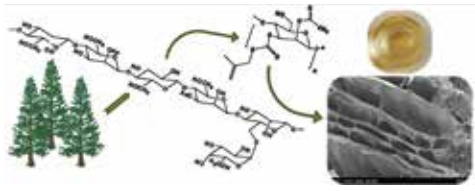


Gluten foam.

Renewable gels

In an ongoing and future switch to a bioeconomy there is huge potential in identifying a wide range of functional source materials for future material development that do not compete with food production. In this project the scientists have worked to utilize the oligosaccharide and polysaccharide fractions from the by-products and process water waste streams from the timber, pulp and food industries.

Carbohydrates are extracted and refined by the addition of vinyl groups and other side chains to specifically engineer syntheses that facilitate the cross-linking of the polymers so that hydrogels are formed. The new materials are based on a renewable polymer source and have excellent abilities to absorb and bind water. The cross-linking chemistry can be varied to achieve optimal swelling levels, combined with the desired abrasion resistance and retention capabilities. The function of the absorbents developed will be optimized with respect to swelling capacity for the intended purpose and will be used in the production of a prototype.



Project title
Renewable gels

Project number
2011-1542

Project duration
2012–2014

Funding awarded
SEK 3 335 000

Project leader
Ann-Christine Albertsson
KTH
aila@polymer.kth.se

Project title
Cell assembly

Project number
2011-1930
ERA Wood Wisdom

Project duration
2011–2013

Funding awarded
SEK 945 000

Project leader
Lars Berglund
KTH
blund@kth.se

Cell assembly of wood composites from nanofibres

The wood composites of today are moisture sensitive and have very poor abrasion resistance and viscosity. In contrast, wood has very good properties as a result of its sophisticated nanostructure and order of hierarchy. But we are limited in our abilities to influence these structures, for example by creating complex geometries. By using the nanofibres in cell walls we open up new opportunities. It is possible to create nanocomposites, nanopaper, aerogels and inorganic hybrids with vastly improved performance. The role of KTH in this international project is to create nanofibres and work to improve the mechanical properties of the materials. The scientific questions being examined concern understanding of the deformation mechanisms.

Project title
Natural fibres for thermoelectric textiles

Project number
2012-605

Project duration
2013–2016

Funding awarded
SEK 3 200 000

Project leader
Christian Müller
Chalmers
christian.muller@chalmers.se

Natural fibres for thermoelectric textiles

Natural fibres from animals and plants have been traditionally used to manufacture textiles. Today we instead use a large amount of synthetic fibres, but in recent times these have become controversial because of their impacts on the environment. Interest has therefore grown in material that is renewable and does not result in increased carbon dioxide emissions. To be able to compete in the global textile market some form of added value is necessary. Electronic textiles are of particular interest, as these can function as a platform for mobile devices and sensors. But these require an independent energy source that can replace conventional microbatteries. This project aims to fulfil these needs.

The researchers want to implement textiles manufactured from natural fibres, but with the additional property of being able to use body heat as an energy source. The potentially most promising semiconductor for this purpose, conjugated polymers, would then function as an electronic dye. The scientists want to integrate these polymers with various natural fibres from the national flora and fauna, such as flax, wood and wool. This would give high-performance thermoelectric fibres that can be woven into durable and flexible textiles.

Antifouling paints for marine constructions

The problem of biological growth (fouling) is different for boats than it is for static marine constructions, such as wave installations and tidal water facilities for energy production and desalination. In the case of boats one problem is increased fuel consumption due to increased friction. On static constructions the fouling results in increased weight and biocorrosion. The focus of this project was to prevent fouling on static marine constructions in an environmentally friendly way, as well as fulfilling the requirement for longer service intervals. To inhibit the organisms under study the molecules do not need to be encapsulated in an eroding paint. This has opened up the possibilities to use material with an even lower rate of release and better resistance to both UV light and corrosion.

The objective was to develop an antifouling system to "prevent" the release of substances – a paradigm shift in comparison to the current antifouling paints with their continuous release of bioactive substances into the environment. The concept is to instead create a "contact active" surface. This places new demands on both the molecules themselves and the carrier matrix. Molecules with high affinity for the paint components and high activity against microorganisms are of interest. An important part of the project is to ensure that the molecules are bioaccessible throughout the time period that the organisms are present on the surface.

Project title
Design and evaluation of contact active antifouling coatings for static marine constructions

Project number
2012-981

Project duration
2013–2014

Funding awarded
SEK 2 950 000

Project leader
Mattias Berglin
SP-Technical Research Institute of Sweden
mattias.berglin@sp.se

Per Borchardt carrying out field trials of an antifouling system.
Photograph: Mattias Berglin

Foamed materials from forestry waste streams

Commercial foams, such as those used as packaging, absorbents and medical device products are currently produced primarily from fossil sources. In this strong research environment SmartFoam is developing new foam materials based on hemicellulose sources, a renewable by-product from forestry anwd agricultural production. The source material is available in huge quantities at potentially competitive prices, and increased use would provide added refining value for forestry and agricultural raw materials. But research is

Project title
Foamed materials for packaging and absorbents based on forestry by-products

Project number
2013-64
Strong research environment

Project duration
2013–2017

Funding awarded
SEK 25 000 000

Project leader
Anette Larsson
Chalmers
anette.larsson@chalmers.se

Extruding hemicellulose-based foamed material.
Photograph: Kerstin Jönsson

needed to develop new foam materials with bespoke functionality for packaging and medical device purposes.

Within SmartFoam the extraction and modification methods for the raw materials are being developed, both with regard to formulation and process technology, for the production of foamed material intended for large-scale production. SmartFoam will generate new knowledge, particularly in the following areas:

1) Extraction and chemical modification of hemicellulose for optimal foaming qualities.
2) Effects of the characteristics of the source material and mixed material on the water resistance, plasticising, foaming and function of the foam.
3) Effects of additives, such as nanocrystalline cellulose, on the structure of the foam material.

Project title
Highly selective electrocatalysts for anodic oxidation

Project number
2013-758

Project duration
2013–2016

Funding awarded
SEK 3 933 000

Project leader
Ann Cornell
KTH
amco@kth.se

X-ray diffractometer used in the project.
Photograph: Joakim Bäckström

Energy efficient electrodes for water purification and chemical production

Is it possible to dictate which reactions will occur at an electrode by designing advanced electrode material with special catalytic properties? It was discovered recently that electrodes coated with a layer consisting of a mixture of tin, antimony and nickel oxides were surprisingly energy efficient in the generation of ozone through electrolysis – far better than had ever previously been reported for electrode materials. Without nickel, added in extremely small quantities, no ozone was formed at all. The electrodes have also been shown to give good results in the decomposition of organic molecules by anodic oxidation in simulated sewage water. Why is nickel necessary in the electrode, and how does the catalyst function in ozone formation? Can this knowledge help us to design electrodes for use in other processes?

The synthesis of the electrodes involves several different steps. The researchers are determining how different conditions in the production of the electrodes affect the resultant electrode's properties. The work is primarily experimental and comprises using a range of different techniques to characterise the electrodes. If it is possible to gain a better understanding of how the catalysed

reactions work for this interesting material it should be possible in the future to design more energy efficient electrodes for water purification and for the production of various chemicals.

Bioactive-silk for healing infected wounds

New methods of treatment are needed to combat the increasing incidence of pathogenic resistant bacteria. Spider silk has been used for wound healing in traditional medicine. In this project bioactive-silk is being developed by coupling spider silk to molecules from the body's own immune defence system to develop a new strategy for the treatment of slow-healing wounds, independent of conventional antibiotics.

The unique proteins of spider silk are arranged in such an artful way that the material has both strength and elasticity. The scientists can now produce miniature variants of the proteins (spidroines) that the spider itself uses. When they have purified the mini-spidroines these spontaneously form fibres that resemble spider silk. As spider silk has good biocompatability the researchers are using this as a base to develop material for biomedical applications. By using modern molecular biotechnology they can also now couple other active molecules to the spider silk to develop an entirely new type of bioactive-silk intelligent biomaterial. In this project they are coupling the silk to molecules from the body's own defence mechanisms, bactericidal enzymes and antibacterial peptides. In addition, they are designing their bioactive-silk to promote the growth of skin cells necessary for wound healing.

Project title
Bioactive-silk – a novel material for healing infected wounds

Project number
2013-883

Project duration
2014–2016

Funding awarded
SEK 3 920 000

Project leader
My Hedhammar
KTH and SLU
myh@kth.se, my.hedhammar@slu.se

A fibre made from spider silk protein with incorporated antimicrobial peptides.

Project title
Zeolitmembran för effektiv rening av biogas

Project number
2013-1684

Project duration
2014–2016

Funding awarded
SEK 3 013 000

Project leader
Jonas Hedlund
Luleå University of Technology
jonas.hedlund@ltu.se

Zeolite membranes for biogas purification

This project is developing zeolite membranes to separate carbon dioxide from biogas in a cost effective and energy efficient way. A good membrane process can be utilized to significantly reduce the costs of upgrading biogas to compressed natural gas for vehicle fuel.

The researchers have to date evaluated membranes containing hydrogen ions and have determined that the flow of carbon dioxide through the membrane is extremely high, which is very good. But the selectivity is unfortunately not satisfactory, which results in an excessive loss of methane through the membrane. The scientists are now working to improve the selectivity of the membrane and will in the first instance evaluate membranes made from zeolite ZSM-5 (which has a pore size of 5.5 Å) that also contain sodium or barium ions instead of hydrogen ions. In parallel they are also working (in a second project) to develop membranes with a smaller pore size (4 Å), which should be much more selective.

The researchers produce the zeolite ZSM-5 membranes by first attaching a monolayer of 50 nm zeolite crystals to a porous carrier material comprised of aluminium oxide. In the next step the zeolite crystals are allowed to grow to form a continuous film that is 500 nm thick. The zeolite membrane is then tested for its separation of carbon dioxide from dry methane gas.

Shahpar Fouladvand evaluating a zeolite membrane.
Photograph: Lubomir Novotny

Project title
New understanding and development of novel red phosphors for solid state lighting

Project number
2013-1723

Project duration
2014–2016

Funding awarded
SEK 4 111 000

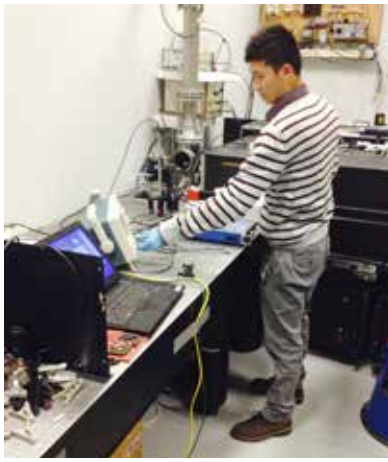
Project leader
Maths Karlsson
Chalmers
maths.karlsson@chalmers.se

New red phosphors for semiconductor lighting

Lighting accounts for around 20 percent of global total electricity consumption. Therefore new energy efficient and eco-friendly light sources are needed that can replace the old inefficient technology (light bulbs) currently being phased out, as well as the lighting that is an environmental problem (fluorescent lighting that contains mercury). This project will develop new red light emitting phosphors for the production of white light through the use of light emitting diodes (LED). Within the framework for existing technologies for the production of white light with light diodes there is a current paucity of efficient and cheap phosphors that emit red light when they

are irradiated with blue or ultraviolet light. The objective is to contribute to the development of new material that performs better than the materials available today.

The development of LEDs for the production of white light is a very promising lighting technology that has the potential to be able to save multimillion euros in annual energy costs. Investigations have shown that the market for phosphor-based light diodes for the production of white light will increase by several hundred percent over the next five years. This project can provide a significant breakthrough in basic knowledge and in the development of the next generation of lighting equipment.



Doctoral student Yuan-Chih Lin beside a free-electron laser in Nijmegen, Holland.
Photograph: Maths Karlsson

Sustainable production of textile fibres from forestry sources

The most common way of manufacturing textile fibres from wood-based cellulose has for more than a century been the viscose process, but this unfortunately has a major environmental impact. In this project the goal is to identify a number of solvents that demonstrate potential for use in the sustainable production of textile fibres from wood-based cellulose.

A major focus is on understanding how the interactions between the solvents and cellulose affect spinning and fibre properties. The scientists will work with Swedish forestry source materials that will be categorised in detail by Södra Innovation. The material will then be solubilised in the selected solvent systems and investigated using the advanced X-ray, neutron and light-scattering techniques that are available in order to understand the interactions between cellulose and the solvents. The optimized cellulose solvents will then be characterised by Swerea IVF and will then be spun into textile fibres using the various wet spinning techniques currently used industrially. A strength of the project is that it has the competence to be able to evaluate the entire chain from the source material, via cellulose solvent investigation and fibre spinning, to the textile fibre end product.

Project title
New sustainable solvent systems for the next generation regenerated cellulose textile fibres based on Swedish forest resources

Project number
2014-141

Project duration
2015–2017

Funding awarded
SEK 5 001 000

Project leader
Tobias Köhnke
Swerea IVF
tobias.kohnke@swerea.se

Project title
Turning forestry biomass into sustainable nanocellulose-based materials

Project number
2014-151

Project duration
2014–2016

Funding awarded
SEK 5 945 000

Project leader
Ulrica Edlund
KTH
edlund@kth.se

Sustainable nanocellulose materials

A multidisciplinary collaboration is laying the groundwork for the development of new, sustainable and safe material based on nanocellulose (NC), with a focus on the packaging sector. The platform will enable the development of a new generation of sustainable and non-hazardous NC-based products. New green methods for chemically modifying NC increases performance and is a vital step in producing NC-based composites with suitable properties. The health aspects of the new nanomaterials are important and should be investigated at an early stage in the implementation process and methods to do this will be developed. SwedNanoTech is a key partner in disseminating the results. NC-based biocomposites will be developed and demonstrated in collaboration with industrial partners in the project; Stora Enso and Biobag.

Project title
Engineered Wood and Biobased Building Materials Laboratory (EnWoBio)

Project number
2014-172

Project duration
2014–2016

Funding awarded
SEK 12 066 000

Project leader
Magnus Wålinder
KTH
magnus.walinder@byv.kth.se

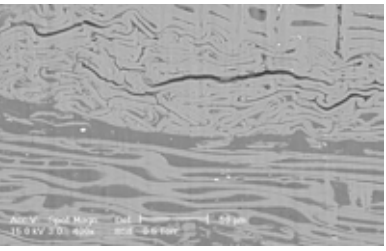


Image taken with a scanning electron microscope shows an example of the complex micromorphology in a wood-plastic composite. The light grey areas are wood cells and the dark grey areas are thermoplastic.

Engineered biobased construction materials

This project will develop revolutionary new construction materials, for example novel types of naturally modified wood and biocomposites. A rapidly growing area is wood frameworks in what is known as cross-laminated timber (CLT), a type of super-plywood. The project is divided into two collaborative parts: 1) material science focussed on material analysis and wood modification, and 2) engineering-based demonstration of the different material systems, including evaluation of the environmental and social economic consequences.

Increased durability, for example through increased resistance to biological decomposition, must be assured for the new material to be market competitive. A better understanding of the material mechanisms is essential, for example how the absorption of moisture is linked to the dimensional changes in the wood and what methods of "customization" can affect this. Many modern technologies, such as gas chromatography and magnetic resonance, are now available to provide us with the possibilities to better understand and develop wood material science.

Cellulose based fibres with high modulus and strength

The researchers in this project are making fibres from wood sources. They especially want to investigate the possibilities that have been created by some new technologies they have developed over recent years. They will in part investigate the purely technical potential of their fibres in textiles and composite applications and in part will examine the degree to which these can contribute to sustainable development. They are starting with cellulose from wood, partly solubilised in molecular form and partly in fibril form (many molecules joined together but still much thinner than a strand of hair). The project aims to 1) make fibres that are as optimal as possible, 2) develop the technology so that it comes closer to being implemented in industrial production, and 3) assess the economic and ecological potential represented by the fibres. If it is possible to replace glass fibre and cotton with fibres from forestry sources produced in a resource-efficient manner there would be major environmental benefits and an increased market for Swedish forestry products.

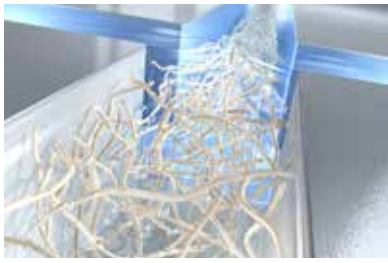
Project title
Continuous cellulose based fibres with high modulus and strength

Project number
2014-183

Project duration
2014–2016

Funding awarded
SEK 7 742 000

Project leader
Fredrik Lundell
KTH
fredrik@mech.kth.se



Fibril streams are joined into a fibre in the research apparatus. Photograph: DESY/Eberhard Reimann

Cellulose-based insulation products

The aim of this project is to design sustainable cellulose-based insulation material as an alternative to mineral wool for the production of energy-efficient products for construction applications. These new products from renewable sources can reduce the use of synthetic materials. The challenge is to create an insulation sheet that has the correct properties for processing, and to identify suitable binding agents and functional chemicals for fire and mould resistance that are approved from a health perspective. Important product characteristics are heat and sound insulation. The project has access to advanced analysis methods at KTH, testing of flame resistance at SP, and pilot and also full-scale trials at Icell in Älvdalen.

Project title
Energy-efficient cellulosic insulation products for green building solutions

Project number
2014-959

Project duration
2015–2017

Funding awarded
SEK 6 608 000

Project leader
Monica Ek
KTH
monicaek@kth.se

The ICell factory in Älvdalen. Photograph: Roger Gudmundsäter

Sustainable Building and Planning – Technologies and Processes

These projects deal with energy-efficient systems for heating, cooling and ventilation, smart windows, concrete reinforcement, land decontamination, dehumidifying greenhouses, solar energy in urban planning, vertical growing and green roofing. A number of projects deal with renovation, including risk assessment, governing policies, decision-making tools, energy efficiency and construction products.

Energy-efficient systems for heating, cooling and ventilation

Buildings contain many small and medium-sized pumps and fans for heating, cooling and ventilation. Low efficiency levels, large numbers and long operating durations result in large total electricity consumption. Even systems intended as low energy systems, such as photovoltaic systems and free cooling and heating pumps, can still have high electricity consumption. This project has addressed the possibility of reducing electricity consumption in the construction sector by the use of more efficient pumps and fans. It has been demonstrated that modern technology can result in a reduction in electricity consumption of several terawatt hours per year in Swedish buildings, as well as significant reduction in heating requirements. The researchers have studied, among other things, new pumps, fans and motor technologies, risk management in terms of the electricity grid, storage streams and an entirely new system concept. The project has shown that the proposed system solutions can reduce pump power and energy requirements by 50–90 percent.

The project has been carried out in collaboration with the Division of Building Technology and the Division of Electric Power Engineering at Chalmers, and has be co-financed by the Göteborg Energi research foundation, the CERBOF research program and 28 companies.

Project title
Efficiency of building related pump and fan operation – System solutions, motor technology and control – Stage II

Project number
2008–99
Formas/BIC

Project duration
2008–2010

Funding awarded
SEK 3 780 000

Project leader
Per Fahlén
SP-Technical Research Institute of Sweden
per.fahlen@sp.se

A BLDC motor with an extremely high efficiency level.
Photograph: Johan Åström

Smart windows for energy-efficient housing

The researchers have developed smart windows with variable transparency for solar energy. Electrochromic materials, the optical properties of which can be altered by applying an electrical current, are a commercial technology today. A lesser used method is thermochromal layers that change transparency when their surroundings reach a certain temperature. Improved energy efficiency could be achieved using a pane with an electrochromic device and a pane that has a thermochromic layer or plastic film, for example in triple-glazed windows.

This project involved around ten scientists at the Division of Solid State Physics at Uppsala University. They studied the optical and electrochemical properties of

Project title
Smart windows with integrated electrochromic and thermochromic functionality

Project number
2008-141, 2009-332, 2012-800
Environmental Technologies Program

Project duration
2008–2010
2010–2012
2012

Funding awarded
SEK 1 903 000
SEK 2 430 000
SEK 1 465 000

Project leader
Gunnar Niklasson
Claes-Göran Granqvist
Uppsala University
gunnar.niklasson@angstrom.uu.se
claes-goran.granqvist@angstrom.uu.se

Prototype of a smart window containing four panes, each of which is 30 x 30 cm in size. Two of the panes are light and two are dark. Note that the window shows a reflection of the surroundings independent of the light conditions.
Photograph: Ångström Laboratory

thin layers and nanoparticles of transition metal oxides, as well as the durability of the material. The researchers have shown that impedance spectroscopy is a good method for studying the stability of electrochromic layers. They have also shown that mixed oxides can have improved functional properties and that thermochromal material can be significantly improved using nanoparticles embedded in a matrix.

The research was performed in collaboration with the Swedish company ChromoGenics AB, which is an international leader in the area of technology for windows with variable transparency. A production facility is being planned. Parts of this facility were installed in the spring of 2015 at ChromoGenics. Other parts currently include manufacture by an American company.

Project title
A design tool for energy saving electrochromic windows

Project number
2008-158
Environmental Technologies Program

Project duration
2008–2011

Funding awarded
SEK 1 543 000

Project leader
Göran Lindbergh
KTH
gnli@kth.se

Design tools for electrochromic windows

This project was an industrial doctoral student project affiliated with ChromoGenics AB. The goal was to create design tools for electrochromic windows (EC windows). The cooling of buildings represents a large portion of the construction sector's total energy consumption. EC windows have great potential to be able to improve indoor climate comfort and save large amounts of energy. EC windows can be compared to a thin-film battery where the charge level can be seen in the optical absorption, which increases with increasing charge levels and vice versa. The unique properties of the EC technology to use a minimal amount of energy control the absorption of solar energy and visible light can reduce the cooling requirements in buildings. But for introduction onto the market it is necessary to be able to produce larger EC surfaces with the same performance capabilities. One challenge is to be able to design them to have a rapid and even colouring and bleaching.

A cost efficient approach has been introduced in this project. A theoretical model has been developed and validated. The two-dimensional current distribution model developed can calculate how the absorbance changes over time for different areas of the window's surface.

New method for timber grading

This project has developed a new method for the strength grading and sorting of construction timber. This type of sorting means that timber for use in load-bearing construction is divided into different load-resistant categories. This is done using methods that often include measuring the average rigidity (elasticity module) of the plank. Using known statistical correlations between rigidity and strength the load-resistant strength can then be predicted and the plank can be assigned to a category. Current sorting methods are however limited in their precision, which leads to poor utilization of the constructive potential of the timber.

This research has resulted in an entirely novel sorting method based on laser scanning. Using this new method significantly better precision can be achieved than with current methods. It is predicted that the new method will be commercially launched in 2015. Using this method timber with greater strength and rigidity will be able to be utilized. The project, as well as subsequent research, has been carried out by five scientists at Linnaeus University and SP Trä in Växjö. The work has included the company Innovativ Vision AB, the manufacturer of the timber scanner WoodEye, and Dynalyse AB, the manufacturer of the sorting machine Precigrader. The sawmill companies Vida, Derome and Södra Timber have also participated.

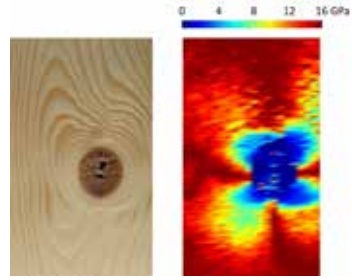
Project title
Timber grading using image analysis and finite element modelling

Project number
2008-970

Project duration
2009–2011

Funding awarded
SEK 2 400 000

Project leader
Anders Olsson
Linnaeus University
anders.olsson@lnu.se



Evaluated elasticity module around a knot.
Photograph: Jan Oscarsson

Full-scale test of aerogel windows

A normal wall has good thermal insulation but doesn't utilize solar energy. A window uses solar energy but loses a large amount of heat. An ideal building surface element would combine the insulating properties of the walls with the high solar energy transmittance of windows. This objective can be achieved using an Airglass window.

The company Airglass AB in Staffanstorp manufactures large, transparent sheets of aerogel, a material comprised of quarts and a great deal of air that has unique properties. Aerogel has the shortcoming of scattering light to a certain extent, so that the area around it can seem out of focus. This project has further developed aerogel so that the light scattering effect is reduced by placing the material between two sheets of glass that absorb or reflect parts of the blue light spectrum where aerogel has its greatest light scattering effects. An Airglass window has been tested in full-scale on a demonstration wall.

Project title
Demonstration and development of a large area Airglass window

Project number
2008-2187
Environmental Technologies Program

Project duration
2009–2011

Funding awarded
SEK 1 396 000

Project leader
Björn Karlsson
Mälardalen University
bjorn.karlsson@mdh.se

Project title
Electronic labels for wireless sensing of humidity for the home building and renovation industry

Project number
2008-2188
Environmental Technologies Program

Project duration
2009–2011

Funding awarded
SEK 3 882 000

Project leader
Isak Engquist
Linköping University
isak.engquist@liu.se

Electronic sensor tags to eliminate dampness

Dampness in buildings in Sweden annually causes damage of more than SEK 5,000 million. This moisture damage is often caused by water leakage or condensation and the progression of the problem is often concealed inside walls, floors and ceilings. The purpose of this project was to develop, manufacture and test wireless sensor systems that can detect moisture in concealed spaces, with a focus in part on solutions based on what is known as the RFID-standard for wireless communication and in part on solutions involving printed circuits.

The project has successfully demonstrated several possible methods of construction to achieve its targets. The RFID-based solutions use commercial chips and readers, they can transmit a unique ID for each sensor and can offer the greatest remote monitoring distance. Printed circuits use a specially developed laser and offer the lowest cost per sensor tag.

The system using printed moisture sensor tags has received further funding from Vinnova and has resulted in a spin-off company, Invisense AB, which is further developing the concept. With a successful commercial introduction the system will mean savings in the form of reduced costs for maintenance and repair. As dampness and mould problems will be able to be detected at an earlier stage the indoor climate will also be positively affected.

Project leader Isak Engquist installing prototypes of moisture sensor tags in a building being constructed in Norrköping, in collaboration with PEAB.
Photograph: Tommy Höglund, Acreo

Project title
Tekocrete-Technical textiles for production of sustainable self-cleaning concrete surfaces

Project number
2009-184
2012-261

Project duration
2009–2010
2012–2015

Funding awarded
SEK 1 984 500
SEK 4 257 000

Project leader
Katarina Malaga, Kristian Tammo
CBI Betonginstitutet AB
katarina.malaga@cbi.se
kristian.tammo@cbi.se

Technical textiles for thin concrete surfaces

These projects will determine what technical possibilities there are to use smart technical textiles and other types of modern reinforcement to produce concrete wall panels that can be used for renovation, primarily in the Million Programme. The reinforcement analysed does not need the concrete as a corrosion protectant, which means there are significantly lower demands on the outer cladding layer and thickness of the façade panel surface.

The researchers are also developing the anchorage of the new thin cladding panels, optimising insulation with regard to heating and moisture, and evaluating the new properties of the smart concrete, for example with regard to water repelling and self-cleaning surface capabilities.

Full-scale trials have yielded promising results and there are currently a number of types of reinforcement and anchorages that are well suited for use with thin concrete façade cladding panels. Using these new types of reinforcement the concrete façade cladding panels can be significantly thinner, with a thickness of 20–40 mm, compared to the cladding panels of today that are 70–90 mm thick. Thin cladding provides the possibility to use thicker insulation, facilitates ease of transport and installation and paves the way for more cost-efficient smart concrete.

The research is being performed in collaboration with CBI Betonginstitutet AB, SP-Technical Research Institute of Sweden, Luleå University of Technology, Strängbetong, STO Scandinavia, Halfen, MA Arkitekter, FOV Fabrics, SABO and Stockholmshem.

Remediation of contaminated areas

Remediation of contaminated land is a very common part of construction projects in the built environment. The method most widely used is excavation and disposal, a method that is often very expensive and is not sustainable in the long-term.

The overall objective of these projects has been to develop a practical method that can be used for the assessment of sustainability and cost-efficiency for different remediation methods. Determining the effects of the remediation method on the different land functions for the ecological system after decontamination was of particular interest. The primary results of these projects have been the method SCORE (Sustainable Choice Of REmediation) and SF Box (Soil Function Box). SCORE allows different criteria for economic, social and environmental sustainability to be evaluated jointly to provide a measurement of total sustainability. SF Box allows indicators of land function for ecological systems to be evaluated and used to classify the effects of the remediation method on subsequent land function. The methods are integrated with each other and have been applied in four different case studies.

The work has been carried out in a collaboration between Chalmers, NCC Teknik, Statens geotekniska institut (SGI), Umeå University and SLU. Around 15 researchers have participated in the projects.

Project title
Sustainable and cost-effective remediation of contaminated land in the built environment

Project number
2009-206
2009-781

Project duration
2009–2013
2010–2013

Funding awarded
SEK 5 601 150
SEK 6 075 000

Project leader
Lars Rosén
Chalmers
lars.rosen@chalmers.se

Sustainable remediation means that social, economic and environmental criteria are used in the choice and design of the clean-up method.
Photograph: Thomas Liljedahl

Project title
Removal of passivating surface layers from chalcopyrite for increased biomining efficiency

Project number
2009-657

Project duration
2010–2012

Funding awarded
SEK 2 849 000

Project leader
Åke Sandström
Luleå University of Technology
ake.sandstrom@ltu.se

Copper leaching using microorganisms

The aim of the project was to make it possible to produce copper using a cheap method where microorganisms are used to bring copper ions into solution (leaching) so that the copper metal can be recovered by electrolysis. The mineral chalcopyrite ($CuFeS_2$) is the most abundant copper mineral, but it is very difficult to leach as the surface becomes passivated after a relatively short time, with a poor copper yield as a consequence. The purpose of the project was to investigate why the surface becomes passivated and if it would be possible to remove the passivated outer layer. The project has been an interdisciplinary project involving researchers from the areas of hydrometallurgy, microbiology and surface chemistry, and has been supported by Boliden Mineral AB.

The researchers have shown that the time taken to leach the copper primarily depends on the redox potential of the solution and that it does not matter how the correct potential is maintained, in other words electrochemical or bacteriological methods are equivalent. It has not been possible however to determine what causes the passivation of the surface, but several candidates have been discussed and discounted. When the problem of passivation has been fully solved it will be possible to produce copper using the cheap high-yield leaching technique from sources containing low amounts of copper.

Bioleaching of chalcopyrite in 45 °C bioreactors using moderately thermophillic bacteria.
Photograph: Mohammad Khoshkhoo

Project title
Risk Assessment of building physics performance (heat, air and moisture) in retrofitting existing building stock (RAP-RETRO)

Project number
2009-1169

Project duration
2010–2012

Funding awarded
SEK 2 430 000

Project leader
Jesper Arfvidsson
Lund University
jesper.arfvidsson@byggtek.lth.se

Risk assessments for renovations

The purpose of this project was to structure the Swedish participation in a project run by the International Energy Agency (IEA) concerning the development of tools to provide better information about the outcomes of renovation measures in terms of energy use, costs and function. Ten Swedish researchers have worked together with researchers from Austria, Belgium, Canada, Denmark, Finland, Germany, Holland, Portugal, England and the USA.

The work has been carried out in the form of four subproject activities. In activity 1 a dataset has been compiled that can be used by researchers and practitioners to examine energy, costs and performance, materials and

building services, as well as renovation methods. In activity 2 the uncertainty of potential benefits (reduced energy use) and risks (increased moisture risks) as a result of renovation have been measured. In activity 3 case studies have been examined. Experience from completed and planned renovations has been used to focus on the relevant questions in the planning, construction and operational phases. Three cases from different countries have been studied, one of these from Sweden (Sigtuna-Bostäder). Activity four has dealt with practices and guidelines. An important result has been guidelines for how the established regulations for risk assessment should be used in practice.

Photograph: Skanska

High-efficiency heat insulation in old buildings

Project title
Retrofit applications on old buildings using highly efficient novel thermal insulation materials

Project number
2009-1513

Project duration
2010–2012

Funding awarded
SEK 3 240 000

Project leader
Carl-Eric Hagentoft
Chalmers
carl-eric.hagentoft@chalmers.se

Many older buildings have unsatisfactory energy performance. One way to reduce energy use is to add additional insulation to the outer walls. But many older buildings are regarded to be important to preserve because of their historical and aesthetic contribution to the urban environment. This often restricts the placement and thickness of insulation. Vacuum insulation panels (VIP) provide great potential to reduce the necessary thickness of the insulation used. This project has investigated the possibilities, limitations and risks of using VIPs in older buildings.

Some of the work was performed in close collaboration with Familjebostäder i Göteborg AB. A former governor's mansion in Gothenburg was externally insulated with VIP. Temperature and moisture measurements showed that the moisture levels were substantially reduced in the additionally insulated walls than in an adjacent façade. It was calculated that the energy used for heating the building was reduced by 24 percent. A measurement method to identify damaged VIPs was developed. This method needs to be developed further to be able to be used on construction sites.

This project has demonstrated that energy use can be substantially reduced by using VIP in old houses. Subsequent research has shown that vacuum insulation can also be suitable for use as supplementary insulation in brick walls.

Vacuum insulation panels being installed.
Photograph: Pär Johansson

Project title
ACES – A concept for promotion of sustainable retrofitting and renovation in early stages

Project number
2009-1841
Formas/BIC, Eracobuild

Project duration
2009

Funding awarded
SEK 2 362 000

Project leader
Folke Björk
KTH
folkeb@kth.se

Encouraging renovation results

To encourage property owners to renovate their buildings to improve energy use and the indoor climate it must be able to be demonstrated that the investment will yield results. Energy efficiency, better indoor climate and reduced risk of dampness damage are of interest to countries such as Sweden, Denmark and Cyprus. Researchers from these three countries took part in the Eracobuild project. This project is also a Formas-Bic project, with a defined association with the sector.

Operative decision-making support is a process that has been developed by this project in collaboration with Riksbyggen. This is a method to include energy renovation when other retrofitting work is carried out. As the researchers had access to the Swedish Green Building Council database they were able to investigate what information required for environmental certification was most difficult to provide. This could be good supporting information for planning of expansion of consultants within the area of construction technology and the environment.

Converting to water heating and geothermal pump sources is popular, but also means a large investment. This project has demonstrated how energy savings can be assessed using relatively simple methods to derive an energy signature from temperature data and data from electricity bills. In this way savings can be assessed even if the data is incomplete.

Project title
Energy efficient dehumidification in greenhouses through interchange of heat – technical solutions and economic saving prospects

Project number
2009-2029

Project duration
2009–2014

Funding awarded
SEK 900 000

Project leader
Sven Nimmermark
SLU
sven.nimmermark@slu.se

Energy efficient dehumidification of greenhouses

Greenhouse cultivation requires careful climate control to achieve good production results. In new, well-sealed and well insulated greenhouses the moisture levels are often too high, which can lead to non-permissive growing conditions due to condensation and growth on coverings, risk of disease and reduced transpiration of the plants, resulting in a reduced yield. A common way to address the problem in commercial greenhouses is to ventilate the moisture out by opening roof hatches. This method of dehumidifying is energy consuming and impacts the environment.

This project studied the possibilities of saving energy by using fan-controlled dehumidification using heat-

exchange between incoming and exiting air. Measurements were carried out to determine performance in different climate conditions and the temperature efficiency level of the heat-exchanger was determined for different temperatures and humidity levels. With knowledge of the operating conditions for the aggregate the energy savings on an annual basis were then calculated.

The results indicate that dehumidification comprises a significant cost in the total use of energy in greenhouses. The project has demonstrated the possibilities to reduce energy use and consequently gain positive environmental effects, as well as improved economy for the growers.

Cucumber plants in a greenhouse.
Photograph: Sven Nimmermark

Tomorrow's solutions for houses today

"Homes for tomorrow" is a strong research environment that focusses on developing exciting innovations for our homes. Examples are lighter and more flexible building exteriors that are more efficient from an energy and resources point of view, new architecture, design and acoustics for sustainable living, as well as new energy systems for indoor environments. New carbon dioxide neutral cladding materials and management systems for energy and resources in the home are two innovations that have come from this research.

The work has been performed by doctoral students at Chalmers. The construction industry has been involved through studies in real situations. This has resulted in HSB Living Lab, where new knowledge and innovations from the project are further tested before being launched on the market. Living Lab has been built by HSB but it is an open resource for the Swedish construction industry. Other collaborative partners are Tengbom, PEAB, Electrolux, Bengt Dahlgren and Göteborg Energi. New innovations are also created in HSB Living Lab through co-creation workshops. One example is the new social laundry room that has been developed in a collaboration with NASA and Rice University, and that Electrolux will build in the lab.

Homes for tomorrow has received continued funding from the EU Climate-KIC (Building Technology Accelerator) for the period 2015–2020.

Project title
Homes for tomorrow. Building solutions for tomorrow as a reference for today

Project number
2010-49
Strong research environment

Project duration
2010–2014

Funding awarded
SEK 25 000 000

Project leader
Greg Morrison
Chalmers
greg.morrison@chalmers.se

HSB Living Lab will have 40 students permanently living in the new material-clad building with new systems for energy management. This is the first Living Lab in the world with homes that people will actually live in permanently.
Illustration: Tengbom arkitekter

Project title
Strategies for integrated sustainable renovation: Focus on the Swedish domestic building stock ´folkhemmet´ in the pre-boom era

Project number
2010-252
Eracobuild

Project duration

Project duration
2010–2012

Funding awarded
SEK 2 458 000

Project leader
Liane Thuvander
Chalmers
liane.thuvander@chalmers.se

Sustainable renovation of apartment buildings

The multi-storey apartment buildings built between 1941 and 1960 now need extensive renovation. The goal of this project was to develop strategies for sustainable decision-making for these renovations. The researchers wanted to weigh together the more easily defined aspects, such as environmental performance, energy efficiency and economics, with more difficult to define aspects such as cultural history, architectural and social values.

The project has been carried out in collaboration with Chalmers and partners from the sector, including other housing companies, architect firms, technical consultants, construction firms and representatives from Hyresgästföreningen, Göteborgs Stadsmuseum, Stadsbyggnadskontoret in Gothenburg and Västra Götaland region. The collaborative arena has been used to bring together stakeholders that would normally not meet in the early phases of a renovation project.

The results have been two working methods that can support decision-making in renovations. This is in part a method known as a "strategy matrix", which is a checklist to allow rapid identification of conflicts between different values, and in part is a method called deeper dialogue with residents, to more clearly integrate the perspectives of the end user in the renovation process and involve more stakeholders.

The project is also a European collaborative project within the Eracobuild network, with partners from Switzerland (ETH Zürich) and Austria (TU Vienna).

Project title
Policy instruments for innovation of energy efficient retrofit measures in existing buildings

Project number
2010-254
Eracobuild

Project duration
2010–2012

Funding awarded
SEK 1 254 000

Project leader
Lena Neij
Lund University
lena.neij@iiiee.lu.se

Policy instruments for energy-efficient renovation

Most of the housing in Europe today is more than 40 years old. But both technical guidelines and economic incentives are often lacking to facilitate renovation for better energy efficiency and healthier living. Researchers in the Eracobuild project have studied experience and guidelines for renovations in Denmark, Finland, Romania, Sweden and Switzerland. The focus has been on more energy efficient living.

The results show that:
1) Energy efficient renovation measures are cost-effective,

2) It is more cost-effective to invest in combinations of multiple measures for energy efficiency than to invest in one measure at a time,
3) The cost-efficiency of the renovation depends on the type of building, and
4) High-technology and more complex renovations are increasingly becoming more common. The reason that more complex renovations are being performed, despite requiring more planning and coordination, are that they often result in additional improvements.

All of the countries in the study have experience of governing policies for energy efficient renovations at national level. The stakeholders in these countries have shown interest in introducing more stringent national building requirements and local initiatives, as well as the need for new financing models.

Building products and materials for renovations

The construction sector has a large impact on the environment through materials and energy use, waste production and emission of environmentally hazardous substances. This project has studied lifecycle-based methods and tools for the assessment of environmental and sustainability aspects, based on EU building legislation. The study was carried out as a joint Nordic Formas-BIC/Eracobuild project with participants from Finland, Denmark and Sweden.

The final report includes:
1) A summary of the current situation and the future requirements concerning hazardous substances in construction products in Europe,
2) Evaluation and characterisation factors for toxicity and guidelines for the use of standardised test data in LCA, and
3) An overview and proposals for harmonizing scenarios and models for risk assessment and LCA (environmental declarations, EPD).

One conclusion is that it is very important to include information about how a construction product is recycled and not to just assume this from its constituent components.

Project title
Sustainable construction products and materials for renovation – Methodology for harmonized assessment and performance criteria for BWR3 and BWR7

Project number
2010-256
Formas/BIC, Eracobuild

Project duration
2010–2012

Funding awarded
SEK 1 017 000

Project leader
David Bendz
Swedish Geotechnical Institute, SGI
david.bendz@swedgeo.se

Harmonizing risk-based and LCA-based scenarios for the distribution of environmentally damaging substances is advantageous as this is more uniform, quick and easy. Subsequent research within the framework of the IVL project "Robust LCA" has resulted in a common approach for producers and entrepreneurs with regard to result reporting of LCA based on the TC 350 standards of the CEN committee.

Project title
Renobuild – Sustainable renovation of buildings supported by a decision support tool

Project number
2010-304
Formas/BIC

Project duration
2010–2014

Funding awarded
SEK 3 483 000

Project leader
Kristina Mjörnell
SP-Technical Research Institute of Sweden
kristina.mjornell@sp.se

Photograph: Kristina Mjörnell

Decision tool for sustainable renovations

The purpose of this project was to determine how to evaluate different renovation alternatives according to different sustainability criteria. To compare profitability for various alternatives the researchers selected a life-cycle costing tool. To compare how different corrective measures alter the environmental impact of a building, a simplified life-cycle analysis tool has been developed. To compare different alternatives from a social perspective a list of social indicators for renovation has been compiled.

This methodology has been used to evaluate different renovation alternatives for a kindergarten school and an apartment building. The advantages of the method are that the property administrator can obtain a comparison between different renovation alternatives from a sustainability perspective. This means that renovation measures that involve marginally higher investment but that can yield significant environmental and social benefits can be considered.

Six researchers from SP-Technical Research Institute of Sweden have developed the methodology and tools, in addition to the LCC tool that was developed by Älvstranden Utveckling AB. Other companies and municipalities that have participated are Ramböll, Kjellgren Kaminsky Architecture, Peab, Kanico AB, as well as Borås City Council and the Municipality of Nyköping.

Learning for energy efficiency

The ClueE-project has examined the social science obstacles preventing the adoption of far reaching energy efficiency measures in conjunction with the renovation of Million Programme housing areas.

The researchers have carried out studies in Alingsås, as well as in Gårdsten and Backa in Gothenburg. The issue of imposing high demands for energy efficiency in housing areas that are already heated by almost fossil-free district heating and where the poorest population groups live was called into question. Over the longer term, by year 2050, it can however be profitable to impose higher energy standards. Important driving forces are "sustainable complete solutions", which business model and housing company is selected, the necessity for widespread policy agreement in the municipality and close dialogue with the residents.

The legal standards appear to be relatively meaningless at present with regard to what is happening in the individual housing areas. The newly renovated energy efficient houses are not being sought by tenants seeking a particular lifestyle – most of the residents are from the local area or lived in the buildings before and after the renovations. A more general conclusion is that more research into energy efficiency should be focussed on the business sector and the private housing market, particularly with regard to the fossil fuel-use aspect.

The project group comprised technical engineers, economists, lawyers, political scientists and behavioural scientists.

Project title
Learning for collaborative energy efficiency in urban residential areas

Project number
2010-355
Sustainable Urban Development

Project duration
2010–2012

Funding awarded
SEK 1 495 000

Project leader
Ylva Norén Bretzer
University of Gothenburg
ylva.noren-bretzer@spa.gu.se

Gårdsten in Gothenburg was one of the housing areas studied in the CluE project.
Photograph: Johanna Selin

The CluE group in discussion. Project leader Ylva Norén Bretzer is on the left.
Photograph: Carolina Hiller

Solar energy in urban planning

There is great potential to use solar energy in cities as the city buildings can be used to apply solar energy technology. Concomitantly the cost of solar energy solutions has reduced dramatically and in time the costs could become so low as to be regarded as an alternative material in conventional sun screens, windows, outer surfaces of buildings and roofing.

This study has however demonstrated that there is a lack of structures and support for the development of solar energy in Swedish cities. There are still few stakeholders

Project title
Solar energy in urban planning

Project number
2010-404

Project duration
2010–2014

Funding awarded
SEK 2 400 000

Project leader
Lena Neij
Lund University
lena.neij@iiiee.lu.se

Study of solar energy potential for the Hyllie area in Malmö.
Source: Jouri Kanters

actively working with solar energy and the support for knowledge development is limited. Solar energy is not included in the traditional urban planning process and therefore city planners do not normally work actively with issues concerning solar energy. The property owners and architects in the country do not have any great interest in solar energy either.

For city planners and other interested parties to be able to utilize the potential of solar energy planning tools and solar charts are required. This project has developed and analysed different methods for developing solar charts and has also worked with support for planning solar energy in new areas. Together with city planners from Malmö and Lund the researchers have examined the solar energy potential in the Malmö Hyllie and Lund Brunnshög areas. This project has also provided indicators of the possibilities and barriers to connecting solar power to the electricity grid.

Robust and durable vacuum insulation

Project title
Robust and durable vacuum insulation technology for buildings

Project number
2010-1161

Project duration
2011–2015

Funding awarded
SEK 6 486 000

Project leader
Kjartan Gudmundsson
KTH
kjartan@kth.se

Vacuum insulation panels, with their excellent insulation capabilities, offer an exciting alternative to traditional insulation materials, as they only need to be a fraction of the thickness of the insulation layer. This project will meet the urgent need for robust and detailed construction technology solutions for vacuum insulation panels. Different construction solutions have been examined with regard to moisture and heat transfer using dynamic simulations of moisture performance and modelling of thermal bridges and resulting U ratings. Full-scale trials in climate chambers and field measurements have also

been carried out. The project also includes studies of how the new, cheap aerogel material that can be used in vacuum insulation panels can be modified, which has comprised developing a new measurement technique for evaluating the thermodynamic properties of the core material.

The project will result in a proposal for construction technology solutions and methods for evaluating and developing the next generation of vacuum insulation panels and the super-insulation of the future. The research group has consisted of researchers from KTH and from Svenska Aerogel in Gävle.

Wall construction of light concrete with vacuum insulation panels being tested in a climate chamber at the Department of Civil and Architectural Engineering at KTH.
Photograph: Peyman Karami

Vertical greenery as a building material

Climbing vegetation growing on walls is one way of creating a greener environment in densely built areas where it not possible to grow plants on the ground. Green walls will likely become part of greener urban construction in the future.

There is limited knowledge about the use of green walls in the Scandinavian climate. The researchers in this project have studied establishment techniques, choice of plants and plant husbandry. They have also investigated how a green wall can affect the climate shell of a building and the surrounding climate. They have been able to demonstrate that it is possible to establish and maintain different types of green walls in the Scandinavian climate. There are functioning plant materials that can be used. The vegetation can be based on plants with different strategies and as a combination of rapid coverage types with more slowly growing accents.

The systems affect the temperature and moisture balance in the underlying wall. The systems protect from rain, which gives drier conditions behind the vegetation system. It is however of utmost importance that the underlying wall is protected from water spray from the green wall irrigation system. The energy balance in a poorly insulated wall can be improved as the winter temperature is higher in the air-space behind the vegetation panel and the panel provides shade during the summer. This project was a collaboration between SLU, Malmö University, Cec Design AB and Peab.

Project title
Vertical greenery as a modern building material and its consequences for building performance and street canyon climate

Project number
2011-230
Formas/BIC

Project duration
2011–2013

Funding awarded
SEK 3 000 000

Project leader
Tobias Emilsson
SLU
tobias.emilsson@slu.se

Felt pocket module **Panel module**

Photograph: Tobias Emilsson

Project title
Enabling buildings as an active component in the future energy system. How to handle barriers, tools and new business models?

Project number
2011-231
Formas/BIC

Project duration
2011–2013

Funding awarded
SEK 2 998 000

Project leader
Fredrik Wallin
Mälardalen University
fredrik.wallin@mdh.se

Barriers to collaboration between the energy and construction sectors

This project aimed to identify the obstacles preventing collaboration between the energy and construction sectors. The researchers have investigated the perspectives of important stakeholders in the energy and construction sectors when it comes to energy production and energy use in order to understand what can be done to achieve more efficient collaboration between these two sectors. The project began as a literature study. Subsequently 23 people from the energy and construction sectors, universities and municipalities were interviewed. Based on these interviews an e-questionnaire was created that was sent to 844 people working with district heating, the electricity grid, commercial electricity supplies, housing and construction companies.

The results showed that business models that are offered by the energy sector today (particularly within the district heating sector) create barriers to efficient energy use in buildings. In addition customers have poor incentive to be more active in terms of their energy use due to low energy prices, small price variations over 24 hour periods and political uncertainty about support for the installation of solar panels. These results can contribute to a better understanding of the obstacles, in order to achieve a more comprehensive collaboration between the energy and construction sectors.

Project title
Copper-tolerant wood degrading fungi: Their decay potential towards Cu-based wood protection systems and molecular mechanisms of Cu-detoxification

Project number
2011-416

Project duration
2012–2014

Funding awarded
SEK 3 611 000

Project leader
Daniel Geoffrey
SLU
geoffrey.daniel@slu.se

Copper-tolerant wood-degrading fungi

Despite new environmentally friendly wood protecting systems, wood decay protectants around the globe are still to a large extent based on copper, as copper offers a broad spectrum of protection at an affordable cost. In recent years however there have been alarming reports of premature failure of copper-treated posts in Sweden and abroad. These failures have been regarded to be caused by aggressive, copper-tolerant fungi that rapidly degrade the copper-treated wood after only a few years. It is now feared that this problem will increase in the future, as even new protectant systems that are based on micro-ionised copper will possibly not be sufficient to protect against this type of fungi.

This project has shown that the aggressive fungi that are involved in the early stages of the decay of wood

and timber belong to the brown rot and soft rot groups, which have remarkably high copper tolerance. The researchers are therefore focussing on characterising the fungi involved in the early attacks and elucidating the mechanisms available for copper detoxification. A number of ultra-structural, biochemical, molecular and conventional analyses have been integrated to gain a deeper understanding of the decay capabilities and mechanisms that these copper-tolerant fungi use so that a basis for new ideas on how to protect wood and timber against these fungi can be established.

A copper-treated wooden post that has been destroyed by copper-tolerant brown rot fungus after only two years.
Photograph: Daniel Geoffrey

IT in green daily living

Can IT help people to live in a greener way? Over the past 10 years the IT area has been of interest with regard to sustainability. This has resulted in systems and products, for example to help households reduce their electricity use or to help individuals choose green transport alternatives. The focus has often been well defined aspects of a sustainable society. But sustainability is much more than that. By interviewing families who voluntarily live simply for environmental and quality of life reasons the researchers have attempted to understand the practical aspects of the challenges in striving to achieve sustainability in society today, with the goal of investigating how we can better design IT to meet sustainability needs. Two groups of families in the north east of the USA have been interviewed, in part "simple living"" families and in part families making their livelihood by organic farming.

The studies have shown that IT both facilitates and prevents a more environmentally friendly lifestyle. For example, IT is invaluable in finding information, but also contributes to the consumerism and increased expectations for communicating and sharing on the Internet. This project has also provided important insights into how the IT area could be better at collaborating with other stakeholders in society.

Project title
Designing IT for ´Simple Living´: Taking a human-computer interaction perspective on environmental and human sustainability

Project number
2011-1523

Project duration
2012–2014

Funding awarded
SEK 3 265 000

Project leader
Maria Håkansson
Chalmers
maria.hakansson@chalmers.se

The interior of a "simple living" home – the family provides an example of the use of digital technology. The screen is concealed behind a throw-over blanket and children's sketches.

Boots in the home of one of the interviewed organic farming families.
Photographs: Maria Håkansson

Project title
Sustainable thermal acoustic retrofit (S.T.A.R)

Project number
2011-1813
Formas/BIC, Eracobuild

Project duration
2011

Funding awarded
SEK 1 200 000

Project leader
Delphine Bard
Lund University
delphine.bard@construction.lth.se

Thermal and sound insulation for renovations

The purpose of this Eracobuild project was to develop methods for the retrofitting of old buildings in terms of thermal and sound insulation. The project is part of a European project with the participation of researchers from Belgium and Scotland, as well as industry representatives, primarily from the consultancy sector (WSP and Simmons akustik & utveckling AB). The Swedish part of the project shall in part provide a background for the typical building façades of northern Europe and how these can be renovated in an acoustically beneficial way, and in part shall describe how sound insulation improvements can be modelled more thoroughly.

The researchers have examined field data and calculations made using commercially available software. This material has then been used to build models of different façade constructions and then to refine these to make the models more practically useful for more thorough design of insulation against airborne sound.

The material that was used has been compiled in a report, in addition to a database with the building façades that were included in the study. This is something that can be of great benefit to industry and for continued research involving the calculation models. In an extension of the project the models could be developed and used to optimise both thermal and sound insulation for façade renovations. This would enable more cost-efficient and optimized renovations where more aspects are taken into consideration in one and the same model.

Project title
Support systems for sustainable entrepreneurship and transformation (SHIFT):

Project number
2011-2152
EcoInnovera

Project duration
2012–2015

Funding awarded
SEK 3 395 000

Project leader
Magnus Klofsten
Linköping University
magnus.klofsten@liu.se

Support systems for sustainable entrepreneurship

SHIFT (Support Systems for Sustainable Entrepreneurs and Transformation) is a research project within the EU EcoInnovera programme. Eco-innovation and a green economy is high on the EU agenda, but support for small businesses that run sustainable operations is less developed at the EU level. Based on a combination of theories within the area of sustainability, innovation and entrepreneurship the researchers are studying aspects of the publicly funded support system for small eco-businesses

in Finland, Germany and Sweden, for example by examining incubators, universities, regional business developers and financiers. Questionnaires, interviews and case studies are used to describe how such organisations support companies. The researchers provide good examples and propose genuine and realistic recommendations for how the support system can be developed to create more and more successful small eco-businesses.

SHIFT is a collaborative project jointly run by Sweden, Germany and Finland. In each country the respective research groups are working with national and regional stakeholders. In Sweden these are Vreta Kluster and Föreningen Cleantech Östergötland.

The SHIFT research team in 2013.

Energy efficiency in renovations

This project intends to develop methods to bring research and practice closer together and facilitate future collaborations to achieve less energy use in Million programme housing. The aim is for the research results to be better utilised and the practical experience of companies to be better integrated into research.

Four scientists are working on the project; two with energy technology and two with social science backgrounds. The research is being carried out jointly with AB Stångå staden in Linköping. Several employees of the company are also involved in the practical research work. This project contributes to closing two knowledge gaps, the gap between commercial practice and academic knowledge and the gap between the technical potential to introduce energy-saving measures and the actual results of the investments made.

The researchers are involved in the project planning of renovations, they contribute with research-based knowledge and study how the commercial planning process is carried out. In addition, the researchers conduct interviews with company employees. They also arrange seminars based on requests from the company participants and organise study visits to companies, both within and outside Sweden, that have carried out similar renovation projects.

Project title
Doing CAREER – Energy efficiency in Million-program building renovation: a collaborative research program for integrative knowledge development

Project number
2012-246

Project duration
2012–2015

Funding awarded
SEK 6 589 000

Project leader
Kajsa Ellegård
Linköping University
kajsa.ellegard@liu.se

Researcher Katharina Reindl installing a weather station.
Photograph: Lina Lundgren

Project title
Procedures for sustainable renovation

Project number
2012-248

Project duration
2013–2015

Funding awarded
SEK 2 891 000

Project leader
Tove Malmqvist
KTH
tove.malmqvist@abe.kth.se

Procedures for sustainable renovation

The researchers are developing tools and processes for green and sustainable renovation policies in collaboration with companies such as HSB, Riksbyggen, Botkyrkabyggen, ROTpartner, Uppsalahem, Fastighets AB Seglet, Bengt Dahlgren AB and WSP. Eco-policies are not just about energy issues, they also address indoor climate and choice of materials, for example.

The objective is to compile a manual that provides tangible guidance, not least for property owners and housing associations that will renovate their buildings. The manual will provide suggestions for checklists, tools, environmental programmes and environmental targets to work with in renovation projects to better manage environmental and sustainability aspects of renovations. Renovation situations are a good opportunity to make environmental improvements in buildings.

The researchers propose how different environmental assessment tools can be used in renovation processes, for example the Swedish environmental certification system, Miljöbyggnad. They are developing a simple calculation tool that can be used at an early stage in the renovation process to test different potential renovation measures, such as façade insulation of different thickness, replacement of ventilation systems or installation of more energy-efficient windows, and can quickly determine how such measures will impact energy performance, climate effects and costs.

Renovation represents an important opportunity to environmentally upgrade a building.
Photograph: Birgitta Johansson

Project title
Facing the energy challenge: Innovative business models for renovation of buildings

Project number
2012-253

Project duration
2012–2015

Funding awarded
SEK 4 660 000

Project leader
Pernilla Kristensen Gluch
Chalmers
pernilla.gluch@chalmers.se

Decision and business models for energy-efficient renovation

The two sub-projects of this project focus on two key stakeholder groups for the construction sector in achieving energy targets set by politicians: public construction organisations and private house owners. The first sub-project is investigating the role that civil servants, such as construction project managers, energy coordinators and energy experts, have in implementing and achieving energy targets. Sub-project two is studying how small and medium-sized energy companies can make it easier for house owners to choose energy-efficient solutions when they carry out renovations.

The project is a joint collaboration with Västfastigheter, the City of Gothenburg and Bengt Dahlgren, as well as a further 18 SME construction companies in the Västra Götaland region. The project will lead to advice and recommendations for how civil servants can achieve the energy targets set by politicians, but will also provide advice for the politicians making the decisions in terms of what prerequisites the civil servants require.

The project will develop new business models and create new collaborations between construction and energy companies with a focus on increasing the number of energy renovations of individual family homes, as well as contributing to Swedish construction giants taking a leading role in the development of an energy-efficient and sustainable built environment.

Doctoral students Kjerstin Ludvig and Veronica Carlsson are working on the project.
Photograph: Kristin Fridholm

Photovoltaic systems on apartment buildings

Roof-mounted photovoltaic systems are the most rapidly growing global source for electricity provision. The northern latitude and low energy prices have previously limited Sweden's use of photovoltaic system facilities to summer houses. Solar electricity has however become more interesting for other types of buildings due to the rapidly lowering costs for solar power and rising electricity prices. Apartment blocks are of particular interest as large installations can be built using better technology that is more economic.

In this project the current and future photovoltaic system technology and the Nordic electricity market is examined to understand the opportunities and the risks of introducing photovoltaic systems for Swedish apartment buildings. The analyses are being carried out from the perspective of a housing association investing in their own energy system and from the perspective of the energy system in general. The technological possibilities for apartment buildings, as well as thermal energy storage in combination with heating pumps and energy storage for electric cars will also be examined.

The research results will provide property owners, housing association boards and building administrators with information to enable smart decisions about energy use and the alternative technologies available, lifestyles and investments. The project is being carried out jointly with Riksbyggen and Sustainable Innovation.

Project title
Photovoltaics on the roofs of apartment buildings owned by tenant owners' associations

Project number
2012-256

Project duration
2012–2015

Funding awarded
SEK 6 209 000

Project leader
Björn Palm
KTH
bpalm@energy.kth.se

Photovoltaic cells on the roof of a large building.
Photograph Nelson Sommerfeldt

Project title
Design for mitigating emission of greenhouse gases in industrialized construction

Project number
2012-1032

Project duration
2013–2015

Funding awarded
SEK 3 150 000

Project leader
Thomas Olofsson
Luleå University of Technology
thomas.olofsson@ltu.se

Reduction of greenhouse gases from industrial buildings

A report from the Royal Swedish Academy of Engineering Sciences (IVA) and the construction sector organisation Sveriges Byggindustrier (2014) indicates that the emission of greenhouse gases from construction processes is as large as the emissions from all private cars in Sweden. New planning and project planning methods are needed for construction projects to be able to evaluate and reduce energy consumption and greenhouse gas emissions from the manufacturing of components, materials and transport in the construction supply chain.

This project will develop analysis and simulation tools to be able to quantify and compare different design alternatives with regard to greenhouse gas emissions. The approach is to calculate the energy use and climate effects of EPDs (the EU environmental product declarations) on goods and materials, supplemented by the energy and environmental impacts of planned transport and installation at building sites. The researchers are working with construction and entrepreneur companies developing industrial construction platforms for buildings and installations, where these methods will be used to assess and develop designs to reduce environmental impacts.

Project title
Improvement of the steel-concrete interface for more durable and greener reinforced concrete structures

Project number
2013-1080

Project duration
2014–2016

Funding awarded
SEK 5 030 000

Project leader
Luping Tang
Chalmers
tang.luping@chalmers.se

More sustainable reinforced concrete structures

Concrete structures often suffer extensive damage as a result of rebar corrosion, resulting in major repair costs. Commerce and communities are also affected by the costs of disruption to traffic, highways, railways, air travel and shipping.

The purpose of this project was to develop techniques to improve the corrosion resistance of the interface between steel and concrete. Using a different and more energy efficient manufacturing process for steel reinforcement, with optimising of the oxide scale properties, a more corrosion resistant reinforcement with an extended lifespan could be obtained.

The characteristics of the steel-concrete interface were examined in the project by detailed studies of the microstructure of the steel and the chemical composition and

properties of the oxide scale. How the corrosion of steel inside the concrete is affected by defects in the concrete and by the chemical composition, thickness and electrochemical properties of the oxide scale will be investigated by electrochemical measurements.

Holistic approach for sustainable renovation

Within this strong research environment a collection of researchers and stakeholders from the building and planning sector will compile the existing research and results from previous renovation and research projects, develop methods and tools for carrying out sustainable, integrated renovation and will use these in some research projects that will be studied particularly thoroughly, followed up and evaluated. Approximately 30 scientists from higher education colleges and universities will participate in the project and 27 companies, government agencies and organisations have committed to the project as co-financiers and collaborative partners.

The project is transdisciplinary and concerns five research areas: 1) Administrative perspectives in the decision process and the role of the construction companies, 2) Integrated, holistic design and efficient renovation processes, 3) Economic challenges and opportunities when renovating, 4) Resident participation and democratic decision processes, and 5) Innovation and learning. The researchers are working with five work packages where they will establish a knowledge base, study previous renovation projects, introduce innovation and demonstration in new renovation projects through Living Labs (living laboratories where researchers, companies and residents interact) and action research, develop new or improve existing methods and tools for sustainable renovation, and work with communication, dialogue and dissemination of the results.

Project title
National Transdisciplinary Centre of Excellence for Integrated Sustainable Renovation

Project number
2013-1804
Strong research environment

Project duration
2013–2017

Funding awarded
SEK 22 985 000

Project leader
Kristina Mjörnell
SP-Technical Research Institute of Sweden
kristina.mjornell@sp.se

Kick-off for the strong research environment SIRen was held in May 2014 in Lund.

Project title
Reuse of building material components

Project number
2013-2120
Nordic Built

Project duration
2014–2015

Funding awarded
SEK 230 000

Project leader
Catarina Thormark
Malmö University
catarina.thormark@mah.se

Reuse of building materials

This project will use demonstration models to investigate new possibilities to reuse dismantled building components and materials. All stages of reuse will be considered; reuse, reconditioning, integration into construction, construction and marketing. This project will provide guidelines for new ways for organisations, tendering processes and trade to reuse building material components. The purpose is to stimulate the Nordic market for recycled components and in this way contribute to energy and resource savings and concomitantly generate profitable businesses and architectonic identity.

The goal is to change the status of dismantled building components from waste to worth – from down-cycling to a resource with its own identity. The project will be reported in the form of demonstration models of developed products and principles, an exhibition, a website and a report. Vandkunsten Arkitektkontor & Genbyg in Copenhagen, Asplan Viak in Oslo, and Malmö University are some examples of the project participants.

Project title
Low temperature heating and high temperature cooling in refurbishment and new construction of buildings

Project number
2013-2121
Nordic Built

Project duration
2013–2018

Funding awarded
SEK 2 860 000

Project leader
Sture Holmberg
KTH
sture.holmberg@byv.kth.se

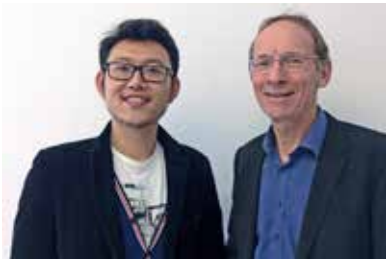
Low temperature heating and high temperature cooling

The purpose of this project is improved energy efficiency, good indoor climate and reduced environmental impact for water-based heating and cooling of existing and new buildings. Low temperature heating and high temperature cooling is used in the piping system in relation to the reference object. Innovative installation solutions for both homes and commercial properties are a focus of the project. As low temperatures are used for heating, the available energy in nature increases, heating pumps become more efficient and heat loss to the surrounding environment is reduced.

In many buildings, especially office buildings, there is an increased need for cooling, which is partly due to the increased internal heating load. In well-insulated buildings the excess heat can be a problem and the comfort needs should be able to be managed with cooling technology.

A renovation concept for specially selected house-types and offices will be established. Advanced computer simulations and field measurements will be important

aspects of the evaluation of potentially suitable renovation measures. The collaboration of commerce is very important in the implementation of new technological solutions to achieve set targets. Research groups and industry participants in three Nordic countries, Sweden, Denmark and Finland, are taking part in the project.



Doctoral student Qian Wang and project leader Sture Holmberg work at the Department of Civil and Architectural Engineering at KTH.
Photograph: Sasan Sadrizadeh

Airborne infection spread in operating rooms

This project will map the airborne infection pathways in operating rooms. A critical review of the operating rooms at the new Karolinska Hospital is included. The project has a special focus on the importance of the ventilation. To achieve an overview of the interactions between the movement of air and the spread of contaminants, the air circulation in operating rooms must be studied carefully and the spread of contaminating particles must be mapped. In this aspect a number of previous studies have not been sufficiently thorough. Advanced simulation techniques are accessible for the purpose of the project via the KTH supercomputer and these are an important complement to the measurements.

For both the experimental measurements and the numeric simulations it is essential that the air flow and the thermal and geometric conditions in the operating rooms are documented in detail. When agreement has been achieved between experiments and simulations for certain set parameters the simulations can be used for the generalisation of new conditions. In this way the study will be able to determine how changes in the amount of air, ventilation principles, the generation of contaminants, thermal conditions, the presence of people and the geometry of the room affects the exposure to contaminants in critical areas. This information is essential for the future planning of safe operating rooms.

Project title
Coordinated effort against airborne infection spread in operating rooms

Project number
2014-460

Project duration
2015–2018

Funding awarded
SEK 2 381 616

Project leader
Sture Holmberg
KTH
sture.holmberg@byv.kth.se

Photograph: Shutterstock

Project title
Sustainable design of fatigue-loaded steel structures

Project number
2014-638

Project duration
2015–2017

Funding awarded
SEK 3 788 097

Project leader
Mohammad Al-Emrani
Chalmers
mohammad.al-emrani@chalmers.se

Sustainable design of steel constructions

The production of steel is a very energy intensive process. Since the 1970s however, the energy consumption per tonne of produced steel has been reduced by approximately fifty percent, and a large proportion of current production comes from recycled material. Today new high tensile steel types are produced that facilitate lighter constructions with less material consumption. Car manufacturers have improved welding and production techniques by focussing on high tensile steel and have succeeded in reducing car weights by around 25 percent. The construction industry, which represents half of all steel consumption globally, to a large extent uses the same steel types and production methods as it did 30 years ago. There is therefore a great need for new technological solutions and innovations to enable a more rational design and production of steel constructions.

The purpose of this project is to introduce and develop post-weld treatment as a method of optimising the dimensioning of fatigue-loaded steel constructions. Post-welding is expected to result in major material savings and therefore also to lighter and more cost-efficient constructions. There will also be major benefits in the form of more environmentally friendly transport and improved safety at construction sites.

Project title
Improving green roof performance in demanding climates using the ecosystem mimicry concept

Project number
2014-854

Project duration
2015–2017

Funding awarded
SEK 5 955 504

Project leader
Godecke Blecken
Luleå University of Technology
godble@ltu.se

Green roof performance in demanding climates

The hypothesis of the researchers is that there are major opportunities to develop the design of green roofs. This project uses the innovative method based on the assumption that in the ecosystem under similar conditions as those of the green roof there are a number of plant types that in combination can contribute to improved performance. After performing an inventory of the plant types the researchers will select a number of species based on their functional qualities that may make them suitable for green roof use. Laboratory tests will be carried out to investigate how these different green roof variants function in comparison to the data collected in the field.

This research is of importance for the future success of green roof use in Sweden. As our climate is so cold there is a risk that green roof performance is not satisfactory. More intelligent and flexible design is needed to be able to utilise the potential of green roofing. This research is also of great economic interest. The green roof industry is growing rapidly. This project will enable the industry to deliver better functioning and more advanced, flexible solutions.

The project is a collaborative project between Luleå University of Technology and the University of Melbourne in Australia.

The researchers are studying a green roof in Luleå.
Photograph: Laura Merriman

Project title
Stability and functionality of grouted silica gels

Project number
2014-1158

Project duration
2014–2017

Funding awarded
SEK 4 319 355

Project leader
Zareen Abbas
University of Gothenburg
zareen@chem.gu.se

Silica gels in underground construction

This project will evaluate factors that affect the stability and function of silica gel in underground constructions. Tunnels are economically and environmentally advantages for future infrastructure project. Seepage in bore holes is the major problem and it is essential that these can be injected into to stop seepages. Currently cement is the material that is most often injected to stop seepage. But is difficult to use cement in small crevices. In recent times injection materials based on organic substances have been used. The experience gained from the Hallandsås tunnel however has now led to a search for more environmentally friendly material. Nanoparticles of silica (quartz, SiO_2) represent one such material.

A suspension of SiO_2 particles and sodium chloride can be injected into small crevices to form a gel that seals these fissures. As the gel consists of nanoparticles it is important to know what the long-term stability will be. In this project comprehensive laboratory studies will be carried out to investigate stability and these results will be compared with experience from field trials. A model for the simulation of long-term stability of injected silica gel in different environments will be developed. Svenska Kärnbränslehantering AB (SKB) and the Swedish Transport Administration (Trafikverket) number among the companies and agencies who have expressed interest in the project.

Injected silica gel.
Photograph: Johan Funehag

Project title
Funtionalized graphene reinforced cementitious materials for greener construction

Project number
2014-1282

Project duration
2015–2017

Funding awarded
SEK 4 808 007

Project leader
Johan Liu
Chalmers
johan.liu@chalmers.se

Graphene-reinforced cement-based building materials

Cementitious materials, such as concrete, are in a class of their own in volume terms as being the most used solid material in the world. The lifetime of concrete constructions is therefore of enormous importance for sustainable spatial planning. Cementitious concrete is brittle and porous and must be reinforced with steel.

This project aims to improve the fundamental properties of brittle cement-based materials and corrosion-sensitive steel rebar by developing cost-effective solutions based on surface-modified graphene and cement hydrates. To achieve these aims the researchers will firstly create a homogeneous mixture of graphene as an additive.

They will do this by forming a chemical bond between graphene and different oxides that are present in concrete. These combined structures will then be studied using a battery of mechanical and microscopy methods. It is anticipated that the mechanical load-resistant strengths will increase dramatically, especially the tensile strength of cement. By increasing the mechanical load-bearing strength the long-term duration of building constructions will increase, which will mean less use of cement and steel in concrete and therefore will contribute to a greener construction industry with less emission of carbon dioxide.

Environmental Protection Technology

The projects in this section include water purification (drinking water, stormwater and sewage), phosphor recycling, energy efficient eradication of Legionella, binding toxins in bottom sediment, conversion of stored methane, recovery of metals from soil, stabilizing mining waste and new technologies to protect plants from insect pests.

Improved biofilms for nitrogen removal

To achieve the "Zero eutrophication" environmental quality objective water purification plants need to be able to remove nitrogen from wastewater more efficiently. Optimization of these processes requires more knowledge about the biology. Nitrogen removal is always carried out using various types of bacteria. These bacteria often grow on biofilm surfaces. These projects generate more knowledge of how these bacteria function in biofilms.

Samples from wastewater purification plants are analysed using advanced molecular biology and microscopy methods. The structure of the biofilms is examined, individual cells identified and their activity and position in the biofilm is analysed. These parameters are crucial for the purification process. Experiments to study different processes are performed in a large pilot facility at the Sjölunda water treatment plant in Malmö. These projects have provided improved knowledge about bacterial biofilms and about the ecology and role of the nitrogen-converting bacteria in the purification process. New knowledge about the activity of the bacteria has also led to improvements in the process at Ryaverket in Gothenburg.

The project work has been carried out by a larger cartel, including scientists and doctoral students at the University of Gothenburg, Chalmers and KTH, collaboration with several water purification plants and Anox-Kaldnes AB in Lund.

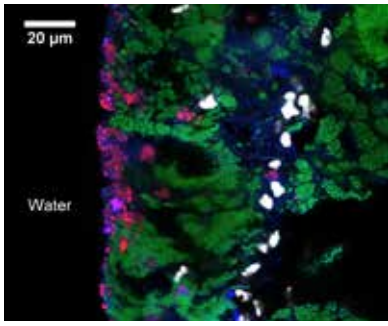
Project title
Improving biofilm technologies for nitrogen removal in wastewater

Project number
2008-131, 2010-2259
Environmental Technologies Program

Project duration
2008–2010
2011–2015

Funding awarded
SEK 2 038 000
SEK 3 229 000

Project leader
Malte Hermansson
University of Gothenburg
malte.hermansson@cmb.gu.se



Part of a biofilm from a reactor for nitrogen removal.

CARBOCAP – thin layer binding of toxins in bottom sediment

Many environmental toxins accumulate in bottom sediment. Different remediation methods are used. In the aquatic environment these often involve dredging and land-fill disposal of contaminated sediment. This project has tested a new remediation method named thin-layer capping. The method involves covering the contaminated sediment with a thin layer of non-contaminated clay mixed with a strong sorbent. As the environmental toxins are strongly bound to the sediment their accessibility for living organisms is reduced.

One sorbent that has already been tested in the USA is activated carbon. The researchers have used laboratory

Project title
In situ capping with carbon sorbents – a new ecologically sustainable technique for sediment remediation

Project number
2008-182
Environmental Technologies Program

Project duration
2008–2013

Funding awarded
SEK 4 370 000

Project leader
Jonas Gunnarsson
Stockholm University
jonas.gunnarsson@su.se

Activated carbon and clay is added to the bottom sediment in the Grenland fjord in Norway. The bottom of the fjord has high concentrations of dioxin.
Photograph: Jonas Gunnarsson

Project leader for CARBOCAP, Jonas Gunnarsson.
Photograph: Katja Amstaetter

studies and aquarium trials to test different types of mineral materials (sand, clay and limestone) and different organic carbon sorbents (from coconut, mineral coal and lignin). They have then added activated carbon and other material in situ, in a large experiment in Grenland fjord in Norway. The production of activated carbon from softwood has been carried out in a collaboration involving researchers from Stockholm University, Innventia AB and the Norwegian Geotechnical Institute (NGI). Researchers from Umeå University and from the Norwegian Institute of Water Research (NIVA) have also participated in the project.

The results have shown that capping with activated carbon reduces the exposure of aquatic microorganisms to environmental toxins. Thin-layer capping can however also be detrimental to the bottom fauna. Four years after the addition of activated carbon to the Grenland fjord the species diversity in the fjord is still reduced. Before this method can be recommended for use in the Baltic Sea more pilot field tests are necessary to investigate the potential long-term negative effects on the bottom-dwelling ecosystem.

Project title
Energy and cost-effective process for the reduction of nitrogen oxides in combination with carbon dioxide removal in power plants

Project number
2008-2156
Environmental Technologies Program

Project duration
2009

Funding awarded
SEK 749 000

Project leader
Ingemar Odenbrand
Lund University
ingemar.odenbrand@chemeng.lth.se

Removal of carbon dioxide in power generation

Carbon dioxide must be removed whenever possible from the flue gases from combustion. Vattenfall has tested the OxyFuel process, which uses an excess of oxygen instead of air in the combustion process. Carbon dioxide can be separated in liquid form. The concentration of nitrous oxides (NOx) in the system is however high. Hulteberg Hydrogen Solution AB proposed a process to utilize the high NOx concentrations as an advantage and made the process autothermic by using the reaction heat generated in a reduction reaction between nitrous oxide and ammonia – a solution that is the first of its kind in the world. Catalysts from commercial suppliers were evaluated in the project.

Minimizing environmental toxins from co-combustion

This project has been carried out in collaboration with Vattenfall AB and SCA. The purpose was to develop new methods to prevent the formation of persistent organic pollutants (PoPs) and to clarify which Pops are formed in facilities that burn biofuel and the waste products from the pulp and paper industry. Biofuels for combustion in modern full-scale installations normally do not exceed the set emission limits, but when fuel containing chlorine and metals are co-combusted emission levels can rise. Reducing the formation of PoPs in the combustion chamber is more important from an environmental standpoint than relying on scrubbing of the flue gases and post-treating the waste products from purifications.

Biomass (bark, sawdust, forestry waste, wood shavings) and the process waste from the pulp and paper industry was combusted in an SCA facility. The results demonstrate that techniques that utilize the addition of ammonium sulphate reduces the formation of dioxins. Laboratory tests using the same fuel in a combustion reactor at Umeå University confirmed what had been observed in the full-scale tests, that the addition of ammonium sulphate to flue gases partially prevents the formation of PoPs. As a result of this project industrial partners have developed a work plan to facilitate the work at all stages to achieve as low emission levels of PoPs as possible.

Project title
Minimization of organic pollutants in the co-combustion of biofuels with rest products from pulp and paper industry

Project number
2008-2170
Environmental Technologies Program

Project duration
2009–2010

Funding awarded
SEK 1 926 000

Project leader
Stina Jansson
Umeå University
stina.jansson@chem.umu.se

Biofuel pellets being replenished prior to a lab-scale combustion test.
Photograph: Andreas Nilsson

Bacterial composition determines sludge properties

In the activated sludge process for the purification of sewage it is the microorganisms, principally the bacteria that through different decomposition processes purify the sewage. Separation of the active sludge, which is normally carried out in sedimentation tanks, is essential for an efficient purification process. A common problem is sludge with poor aggregation characteristics and to a large extent it is the composition of the bacterial populations that determines this.

The development of molecular biology has opened up new possibilities and identification of the bacteria can be carried out using DNA in composite ecosystems, such

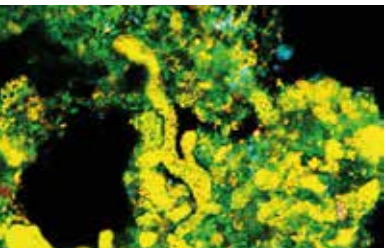
Project title
Governing factors for bacterial adhesion and aggregation in activated sludge and their effect on wastewater treatment

Project number
2008-2192
Environmental Technologies Program

Project duration
2009–2014

Funding awarded
SEK 2 776 000

Project leader
Britt-Marie Wilén
Chalmers
britt-marie.wilen@chalmers.se



The development of molecular biology has opened up new possibilities for the identification of bacteria in activated sludge in situ.

as sludge aggregations. This project has improved the understanding of the factors that determine the structure of the bacterial populations in the sludge. The results have demonstrated that certain groups of bacteria can be correlated to different sludge properties. In addition the microbial composition correlates with particular process parameters, such as temperature, that vary during the year, but there is also a stable population that is presumably dependant on the process design at the water treatment plant. This project has been carried out in collaboration with Gryaab in Gothenburg.

Project title
Triggered phosphorus recovery using reactive filter materials – tapping into the potential of wastewater as a key resource

Project number
2009-1499

Project duration
2010–2012

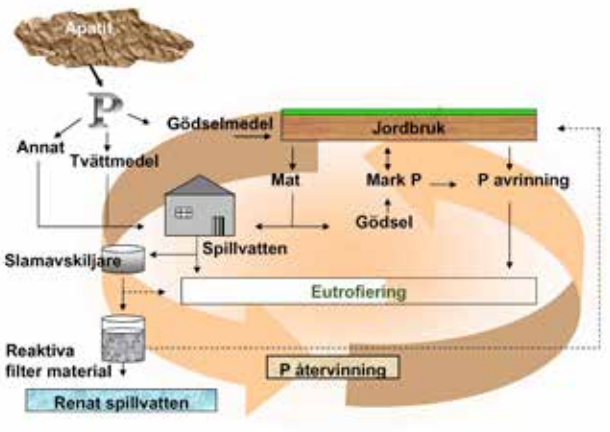
Funding awarded
SEK 3 067 000

Project leader
Gunno Renman
KTH
gunno@kth.se

Efficient phosphorus recovery using reactive filters

What roles do bacteria and organic material have in the phosphorus binding capabilities of reactive filter materials? These filters can be used to purify sewage and other wastewater streams that have elevated concentrations of phosphorus. With better knowledge of the factors that can disrupt the sorbing of phosphorus the filter materials can be further developed and the system can be optimized.

In two field trials the wastewater from four households was passed through two different filter materials; blast-furnace dross and Polonite. Phosphorus and bacteria were studied, as well as how the binding to the filter material was affected by high or low concentrations of organic material in the wastewater. In laboratory tests the filter material Sorbulite was also investigated. The results showed the great importance of low concentrations of



Reactive filter material in specially designed circulation cycle drains can be used to close the circulation cycle for phosphorus in domestic wastewater.
Illustration: Victor Cucarella

organic substances in the wastewater for obtaining a good phosphorus reduction and extended usable lifetime of the filter material. Polonite had a better ability to bind phosphorus and dead bacteria than the Sorbulite did. On the other hand Sorbulite had a better ability to separate nitrogen and organic material. The conclusion was that Sorbulite is also a potential filter material for the removal of phosphorous and nitrogen from wastewater. One way to optimize the process would be to use both Polonite and Sorbulite. The results have been implemented in the small-scale drainage sector and in a spin-off company.

Gunno Renman (nearest the camera) holds a field lecture on how individual wastewater installations with filter bed technology should be constructed.
Photograph: Agnieszka Renman

Novel method of methane conversion in landfills

Almost 10 percent of all methane emission globally comes from landfills. Methane is 23 times more efficient at trapping heat than carbon dioxide. This means that even small amounts of methane contribute to global warming. It is important to discover methods to reduce methane emission from landfills. The n-damo bacteria is a relatively new discovery and is highly interesting as it can oxidise methane into carbon dioxide in an oxygen-free environment. The bacteria can use nitrate or nitrite instead of oxygen.

The purpose of this project was to investigate the possibilities of using n-damo bacteria to reduce methane gas emissions from the Albäck landfill in Trelleborg. Different molecular biology tools were used to characterise the microorganisms, such as PCR, cloning and DNA sequencing. The results showed that living n-damo bacteria were actually present at the landfill site. If there are n-damo bacteria they could also oxidise methane to carbon dioxide in an oxygen-free environment. There is now major potential to solve the mystery of how landfills could be simply and efficiently treated to reduce the emission of methane gas. By understanding n-damo bacteria measures could be introduced to mitigate methane leakage and to take measurements to show the order of magnitude of the methane emission from methane-rich land, such as moss, bogs and thawing tundra.

Project title
Novel method of methane conversion in landfills

Project number
2009-1994
Environmental Technologies Program

Project duration
2010–2012

Funding awarded
SEK 2 976 000

Project leader
Kenneth M Persson
Lund University
kenneth.persson@tvrl.lth.se

Photograph: Shutterstock

Researchers studying water resource planning and waste management at Lund University have worked together with microbiologists on this project. The work has also been carried out in close collaboration with the waste management sector, in particular the southern Skåne waste management company SYSAV, Sydskånes Avfallsaktiebolag in Malmö.

Project title
Energy-efficient eradication of Legionella and other bacteria in water

Project number
2009-2110
Environmental Technologies Program

Project duration
2010–2012 and 2014–2015

Funding awarded
SEK 3 826 000

Project leader
Bo Nordell
Luleå University of Technology
bon@ltu.se

Photograph: Shutterstock

Energy-efficient eradication of Legionella

This project has developed its energy-efficient "Duck Foot Heat Exchanger" model for the thermal treatment of bacteria-contaminated water. The method was originally designed to combat Legionella bacteria in water, but it also works against cholera and other known bacteria in water.

Water temperatures of 20–45 °C are most permissive for the growth of Legionella. At temperatures higher than 70 °C the bacteria die immediately, but the problem is the high energy cost. The method developed in the project raises the water temperature so that the bacteria die, but by using an internal heat exchanger the heat used to decontaminate the water is recycled. The method imitates the blood circulation system that enables certain types of birds to be able to walk "barefoot" on ice without any significant heat loss.

Globally 1.5 million people die each year from lung infections that are primarily caused by Legionella infections. The problem is greatest in poor countries, but it has grown strongly in Europe in recent years. One reason for this can be that renewable energy and low temperature systems (accumulator tanks) are permissive to Legionella growth. It is naturally of great interest to be able to simply and cheaply prevent future outbreaks. This project has been carried out as a collaboration between Algeria and Sweden.

Anammox for energy-efficient nitrogen removal

The most common method for the removal of nitrogen from wastewater requires large tank volumes, a lot of energy for aeration and an external charcoal source. A new method for nitrogen removal, the deammonification process, is based on the use of a particular type of bacteria known as anammox bacteria. The method needs less aeration and does not require organic charcoal.

In this project the deammonification process has been studied at low temperatures and nitrogen concentrations, which are characteristic for primary wastewater streams. The researchers have carried out pilot-scale trials at Hammarby Sjöstadsverket in a reactor with a biocarrier. The process was stable down to 13 °C, but the anammox activity dropped noticeably at temperatures between 16 and 13 °C. Lowering the temperature also had a marginal effect on the composition of the bacterial population. Lowering the nitrogen concentration in the wastewater at 13 °C made little difference to the nitrogen removal efficiency or the composition of the bacteria.

Project title
Use of Anammox for a more efficient nitrogen removal in wastewater treatment plants

Project number
2010-140
Formas/Svenskt Vatten

Project duration
2010–2013

Funding awarded
SEK 1 100 000

Project leader
Elzbieta Plaza
KTH
elap@kth.se

Pilot plant for the study of deammonification.
Photograph: Jozef Trela

Enhanced energy efficiency in wastewater treatment

This project has developed a data benchmarking tool for the assessment of water quality, operational costs, resource efficiency and climate impacts in an integrated manner. The tool is based on Benchmarking Simulation Model No. 2 (BSM2) but has been expanded with refined evaluation of energy use and models for greenhouse gas emissions, among other things. This enables operating and control strategies to be evaluated from a wider sustainability perspective. The results are also assessed from a lifecycle perspective. In total this will be of great benefit for the water treatment plants that want to use models and simulations to develop their purification processes.

Preliminary results show that in many cases there is a conflict between energy efficiency (cost reduction) and

Project title
Development and dynamic analysis of operational strategies for enhanced energy efficiency of wastewater treatment systems

Project number
2010-141
Formas/Svenskt Vatten

Project duration
2010–2014

Funding awarded
SEK 2 050 000

Project leader
Ulf Jeppsson
Lund University
ulf.jeppsson@iea.lth.se

greenhouse gas emission, for example. Nitrous oxide emission from the biological processes under non-permissive conditions predominates, but diffuse emission of greenhouse gases from water treatment plants and the energy that has been consumed for the production of chemicals and charcoal sources, for example, is also of significance.

A fully developed model is being verified and validated in a full-scale trial at Käppalaverket on Lidingö, where the energy consumption and greenhouse gas emission is being monitored for the entire treatment plant.

Project title
Reduce the greenhouse gas emissions from Swedish wastewater and sewage sludge management

Project number
2010-148
Formas/Svenskt Vatten

Project duration
2010–2014

Funding awarded
SEK 2 700 000

Project leader
Håkan Jönsson
SLU
hakan.jonsson@slu.se

Agnes Willén taking gas samples to measure greenhouse gas emissions from sludge storage.
Photograph: Dick Gillberg

Emission of greenhouse gases from wastewater and sludge treatment

The objectives of this project were 1) to generate new knowledge about the emission of greenhouse gases from wastewater and sludge processing, and 2) to provide good decision-making support for how emissions can be minimized. In this project the emission of nitrous oxide and methane was monitored from reject water purification in SBR reactors, from reject water purification using the anammox process, from different types of sludge storage for one year and from different distribution strategies for two types of sludge. (Reject water is the water that results from the process of removing water from sewage sludge.)

The measurements of reject water from the anammox process showed consistently low nitrous oxide emission levels. Short-term measurements at a reject water facility using nitrification/ denitrification in an SBR reactor showed that the emission of nitrous oxide could vary greatly. System analysis showed that the greenhouse effects from reject water purification using SBR could be significantly greater than from the rest of the entire water treatment plant. This is concerning, but the supporting data is not comprehensive enough to provide unequivocal advice.

The greenhouse effects from the management of the sludge produced were significant and were dominated by emissions from storage, while the emissions from the distribution and use as a fertilizer were small. Emissions from sludge can be minimized by minimal storage times and deammonification of the sludge. Deammonification eliminated emissions from the storage of nitrous

oxide and greatly reduced the emission of methane. This project was described in a development report from the Swedish municipal water research fund, SVU (Svenskt Vatten Utveckling (2015-02)).

The research group surrounding Håkan Jönsson. The project was carried out by researchers from SLU, KTH, IVL and JTI.
Photograph: IVL Swedish Environmental Research Institute

Biofilters for stormwater purification

Sweden lacks local experience about the performance of stormwater biofilters. These filters are used to hold back and purify stormwater. The risk exists that these do not function optimally during the winter. In winter and spring there can be problems with the efficiency of purification as the salt content in the stormwater (and therefore the proportion of metals in solution) is elevated and the biological processes and plant growth capabilities are negatively affected by low temperatures.

The researchers have investigated the effects of salt, temperature and water saturation zones on the removal of metals, sediment and nutrients. A preliminary assessment shows that stormwater biofilters can be a good solution for stormwater management, even in areas that have cold climates. The project carried out laboratory experiments to find the right types of plants for biofilters in Nordic conditions.

Stormwater biofilters, with and without water saturation zones, were investigated at different temperatures with regard to their capability to reduce the amounts of certain bacteria. Preliminary results indicate that stormwater biofilters with water saturation zones remove bacteria better than normal stormwater biofilters. These results will support the implementation of stormwater biofilters in Sweden and the results have been disseminated via the Stormwater&Sewers cluster in Luleå.

Project title
Advancing stormwater biofiltration: overcoming obstacles for increased implementation

Project number
2010-787

Project duration
2011–2014

Funding awarded
SEK 4 875 000

Project leader
Godecke Blecken
Luleå University of Technology
godble@ltu.se

In a project in Luleå scientists are identifying plants suitable for biofilters in Nordic conditions.
Photograph: Godecke Blecken

Project title
Microelectrode arrays for drinking water quality monitoring

Project number
2010-1062

Project duration
2011–2014

Funding awarded
SEK 4 412 000

Project leader
Mats Eriksson
Linköping University
mats.eriksson@liu.se

Microelectrode arrays for drinking water quality monitoring

The aim of this project was to develop new sensors based on microelectrode arrays suitable for continuous monitoring of water quality at water purification plants, in water distribution pipes and in buildings. The work has primarily been carried out at Linköping University, but some sensor manufacturing has taken place at Printed Electronics Arena in Norrköping and at Electrum in Kista. The sensor method builds on a previous discovery known as the "electronic tongue". Further development of this electronic tongue into microelectrode arrays means that the sensors will function much better in drinking water and in sewage, where the low electronic conductivity otherwise limits monitoring measurements.

One type of microelectrode that has been studied builds on what is known as a microband, as well as arrays of these. Despite their simplicity these sensors have the characteristics expected of microsensors in terms of rapidity and detection limits. They can also be customized and have the potential to be mass produced at low costs. Another sensor type is manufactured from silicon and contains several hundred microelectrodes in the array. The microelectrodes are manufactured from different materials, including gold, platinum and rhodium. The results in this project have been so encouraging that the researchers are now involved in a Vinnova project to investigate the possibilities of founding a spin-off company to commercialize the research results.

Project title
Small-scale purification of bathing, dishwashing and laundry water – production of a water resource

Project number
2010-1134

Project duration
2011–2015

Funding awarded
SEK 4 903 000

Project leader
Håkan Jönsson
SLU
hakan.jonsson@slu.se

Grey water as a water resource

This project will contribute knowledge to develop simple and cheap systems for the local purification of water from bathing, dishwashing and laundering (grey water) to provide a safe resource suitable for irrigation and replenishing ground and stormwater. The researchers have studied the management of grey water using filter beds comprised of three different filter materials; bark, activated charcoal and sand. In the laboratory, bark and activated charcoal have demonstrated very good reduction of suspended particles, biological oxygen demand (BOD), phosphorous and pathogenic organisms. The

treatment of highly concentrated grey water and high flow rates have been studied. Bark and activated charcoal gave much better purification results than sand, especially for the reduction of biological oxygen demand (BOD). The hygiene risks of using the treated water were also studied.

Several municipalities currently recommend separate drainage systems that collect water from toilets in tanks and purify grey water locally. Internationally the need for good and robust purification of grey water is enormous, as more than 80 percent of the world population produce sorted-at-source grey water that is often poured directly onto the ground, resulting in major sanitary problems.

Purification of grey water being studied in columns containing bark, activated charcoal and sand.
Photograph: Sahar Dalahmeh

Purification of wastewater using granular sludge

A new technique for purifying wastewater is to use aerobic granular sludge. The granules are highly compact, round aggregates of bacteria that have extremely good separation properties. This enables a very compact purification process. The formation of the granules only takes place under certain conditions, such as high turbulence, high organic burden and a subsequent extended period of aeration and a short sedimentation period. As the granules are relatively large, often 2–3 mm, internal zones are formed that have different environmental characteristics that can be utilised to promote different simultaneous degradation processes. The knowledge of how granules are formed is limited and the challenge lies in being able to regulate the growth of the granules so that the system is permissive for those microorganisms that have the ability to form granules instead of flock aggregates.

The establishment of a granule reactor was studied in one of the projects to understand the mechanisms regulating granule formation and whether it is only certain groups of bacteria that have the ability to form granules. Different research has also been carried out where the relationships between different organic materials and nitrogen in the wastewater have been varied to examine how this affects the granule-forming mechanisms and how the organic material and nitrogen is reduced in the reactor. The microbial populations in the granules have been studied using molecular biology methods to map the selection mechanisms in the system when the system

Project title
Aerobic granular sludge membrane bioreactor for nutrient removal from wastewater

Project number
2010-1716
2013-627

Project duration
2011–2013
2014-2016

Funding awarded
SEK 3 950 000
SEK 4 505 000

Project leader
Britt-Marie Wilén
Chalmers
britt-marie.wilen@chalmers.se

Aerobic granular sludge.
Photograph: Britt-Marie Wilén

is initiated using active sludge from a wastewater treatment plant. The results demonstrate that the granulation process happens rapidly when there is a gradual reduction of the sedimentation time. The populations change rapidly during the start-up phase and the granules have high purification efficiency for organic material and nitrogen.

A new type of purification process is being studied in another project, where aerobic granular sludge is combined with membrane filtration (MBR). The challenge is to achieve stable granules in a system where both the selection mechanisms for the bacteria are different and where the forces on the granules are likely to be greater in comparison to a granular reactor without membrane filtration. The research results will hopefully lead to MBR processes with significantly less aggregate formation and higher purification efficiency. This technique is likely to be most suitable for smaller purification plants and for purification of substreams. In time the results may even be used on a more global scale, where many countries have a shortage of water and reuse of grey water becomes more important. Membrane bioreactors are suitable for use in this context as they consistently produce water of high purity.

Project title
Sequential remediation of soil with complex contamination

Project number
2010-2254
Environmental Technologies Program

Project duration
2011–2013

Funding awarded
SEK 3 585 000

Project leader
Jurate Kumpiene
Luleå University of Technology
juku@ltu.se

Sequential remediation of soil with complex contamination

The aim of this project was to decontaminate polluted soil in an environmentally and resource-efficient manner so that the remediated soil can be left in situ or landfilled in a safe way. Reduced remediation costs would enable treatment of more sites.

Together with RagnSells AB, the researchers examined the possibilities of altering the hazardous nature of the material using different treatments to remove or bind hazardous substances. It is a great advantage if mixtures of different types of contaminants can be managed in the same process. The methods developed in the project included the chemical extraction of arsenic (As), mercury (Hg) and polyaromatic hydrocarbons (PAH) using degradable solvents in combination with purification of the wash water and stabilising of the arsenic-contaminated soil. Waste products were used in all of these processes,

for example from sewage and energy industries; waste products that in turn must be treated and managed. In other words, waste was used to process waste.

The results demonstrated among other things that the washing effects of the degradable solvents developed were just as great as the commonly used, but non-degradable wash solutions currently on the market. In addition up to 99 percent of the contaminants in the washing solution could be removed using a filter produced from sewage sludge.

Upper panel: Production of solution from waste in a large column, coupled to soil washing in small columns. Lower panel: Stabilising metals in an oxygen-free environment by precipitation of metal sulphides.
Images: Jurate Kumpiene

Destruction of POPs in waste products

This project investigated the possibilities of detoxifying dioxins, furanes and persistent organic pollutants (POPs) from ashes using microwaves as an energy source. Researchers from Umeå University worked in collaboration with Stena Metall. The organic pollutants studied are bound to carbon particles in the ash and degraded at high temperatures. Microwaves generate high temperatures when carbon particles effectively absorb microwaves. This make microwaves a suitable candidate as an energy source for the post-treatment of ash to degrade POPs.

In the first phase ash was treated with microwaves in a laboratory scale reactor using 3 kW, with ash amounts of up to 200 g. Trials have also been performed using a smaller scale and batches of 2 g at the University of York. As a complement, the same ash was treated with a conventional heat treatment to be able to evaluate the benefit of using microwaves as an energy source.

Initial results demonstrated that POPs could be degraded when the ash was exposed to microwaves, and that dioxins and furanes are affected differently by the treatment. The composition of the ash affects the possibilities of detoxifying the ash from POPs. The treatment using microwaves makes shorter treatment times possible in comparison to conventional heat treatment, which could mean large time savings in a potential treatment process.

Project title
Destruction of POPs in solid by-products using microwave pyrolysis, a new remediation tool

Project number
2010-2276
Environmental Technologies Program

Project duration
2011–2013

Funding awarded
SEK 2 140 000

Project leader
Lisa Lundin
Umeå University
lisa.lundin@chem.umu.se

Lisa Lundin prepares ash for microwave pyrolysis at the University of York.
Photograph: Eva Weidemann

Project title
Soil washing and recovery of copper and chromium from highly contaminated soils

Project number
2010-2282
Environmental Technologies Program

Project duration
2011–2014

Funding awarded
SEK 1 040 000

Project leader
Karin Karlfeldt Fedje
Chalmers
karin.karlfeldt@chalmers.se

Soil washing and recovery of copper and chromium

There are more than 80 000 potentially contaminated areas in Sweden and metals are a big problem at around half of these sites. Land-fill is the most common method of remediation, but this is not sustainable in the long-term, among other things because the valuable metals in the land-filled masses are not recycled. This project aimed to develop a laboratory-scale method to decontaminate land polluted with metals in an environmentally friendly and sustainable way and to concomitantly recover valuable substances.

The basis for the process was to wash out interesting metal pollutants using different leaching solutions, preferably acids from waste streams, and to recover the metals from the leaching solutions. It has been demonstrated that copper can be efficiently leached from contaminated soil, while chromium is more difficult. It is possible to recover copper with high purity (>99.9 percent) from the leaching solution. The remaining soil waste contains lower concentrations of potentially toxic metals after the washing process and can in certain cases be managed at land-fills for non-hazardous waste. The method has great potential and if given the opportunity to be tested on a larger scale could result in the first sustainable remediation method for metal contaminated areas, where previously untapped resources are used.

The researchers have collected soil samples from an area in Dalsland that is heavily contaminated with copper.
Photograph: Karin Karlfeldt Fedje

Project title
Using green liquor dregs from the paper industry for stabilisation of sulphide-bearing mine waste – solving two waste problems at the same – STABWASTE

Project number
2011-1146

Project duration
2012–2015

Funding awarded
SEK 3 830 000

Project leader
Björn Öhlander
Luleå University of Technology
bjorn.ohlander@ltu.se

Two waste problems – one solution

Mining generates large amounts of waste in the form of gangue and enriching sand. When sulphide-containing mined waste is oxidized in contact with air and moisture an acidic leachate is formed that can have high metal content, which can lead to negative environmental impacts. This can proceed for hundreds or thousands of tears in individual land-fill sites. Two common ways to manage the problem of acidic leaching are either to limit the amount of oxygen exposure of the waste or to add limestone the acidic liquid, which results in large amounts of potentially toxic sludge.

Use of other materials, such as industrial waste, to prevent the negative effects would solve two waste problems at once. This project has studied green liquor, and alkaline waste product from the paper industry. The goal was to develop methods for using green liquor to prevent the formation of acidic leachate using mixtures of the mining operation's own enriching sand or unclassified moraine to construct a covering layer for mining waste land-fill, or as an additive to gangue to create a coating for the reactive mineral surfaces. The project used laboratory trials in combination with full-scale trials in close collaboration with the mining company Boliden & Dragon Mining and with the forestry industry through its partnering organisation Processum.

Test surface at Brännkläppen outside Boden where a mixture of moraine and green liquor is spread out as a covering layer.
Photograph: Maria Mäkitalo

Nanotechnology for protection against insect pests

This project had the goal of developing new and powerful ways to augment the natural defence mechanisms of plants and increase their tolerance to stress, in the first hand from insect pests. This is of great importance in an increasingly warmer and damper climate in which insect pests flourish.

The researchers studied how nanoparticles could be used to provide the plants with specific microelements to prevent insect attack, or to "teach" the plants to produce odours to scare away the insects or, alternatively, to improve the ability of the plants consolidate contact and collaboration with plant-protecting microorganisms (biopesticides).

The researchers produced nanoparticles from common minerals, such as sand and limestone, and studied how

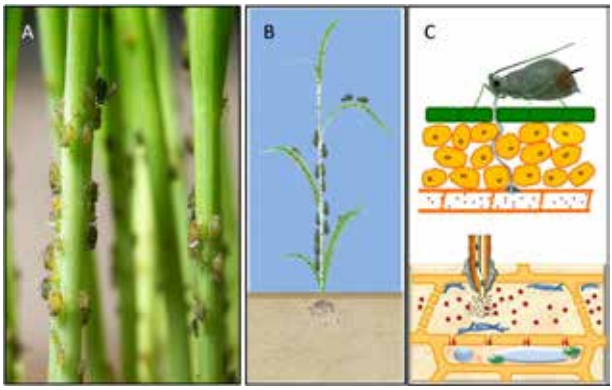
Project title
Nanotechnology for innovative protection against insect pests

Project number
2012-581

Project duration
2013–2015

Funding awarded
SEK 4 500 000

Project leader
Vadim Kessler
SLU
vadim.kessler@slu.se



Aphids on a plant and a schematic representation of the project concept – to strengthen the resistance of a plant to aphids through the uptake of mineral nanoparticles.
Image: Velimir Ninkovic and Robert Glinwood

these could be administered to plants together with microelements, biopesticides and repellents. They have shown that with the help of nanotechnology that it is possible to multiply the resistance of plants to drought and diseases several-fold. The researchers have even learned to produce surface-modified limestone particles that, if taken up by the plant, could hopefully prevent aphids from sucking the juices of the plant. It has been shown that mineral nanoparticles can significantly improve the collaboration between plant roots and biopesticide microorganisms.

Project title
Nanostructural devices for water cleaning

Project number
2012-771

Project duration
2013–2016

Funding awarded
SEK 5 826 000

Project leader
Martin Andersson
Chalmers
martin.andersson@chalmers.se

Photograph: Simon Isaksson

Water purification modelled on cell walls

Can we mimic nature to purify water? Nature purifies water in a very energy efficient way. For basic water purification natural resources are in use today to separate water from particles and dirt by pumping water through gravel beds. The next step in natural water purification involves more refined methods that result in us being able to eat the fruit from a tree that otherwise survives on undrinkable water. The cells of the tree purify its water, and the cell walls are the most important component in this process. The cell walls protect the cell from surface threats, but must at the same time allow the uptake of water to enable the cell to survive. Water transport is achieved using aquaporins, proteins that form water tunnels through the cell membrane. These are very efficient and selective. Only H_2O is allowed to pass through.

Nature has provided us with a very energy-efficient and selective water filter. Can we benefit from this? This project is focussing on developing a simplified natural water filter. This is composed of aquaporins in a lipid bilayer that is placed on a stable foundation of porous silica. The lipid bilayer functions as a barrier that only the water that passes through the aquaporins can pass. The clean water then flows through the pores in the silica, leaving behind the undesired chemicals or particles.

Titanium-based ion-exchangers for water treatment

The goal of this project is to develop efficient, regenerable and relatively cheap titanium-based ion-exchangers (Ti-IE) for the removal of toxic metals from sewage water. The world's production of sewage is estimated to be around 1 500 km³ a day. Traditional methods for purification do not fulfil the EU target limits and are expensive. The development of Ti-IE-adsorbents would be of ecological and economical interest to society. Titanium phosphate material has already demonstrated high selectivity for metal cations, which has led to increased interest in the adsorbents.

The project comprises three scientists from Luleå University of Technology who are working together with researchers at the Kola Science Centre in Russia and collaborating with Boliden AB. The adsorption capacity of the adsorbents is first studied in batches before progressing to column studies. Characterising different Ti-IEs is carried out using various analysis methods to determine the structure and properties of the adsorbent. One particular adsorbent developed at Luleå University of Technology has demonstrated very good adsorption properties in comparison to amorphous titanium phosphate that was previously developed at the Kola Science Centre. Further experiments are being carried out to determine the exact structure and surface properties of the adsorbent.

Project title
Titanium-based ion-exchangers for water treatment

Project number
2012-1410

Project duration
2013–2016

Funding awarded
SEK 3 018 000

Project leader
Oleg N. Antzutkin
Luleå University of Technology
oleg.Antzutkin@ltu.se

Titanium phosphate adsorbent with different metal ions adsorbed from water solutions.
Photograph: Oleg N. Antzutkin

Biosorption in activated sludge processes

The activated sludge process is a very common method used in the purification of sewage. It is primarily used to remove organic contaminants, through oxidation or adsorption. We know relatively well how the oxidation process works, but the mechanisms that regulate the adsorption process are less well known. The purpose of this project is to investigate how the properties of sewage and the activated sludge influence the adsorption of organic substances. The researchers take sewage and sludge samples from water purification plants and then

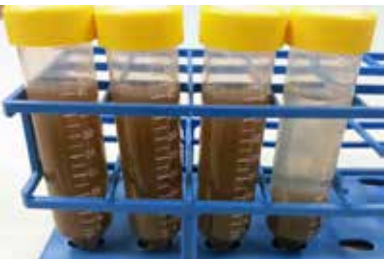
Project title
Biosorption in the activated sludge process: mechanisms, kinetics, and implications for process design

Project number
2012-1433

Project duration
2013–2016

Funding awarded
SEK 4 481 000

Project leader
Oskar Modin
Chalmers
oskar.modin@chalmers.se



Mixtures of activated sludge and sewage.
Photograph: Oskar Modin

perform adsorption experiments in the laboratory. The municipal drainage organisations Gryaab and VA Syd are also participating in the project.

Results to date have demonstrated that activated sludge can adsorb 0–100 mg of organic material per gram of sludge. The type of sludge has a major effect on how much can be adsorbed. The hope is that by better understanding the mechanisms that influence the adsorption process there will be better opportunities to model and design activated sludge processes where adsorption plays a key role. The development of new activated sludge processes where adsorption and other non-oxidative mechanisms are used is a research area that is attracting increasing attention. This can result in more sustainable water purification that consumes less energy and where the organic content of the sewage can be used, for example, to produce biogas, biodiesel or other resources.

Organic contaminants in stormwater

Project title
Removal of organic contaminants in stormwater treatment facilities

Project number
2012-1607

Project duration
2013–2015

Funding awarded
SEK 3 809 928

Project leader
Karin Björklund
Chalmers
karin.bjorklund@chalmers.se

Samples of sediment from a subterranean stormwater pool.
Photograph: Karin Björklund

Stormwater contains organic contaminants in concentrations that often exceed environmental quality target norms. The purification of stormwater is therefore regarded to be of major importance if we are to achieve good water quality objectives. This project has focussed on the removal of organic contaminants using retention dams and filters with adsorbing media. Material suitable for use in adsorption filters was tested and compared with regard to its capacity to adsorb contaminants, both in beaker-scale tests and by allowing contaminated stormwater to pass through filter beds in pilot-scale tests. The separation capabilities of dams were studied in the field by measuring inflowing and outflowing water concentrations and volumes, as well as by examining the contaminant levels in stationary matrices (biofilms and sediment).

To date the researchers have shown that several cheap waste products, such as plastic fibres, bark and wood shavings, can be used advantageously to capture organic contaminants in stormwater, but that other types of material, such as minerals, are needed to remove metal contamination. The goal is that this research will contribute to more efficient methods for the treatment of stormwater, which can result in healthier watercourses.

The results are of interest to stakeholders responsible for stormwater quality, for example landowners, municipalities, transport and environmental agencies. The studies have been performed in collaboration with researchers at Chalmers and at the University of British Columbia (Vancouver), as well as with developers of filters and technology consultants in both Sweden and Canada.

Traffic is one of the major sources of organic contaminants in stormwater.
Photograph: Karin Björklund

Fluorescence-based indicators of drinking water disinfection

Organic material is present in all water from natural sources. The amount and character of the organic material affects the cost and efficiency of drinking water purification. Disinfection by chlorination and/or UV-irradiation is the final step in the drinking water purification process, but little is known about how variations in the composition of the organic material affect disinfection.

The purpose of this project is to gain greater control over the disinfection of drinking water and to obtain more reliable drinking water quality at lower costs. Certain components in organic material protect microbes during the disinfection process. Other components produce undesirable by-products (odours and contaminants), or lead to the regrowth of microbes in the

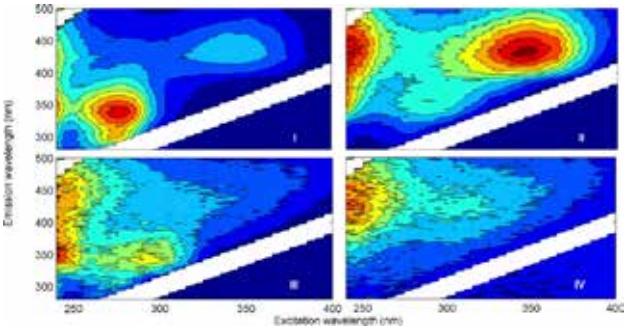
Project title
Novel fluorescence-based indicators of drinking water disinfection

Project number
2013-1214

Project duration
2014–2016

Funding awarded
SEK 6 394 000

Project leader
Kathleen Murphy
Chalmers
murphyk@chalmers.se



The fluorescent "fingerprint" of the water shows how the character of the organic material changes during the processing of drinking water.

drinking water. This project will develop better methods for the monitoring of these components. This is being carried out by the research group DRICKS at Chalmers, in collaboration with suppliers of drinking water throughout Sweden. The researchers will identify the different components in the organic material by using fluorescence spectroscopy, which is a rapid and cheap method that can be a target for online implementation. The researchers are collecting the "fingerprint" of the water samples using fluorescence at different stages of the disinfection process to identify patterns in the composition of the organic material.

Project title
Fatal attraction to yeast and virus – a novel insect control method

Project number
2013-1636

Project duration
2013

Funding awarded
SEK 1 994 000

Project leader
Peter Witzgall
SLU
peter.witzgall@slu.se

Fatal attraction between yeast and virus

Yeast that attracts insect larvae – in combination with a pathogenic virus – is the basis for a new control technique to combat insect pests. The yeast stimulates the insect larvae to eat to ensure that it ingests the virus. The method is environmentally friendly and the virus selected is also species specific. The hypothesis is that the technique can be developed to include a number of economically important butterfly/moth pests. The first field trials with the Codling moth (Cydia pomonella) and the night migrating fall armyworm (Spodoptera frugiperda) have been very promising.

In Sweden SLU has worked together with Mid Sweden University to develop the yeast formulations for field trials, which have then been carried out by researchers in Argentina, Colombia, Italy and the USA. A spin-off company, Phero.Net AB, has patented the method.

The researchers have identified the substances that control the chemosensory behaviour of the larvae. Molecular biology methods are used to determine the microorganism strains and to map the synthesis pathways for the bioactive substances. The method offers exceptional possibilities to develop an entirely new plant protection technology that can contribute to the control of insect pests that attack globally important crops such as beans, rice and soya.

A larvae of the Codling moth producing yeast in the apple variety Discovery. The old scarring to the left shows that the yeast protects against fungal infection, as the apple has not rotted. In the new hole on the right the larvae is producing yeast instead of eating the fruit to any great extent.
Photograph: Peter Witzgall

Early detection of potato virus infections

The purpose of this project is to develop a sustainable method of protection against potato virus infection in the production of seed potatoes. A healthy seed potato is one of the most important prerequisites for potato growing. Preliminary results show that infra-red (IR) cameras can be used to detect virus infections long before the symptoms become visible to the naked eye.

By combining entomology, plant culturing technologies and the most recent advances in remote imaging analysis a new method will be developed for the automated detection of potato virus-infected plants. The researchers are investigating leaf temperature changes in virus-infected tissue using an IR camera to study the infection dynamics.

New methods of image processing and pattern recognition will be developed to enable the construction of mechanised tools to detect and automatically remove virus infected plants from potato fields. Collaboration with potato growers and Termisk Systemteknik AB, a company specialised in the development of IR camera systems, increases the possibilities of developing commercial products. The new method, based on thermal sensor technology, will reduce the spread of the virus significantly and will contribute to higher yields and reduce environmental effects within seed potato production.

Project title
Detecting and monitoring potato virus infections using infrared technology

Project number
2014-495

Project duration
2015–2017

Funding awarded
SEK 5 391 000

Project leader
Velemir Ninkovic
SLU
velemir.ninkovic@slu.se

Velemir Ninkovic measuring potato leaf temperatures with an IR camera.
Photograph: Dimitrije Markovic

The mission of Swedish Research Council Formas is to promote and support basic research and need-driven research in the areas Environment, Agricultural Sciences and Spatial Planning. The research that is funded should be of the highest scientific quality and relevance to the areas of responsibility of the Council. Formas may also fund development projects to a limited extent.

Forskningsrådet för miljö, areella näringar och samhällsbyggande, Formas
The Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning
P.O. Box 1206, SE-111 82 Stockholm, Sweden. Visitors: Kungsbron 21
Phone: +46 (0)8 775 40 00, Fax: +46 (0)8 775 40 10
E-mail: registrator@formas.se
www.formas.se