Annual Report 2018

Bio4Fuels

Norwegian Centre for Sustainable Bio-Based Fuel and Energy

Enabling sustainable biofuels production in Norway

Table of content

Authors

Duncan Akporiaye, Janne Beate Utåker, Odd Jarle Skjelhaugen, Torjus Folsland Bolkesjø.

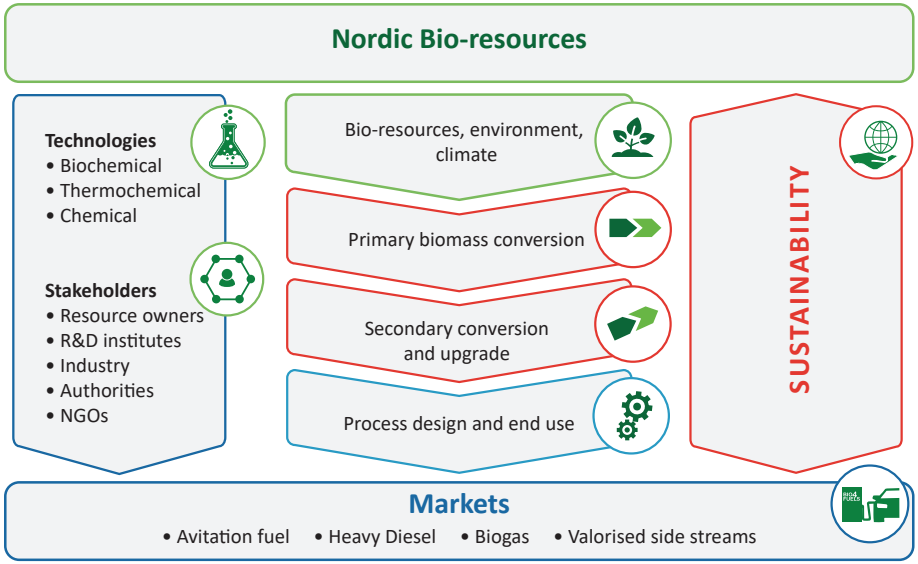
Layout: T. Heggenhougen, SINTEF
Front page: St1 cellulosic ethanol plant in Kajaani, Finland

Delivery of Biojetfuel to Bergen airport. Photo: Avinor

Vision

Enabling sustainable biofuels production in Norway

Bio4Fuels aims to contribute to the reduction of emissions from the Norwegian transport sector through coordinated research efforts to establish the basis for sustainable routes to advanced biofuels.



From the chair of the board and centre leader

The focus of Bio4Fuels FME in 2018 has continued to address the building up of the Centre's activities within the major value chains that are considered most relevant for Norway. Looking forward, Bio4Fuels has initiated a Self-evaluation exercise required by the Research Council, aiming to provide the Board with the basis for reviewing and considering recommending adjustments of the operation and focus of the Centre.

The area of Biofuels has continued to be a matter of debate nationally and internationally, making the role of Bio4Fuels as a research-based Centre increasingly important.

The need for viable routes to production of Biofuels was the topic of the annual Bio4Fuels days conference, which coincided nicely with the release of the report from the IPCC on the status of climate mitigating actions and IEA with respect to the role of Biofuels. In addition to this, other highlights from 2018 were the completion of the report on the effect of research in bioenergy, webinars and workshops addressing different aspects of the biofuels value chains, as well as the publication from Francesco Cherubini in the prestigious Nature journal.

Hans Aasnæs,
Chair of the Board

Duncan Akporiaye,
Centre leader

Summary

The ambition of the Bio4Fuels FME Centre is to reduce the impact of climate gas emissions from the transport sector through sustainable and economic production of Biofuels from low-grade fractions of wood from the forest and waste from agriculture.

In addition to the routes from Biomass to Biofuels, it is also important to convert side streams and biproducts from the processes to products of higher value. The main issues being addressed for viable commercial production of Biofuels from Biomass are related to the economics and sustainability of the processes. The research activities in the Bio4Fuels Centre address these central issues through:

- Improving the technologies and economics of processes for converting Biomass to Biofuel
- Investigating the sustainability and impact of large scale use of low grade Biomass for Biofuels production
- Evaluating and designing the process concepts and testing the quality of the Biofuels for existing engines

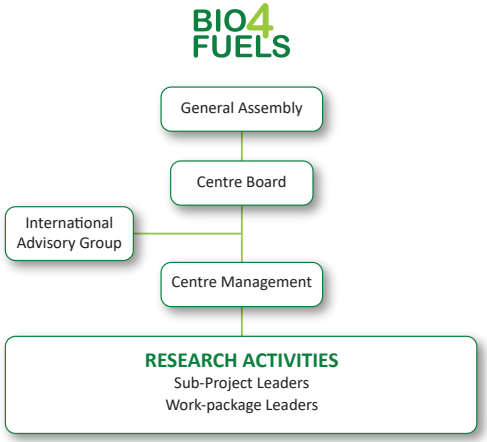
Since the establishment of the Bio4Fuels, the prospects for production of biofuels in Norway has increased significantly through the activities of key Stakeholders; with activities ranging from the world's largest liquified biogas plant, through to maturing plans for pilot and demonstration units based on liquefaction technology.

There have been important changes in the Centre, with the welcoming of the Neste as partner, and changes in the membership of the board and leadership of the main subprojects. The second "Bio4Fuels" days annual meeting, was organized at Gardermoen. With the background of the release of the IPCC climate report, the plenary session had contributions from Adam Brown of IEA as well as European and Norwegian perspectives from EERA and the Environmental agency. The excursion to visit Oslo Recycling Agency's biogas plant gave insight to the accelerating success of commercial biogas units throughout Norway. Bio4Fuels has established its international links and associated projects with research partners and stakeholders participating in an additional 4 new EU projects. We have also taken up a role in the in the Advanced Biofuels innovation challenge of Mission as well as in the IEA Bioenergy Task 39 and 45.

Bio4Fuels organization

The Bio4Fuels' Board

Hans Aasnæs	UMOE AS	Chair
Tyra Marie Risnes	Østfold County Council	Stakeholders
Erlend Grøner Krogstad	Norges skogeierforbund	Resource partners
Ingo Machenbach	Silva Green Fuel	End Users
Kine Svensson	CAMBI	Technology partners
Petter Røkke	SINTEF	Centre Leader Institute
Ragnhild Solheim	NMBU	Host Institute
Terese Løvås	NTNU	R&D partner
Philip Andre Reme*	RISE PFI	R&D partner
Per Arne Karlsen	Research Council of Norway	Observer



*Rotation between RISE PFI, USN, IFE, NIBIO

The Bio4Fuels' Management Team

Dr. Duncan Akporiaye	SINTEF	Centre Leader
Prof. Svein Jarle Horn	NMBU	Deputy Centre Leader
Prof. Odd Jarle Skjelhaugen	NMBU	Industrial Liaison
Dr. Janne Beate Utåker	NMBU	Administrative Manager
Ann-Solveig Hofseth	NMBU	Financial Officer
Christel Celine Nguyen	NMBU	Financial Officer
Frode Bjerkås	NMBU	Communication specialist

The international advisory group (IAG)

Advisor	**Affiliation**	**Area of expertise**
Prof. Patricia Thornley	Supergen Bioenergy Hub, Univ. of Manchester, UK	Sustainability
Prof. Kristiina Kruus	VTT, Finland	Biochemical Processes
Dr. David Dayton	Research Triangle Institute (RTI), NC (USA)	Thermochemical Process

Bio4Fuels partners

- Research partners in Norway
- NMBU – The Norwegian University of Life Sciences
- SINTEF
- NTNU – The Norwegian University for Science and Technology
- NIBIO – The Norwegian Institute of Bioeconomi,
- IFE – Institute for Energy Technology
- RISE PFI – Research Institutes of Sweden – Paper and Fiber Institute
- USN – The Univeristy College of South East Norway

Bio4Fuels stakeholders

Bioresource owners

The Norwegian Farmers Union

The Norwegian Forest Owners' Federation

Ragn Cells AS

The City of Oslo, The energy recovery unit

Biofuel and biochemical producers

Silva Green Fuel AS

Biozin AS

Perstorp Bioproducts AB (SE)

Borregaard

Biokraft

Ecopro AS

Norske Skog Saugbrugs

Solenis Norway AS

Alginor ASA

Neste (FI)

Tech./knowledge providers, Norwegian

Herøya Industry Park

Cambi AS

Hyperthermix AS

Norse Biotech AS

Energi Norway AS

Zeg Power AS

UMOE AS

Tech./knowledge providers, Int.

Biomass Technology Group (NL)

Johnson Matthey (UK)

Novozymes (DK)

Pervatech (NL)

Haldor Topsøe (DK)

Steeper ENERGY (DK)

Lund Combustion Engineering as (SE)

Photo: Avinor

Government and State Partners
Østfold Fylkeskommune
Hedmark Fylkeskommune
Akershus Fylkeskommune
Oppland Fylkeskommune
Trøndelag Fylkeskommune
Follorådet
Miljødirektoratet
Statens Vegvesen
NVE
Innovasjon Norge

Biofuels distributors and end users
Eco1 as
St1 Norge as
Preem (SE)
Volvo Group Trucks Technology (SE)
Avinor

Photo: Ruter AS and Bonanza AS

Highlights from 2018

Bio4Fuels' webinar

Date: June 15, 10 am - 11 am

Topics: Transportation biofuels in the EU after 2020: the red recast directive proposal

Link to presentation (pdf) and Webinar (MP4) here: https://www.nmbu.no/en/services/centers/bio4fuels/news/node/37072

Fuels of the future - a one-day open workshop

Date: September 13,

Topics: Integration, Gasification and Fermentation

Radisson Blu Royal Garden Hotel, Trondheim
Arranged by: the complementary projects AMBITION and Bio4Fuels

Bio4Fuels days

Date: October 11 – 12,

Topics: the Bio4Fuels Value Chain (SP1, 2, 3, and 4)

Quality Airport Hotel Gardermoen

The Bio4Fuels 2018 autumn workshop at NTNU - the Norwegian university of science and technology

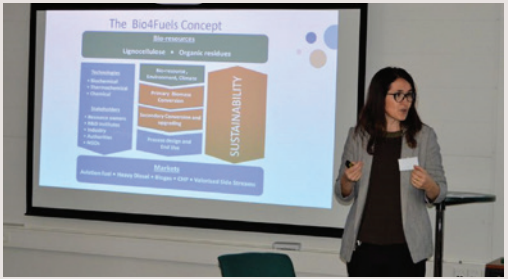
Date: November 5,

Topics: Transportation fules

NTNU, Trondheim, Norway

Bio4Fuels Lunch Meetings

Seven meetings arranged at Ås and in Trondheim with Centre information and scientific presentations.



Bio4Fuels insight

Short films from students and PhD's - understanding biofuels

The Bio4Fuels Centre has encouraged our PhD and Post-doctoral candidates to be active in promoting and explaining their research activities.

Three candidates have been actively involved in creating a few short videos outlining the content and importance of their research within the whole context of Biofuels.

Fermentation
Simona Dzurendova
PhD Fellow, NMBU

Video: https://vimeo.com/326620989/137e501594

Engine design for biofuels
David Emberson
Postdoc, NTNU

Video: https://vimeo.com/329278272

Enzymatic saccharification
Line Degn Hansen
PhD Fellow, NMBU

Video: https://vimeo.com/329278260

Bio4Fuels Industrial stakeholders insight

Silva Green Fuel demo-plant in progress

Statkraft and the Swedish Sødra Cell established in 2015 the company Silva Green Fuel to develop a concept for large forest-based biofuel production plants. During two years, 30 processing technologies were tested. In parallel, Silva joined several R&D-projects relevant for this testing.

The winner was Hydrothermal Liquefaction, HTL, developed by the Danish company Steeper Energy. The technology is based on supercritical conversion of biomass, a process with high pressure and high heat. Silva collaborates with Steeper in finding technology- and process-varieties that do not put many restrictions on the feedstock quality. But at the same time, these varieties also cause the highest risk. In the demo-plant, near-full-scale tests will be conducted. However, at a lower cost than in a commercial plant.

Silva decided in 2017 to build this HTL-plant. It will be located at Tofte in Hurum, the same site as Sødra operated its cellulose factory some years ago. During 2018 the test facility has been planned in detail.

If good results from the demo-plant during 2019-2021, several full-scale factories will be planned, within and outside Norway.

Each with a production capacity of 100-150 million liters drop-in quality biodiesel annually. As a comparison, the advanced biodiesel production-capacity in E28 was about 33 million liters in 2016.

Visualisation of Silva Green Fuel's demo-plant

St1 cellulosic ethanol plant in Kajaani, Finland

St1

ST1 owns bioethanol plants in Finland and Sweden and is running an oil refinery in Gothenburg. The company operates retail station chains under the brand names of St1 and Shell in the Nordic countries. Thus, St1's main business and source of income is in the traditional oil industry, but the revenues are invested back into renewable energy like windmill parks, geothermal and biofuels. St1 is producing bioethanol from food industry side streams and lignocellulose waste.

In Kajaani in Finland, St1 has built a 10 million liter demonstration plant where advanced bioethanol is produced from softwood using an in-house developed process called Cellunolix™. Additional products from this biorefinery are lignin, turpentine, furfural, concentrated fermentation rank and CO_2.

The process is based on steam explosion pretreatment, enzymatic hydrolysis, fermentation and distillation. St1 has made a letter of intent with Viken Skog to construct a similar Cellunolix® ethanol plant in the industrial area of Follum in Hønefoss, utilizing the existing industrial infrastructure and equipment from the former paper-mill. The planned production capacity of the plant is 50 million liters of advanced cellulosic bioethanol for transportation, using local forest industry residues as feedstock.

In the Kajaani plant, the annual production volume of lignin side products is approximately double of the bioethanol volume. Therefore, the revenues from lignin is important for the cost effectiveness of the entire process. In solid form, lignin can be used for materials, biofuels or animal feed applications. Liquefied lignin streams may be upgraded and co-fed into oil refinery streams or potentially converted into jet fuel. From the industrial point of view, it is utmost important to create profitable business from lignin to promote the transformation from fossil energy resources to carbon free renewable energy production.

R&D is important for St1 and the company is an active partner in Bio4Fuels. In December 2018 researcher Timo Leskinen from St1 was visiting NMBU. Together with prof. Svein Horn and PhD student Line Hansen, both from NMBU, he carried out a range of novel steam explosion experiments on softwood samples. The effect of these pretreatments on enzymatic hydrolysis is being analyzed, and will help St1 improving their bioethanol process.

Jens Ulltveit-Moe
UMOE

UMOE - Renewable fuels as seen from an investor

Umoe´s role in the green economy - Umoe's mission is "Building sustainable value", says founder and CEO Jens Ulltveit-Moe. My contribution is basically leading by example. With Umoe, I can actually make a change by producing low carbon fuel, by reducing the cost of renewables and by running companies within that field as best as I can. That is tangible, meaningful, and I think also the longer term, profitable. I think this is a unique opportunity of making money and do the right thing at the same time. Those opportunities don't come around that often.

A long-term future for the green economy - For me the essence of the strategy is a concentration now on renewable energy in the economy. That is a big change and a long-term future in renewables. It is in my mind very promising. By going there, we are following a rising trend as opposed to that for the fossil industry, which is at a declining trend.

Invest in green energy now - In five years next to nothing will have happened. It will be a reduced cost in renewables, but the political actions will be very weak. Ten years ahead I think the crises will be very apparent, and there will be a very strong government action. That is the time when renewables will become truly profitable, when there will be stranded assets on the fossil side, and we will have a sharp reduction in CO_2-emissions. The combination of lower renewables cost and government actions means that we probably will solve the climate crises in the end. The big change, when renewables cost less than fossil fuels, is something that was kickstarted by the government, but really created by businesses. In Umoe we are very proud to be part of that trend. What we do is developing our companies and investing in other companies that can do their part of this important job.

In Brazil, Umoe Bioenergy produces sustainable bioethanol from sugar cane, a fuel costing less than fossil fuels.

AVINOR - Norway first with mandatory drop in requirement for jet biofuel

Avinor owns, operates and develops a nationwide network of 45 airports for the civil sector and a combined air navigation service for the civil and military sectors. Sustainability is high on the agenda, and actions leading to lower carbon footprint from airport operations and aircraft have high priority.

Biodiesel for airport operation - Phasing in advanced biodiesel is an important action to reduce greenhouse gas emissions from the airport operations. About half of Avinor's own emissions arise from the airport vehicles. In 2018, 320 000 litres advanced biodiesel for the vehicles and 67 000 litres biooil for heating was phased in at the following airports: Oslo, Trondheim, Bergen, Ålesund, Molde and Kristiansand. Biodiesel consumed at Avinor's airports fulfills EU's sustainability criteria and does not contain palm-oil or palm-oil products.

Bergen Airport Flesland installed a 30 m3 tank for biodiesel in September 2018, available to all partners operating at the airport. At Trondheim Airport Værnes, the biodiesel blend was about 28 %, and at Oslo Airport 20 %. The 2019 target is to further increase the biodiesel volumes for Avinor as a whole.

Mandatory drop in requirement for jet biofuel in aviation - In the National budget 2019 the Government decided a mandatory drop in requirement of 0,5 % advanced jet biofuel for aviation, starting in 2020. Norway is the first country in the world to introduce such a mandate. The blending has to be reported to the Norwegian product register, and biofuels from problematic feedstocks like palm-oil will not be accepted. Avinor and CAA Norway (Civil Aviation Authority of Norway) have, on behalf of the Ministry of Transport and communications, contributed to the background information and consultation documents. The Government's target for 2030 is 30 % advanced biojetfuel in the aviation fuel sold at Norwegian airports.

Biodiesel fuelled Sweeper snow-plough at Bergen airport. (See also photo page 2 for biojetfuel delivery to Bergen airport.)

BIOZIN - Including crude-oil step in the biofuel production

The company Biozin Holding AS, established in 2017, is owned by Bergene Holm AS, the second largest saw-mill company in Norway. Biozin targets to produce biocrude oil in several decentralised plants in Norway located near the forest feedstocks. The biocrude oil will be sold to Preem AB, the largest oil refinery in Scandinavia, for upgrading to advanced biofuel. Biozin and Preem have signed a long-term collaboration agreement, and both are Bio4Fuels-partners. The decentralised biocrude oil production will reduce transportation cost for the feedstock and open up for cheaper and smaller biocrude oil processing plants. The challenge has been to find the best processing technology.

Biozin conducted in 2018 a concept study to find the best technology and value chain. The outcome was positive. The reduced carbon footprint will be about 90 % compared to fossil fuel. The Biozin-owners have decided to go on to the next step; pre-engineering of a plant to be built near Bergene-Holms sawmill in Åmli in Agder county, a region with large forest resources. The facility will use the same feedstock supply chain as the sawmill, but will include forest residue, non-commercial and other types of softwood. Also, by-products from the sawmill will be utilized. The facility can be one of the first of its kind world-wide, and will be based on the Shell-owned IH2 thermochemical processing technology.

In Bio4Fuels, Biozin and Preem mainly follow the value-chain initiatives to find if there are steps that can be addressed to improve profitability and/or climate impact. “When working at a full scale level we want to put all questions on the table to launch smooth roll out of the chain of facilities producing the second generation biofuels in Norway”, Mikhail Tsypkin, Biozin CTO, states.

Biozin has decided to perform pre-engineering study for the facilitiy with location next to the Bergene Holm saw mill Nidarå in Åmli (Photo: Bergene Holm AS).

BIOKRAFT AS

Biokraft completed and commissioned the world´s largest production facility for LBG (liquid biogas), located at Skogn in central Norway, in the summer of 2018. The factory was officially opened by Prime Minister Erna Solberg on September 2nd 2018, in a ceremony attended by over a hundred dignitaries. The Prime Minister issued thanks to Biokraft for moving Norway towards a greener future.

The completion of the LBG facility coincide with the introduction of heavy-duty vehicles by Volvo, Scania and Iveco that are unique for renewable vehicles in combining long distance with maximum loads, making it possible to replace diesel trucks.

Biokraft´s factory uses a variety of substrates in their process including waste products from fish farming, poultry, industry and manure, as well as biproducts from paper production supplied by their neighbour Norske Skog. In addition to building the world´s largest LBG plant, Biokraft also set a speed record in getting it up to production capacity.

Biokraft is ever chasing profitability and, as such, Biokraft is involved in several projects with the aim of improving the process, use new substrates as well as looking at new ways of utilizing by-products of the plants in a more optimal way. Thus, R&D is important for Biokraft and they are involved in the biogas research in Bio4Fuels.Biokraft´s factory at Skogn will initially produce 12.5 million normal-cube-metres (Nm3) of LBG (biogas), with an energy contents of approximately 125 GWh per year. Biokraft intends to double this production capacity at Skogn shortly, and are currently working on several new projects.

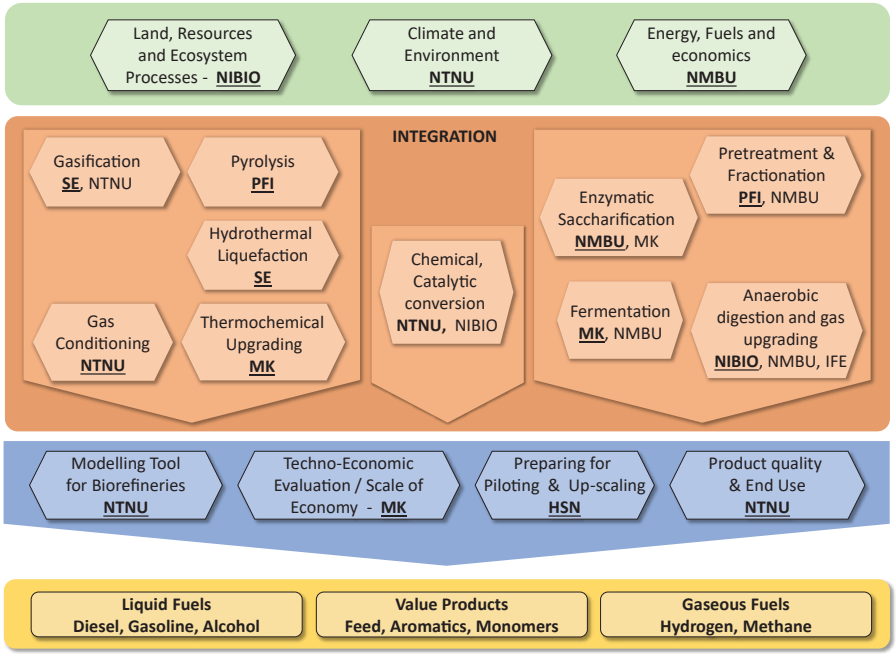
The researchers look forward to test in a continuous system and larger scale. In addition: If the methane is used for producing proteins or materials, not as a fuel in a combustion motor, then we here have a carbon capture system in the waste sector.

Official opening of Biokraf factory at Skogn by Prime Minister Erna Solberg, September 2nd 2018

Scientific activities

The scientific activities in Bio4Fuels are structured according to the value chains going from accessibility and sustainability of bioresources through to the economics for production and end use.

As shown below, the high-level value chain (SP (sub project)) establishes interaction across focussed research activities (workpackages (WP)) addressing the four challenges of bioresources (SP1), Primary conversion (SP2), Upgrading (SP3) and end use. Within this organisation, Bio4Fuels has the flexibility to coordinate activities along focussed value chains looking at addressing specific challenges of the main technologies for conversion and upgrading. These include thermochemical, chemical and biochemical conversion approaches.



Biofuels and climate change: Forest for sustainable flying

Forests may offer us more than timber and ecosystems services; they may offer a more sustainable way of flying. This was proposed in a new paper published in Nature Sustainability by NTNU researchers Otavio Cavalett and Francesco Cherubini. Cherubini heads up the Bio4Fuels sub-project on Bio-resource, Environment and Climate. The full paper: https://rdcu.be/bbB2K.

In a post on Nature's sustainability community blog, Cavalett, explains this further. Renewable jet fuels promotes sizeable climate mitigation benefits. Sometimes, though, this comes at a cost of unexpected implications to other Sustainable Development Goals. Yet, most of these adverse side effects are attenuated when improved conversion technologies and cleaner inputs are used for renewable jet fuel production.

Liquid biofuels: Converting wet biomass

Hydrothermal liquefaction (HTL) and hydrothermal carbonization (HTC) are processes of particular interest to convert wet biomass to respectively primarily liquid biofuel and biochar. However, inorganics (ash) present in the biomass may cause operational challenges, e.g. corrosion and reactor clogging. It is therefore important to be able to predict and understand their fate (speciation and phase distribution) with the aim of mitigating any detrimental effect, especially when upscaling the process.

Thermodynamic equilibrium calculations (based on Gibb's free energy minimization and a Matlab-based model initially developed at Delft University of Technology) was used to simulate hydrothermal process conditions for a variety of feedstocks. The initial findings investigating the HTC conditions suggest that the ideal temperature with regards to minimize reactor clogging should be decided based on the feedstock composition.

Feedstocks high in Si, but low on other inorganic elements should be run on high temperatures. Feedstocks high in Ca, Mg and P, but low on Si should be run on low temperatures. As Cl chemistry is not affected by feedstock concentration nor temperature, the only thing one can do to minimize corrosion by Cl is to avoid feedstocks high in Cl.

Biofuels resources: novel enzymatic saccharification mechanism

In collaboration with industry partners, the Bio4Fuels research team has successfully applied a novel enzymatic mechanism for biomass saccharification.

By 2017, Bastien Bissaro, a guest researcher from INRA (France) and the NMBU team led by Prof. Vincent Eijsink discovered that oxidative enzymes called LPMOs (lytic polysaccharide monooxygenases) do not need oxygen but hydrogen peroxide to break down cellulose. To implement this ground-breaking discovery in industrial biorefining, the setups currently in use for enzymatic saccharification needed to be reconsidered.

In 2018, a team led by Profs. Svein Horn and Vincent Eijsink has been working in close collaboration with Bio4Fuels partners Novozymes and Borregaard to develop an industrial setup in order to harness LPMO action in a more efficient way. In a recent publication in the journal Biotechnology for Biofuels, the team showcased the successful application of hydrogen peroxide for improving saccharification of Borregaard's BALI-pretreated spruce (see Figure, next page). We believe that this is only a start and that there is still much more to be achieved.

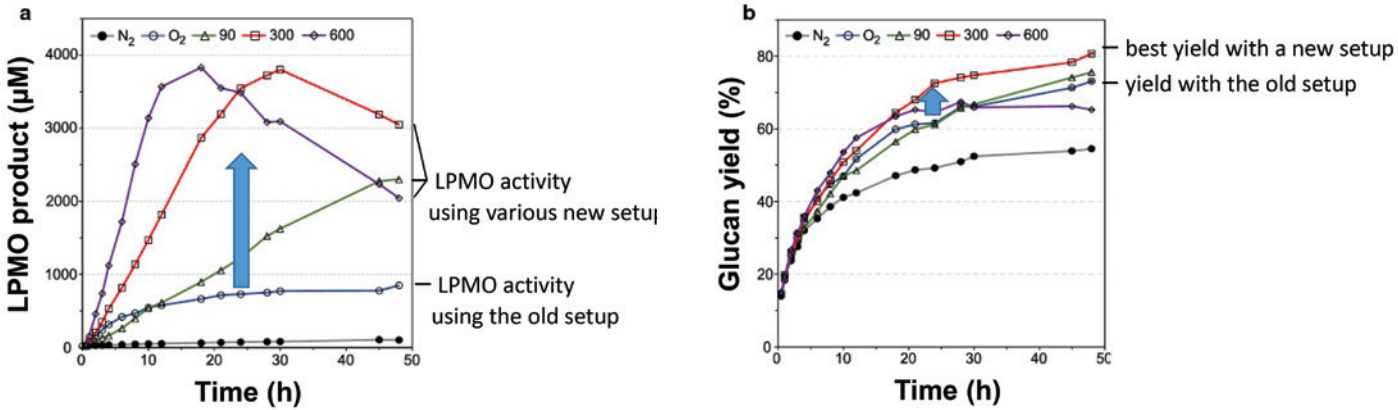
The NMBU team has been disseminating information about the recent developments at the most relevant conferences in the field worldwide, including the GRC (Gordon Research Conferences) on Cellulases and Other Carbohydrate-Active Enzymes (by Bastien Bissaro, July 2017), Symposium on Biotechnology for Fuels and Chemicals (by Svein Horn, May 2018), the Lignobiotech V Symposium (by Svein Horn, Aug 2018), an EMBO Workshop entitled Enzymes, biocatalysis and chemical biology (by Anikó Várnai, Sept 2018) and the GRC on Metals in Biology (by Vincent Eijsink, Jan 2019). siste side

The leading role of the NMBU team in this field has been also recognized through a number of recent invited review papers for prestigious journals, namely *Microbiology and Molecular Biology Reviews, Biotechnology for Biofuels, ACS Catalysis and Current Opinion in Structural Biology.*

In relation to Bio4Fuels, the add-on project Enzymes4Fuels, funded by the Research Council of Norway, has been started up in 2018.

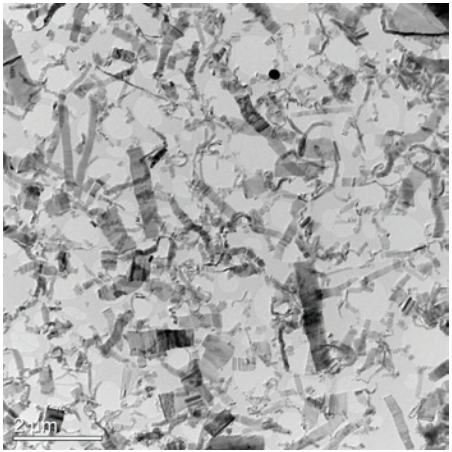
This project will work synergistically with Bio4Fuels to investigate the role of hemicellulases in biomass saccharification and to find ways for obtaining a lignin fraction with improved properties for lignin valorization.

Figure showing how the action of LPMOs and, consequently, the total saccharification yield is boosted by changing to the new saccharification setup. The figure has been adapted from the publication by Müller, Chylenski et al. in Biotechnol Biofuels 11:209.



Biomass to chemicals

This project is a close collaboration with a leading Danish catalyst, and process company Haldor Topsoe and NTNU. They are developing a process to produce chemicals from sugars. Selective hydrogenation of hydroxyacetone to 1,2-propanediol represent a important step in this process as well as other processes in upgrading biomass to chemicals. Copper based catalyst shows high activity in this reaction, however catalyst deactivation through particle agglomeration, coke formation etc. could be problematic for commercial process. In this project, carbon nanofibers (CNF) interfaces are engineered to tune the interface interaction between metal and carbon surface, hence tuning the reactivity and stability of the supported metal catalyst. The CNFs are prepared by chemical vapor deposition. The effect of copper precursors and solvents will be investigated. The CNFs supported samples will be benchmarked with some commercial carbon supported catalyst.



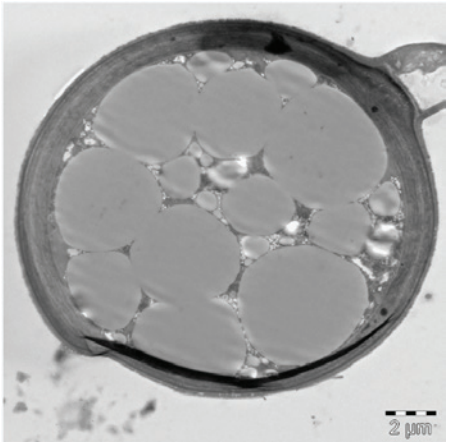
TEM image of prepared PCNF

Fermentation

Lignocellulose hydrolysates have been evaluated for the production of fungal lipids by oleaginous fungi Mucor circinelloides. After optimization of macro- and micronutrients the biomass and lipid yield on liglocellulose hydrolysate media was higher than on the control synthetic medium. This is a promissing first results using Norwegian spruce lignocellulose hydrolysates for fungal lipid production.

Five moderate thermophilic microorganisms have been selected as anaerobic thermophilic biorefinery candidate strains for further development in Bio4Fuels, i.e. *Clostridium thermocellum, C. thermobutyricum,*

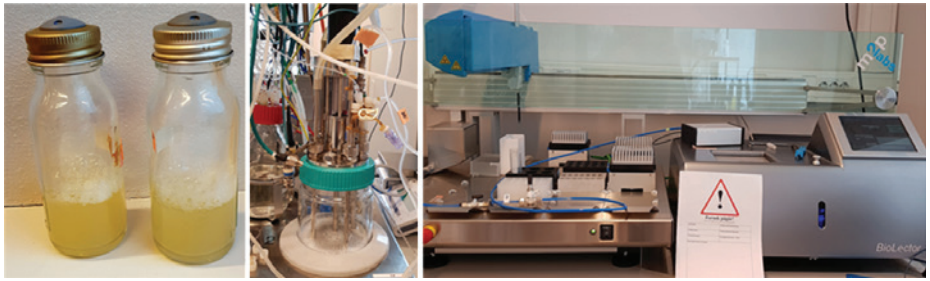
C. thermopalmarium, Thermobacterium thermosaccharolyticum and *T. saccharolyticum.*



Hyphae section of oleaginous fungi Mucor circinelloides showing accumulation of fungal lipids.

A systematic study of these strains with respect to the production of higher alcohols and organic acids on defined growth substrates and lignocellulose hydrolysates, as well as strain robustness, has been initiated.

Microbioreactor technology (BioLector) with the possibility of monitoring 48 cultures in parallel under anaerobic conditions has been implemented as the basis for systematic bioprocess development, in comparison to standard fermentations in serum flasks and DasGip 1 L stirred tank bioreactors.



Clostridium sp. fermentations at different scale; serum flasks (left), DasGip bioreactors (middle), BioLector microbioreactor system (right).

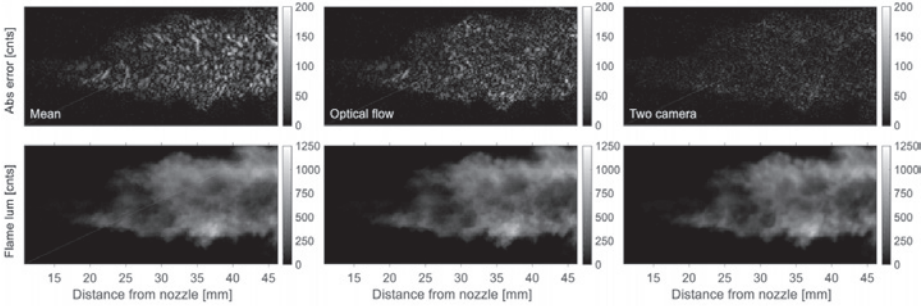
Biofuels end use: in-flame combustion processes

The understanding of in-flame combustion processes resulting in formation and oxidation of soot is of great importance since the underlying physical phenomena are not fully understood, especially for oxygenated fuels such as biofuels. Numerical simulations provide insight to complex processes that are hard to capture in physical experiments, but the models used for running the simulations require validation from experimental results. Temporally and spatially resolved in-flame soot measurements in engines are hard to perform since the process occurs over a few milliseconds, optical access is usually limited, and the environment in the combustion chamber is harsh, i.e. large density gradients, high temperature and high concentrations of soot. The in-flame measurements are thus prone to large errors.

This study presents diagnostic development of diffuse back-illuminated extinction imaging of soot. The method provides high temporal and spatial resolution of the line-of-sight optical density of soot (KL) in compression-ignited fuel sprays relevant to automotive applications. The method is subjected to two major sources of error, beam steering effects and broadband flame luminosity effects. These were investigated in detail in a direct injection combustion chamber with diesel fuel, under high and low sooting conditions. A new method for correcting flame luminosity effects is presented and involves measuring the flame luminosity using a separate high-speed camera via a beam splitter, i.e. a two-camera method. The new method yields 50% lower errors than the most promising method (optical flow method).

All experiments were performed using the Optical Accessible Compression Ignited Chamber (OACIC) at the Department of Energy and Process Engineering at the Norwegian University of Science and Technology (NTNU). The OACIC is a reciprocating rapid compression machine equipped with windows, enabling line-of-sight optical measurements of the reacting spray under CI engine conditions.

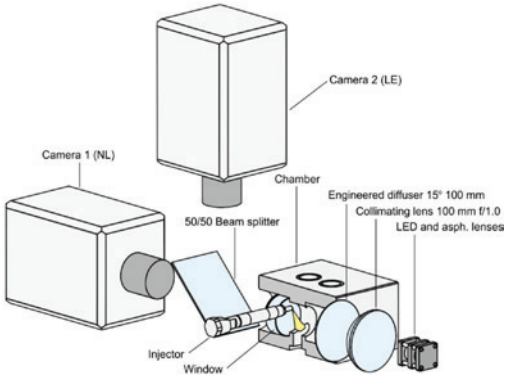
In order to access the errors associated with the estimated flame luminosity



The spray combustion flame inside a compressing engine

distribution (If) after applying the mean, the optical flow or the two-camera method, a sequence of flame only images was collected. The figure below clearly shows that the errors are largest for the mean method, where the turbulent flame structures are not estimated well enough.

However, the novel two-camera method yields a much lower error, and will be used for subsequent studies of fuels and their sooting characteristics. Fuels that will be testes are various biofuels, and relevant soot reducing additives.



Experimental setup of the OACIC.

Reference:

Bjørgen, K.O.P., Emberson, D.R., and Lovas, T., "Diffuse Back-Illuminated Extinction Imaging of Soot: Effects of Beam Steering and Flame Luminosity," SAE Technical Paper 2019-01-0011, 2019, doi:10.4271/2019-01-0011.

International cooperation

Bio4Fuels has from the very start of the operation of the Centre had a significant level of international cooperation at all levels.

International agencies and policy forums

The International Energy Agency has established an important role in collating, reporting within various aspects of Energy. The IEA Bioenergy Technology Collaboration Program is an important arena for collaboration with respect to tracking the status of technology within the Bioenergy area and recommending areas needing increased focus for research. As shown below, partners in Bio4Fuels are already involved in key tasks of specific relevance to Norway and the Nordic countries.

With respect to Bio4Fuels activities, action has now been taken to involve Norwegian partners in the existing Task 39, focussing on accelerating the transition of the production of Advanced Biofuels to commercial scale, as well as the newly established Task 45, focussing on the Climate and Sustainability aspects of bioenergy.

Mission Innovation

Mission Innovation was established as an action following up the historic Paris Agreement, with the explicit goal of significantly increasing the research focussed on mitigating climate change. With respect to this, Norway has joined the Innovation Challenge 4 (IC4), focussed on Advanced Biofuels. With the role of taking part in participating in IC4 on behalf of Norway, Bio4Fuels attended and presented at the International Conference on Sustainable Biofuels, organised jointly in New Dehli, India by Mission Innovation and Biofutures Platform.

International stakeholders

With respect to the consortium of partners, the Centre has the strong involvement of a range of leading Nordic and European technology providers. This Nordic/European network is expanded through the involvement of associated partners, from the USA.

These partners are active in the research activities and also had a significant role in the Bio4Fuels kick-off, providing an international perspective with respect to the state of the art.

These partners will in the future operation of the Centre, will also be active as hosts for short mobility tours of students and researchers from the centre to obtain experience in specific areas in an industry context.

International advisory group

As an important part of the governance of the Bio4Fuels Centre, an International Advisory group has been established with the role of providing an international perspective and evaluation of the scientific activities of the Centre. As outlined under the structure and organisation of the Centre, the members of the Advisory Group have been selected to represent perspectives from Nordic, European and USA, in addition to having deep scientific insight to some of the main pillars of the Centre.

Networks

Combined together in the Centre, most of the research partners have an extensive network of international contacts and collaboration. These include coordinating input to Mission Innovation and representation in EERA.

Bio4Fuels has also been participating in coordinating national input to the European Technology and Innovation Platform within Bioenergy (ETIP).

Owerview of active EU research projects with involvement of Bio4Fuels partners

Name	Project owner	Financed by	Total [mNOK]	Bio4Fuels Platform
AMBITION	SINTEF	H2020-ECRIA	22,5	Biochem./Thermochem
BioRaff	PFI	H2020/Interreg	8,1	Biochem./Thermochem
ERC starting grant to P. Pope	NMBU	ERC	14	Biochemical - Biogas
MetaFluidics	UAM (Spain)	EU - H2020	86	Biochemical - Sugar
BESTER	SINTEF	ERA-CoBioTech; RCN and others	27,7	Biochemical - Sugar
Waste2Road	SINTEF	EU - H2020	60	Chemical
4Refinery	SINTEF	EU - H2020	60	Chemical
LIBERATE	SINTEF	EU - H2020	60	Chemical
ABC4Soil	NTNU	FACE/EEA	4,8	Thermochemical
NextGenRoadFuels	Aarhus (DK)	EU - H2020		Thermochemical
Pulp&Fuels	SINTEF	EU - H2020	49	Thermochemical
SelectiveLi	SINTEF Ind	EU - H2020	5	Thermochemical
DAFIA	Aimplas (Spain)	EU - H2020	58	Biochemical
C1pro	NTNU	ERA-CoBiotech; RCN and others	17,2	Biochemical
Prowood	INBIOTEC-	ERA-IB; RCN and others	17,5	Biochemical
Thermofactories	SINTEF	ERA-MBT; RCN + abroad	22,3	Biochemical
Oxytrain	Un Groningen	MC-ITN	29	Biochemical
OXYPOL	SINTEF Ind	ERA-IB; RCN and others	23,3	Biochemical

EU research programs

Many of the research partners involved in the Centre have established a significant portfolio of European projects, both from FP7 and H2020. As shown in the table below, Bio4Fuels partners were involved in at least 13 active EU projects, with at least 9 projects within H2020.

As shown in the table (left), the projects cover different stages of the Bio4Fuels value chain towards biofuels production, with a total project volume of increasing to approximately 560 MNOK, in spite the completion of a number of projects. This, during 2018, the Bio4Fuels partners were involved in securing at least four new projects: Waste2Road, NextGenRoadFuels, Pulp&Fuels and BESTER.

Mobility

In 2018, Prof Svein Jarle Horn, deputy leader of Bio4Fuels, spent 6 months on a sabbatical at the University of California, San Diego (UCSD). He worked in the group of Stephen Mayfield, which is a world-leading group in microalgae research. The main part of the research was focused on heterotrophic growth of microalgae, and in particular growth of *Chlamydomonas reinhardtii* on acetic acid. The algae was grown using a pH-stat system, and a novel repeated fed-batch strategy was developed for continuous production of microbial cells. Such oil-rich microalgae may be used for production of fuels, chemicals and food- and feed ingredients. Horn is now continuing the microalgae research at NMBU.

Mobility: Horn in the laboratory at UCSD performing growth experiments with heterotrophic microalgae.

Personnel and recruitment

Personnel

SP2 WP-leaders

Morten Seljeskog, SINTEF
Kai Toven, RISE PFI
Judit Sandquist, NTNU
Øyvind Eriksen, RISE PFI
Aniko Varnai, NMBU
Svein Jarle Horn, NMBU

SP 1 WP-leaders

Rasmus Astrup , NIBIO
Francesco Cherubini, NTNU
Torjus Bolkesjø, NMBU

SP3 WP-leaders

Edd Blekkan, NTNU
Roman Tschentscher, SINTEF
De Chen, NTNU
Alexander Wentzel, SINTEF
Tormod Briseid, NIBIO

SP4 WP-leaders

Heinz Preisig, NTNU
Bernd Wittgens, SINTEF
Klaus Jens, USN
Terese Løvås, NTNU

Management & staff

Duncan Apkoriaye, SINTEF
Torjus Bolkesjø, NMBU
Odd Jarle Skjelhaugen, NMBU
Janne Beate Utåker, NMBU
Svein Jarle Horn, NMBU
Frode Bjerkås, NMBU
Christel Celine Nguyen, NMBU

SP-leaders

Francesco Cherubini (SP1), NTNU
Judit Sandquist (SP2), SINTEF
Aniko Varnai (SP3), NMBU
Bernd Wittgens (SP4), SINTEF

Recruitment

Other researchers:

- Boris Zimmermann, NMBU
- Per Kristian Rørstad, NIBIO
- Volha Shapaval, NMBU
- Achim Kohler, NMBU
- Jia Yang, NTNU
- Liang Wang, SINTEF Energy
- Michaël Becidan, SINTEF Energy
- Øyvind Skreiberg, SINTEF Energy
- David Emberson, NTNU
- Roar Linjordet, NIBIO
- Hege Bergheim, NBIO
- Julien Meyer, IFE

International PhD Student group with finance from the Bio4Fuels budget:

* Postdoctoral Researchers with financial support from Bio4Fuels budget

PhD Student Line Degn Hansen, NMBU

This PhD project is a part of the work package ***Enzymatic saccharification*** (WP2.5) and will focus on enzymatic saccharification of Norway spruce, with special attention on process optimization and integration. Biochemical biomass-to-liquid processes and the currently available commercial enzyme cocktails have been developed for grasses and hardwood materials and are not optimized for Norwegian biomass. In this project, we are going to identify enzyme components, such as redox and hemicellulolytic accessory enzymes, that are critical for efficient saccharification of softwood. Moreover, the recent discovery of the novel catalytic mechanism of lytic polysaccharide monooxygenases (LPMOs) creates an opportunity to considerably improve saccharification yields by optimizing process parameters including different feed strategies of H2O2, the enzyme's co-substrate. The obtained knowledge will be applied to allow better integration of the saccharification and fermentation steps. In addition, the effect of pretreatment type on saccharification and fermentation, regarding the composition of enzyme cocktail and process conditions, will also be assessed in order to achieve higher overall yields while minimizing process costs.

PhD Student Ramesh Timsina, USN

This PhD project is a part of the work package ***Preparing for Piloting and Up-scaling*** (WP4.3). The main objective is to establish computational fluid dynamics and process simulation models as basis for the preparation of the pilot plant for biofuel production. The models will include pre-treatment of feedstock, thermal treatment, as well as separation and extraction steps. The thermal conversion technologies gasification, pyrolysis and hydrothermal liquefaction will be studied and evaluated. Experiences from studies in the other work packages will be used to make the framework for the simulation models, and a process flow sheet will be generated. An important part of the project is to find overall process with minimal waste and high-energy yield for such process plants. Based on existing data from experimental work and simulations, reliable process models will be developed. These models will be used to analyse the results of parameter variations to optimize the process design. The process flowsheets will then be the basis for conceptual design operations. A theoretically optimal solution will be chosen for a pilot plant design.

PhD Student Eirik Ogner Jåstad, NMBU

This PhD project is a part of the work package ***Energy, Fuels and Economics*** (WP1.3). The aim of my PhD-project is to use economic models to find implication of forest biofuel production in the Nordic countries. In 2018, had I focus on two studies, one that focusing on implications in the traditional forest sector if large amount of biofuel is produced within the Nordic countries. The second study investigates which level of subsidy needed for making biofuel production competitive with the fossil fuel. The results show that the fossil fuel price has to increase with 2-3x from today's level or the producers has to get an equivalent level of subsidy for making biofuel production competitive at today's raw material costs. Large investments of biofuel will give some structural changes in the traditional forest sector, the main findings is that harvest and utilizing of harvest residues will increase, similar will the net import to the Nordic countries increase simultaneously as the pulp and paper industry will reduce their production.

PhD Student Simona Dzurendova, NMBU

The PhD project is part of work package WP3.4, ***Fermentation,*** where one of the objectives is to develop utilization of lignocellulose hydrolysates as a source of carbon for production of microbial lipids by oleaginous fungi fermentation. Oleaginous fungi are able to produce lipids with fatty acids profile similar to vegetable or fish oils as well as able to perform concomitant production of lipids and other valuable components. Lignocellulose hydrolysates are liquid materials rich in saccharides, but as shown by our studies, it also contains possible inhibitors of fungal growth. Therefore, there is a need to perform high-throughput screening of different fungal strains and growth conditions in order to find the most suitable fungal producer and optimise composition of lignocellulose-based media for the scale up of the process. Currently we are using synthetic growth media for the bioprocess development that allows us to have full control over the effect of certain micro- and macronutrients on the production of lipids and other valuable co-products, such as chitin/chitosan and polyphosphates. For the process development, we are using a micro-cultivation system combined with vibrational spectroscopy.

PhD student Heidi Østby (WP2.5), NMBU

This PhD project is part of the ***Enzymes4Fuels project, an add-on project to Bio4Fuels,*** and is related to the work package Enzymatic Saccharification, WP2.5. There is still considerable potential to improve the efficiency of enzymatic conversion of lignocellulosic biomass, in particular when it comes to Nordic woody biomass. In this project, we will develop new thermostable enzyme cocktails for the conversion of Norwegian woody biomass, primarily softwood, to sugars and lignin fractions. The project will exploit the recent discovery of the hydrogen peroxide-based LPMO catalytic mechanism and hemicellulose-active LPMOs to improve the conversion efficiency.

Additional beneficial effects on efficiency may be achieved by tailoring enzyme cocktails specifically for Nordic woody biomass, with regard to the cellulase mixture and hemicellulases. The key goal of the project is to improve biomass saccharification by the optimal exploitation of LPMOs, and targeted removal of recalcitrant hemicellulose fractions.

Student profile Martina Cazzolaro (WP3.3), PhD student, NTNU

This project is a part of the work package ***Catalysis for biomass conversion to chemicals,*** WP 3.3 and aims to develop a stable copper-based catalyst for selective hydrogenation of hydroxyacetone to 1,2-propanediol, a major commodity chemical. Hydroxyacetone is a by-product of various biomass-based processes: biomass pyrolysis, sugar hydrogenolysis, glycerol dehydration. The main challenge of the project is the catalyst stability towards deactivation. In order to achieve this goal, carbon supports are tested. Platelet carbon nanofibers (PCNF) were prepared via carbon vapor deposition of CO and H2 at 600°C over iron powdered nanoparticles. Various catalysts were prepared using PCNF and varying Cu precursors (nitrate, acetate and basic carbonate) and impregnation solvents (water, ethanol, isopropanol). Characterization of the catalysts and catalyst activity tests will follow. Moreover, surface treatment of PCNF will be explored, as surface oxidation, foreign-ion doping or confinement effect can be used to tune the surface properties of the carbon nanofibers. She also spend 3 weeks in Haldor Topsoe in June 2018 to learn their experiences and I enjoyed a lot the stay there.

Courses given by Bio4Fuels researchers

The researchers connected to the Bio4Fuels Centre are involved in a various courses at NTNU and NMBU. In this way, our research themes and results are present and made relevant for new students in Norway.

Courses at NTNU

NTNU:

- Energy and Process Engineering, Specialization Project - 15 credits (ECTS)
- Engineering Thermodynamics 1 - 7.5 credits (ECTS)
- Thermal Energy, Specialization Project - 15 credits (ECTS)
- Industrial Ecology, Project – 15 credits (ECTS)
- Climate Change Mitigation – 7.5 credits (ECTS)
- Nanotechnology, Specialization Project – 15 credits (ECTS)
- Catalysis, Specialization Course – 7.5 credits (ECTS)
- Chemical Engineering, Specialization Project – 7.5 credits (ECTS)

NMBU:

- Bioenergy – 10 credits (ECTS)
- Applied Biocatalysis and Biorefining, 5 credits (ECTS)
- Energy and Process Technology – 5 credits (ECTS)
- Energy, Environment and Natural Resources – 10 credits (ECTS)
- Energy Systems and Technologies – 10 credits (ECTS)
- Renewable Energy Systems Analysis - 10 credits (ECTS)
- Energy and Society – 5 credits (ECTS)

Acknowledgements

The authors of the annual report would like to acknowledge the help and input from all the contributors. This includes the Chair of the board, management group, Sub-project leaders, Workpackage leaders and all the involved students. We also acknowledge the support and input from the Stakeholders and in particular Biokraft for the cover photo.

We also acknowledge the opportunity of establishing Bio4Fuels as financed by the Norwegian Research Council.

The Research Council of Norway

Bio4Fuels Industrial and public stakeholders

Bioresource owners

NORGES BONDELAG · Norske Skog · RAGN-SELLS · Oslo

Biofuel and biochemical producers

Statkraft · BIOZIN AS · Perstorp · Borregaard · BIOKRAFT · ecopro · Norske Skog Saugbrugs · SOLENIS · alginor · NESTE

Tech./knowledge providers, Norwegian

HIERØYA INDUSTRIPARK · CAMBI · Hyperthermics · NORSE Biotech · SynSel · ZEG Power · UMOE

Tech./knowledge providers, International

btg · JM · novozymes · PERVATECH · HALDOR TOPSOE · steeper ENERGY · LOGE

Government and State Partners

ØSTFOLD FYLKESKOMMUNE · HEDMARK FYLKESKOMMUNE · AKERSHUS fylkeskommune · OPPLAND fylkeskommune · Trøndelag fylkeskommune · folla

Statens vegvesen · NVE · Innovasjon Norge · ENOVA

Biofuels distributors and end users

ECO1 · st1 · preem · VOLVO · AVINOR