# Annual Report 2020

## NORWEGIAN CENTRE FOR SUSTAINABLE BIO-BASED FUELS AND ENERGY

CENTRE FOR ENVIRONMENT-FRIENDLY ENERGY RESEARCH

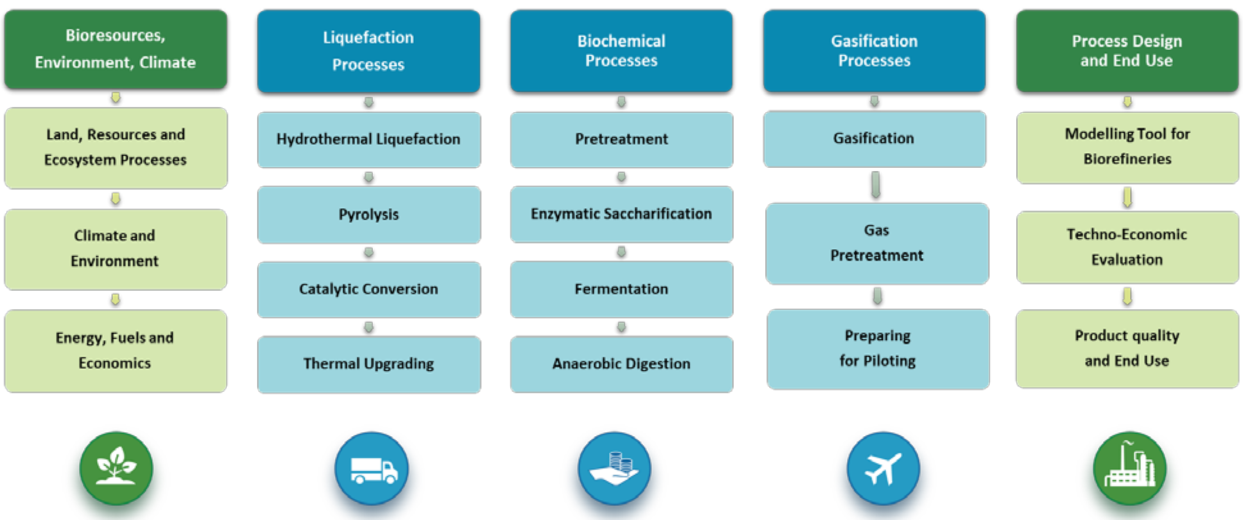
The Research Council of Norway

BIO4FUELS

# 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.




NMBU NTNU NIBIO NORSK INSTITUTT FOR BIOØKONOMI IFE USN University of South-Eastern Norway PFI SINTEF

*Front picture: Oslo City, Romerike biogas plant*

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*Borregaard'sDemo Unit in Sarpsborg. Photo by Martin Lersch, Borregaard.*

# From the Chair of the board and Centre leader

Like everywhere the world over, the Bio4Fuels Centre had to make major adjustments to its activities and operations during most of 2020. For many of the Centre's research partners, they were able to switch over to a flexible combination of virtual operation while keeping as much of the core experimental activities going. The virtual version of the status meetings has given new opportunities and alternatives for flexibility in participation. The virtual version of our annual Bio4Fuels Days allowed us to arrange a dedicated international section with international participants and presenters. This means that we have still been able to generate interesting results and to a large extent follow our plans.

As we approach the halfway milestone for the operation of Bio4Fuels, the Centre management, with the support of the research institutions and stakeholders, has been prepared and delivered the required documentation for the Research Council's midterm evaluation of Bio4Fuels. As input to this, our survey and evaluation of the operation and the "Value-chain" based organization gave positive results with respect to the impact of the changes from the earlier "self-evaluation". The recent evaluation also underlined the escalating importance of our research activities towards realizing the ambitions of the green transition, with many of the processes and expertise being developed being relevant for the wider bioeconomy.

We must also acknowledge and be thankful for the continued support of the Bio4Fuels stakeholders, both industrial and public sector, in spite of the challenging environment they have also been operating under.

Ingo Machenbach,
Chair of the Board

Duncan Akporiaye
Centre leader

# SUMMARY


The ambition of the Bio4Fuels Centre is to reduce the impact of climate gas emissions from the transport sector through sustainable and economic production of Biofuels. Biomass, in particular low-grade fractions of wood from the forest and waste from agriculture, is a renewable resource that can potentially substitute the use of fossil resources in the transport sector, together with other renewable energy solutions.

There are four main routes identified for the Centre

- Breaking down the biomass to separate out the sugars in the biomass for use in fermentation to produce "Bio-alcohols". This can be blended up to certain levels into existing fuels.
- Fermentation of the biomass in the absence of oxygen to produce a "Biogas". This Biogas can be upgraded to methane, liquified or converted to Hydrogen for use as fuels in transport.
- Treatment of the biomass at higher temperatures in the absence of oxygen to produce a liquid "Biooil", which is then upgraded to a substitute Biofuel
- Treatment of the biomass at higher temperatures to convert to a gas, followed by upgrading of the gas to a substitute Biofuel.

In addition to the main routes from Biomass to Biofuels, it is also important to convert side streams and biproducts from the processes to products of higher value than fuels. This can be important to help the overall economics of the commercial process.

In addition to the research on the processes, Bio4fuels has a significant activity focused on issues related to the sustainability and economics related to the production of biofuels:

- 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 process concepts and testing the quality of the Biofuels for existing engines.

From the operation of the Centre so far, the following areas can be highlighted:

- A successful Kick-off meeting was arranged in February 2017, with an international guest list of industrial presenters from all over Europe and the US. This provided industrial perspective of the state of the art for technology along the whole value chain. Using the kick-off as a platform, the Centre has now established a highly competent board, with industry as majority representing the key stakeholders of the value chain.
- The Centre has also established an International Advisory Group with representatives from key research sectors from Finland, United Kingdom and United States.
- Bio4Fuels organises annual "Bio4Fuels days" meeting:
    - 2017: dedicated to the national strategy, with an excursion to visit the production of Paper (Norske Skog AS) and Biogass (Biokraft AS) at Skogn near Trondheim.
    - 2018: taking on an international perspective following the release of the IPCC report, including a visit to the Oslo Biogass production site.
    - 2019: Bio4Fuels took the step towards organising a regular international Bio4Fuels days by arranging a conference in Gothenburg together with the UK Supergen and the Swedish f3 centres. With over 200 participants, the conference was overbooked and provided an important platform discussing important issues within the field.

- 2020: Virtual conference due to Covid-19. International view on biofuels with speakers from the EU Commission, USA, Canada, Finland and England. Virtual visit to Silva Green Fuels plant at Tofte, Hurum. Approximately 80 participants.

- Bio4Fuels have partners that are active in representing Norway in key tasks within the International Energy Association (IEA). Specifically related to addressing important aspects related to realising climate goals dependent on research within Bioenergy. Through NTNU, Bio4Fuels research partners have been active in leading the efforts and contributing to drafting the latest IPCC report on Climate Change and Land.
- Bio4Fuels, together with other FME has charted the effect of Energy research in Norway within the area of Bioenergy. This is on behalf of the Norwegian research Council.
- The Centre is also active in contributing to the background for the debate around the role of biofuels in Norway, through organising and attending Breakfast seminar, organising Webinars and responding to specific topics in the media.
- Partners in the Centre are also extremely well represented in EU H2020 research program with a very significant portfolio of EU projects as well as active coordination with other Research and Industry partners in the EU.
- Bio4Fuels has also carried out a second year "self-evaluation" on behalf of the board. This is the basis for reorganising the Centre's activities towards a stronger focus on the three most important value chains for Biofuels production in Norway.
- Industry partners in Bio4Fuels have established commercial production of liquidfied biogass for heavy duty road and ship transport and plan to build commercial plants in Norway, Sweden and Finland for conversion of biomass to liquid drop in biofuels.

## Bio4Fuels Organization

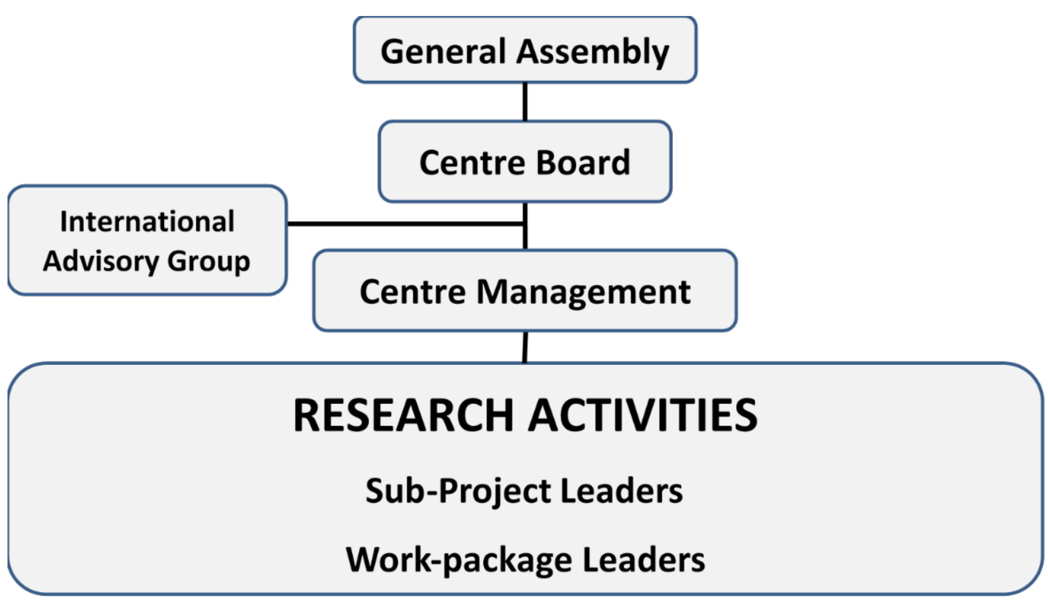



***Figure 1**: Organization of the FME Bio4Fuels Centre.*

## OPINIONS FROM BIO4FUELS' INTERNATIONAL ADVISORY BOARD (IAB)

IAB have been informed about the Mid-term Evaluation process and have read the self-evaluation report which was sent to the evaluation committee in December 2020.

This is their common statement:

*The ambitious goal of Bio4Fuels, the Norwegian Centre for Sustainable Bio-Based Fuels and Energy, is to conduct coordinated research activities to establish the basis for sustainable routes for converting Norwegian biomass resources into advanced biofuels to ultimately reduce greenhouse gas emissions from the Norwegian transportation sector. The Centre has been operating now for three years and has made considerable technical advances in biochemical (aerobic and anaerobic fermentation) and thermochemical (pyrolysis, hydrothermal liquefaction, and gasification) conversion research but more importantly they have been able to secure foundational interest from their industrial partners.*

*The self-evaluation conduction by the Centre leadership successfully refocused efforts across four main values chains 1) biochemical conversion to alcohols, 2) anaerobic fermentation to biogas, 3) biomass liquefaction to fuels and chemicals, and 4) biomass gasification. Sustainability and economics are continually evaluated to ascertain the environmental benefits and commercial viability of the technical options at the core of these value chains. The workplan for the next three years includes complimentary activities compared to what is being done in the biofuels research and development community. For example, novel enzyme cocktails are proposed for biomass deconstruction and conversion of biomass sugars to butanol and butyric acid focuses on fermentation organisms beyond ethanol production. The fate of inorganic contaminants and the impact of process conditions on hydrothermal liquefaction is another example of a complimentary research activity. The economic benefits of the potential for value added chemicals and products within the four identified value chains is a new focus for the Centre and provides an opportunity to optimize the scale of the conversion technology with respect to the available Norwegian biomass resources through process modeling and technoeconomic analysis to maximize sustainability. The commercial impact of the Centre's research and development is continuously reinforced by the participation of the international group of industrial partners and provides Centre graduate students and post docs a unique perspective beyond the scientific contributions of their work.*

*The Bio4Fuels Centre provides a nucleus for sustainable development of biofuels and bioproducts in Norway. Research activities supported within Bio4Fuels have been successfully leveraged by the partners and stakeholders in the Centre to attract additional support for research and development and provide a larger platform for addressing the overall technical and economic challenges within the field. The Centre also provides a strong educational opportunity for faculty, graduate students, and post docs at the partner universities with a unique commercial perspective provided by the international industry partners in the Centre. The proposed workplan for 2021 outlines the activities that continue to support the sustainability goals of the Bio4Fuel Centre.*

*We consider it very important to focus on the sustainability aspects. The major question is how the forest biomass resources are utilized. Therefore, we were very pleased to see that sustainability is now in the focus of the new work plan of the next three years.*

*In SP3 there will be an increased focus on production of advanced fuels (e.g. higher alcohols and biooils) by fermentation with novel organisms and on value-added non-fuel products (e.g. enzymatically* *upgraded cellulose fibers; chitosan and pigments from fermentation). We like this approach very much, focusing only on biofuels would not be relevant. The other product choices i.e. fiber products and chemicals are good choices, and we are sure the sustainability evaluation will be positive for them.*

*Increased collaboration among the research groups are very positive news.*

*We very much appreciate the strong involvement of the industrial partners to the Center, not only domestic but also international companies. This is a very strong indication of a well-chosen research agenda.*

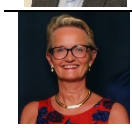
*Prof. Patricia Thornley*
*Aston University (UK)*

*Dean Kristiina Kruus*
*Aalto University Finland (FI)*

*Dr. David Dayton*
*Research Triangle Institute (USA)*

## Centre Board and Management

The Bio4Fuels' Board per December 2020:

| | | | |
|---|---|---|---|
|  | **Ingo Machenbach** | **Silva Green Fuel (Statkraft)** | **Chair** |
|  | Tyra Marie Risnes | Viken County Council | Representing Public Partners |
|  | Per Skorge | Norges skogeierforbund | Representing Resource partners |
|  | Jens Ulltveit-Moe | UMOE | Representing End Users (until September 2020) |
|  | Helle Brit Mostad | Equinor | Representing End Users (from September 2020) |
|  | Kine Svensson | CAMBI | Representing Technology partners |
|  | Petter Røkke | SINTEF | Centre Leader Institute |
|  | Ågot Aakra | NMBU | Host Institute |
|  | Terese Løvås | NTNU | R&D partner |
|  | Arve Holt | ife | R&D partner* |
|  | *Per Arne Karlsen* | *Research Council of Norway* | *Observer* |

**Rotation between PFI, USN, IFE, NIBIO*

## THE BIO4FUELS' MANAGEMENT TEAM:

| | | | |
|---|---|---|---|
|  | Professor Duncan Akporiaye | SINTEF | Centre Leader |
|  | Professor Svein Jarle Horn | NMBU | Deputy Centre Leader |
|  | Dr. Odd Jarle Skjelhaugen | NMBU | Industrial Liaison |
|  | Dr. Janne Beate Utåker | NMBU | Administrative Manager |
|  | Ann-Solveig Hofseth | NMBU | Financial Officer |
|  | Bente Paulsson | NMBU | Communication Officer |
|  | Liv Axelsen | SINTEF | Communication Officer |

## THE INTERNATIONAL ADVISORY GROUP (IAG)

| | Advisor | Affiliation | Area of expertise |
|---|---|---|---|
|  | Prof. Patricia Thornley | Supergen Bioenergy Hub, Aston University, Birmingham (UK) | Sustainability |
|  | Dean Kristiina Kruus | Aalto University, Otaniemi, Finland (FI) | Biochemical Processes |
|  | Dr. David Dayton | Research Triangle Institute (RTI), NC (USA) | Thermochemical Process |

## BIO4FUELS PARTNERS AND STAKEHOLDERS

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

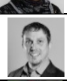
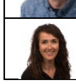
| **Bioresource owners** | **Main interest** |
|---|---|
| The Norwegian Farmers Union | Biogas production from agricultural feedstocks |
| The Norwegian Forest Owners' Federation | Value from forest biomass |
| The City of Oslo, The energy recovery unit | Biogas production from food waste |
| **Tech./knowledge providers, Norwegian** | **Main interest** |
| Herøya Industry Park | Pilot plant construction |
| Cambi AS | Plants for biogas production from organic waste |
| Hyperthermics AS | High temperature biogas production from waste biomass |
| UMOE AS | Biofuel plant investments and management |
| **Tech./knowledge providers, International** | **Main interest** |
| Biomass Technology Group (NL) | Biomass to liquid (btl) pyrolysis |
| Johnson Matthey (UK) | Chemical and catalytic processing of bio-feedstocks |
| Novozymes (DK) | Enzymes for forest based biorefineries |
| Pervatech (NL) | Membrane and separation systems for organic substrates |
| Haldor Topsøe (DK) | Chemical/catalytic processes for several bio feedstocks |
| Steeper ENERGY (DK) | Hydrothermal liquefaction |
| Lund Combustion Engineering as (SE) | Consultancy and software on combustion in motors |
| **Biofuel and biochemical producers** | **Main interest** |
| Silva Green Fuel AS | Biodiesel from forest biomass |
| Biozin AS | Forest based crude oil for biorefineries |
| Equinor | Feed stock supply, value chains, co-processing |
| Perstorp Bioproducts AB (SE) / Adesso Bioproducts | High quality biodiesel |
| Borregaard | Forest-based high value chemicals and bioethanol |
| Biokraft | Biogas from paper mill side-streams and fish waste |
| Ecopro AS | Biogas from organic waste |
| Norske Skog Saugbrugs | Biogas from biorefinery side-streams |
| Neste (FI) | Biorefinery |
| Alginor ASA | Seaweed products from a multifunctional biorefinery |

| Biofuels distributors and end users | Main interest |
|---|---|
| St1 Norge as | Bioethanol production and distribution in Norway |
| Volvo Group Trucks Technology (SE) | Truck engines powered by biofuels |
| Avinor | BioJetFuels for Norwegian airports |

| Government and State Partners | Main interest |
|---|---|
| Viken Fylkeskommune | Sustainability, Resource Use, Transport policy, Techn Econ |
| Innlandet Fylkeskommune | Sustainability, Resource Use, Transport policy, Techn Econ |
| Trøndelag Fylkeskommune | Sustainability, Resource Use, Transport policy, Techn Econ |
| Follorådet | Sustainability, Resource Use, Transport policy, Techn Econ |
| Miljødirektoratet | Sustainability, Resource Use, Transport policy, Techn Econ |
| Statens Vegvesen | Sustainability, Resource Use, Transport policy, Techn Econ |
| Innovasjon Norge | Sustainability, Resource Use, Transport policy, Techn Econ |
| **Non-Governmental Organizations / Trade Organizations** | **Main Interest** |
| NOBIO | Bioenergy, Biofuels |
| Zero | Renewable Energy, Policy |

*Biogas plant at Oslo REG. Photo: Oslo kommune*

## WORK-PACKAGES AND SUB-PROJECTS (AFTER REORGANIZATION)

| Sub Projects Leaders | | | |
|---|---|---|---|
| | *Name* | *Institution* | *Main research area* |
|  | Francesco Cherubini (SP1) | NTNU | Bio-resource, Environment and Climate |
|  | Judith Sandquist (SP2) | SINTEF | Liquefaction Processes |
|  | Aniko Varnai (SP3) | NMBU | Biochemical Conversion |
|  | Morten Seljeskog (SP4) | SINTEF | Gasification Processes |
|  | Bernd Wittgens (SP5) | SINTEF | Process design and End Use |
| **Work Package Leaders** | | | |
| | *Name* | *Institution* | *Main research area* |
|  | Rasmus Astrup (WP 1.1) | NIBIO | Land, Resources and Ecosystem Processes |
|  | Francesco Cherubini (WP 1.2) | NTNU | Bio-Resources, Environment, Climate |
|  | Torjus Bolkesjø (WP 1.3) | NMBU | Energy, Fuels and Economics |
|  | Kai Toven (WP 2.1) | RISE PFI | Pyrolysis |
|  | Judit Sandquist (WP 2.2) | SINTEF | Hydrothermal Liquefaction |
|  | Roman Tschentscher (WP 2.3) | SINTEF | Thermochemical upgrading of bio oils |
|  | De Chen (WP 2.4) | NTNU | Chemo-catalytic conversion |
|  | Mihaela Tanase Opedal (WP 3.1) | RISE PFI | Pretreatment and Fractionation |
|  | Aniko Varnai (WP 3.2) | NMBU | Enzymatic Saccharification |
|  | Alexander Wentzel (WP 3.3) | SINTEF | Fermentation |
|  | Michał Sposób (WP3.4) | NIBIO | Anaerobic Digestion and gas upgrading |
|  | Morten Seljeskog (WP 4.1) | SINTEF | Gasification |
|  | Edd Blekkan (WP 4.2) | NTNU | Gas Conditioning |
|  | Klaus Jens (WP 4.3) | USN | Preparing for piloting and up-scale |
|  | Heinz Preisig (WP 5.1) | NTNU | Modelling Tool for Biorefineries |
|  | Bernd Wittgens (WP 5.2) | SINTEF | Techno-Economic Evaluation and Scale of Economy |
|  | Terese Løvås (WP 5.3) | NTNU | Product quality and End Use |

# HIGHLIGHTS FROM 2020

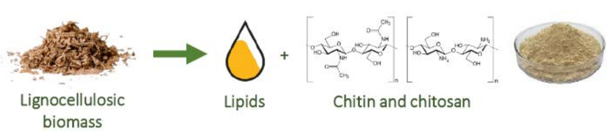
## Research

**SP1 – Scientific Article in Nature Sustainability**
Title: ***The land–energy–water nexus of global bioenergy potentials from abandoned cropland***
Authors: Jan Sandstad Næss, Otavio Cavalett and Francesco Cherubini
*Abstract:*
Bioenergy is a key option in climate change mitigation scenarios. Growing perennial grasses on recently abandoned cropland is a near-term strategy for gradual bioenergy deployment with reduced risks for food security and the environment. However, the extent of global abandoned cropland, bioenergy potentials and management requirements are unclear. Here we integrate satellite-derived land cover maps with a yield model to investigate the land–energy–water nexus of global bioenergy potentials. We identified 83 million hectares of abandoned cropland between 1992 and 2015, corresponding to 5% of today's cropland area. Bioenergy potentials are 6–39 exajoules per year (11–68% of today's bioenergy demand), depending on multiple local and management factors. About 20 exajoules per year can be achieved by increasing today's global cropland area and water use by 3% and 8%, respectively, and without production inside biodiversity hotspots or irrigation in water-scarce areas. The consideration of context-specific practices and multiple environmental dimensions can mitigate trade-offs of bioenergy deployment.
Link to full text article here.

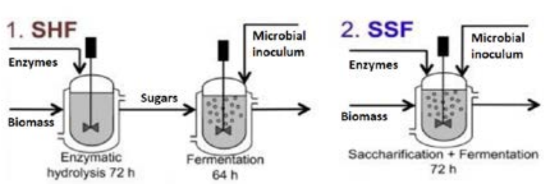
**SP2 - Liquefication Processes**
Hydrothermal liquefaction (HTL) is a thermochemical process that takes advantage of the water in the feedstock, at process conditions where the heat of evaporation for water is avoided and hence pre-drying is not necessary. This makes the process very interesting for high moisture feedstock such as organic residues and sludges.
The technology uses high pressures and temperatures where the water is at sub-or supercritical state. At these conditions, the water alters its physical and chemical properties which result in chemical reactions that dissolve the organic structure of biogenic materials and convert them to fuel intermediates.
Through the Norwegian national infrastructure project, NorBioLab2, SINTEF Energy Research has invested in a continuous lab-scale HTL mini-pilot system, which is now in place and under commissioning. Unfortunately, due to the pandemic, the commissioning is somewhat delayed, but we expect the mini-pilot to be fully operational after the summer break and the experiments can start. The mini-pilot has a capacity of maximum 2 L/h slurry feed and is able to operate at state-of-the-art conditions, i.e. up to 500 °C and 350 bar.
The reactor is built with a research focus, for studying operational issues, such as fate of inorganics, corrosion, and the effect of depressurization on those.
The system has the possibility to include stress loaded corrosion samples for material and weld testing under real HTL environment.

*To facilitate this objective, a relatively large compartment was needed to insert the samples, therefore, a CSTR reactor was selected.*
*The mini-pilot is equipped with dual piston pumps and a two-stage depressurization system to study the depressurization effect on the product composition and distribution.*

**SP3 - Production of fungal lipids and biopolymers (chitin and chitosan) through the process of Simultaneous Saccharification and Fermentation (SSF)**
*Mucor circinelloides*is a dimorphic fungus capable of accumulating large amounts of intracellular neutral lipids (triacylglycerates) as a **potential feedstock for biodiesel production.** It also offers a diverse spectrum of other products through fungal fermentation *e.g.* organic acids, amino acids, enzymes, antibiotics, chitosan and biomass with significant nutritional value.

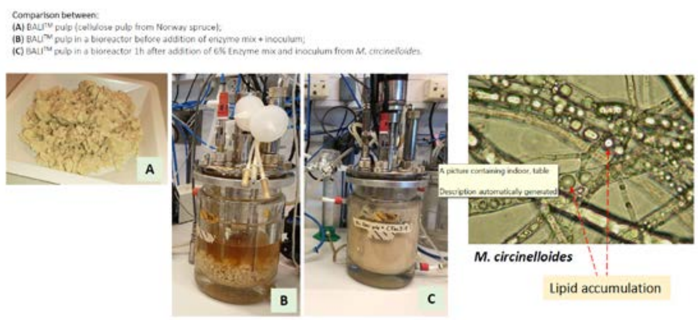



**Objective:**
In Bio4Fuels, we work on **e**stablishing scalable bioconversion of **lignocellulose materials into lipid rich fungal biomass**with a focus on the concomitant production of other metabolites (chitin and chitosan, and polyphosphate).




**Approach:**
Separated Hydrolysis and Fermentation –**SHF (1)** is a conventional method where the hydrolysis of the biomass is carried out ahead of the fermentation process. In **SSF (2)**, the enzymes that catalyse the

hydrolysis of polysaccharides into sugars, and the microorganisms that are fermenting the latter into higher value products, are used at the same time. Therefore, the **sugar production and utilization occur simultaneously. The fermentable sugars are released and consumed continuously throughout the process, which simplifies the process and can lead to improved process economics (CAPEX/OPEX).**
**Results: T**he fungus *M. circinelloides*shows good growth and lipid accumulation activity during SSF fermentation using pulp from Borregaard'sBALITMprocess (microscopical observations, analytics ongoing). It is therefore promising with respect to its application to transform cellulosic residual biomass from biorefineries to higher value products.



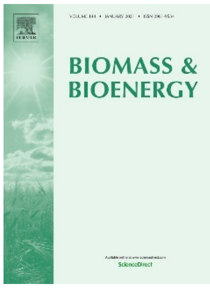

**SP5 - Technical and economical Evaluation**

The work package for technical and economical evaluation covers the bridge between fundamental science and commercial opportunities. The objective is to gather sufficient information from all partners in a given process and the value chain the process is part off. Based on this information we designed and modelled a process to determine its characteristic dimensions which in turn are used to develop a basis for capital and operation costs.

We are now doing an assessment of fermentation from lignocellulose derived sugars to butanol and butyric acid. The value chain consists of a pre-treatment where woody material is converted to sugars. These are fermented in two parallel continuous fermenters and recovered. Subsequently these are esterized to butyl-butyrate which can be used as an additive to aviation fuel.

A pilot plant has been built in recent years, by resources from the IndNor project EcoLodge and FME Bio4Fuels. The results from the pilot plant give valuable insight into the performance of the process and complement available data and demonstrate the feasibility of the process and the most capital extensive units are identified. Given this information we are now looking into how to restructure the process to improve the performance and reduce operational or capital costs at the same time.

## Special Issue of the Journal 'Biomass and energy'




The Bio4Fuels Days 2019 was an international conference arranged together with the f3 Centre in Sweden and the Supergen Bioenergy Hub in the UK. The conference was named *Building a sustainable biofuels industry* and was held in Gothenburg 4-6 November 2019. As a result of the cooperation with Professor Patricia Thornley (Supergen) presentations on the conference are now being published in a special issue of the Journal *Biomass and Energy* in which professor Thornley is Editor-in-Chief. The first six publications can be found here. Guest editors: Marcelle McManus, Svein Jarle Horn, Ingrid Nyström.

## Site Visit – the Norwegian Research Council, 4 June 2020

*AGENDA*

- *Feedback from RCN*
- *Presentation of the Centre*
    - *Organisation, results, plans, recruitment, budget*
- *Bio4Fuels Research Examples*
    - *Roman Tschentscher, Sintef*
    - *Judit Sandquist, Sintef*
- *Bio4Fuels Communication Plan*
- *International Cooperation in the Centre*
- *User Partners' Involvement in the Centre*

The overall feedback from the Research Council of Norway was positive, especially regarding the research activities and achievements. Improvement areas are external communication and research reporting.

## Centre Status Meetings 2020

The self-evaluation process in 2019 concluded that stakeholders ought to be more involved in, and better informed about, the activities in the Centre.

The former "Centre cluster meetings" (for researchers and management) were therefore expanded in 2020, and now include stakeholders. The meeting series has been renamed "Centre Status Meetings", of which there were four in 2020 (including Bio4Fuels Days). Due to Covid-19 the meetings have been virtual, which unfortunately lowers the degree of free discussions. Please see meeting programs on the next page.

equinor

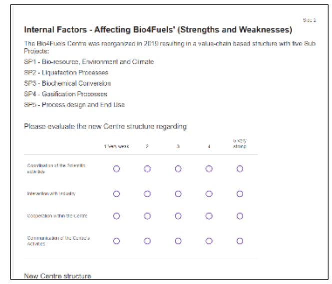
BIOZIN

| Date | Program |
|---|---|
| 14 Feb | Work plans 2020 |
| 12 May | - Stakeholder presentation: ***Equinor and Biofuels***, Helle Brit Mostad, Equinor<br>- ***Norwegian forest feedstock for biofuel production***, Rasmus Astrup, NIBIO (WP1.1)<br>- ***Economic and policy aspects of forest-based biofuels***, Per Kristian Rørstad, NMBU (WP1.3)<br>- ***Biocrude production via pyrolysis and HTL***, Judit Sandquist, SINTEF (WP2.2)<br>- ***Slurry phase upgrading of crude bio oils***, Roman Tschentscher, SINTEF (WP2.3)<br>- ***Integrating biotech routes to biofuels from lignocellulose***, Alexander Wentzel, SINTEF (WP3.3)<br>- ***SER process in biorefinery concepts***, Antonio Geraldo de Paula Oliveira, IFE (WP 3.4)<br>- ***In the making of building blocks for tomorrows bio-jet fuel***, Morten Seljeskog, SINTEF (WP4.1)<br>- ***Status on modelling, cost estimation and performance of advanced biofuel***, Bernd Wittgens, SINTEF (WP5.2) |
| 27 Aug | - Stakeholder presentation: Thomas Skadal, Biozin AS<br>- ***Progresses on environmental sustainability analysis of advanced biofuels***, Francesco Cherubini, NTNU (WP1.2)<br>- ***Novel routes for producing transportation fuel based on pyrolysis technology*** Kai Toven, RISE PFI (WP2.1)<br>- ***Cu catalysts for hydrogenation of hydroxyacetone to PG***, Jia Yang, NTNU (WP2.4)<br>- ***High purity organosolv lignin as a component in biocomposites materials***, Mihaela Tanase Opedal, RISE PFI (WP3.1)<br>- ***Towards more efficient conversion of softwood-type feedstocks with today's state-of-the-art enzyme blends***, Aniko Varnai, NMBU (WP3.2)<br>- ***Methane steam reforming and (R)WGS combined – initial results*** Edd Blekkan, NTNU (WP4.2)<br>- **Simulation of entrained flow gasification reactor with Multi Phase Particle in Cell (MP-PIC) approach,** Ramesh Timsina, USN (WP4.3)<br>- **Modelling Tool for Biorefineries,** Heinz Preizig, NTNU (WP5.1)<br>- **Combustion of diesel/biobased glycerol emulsions in a compression ignition engine,** Terese Løvås, NTNU (WP5.3) |
| 19 Nov | Bio4Fuels Days 2020 |

## SP Leader Meetings

Yet another consequence of the self-evaluation process in 2019 was that the Centre's SP leaders were given the responsibility to follow up the WP leaders with regards to research progress, reporting and workplans. Management has met with the SP leaders eight times during 2020 (virtual due to geography and Covid-19). This has considerably improved the information flow in the Centre, as well as the management of it.

## Mid-Term Evaluation of the Bio4Fuels Centre




All "FME Centres" (Centres for Environment-Friendly Energy Research) financed by the Norwegian Research Council have in 2020 prepared for the mid-way evaluation. Bio4Fuels' management has

- performed an **online survey** among researchers, Board representatives, management and PhD students to obtain input to a SWOT analysis of the Centre – September 2020
- arranged **meetings** with researchers, partners and PhD students to inform about the evaluation process and ask for their opinions of the Centre
- written **three comprehensive reports** to the evaluation committee, based on templates provided by the Research Council of Norway
    - Self-evaluation report with SWOT analysis (Form A)
    - Facts sheet (Form B)
    - Project description for the final three years (Form E)

The evaluation committee received all reports in December 2020.

The evaluation committee was appointed by the Norwegian Research Council in the fall 2020:

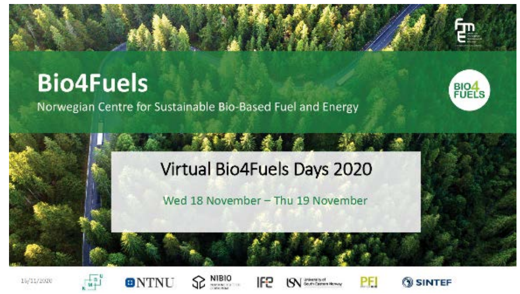
- Professor Mary O'Kane, O'Kane Associates, Australia (generalist - panel leader)
- Dr. Mattias Lundberg, Swedish Foundation for Strategic Research, Sweden (generalist)
- Professor Anne Meyer, DTU, Denmark (Scientific expert)
- Manager Lars Waldheim, Waldheim Consulting, Sweden (Scientific expert)

The committee will meet with representatives from the Bio4Fuels Centre in an online-meeting the 23$^{rd}$ of February 2021. The final evaluation results will be given during the summer 2021.

## External workshops, seminars, webinars in 2020

- Bio4Fuels Webinar «*Norsk skogsektor mot 2050*» by WP 1.3, NMBU, 6 May
  Bio4Fuels Webinar «*Biodrivstoff som klimatiltak i Norge mot 2030*» by Mats Nordum, Norwegian Environment agency, 12 June
- Bio4Fuels Webinar «*Skape grønne verdier – refleksjoner sett fra Norske Skog*» by Carsten Dybevig, Norske skog, 23 October
- e-EUBCE event on "*Incorporating Efficient Bioenergy in Industry*", 6 July
- German Biomass Research Center's forum on Hydrothermal Processes, 25 November
- "*Pellets – en trussel mot klimaet?* », The Norwegian Academy of Science and letters, 2 Sept
- *"Decarbonisation of Transport – Light Duty Vehicles"*. The Norwegian Academy of Science and letters, 9 September

## Bio4Fuels Days 2020 (18-19 November)



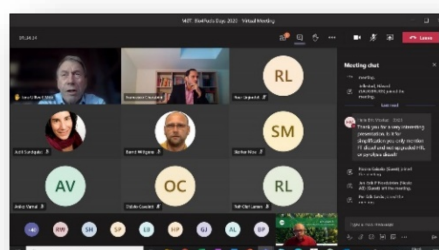

The Bio4Fuels days 2020 was intended to be a physical conference in Drammen, but due to the Covid-19 pandemic it was held as an online seminar 18th and 19th of November. Approximately 80 researchers, industry specialists, and policymakers were virtually gathered to share insight, problems and recent developments within production and use of advanced biofuels.
The first day of the seminar had an international perspective, with presentations from different Bio4Fuels' stakeholders and invited speakers, while day two was an internal seminar for Bio4Fuels' partners. A major contributor to the emission of greenhouse gases is the use of fossil fuels in the transport sector. The EU's European Green Deal aims at becoming climate-neutral in 2050, and to achieve this goal a sustainable biofuel industry needs to be established. In order to meet this goal, demonstration and scale-up of novel processes for production of advanced biofuels is essential.

**New plant at Tofte**

The new demonstration plant of Silva Green Fuel, which is owned by Statkraft and Södra, is now being established at Tofte, and will produce bio-oils from wood using Steeper Energy's technology. The plant will perform hydrothermal liquefaction, which is the direct transformation of biomass into bio-oils under high pressure and temperature. This renewable bio-oil can further be upgraded into advanced biofuels at existing refineries.

Other presenters at the conference were St1, Norwegian University of Life Sciences, Imperial College London, Avinor, and RTI International, all highlighting different aspects of biofuels and their importance for achieving future goals of reducing greenhouse gas emissions from the transport sector.

More research needed




Despite great research progress in the last years, the main bottleneck in the production of advanced biofuels remains the high cost compared to fossil fuels. The production of valuable co-products in biorefining processes may increase the competitiveness of biofuels. Forward, more research and process optimization are needed to make the conversion of biomass to biofuel an economic process.

Meeting program and presentations can be found **here**

## Bio4Fuels Newsletters

To improve the communication of the Centre's activities, newsletters have been sent out to the partners in June, September and December 2020. A person in Management has been dedicated to this work, contacting the research partners in person and collecting the latest within technology, publications, innovation, recruitment etc.


## Doctoral Defense – Eirik Ogner Jåstad (NMBU)

The first of Bio4Fuels' fully financed PhD students to finish his doctorate was Eirik Ogner Jåstad (WP1.3), NMBU. He has investigated how the forest and energy sector will adapt to the production of biofuels and bioheat in the Nordic region in the future. The results show that large-scale biofuel production in the Nordic region will change the traditional forest sector, with considerable benefits for the forest owner. Disputation date: 1 December 2020.

Thesis: link

## Doctoral Defense – Karl Oskar Pires Bjørgen

The 1st PhD in WP5 on product quality and end use defended his thesis on the 6/4 2020. The thesis is entitled «Optical study of Soot Characteristics of Biofuel Spray Combustion». The thesis is devoted to experimental studies of emission formation in internal combustion engines, with special emphasis on biofuels. The fuels tested are especially relevant for the types of fuels studied in Bio4Fuels. He has also further developed advanced optical measurement techniques in the novel optically accessible compression ignition chamber (OACIC). This facility enables measuring the combustion process visually, by using high speed imaging techniques. For interested readers, the thesis can be found online: https://ntnuopen.ntnu.no/ntnu-xmlui/handle/11250/2649320

# BIO4FUELS INDUSTRIAL STAKEHOLDERS INSIGHTS

Novozymes is the World leader in biological solutions. The company specializes in industrial enzymes and microorganisms and markets over 700 biotechnology products. The enzyme production leaves Novozymes with a global enzyme market share of 48 %. Around 14 % of Novozymes´ revenue is re-invested in research and development. Novozymes has a global presence at all levels and is fully capable of delivering to the emerging industry. This can be seen by the current status of R&D activities in four continents, sales offices in more than 130 offices and the enzyme technology improving the daily life of millions of persons around the globe. As a leading biotech company, Novozymes believes that by using industrial biotechnology thousands of everyday products can potentially be re-engineered to deliver enhanced sustainability performance, at no extra cost.


In the past two decades, Novozymes has invested heavily in developing enzyme products to enable the cellulosic ethanol industry, and generation of simple sugars from lignocellulose and municipal solid waste for the bioproduction of other biochemicals. Together with customers, partners, and the global community, we improve industrial performance while preserving the plant's resources and helping to build better lives.

The Novozymes company has supplied enzymes to Bio4Fuels and Borregaard and is directly involved in WP3's research (see below).

## Enzymatic Saccharification – Borregaard and Novozymes

In WP3.2, we work in close collaboration with Bio4Fuels partners Novozymes and Borregaard to improve the efficiency of today's state-of-the-art enzyme blends in depolymerizing softwood-type feedstocks, which are in abundance in Norway. One of our targets is to develop an industrial setup to improve the efficiency of commercial cellulase blends by harnessing the action of oxidative enzymes called LPMOs (lytic polysaccharide monooxygenases) in a more efficient way than it is done in current industrial processes.

The novel process is based on the recent scientific breakthrough by Dr. Bastien Bissaro, a guest researcher from INRA (France), and the NMBU team led by Prof. Vincent Eijsink, that is, LPMOs can utilize hydrogen peroxide much more efficiently than oxygen to break down cellulose.

*Borregaard'sDemo Unit in Sarpsborg, which was used to showcase faster and more complete saccharification of Borregaard'sBALI-pretreated spruce feedstock at demonstration scale, using the recently developed industrial setup, enabling controlled activation of LPMOs in Novozymes' CellicCTec3 cocktail using $H_2O_2$supply. Photo by Martin Lersch, Borregaard.*

In 2019, the team successfully implemented this recently developed industrial setup at demonstration scale at Borregaard's Demo Unit (picture above). Using $H_2O_2$ supply for the controlled activation of LPMOs in CellicCTec3 enabled faster and more complete saccharification of Borregaard's BALI-pretreated spruce feedstock.
In the spring of 2020, scientific publishing has gotten more focus due to limited access to setting up experiments as a result of the lockdown during the early phase of the Covid-19 pandemic. Very recently, a review paper led by Dr. Anikó Várnai on the production of LPMOs with special focus on scale-up and industrial-scale enzyme production has been accepted for publication in the prestigious journal of Biotechnology Advances.
In addition, the NMBU team and Borregaard published the results of the demonstration-scale saccharification study using $H_2O_2$ supply that was carried out at Borregaard's Demo Unit in a joint publication in the journal of Biofuels, Bioproducts and Biorefining.

With $H_2O_2$supply, 15 % higher glucose yield was reached within 40 % less saccharification time compared to the current state-of-the-art process setup that does not employ $H_2O_2$ supply. Importantly, these experiments were done at 2,000 L working volume, and represent the first ever demonstration of this revolutionary technology at such scale.

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Also, Bio4Fuels has hired a new PhD student, Camilla Fløien Angeltveit, who started at NMBU in August 2020 and work on enzymatic saccharification with a focus on the optimization of LPMO activation as well as the identification of limiting enzyme components in Novozymes' state-of-the-art cellulase cocktails. This work will entail close collaboration with Bio4Fuels partners Novozymes and St1.

## Avinor - Sustainable Aviation Fuel (SAF)


Biofuel was certified for use in civil aviation in 2009. Since then, several thousand scheduled civilian flights have been carried out where a percentage of biofuel has been blended into the fuel, and the development of various technologies for the production of jet biofuels has accelerated. A major advantage of biofuels is that they can be blended directly into fossil-based aviation fuel and do not require adaptations to either aircraft engines or distribution systems.

The first flights in Norway using blended jet biofuel were carried out by SAS and Norwegian in connection with the Zero Conference in November 2014. In January 2016, Avinor Oslo Airport, in collaboration with AirBP, Neste, SkyNRG, Lufthansa Group, KLM and SAS, was the world's first international airport to blend biofuel into the regular fuel supply system and to offer biofuels to all airlines refuelling there. SAS and Widerøe offer their customers the purchase of sustainable biofuels when buying tickets. From 2020, it is a requirement that 0.5 per cent of all aviation fuel sold in Norway must be advanced biofuels (with the exception of the Norwegian Armed Forces). Norway is the first country in the world to introduce such a blending mandate. The Norwegian parliament has adopted a target that 30 per cent of aviation fuel in Norway in 2030 will be advanced biofuel.

Together with the airlines and NHO Luftfart, Avinor has explored the possibility of establishing large-scale production of biofuels for aviation, based on local biomass. The analyses show that in Norway, it is primarily forestry that will be able to contribute quantities in the size we are talking about in a sustainable way. The conclusion is that waste and byproducts from forestry could provide enough biomass for 30 to 40 per cent of the fuel demand for Norwegian aviation.

Both in Norway and internationally plans are also being made to produce sustainable fuels from other resources than biomass. So-called electrofuels (e-fuels) have received increasing attention lately.

Roadmap to fossil-free aviation:
For the first time, SAS, Widerøe, Norwegian, Avinor, Norwegian Confederation of Trade Unions (LO) and the Federation of Norwegian Aviation Industries (NHO Luftfart) have worked together to set a common emissions target, and a roadmap to achieve the goal of Norwegian aviation being fossil-free by 2050. This means that from 2050, on scheduled flights in and from Norway, fossil fuels will not be used. The report was published on October 6th and is now translated to English.

Under the Paris Agreement, a large majority of the world's countries have committed to putting measures in place to limit global warming to a maximum of 2°C, preferably 1.5°C. In practice, this

means that by 2050, the world must be an almost zero-emission society. Norwegian aviation is committed to be a driving force to achieving the objectives of the Paris Agreement. Norwegian airlines have already set ambitions targets, and with the roadmap Norwegian aviation signals a clear ambition to be a world leader.

This goal is ambitious and calls for significant investment and changes across the aviation value chain over the next few decades, together with effective measures from the authorities. https://kommunikasjon.ntb.no/pressemelding/the-aviation-industrys-ambitious-goal-norwegian-aviation-to-be-fossil-free-by-2050?publisherId=17507039&releaseId=17898370

## The city of Oslo, Agency of Waste Management (*Renovasjons- og energigjenvinningsetaten (REG)*)

The Agency of Waste Management (REG) is an agency in the municipality of Oslo with the responsibility for collecting and handling household waste for Oslo's residents. We collect and ensure safe treatment of around 17,000 tonnes of household waste per year. The agency collects food waste, plastic packaging, and residual waste, which the residents have sorted into color-coded bags, the food waste in green bags, the plastic waste in blue bags and the residual waste in ordinary shopping bags. The bags are separated in the optical sorting plants at Haraldrud and Klemetsrud. The food waste becomes biogas and biofertilizer, the plastic waste is converted into new plastic products and the residual waste is incinerated and becomes environmentally friendly electricity and district heating.

**Romerike biogas plant**

Romerike biogas plant (RBA), is located at Nes in Romerike in Esval Miljøpark and is built to treat food waste from Oslo's households, but also receives livestock manure and some other biomasses. The plant was in operation in December 2013. Emphasis is placed on energy efficiency and the landfill gas from Esval landfill is utilized as an energy source in the plant. RBA is owned and operated by the Agency of Waste Management.

RBA has a design capacity of 50,000 tonnes, but due to legal restrictions, only 60 % of the capacity is utilized, i.e., approx. 30,000 tonnes of food waste is treated at the plant. Oslo has a goal of 65 % material recycling almost without climate emissions in 2030. As of 2020, the material recycling rate is approx. 39 %.

The food waste becomes emission-neutral biogas and organic biofertilizer. The biogas is upgraded in the gas plant to liquefied biogas (LBG) and is a $CO_2$-neutral fuel for buses and other transport. Biofertilizer is a nutrient-rich fertilizer product for agriculture.


1. Bioreactor
2. Storage tank liquid biofertilizer
3. Storage tank
4. Gas balloon
5. Gas treatment plant
6. Receiving area for food waste

**Biogas**

Biogas is produced by decomposing organic material without access to oxygen. The gas which occurs consists of approx. 65 % methane and approx. 35 % $CO_2$. To be able to use the gas as fuel, $CO_2$ is removed so that the methane content is 97-98 %. Biogas is the most climate-friendly biofuel on the market, and the biogas from RBA has a climate benefit of approx. 91 %, compared to diesel. If the climate benefit for biofertilizer is included, the climate benefit is over 100 % - i.e., a carbon-negative value chain. By using biogas instead of petrol or diesel, you avoid adding new $CO_2$ to the atmosphere. In addition, biogas has a positive effect on local air pollution, because biogas is a very clean-burning fuel with very low particulate emissions. Biogas is currently used on buses and renovation vehicles in Oslo and on heavy transport.

At full utilization, RBA can produce approx. 4.5 million Nm3 of liquid biogas per year. Production is now limited to 60 %, i.e., approx. 2.5 million to Nm3 of liquid biogas per year. The biogas replaces approx. 2.5 million liters of diesel per year.

**Biofertilizer**

The biofertilizer is liquid or solid, with a nutrient content that makes it a full-fledged organic fertilizer product. By using food waste as fertilizer, we preserve important nutrients such as nitrogen, phosphorus, and potassium in the cycle. In addition, biofertilizer is a source of organic material.

After plastic, sand, glass, and other elements have been removed from the food waste, the food waste is hygienized before the microbiological process that makes biogas and biofertilizer starts. The food waste goes through a thermal hydrolysis process (THP), which is a sterilization process where the substrate becomes pathogen-free, i.e., pathogens, weed seeds, fungi and plant diseases are killed by high heat (approx. 133 $^0$). Furthermore, the cell structure in the food waste is decomposed in a so-called flashing process. It means that the cells in the food waste explode when the pressure in the flash tank is lowered rapidly. It contributes to the increased rate of biodegradation in the bioreactors.

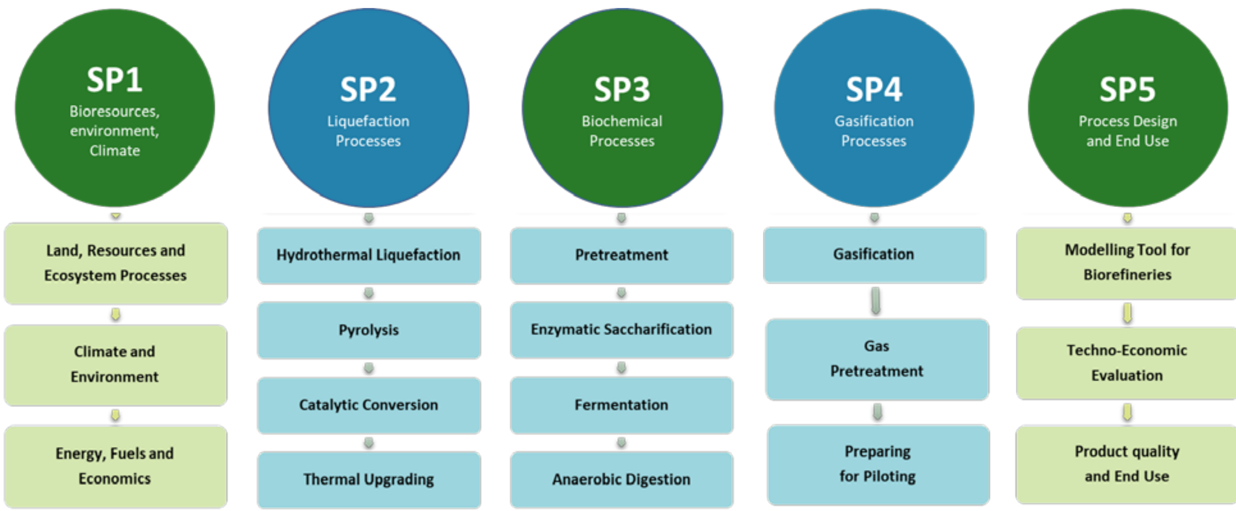
The biogas plant produces both liquid and solid biofertilizer from the bio-residue. Bio-residue is degraded food waste/organic material. In the liquid bio-residue, the dry matter content is approx. 4 %. The solid bio-residue is produced from liquid bio-fertilizer, which has been through a dewatering process. During the dewatering, polymer is added to the bio-residue and is then centrifuged to separate the solid from the water phase. Phosphorus comes with solid biofertilizer, which makes the bio-residue well suited as a soil improver. Biofertilizer is a sustainable alternative to fossil fertilizer, with a very high climate benefit.

Oslo Municipality aims to be an international leading environmental city and is an important contributor in the work for sustainable development, with recycling-based waste utilization.

# HIGHLIGHTS FROM BIO4FUELS' WORK PACKAGES

As shown below, the high-level value chain (SP (sub project)) establishes interaction across focussed research activities (work packages (WP)), addressing the five challenges of bioresources (SP1), Liquefaction Processes (SP2), Biochemical Conversion (SP3), Gasification Processes (SP4) and End use (SP5).

Within this organisational structure, Bio4Fuels has focus on and coordinates the activities along the value chains, addressing specific challenges and bottlenecks needed to go from resources to products using the most relevant technological approaches for biofuels production.



# BIO4FUELS – WP HIGHLIGHTS IN 2020

| ***SP1: Bio-resource, Environment and Climate*** |
| --- |
| - Resource use and availability in Norway.<br>- Climate change impacts and mitigation<br>- Economic policies for sustainable biofuel economy |
| SP Leader: Francesco Cherubini |

| | |
| --- | --- |
| WP1.1 | Land, Resources and Ecosystem Processes (Rasmus Astrup, NIBIO) |
| WP1.2 | Climate and Environment (Francesco Cherubini, NTNU) |
| WP1.3 | Energy, Fuels and Economics (Torjus Bolkesjø, NMBU) |

## *Background and approaches*

This subproject addresses important aspects related to bio-resources with a particular focus to Norway, their management, and the climate change mitigation of biofuel and co-product systems. This includes the availability and options for procurement under different management strategies; the physical attributes of ecosystem structure and processes resulting from different procurement and management strategies. With respect to resource availability, a suite of state-of-the-art modelling tools will be applied to simulate forest state and structure. Biogeochemical (e.g., related to $CO_2$ and other greenhouse gases) and biogeophysical (e.g., surface albedo) changes induced by land management that, in addition to life cycle emissions along the value chain and subsequent use.

The impacts on climate will be computed using up-to-date models and approaches and outcomes will in turn be used to inform policy makers of the best way to manage forestland and bioenergy options under the dual goal of renewable energy supply and climate change mitigation

The economy of biofuels and potential co-products will also be analysed including analysis of current and near-term economic measures and policies governing the many aspects of Scandinavian biofuel economy with the view to outlining potential sound economic policies to enable a sustainable biofuel economy in Norway and Scandinavia.

**2020 SP1 Bioresources, Environment and Climate:**

The activities for *Climate and Environment* (WP1.2) have improved our assessment framework for analysis of biofuel systems in Norway by developing novel approaches that consistently integrate climate forcing agents through the value chain, from resource supply to logistics, biomass conversion to biofuels and final use. We have also performed case-studies specific to quantify the climate change mitigation potential of biofuel options in Norway. Activities within

*Energy, Fuels and Economics* (WP 1.3) are well in line with the original plan.
<u>Achievements</u>

- Three scientific publications. One on aviation biofuels in Norway featured by Nature Sustainability, plus other publications related to the topic of the Centre (including international collaborations).
- Five spin-off/associated projects (4 national, 1 international) connected to the Centre.
- One PhD degree (Eirik Ogner Jåstad) with research resulting in six peer review publications on the economics of forest-based biofuels.

## WP1.1 Land, Resources and Ecosystem Processes - Rasmus Astrup

*New Centre for Research-Based Innovation* (SFI) - *SmartForest: Bringing Industry 4.0 to the Norwegian Forest Sector*
Rasmus Astrup is the Project Manager of the *Centre for Research-Based Innovation* (SFI) project SmartForest, financed by The Research Council of Norway. SmartForest will position the Norwegian forest sector at the forefront of digitalization resulting in large efficiency gains in the forest sector, increased production, reduced environmental impacts, and significant climate benefits. SmartForest will result in a series of innovations and be the catalyst for an internationally competitive forest-tech sector in Norway. The fundamental components for achieving this are in place; a unified and committed forest sector, a leading R&D environment, and a series of progressive data and technology companies. Project period: 2020-2028.

3D representation of a forest
*Photo: Stefano Puliti, NIBIO*

## WP1.2 Bio-Resources, Environment, Climate - Francesco Cherubini

Norway has a non-negligible potential for biofuel production from domestically available biomass resources (mainly woody residues from the forestry industry), which is a promising strategy to stimulate a circular economy perspective, prevent additional pressure on terrestrial ecosystems, and revitalize rural areas. Our previous research within Bio4Fuels has estimated this annual potential and the corresponding biofuel capacity and climate change mitigation benefits when applied to the aviation sector (1). However, the national resources available under today's timber outtake volumes are not sufficient to meet the projected national targets and multiple needs for biofuels from the transport, industry, and residential sectors. A sustainable supply of biomass or biofuels from abroad is key to secure renewable energy use and high levels of climate change mitigation in Norway.

Our research in 2020 included an analysis published by Nature Sustainability of the global area of recently abandoned cropland and the corresponding global bioenergy potentials (2). Growing perennial grasses on recently abandoned cropland is a near-term strategy for bioenergy deployment with reduced risks for food security and the environment. We identified 83 million hectares of global abandoned cropland between 1992 and 2015, corresponding to 5% of today's cropland area. Bioenergy potentials are 6–39 exajoules per year (11–68% of today's bioenergy demand), depending on multiple local and management factors. About 20 exajoules per year can be produced by increasing today's global cropland area and water use by 3% and 8%, respectively, and without production inside biodiversity hotspots or irrigation in water-scarce areas. In another study, we compared energy potentials between bioenergy and PV on recently abandoned cropland to identify the most promising option at a local scale under a range of socio-economic constraints (3).

Our research in 2021 will further develop models and applications to quantify climate change mitigation benefits of advanced biofuels in Norway from domestic and imported resources, and assess the opportunities of biofuels for decarbonization of the road transport sector under the ongoing large-scale electrification of the vehicle fleet.

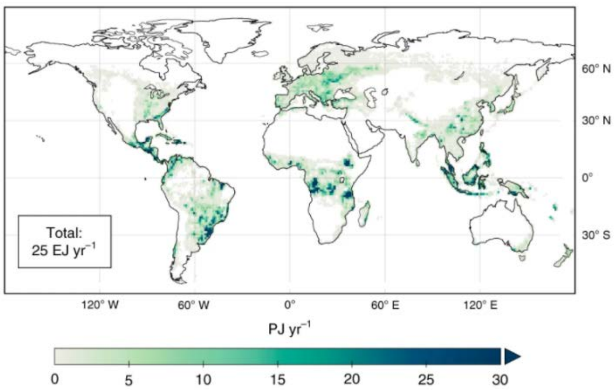



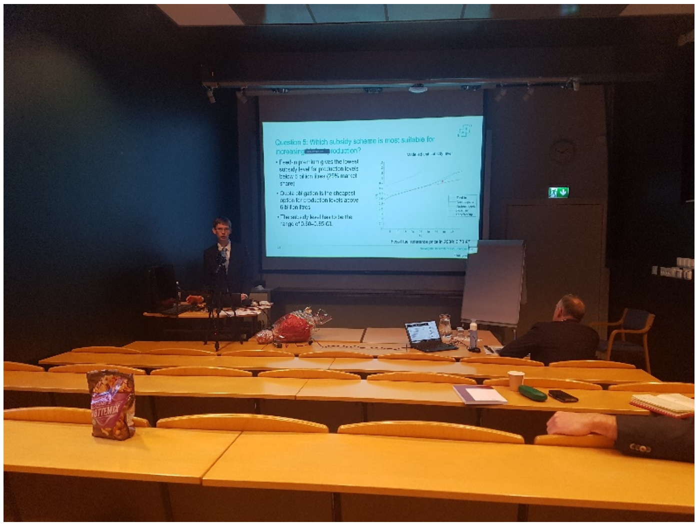

Fig.: Abandoned land (colourbox); bioenergy potentials (3)


(1) Cavalett O. and F. Cherubini (2018) Contribution of jet fuel from forest residues to multiple Sustainable Development Goals, Nature Sustainability 1: 799–807.
(2) Leirpoll M., J. S. Næss, O. Cavalett, M. Dorber, X. Hu, F. Cherubini (2021) Optimal combination of bioenergy and solar photovoltaic for renewable energy production on abandoned cropland. Renewable Energy, 168: 45-56.
(3) Næss, J.S., Cavalett, O. & Cherubini, F. The land–energy–water nexus of global bioenergy potentials from abandoned cropland. Nat Sustain (2021). https://doi.org/10.1038/s41893-020-00680-5.

## WP1.3 Energy, Fuels and Economics - Torjus Bolkesjø

### First Bio4Fuels PhD Candidate graduated

On December 1st, 2020 Eirik Ogner Jåstad defended his PhD thesis "Assessments of the role of bioenergy in the future Nordic energy and forest sectors". Eirik is the first of many Bio4Fuels PhD students graduating as doctors specializing on sustainable transportation solution based on biomass resources.



*Digital disputation. Photo: Per Kristian Rørstad*

In his doctoral thesis, Jåstad investigates the potential and sustainability of the production of biofuels and bioenergy from Nordic forest resources. Jåstad has determined how the forest and energy sector will adapt to the production of biofuels and bioheat and showed that the feasibility of biofuels production from woody biomass is strongly influenced by the development of international market prices.

### Linking sectoral models for improved insights

A main methodological contribution in Jåstad's work was to link a detailed energy system model (Balmorel) to a forest sector model (NFSM). Our aim was to increase the understanding of the combined forest and energy sectors and the feedbacks between these two sectors.

The study discusses the strengths and weaknesses of the integration procedure using a scenario where the fossil emissions in the Nordic countries are reduced by 73% from the 2017 level. The results show that it is likely that the integrated model presents the connection between heat and electricity production better than the two standalone models.

### Joint webinar on the role of bioenergy

On May 20th, 2020 Bio4Fuels WP1.3 and the project BioNEXT hosted a webinar focusing on the role of bioenergy in the future Nordic energy system – in cooperation with WP 1.1. The webinar addressed techno-economic aspects of various bioenergy solutions, market potentials as well as polices for a successful transition to a renewable energy system with bioenergy playing a major role. Close to 100 participants from research, industry, NGOs and the public sector attended the half day webinar.

| ***SP2: Liquefaction Processes*** |
|---|
| - Develop novel technologies for direct conversion of lignocellulosic feedstocks to transport biofuels – through pyrolysis and hydrothermal liquefaction<br>- Increase the robustness of the liquefaction and catalytic processes throughout the whole value chain.<br>- Increase the energy efficiency through the whole value chain |
| SP Leader: Judit Sandquist |

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| WP2.1 | Pyrolysis (Kai Toven, RISE PFI) |
| WP2.2 | Hydrothermal Liquefaction (Judit Sandquist, SINTEF ER) |
| WP2.3 | Thermochemical Upgrading (Roman Tschentscher, SINTEF Industry) |
| WP2.4 | Chemo-catalytic conversion (De Chen, NTNU) |

## *Background and approaches*

The liquefaction value chain focusses on one of the major routes for the conversion of solid biomass to biofuels and related products. The conversion processes involve high temperature treatments that aim to achieve the desired composition of the biofuel. The major challenge is to achieve this in as few processing steps as possible, minimising the overall costs.

This subproject includes two technologies, pyrolysis and hydrothermal liquefaction for biomass conversion to intermediates and two catalytic technologies, one to upgrade the bio-oils to transportation-quality biofuels and a chemo-catalytic conversion to valuable chemical- Ethylene glycol and Propylene glycol production. The sub-project uses mainly experimental approaches.

With regards to pyrolysis, biomass conversion by pyrolysis combined by anaerobic digestion to increase the overall energy efficiency of the process is investigated. In addition, a two-step pyrolysis process, pyrolysis with direct vapour upgrading to produce a higher quality suitable as drop-in fuel for marine or aviation fuel blends is being developed. The HTL work package focuses on the development of a more robust and feedstock flexible technology by understanding and controlling the inorganics during the process through experiments and modelling. In addition, operational challenges such as feeding depressurization and the influence of the feedstock properties are investigated in a continuous mini pilot.

The catalytic processes are focusing on increased simplicity and stability of the catalysts. For upgrading, development of a simple and robust catalytic bio-oil/biocrude upgrading process as well as fractionation and detailed analysis of the different streams are carried out. The main focus of the chemo-catalytic conversion is enhancing the catalyst stability of the copper catalyst.

**2020 SP2 Liquefaction Processes:** In *Pyrolysis* (WP2.1), the experimental results show that that by combining pyrolysis and anaerobic digestion, higher product yields on carbon basis can be obtained as compared to a pyrolysis process alone (no biomethane). In *HTL* (WP2.2) a new continuous mini-pilot has been commissioned and currently running experiments with slurries based on different feedstock. *Upgrading* (WP2.3) is in the process of finding the most suitable catalysts and processes for upgrading the biocrudes from pyrolysis and HTL to high energy density fuels. In *Catalytic conversion* (WP2.4) the stability of new Cu-based catalyst on carbon support was demonstrated after 50h operation time.

The stakeholder involvement is good in all WPs. The SP is generally on track with only slight delays due to the limitations on laboratory access during the pandemic.

Achievements

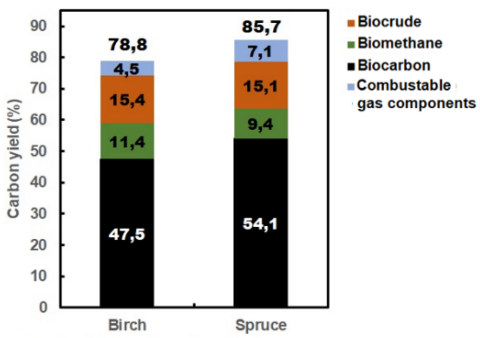
- Book chapter in Upgrading and PhD education and thesis in Catalytic conversion
- Significantly higher carbon efficiency in pyrolysis combined with anaerobic digestion
- Cu-catalyst has no deactivation after 50h
- HTL reactor is operative at SINTEF Energy Research facilities – milestone achieved.
- Co-organized the *Expert workshop Potential of Hydrothermal Liquefaction (HTL) routes for biofuel production* with five European H2020 projects. The workshop in Brussels attracted great interest and all major players within HTL have participated.
- The SP has several coupled EU projects, where the research is undertaken jointly

## WP2.1 Pyrolysis - Kai Toven

Pyrolysis processes are of particular interest for direct conversion of biomass and residue feedstocks into liquid biofuels, biochemicals and biocarbon materials. In Bio4Fuels, the research team at RISE PFI are addressing with two novel conversion routes for cost efficient production of biobased transportation fuel based on pyrolysis technology. First, coproduction of biogas transportation fuel, biocrude and biocarbon is addressed by combining intermediate pyrolysis technology and anaerobic digestion. Second, a novel two-step catalytic fast pyrolysis process is addressed as a route for direct conversion of lignocellulose feedstocks into a low molecular biocrude product suitable for upgrading into a pyrolysis oil quality suitable as drop in fuel in marine or aviation fuel blends.

In 2020, a highlight result is that the Bio4Fuels' research team at RISE PFI has demonstrated that coproduction of biogas transportation fuel, biocarbon and a biocrude product can be obtained with favorable carbon product yields by combining intermediate pyrolysis technology and anaerobic digestion (van der Wijst et al. 2020). Here, severe carbon loss in conventional carbonization processes can avoided by producing aqueous and organic condensates as byproducts and utilizing the aqueous condensate for biomethane production by anaerobic digestion. Product yields obtained in coproduction of biogas transportation fuel, biocrude and biocarbon from Norway Spruce and Birch wood is shown in Figure 1. Here, the biocrude byproduct cannot be utilized as transportation fuel so alternative applications for biocrude will be explored in 2021.

Dr. Kai Toven, Lead Scientist in Biorefining and Bioenergy at RISE PFI, is the National Team Leader for Norway in IEA Task 34 Direct Thermal Liquefaction. Participation in the IEA Task 34 secure cooperation with leading experts within this field.




a) b)

***Photo:*** *The Bio4Fuel research team at RISE PFI are exploring coproduction of biogas transportation fuel, biocrude and biocarbon by combining intermediate pyrolysis technology and anaerobic digestion a) Biocarbon and condensate intermediate pyrolysis byproducts b) Carbon product yields obtained in coproduction of biogas transportation fuel, biocrude and biocarbon from Norway Spruce and Birch wood.*

*Literature*

van der Wijst, C., Ghimire, N., Bergland, W.H., Toven, K., Bakke, R., Eriksen, Ø. (2020) Improved Carbon Balance for Biochar Production by Combination of Pyrolysis and Anaerobic Digestion. Submitted to BioResources

## WP2.2 Hydrothermal Liquefaction - Judit Sandquist

Hydrothermal liquefaction (HTL) is a thermochemical process that takes advantage of the water in the feedstock, at process conditions where the heat of evaporation for water is avoided. This makes the process very interesting for high moisture feedstock such as organic residues and sludges.

The technology uses high pressures and temperatures where the water is at sub- or supercritical state. At these conditions, the water alters its physical and chemical properties which result in chemical reactions that dissolve the organic structure of biogenic materials and convert them to fuel intermediates. Through the Norwegian national infrastructure project, NorBioLab2, SINTEF Energy Research has invested in a continuous lab-scale HTL mini-pilot system, which is now operational, and the first experiments are conducted. This means that **an important milestone** in Bio4Fuels HTL work package **is reached**.

The continuous HTL reactor has a capacity of maximum 2 L/h slurry feed and is able to operate at state-of-the-art conditions, i.e. up to 500 °C and 350 bar. The reactor is built with a research focus, for studying the effect of different feedstock, as well as operational issues, such as fate of inorganics, corrosion, and the effect of depressurization. To facilitate this objective and to counteract the small size, a CSTR reactor was selected. The mini-pilot is equipped with dual piston pumps and a two-stage depressurization system to study the depressurization effect on the product composition and distribution.

The first experiments were carried out both at sub- and supercritical conditions with wood powder as a feedstock in batch and continuous mode as well as algae and residual lignin in batch mode. The results are expected to be published in 2021.

## WP2.3 Thermochemical upgrading of bio oils - Roman Tschentscher

During the year 2020 several developments have been achieved despite the limited lab activities and travel restrictions. Those developments cover several aspects.

*Figure 1: Research visit to Nano4Fuels partner Anna University January 2020.*

The year started with a visit to the NanoCat4Fuel partner Anna University in Chennai/India. Several plans made for joint work and research visits need to be postponed. Still research work on catalytic upgrading of bio crude liquids has continued with further optimisations of the slurry catalyst system. Together with the Anna University the catalyst preparation method was simplified according to green-chemistry principles. As result only ethanol and water are used as solvents for the catalyst precursor. Moving from batch to continuous preparation the average catalyst crystallite size could be reduced below 3 nm, resulting in high activity.

Applying process conditions based on modern liquefaction technologies the degree of hydro-deoxygenation (HDO) is controlled by temperature, assuming sufficient $H_2$-availability. Significant HDO is achieved without addition of catalyst. Still, the catalytic system provides deep hydrogenation and some cracking activity

Methods and protocols for product fractionation and analysis by NMR and GC-MS/FID have been optimised and applied for various bio liquids including HTL oils, pyrolysis liquids and heavy refinery

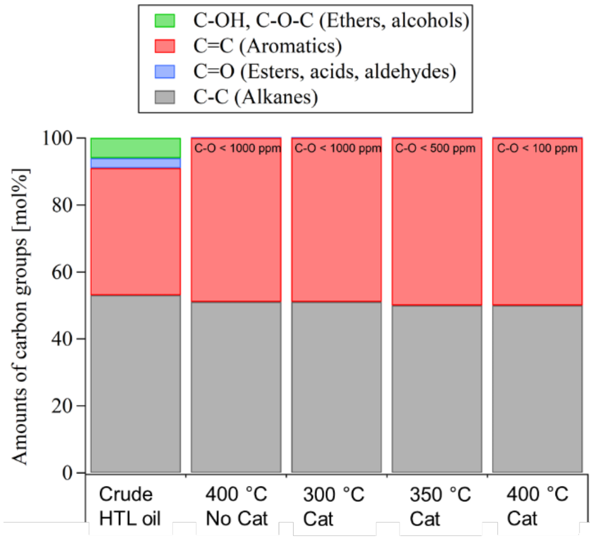



*Figure 2: Product fractions from catalytic and non-catalytic HDO of HTL crude.*

streams. While the focus before was towards the production of liquid fuels or precursors thereof. During 2020 the valorisation of product fractions for higher value applications, such as fillers, polymers etc. became more prominent.

In the field of electrochemical biomass conversion significant progress has been made at SINTEF Industry. Two new colleagues have been hired in Oslo to further strengthen the electrochemistry and catalysis expertise, while the lab capacity in the field was significantly expanded. In the running projects Liberate and Selectively the electrochemical lignin conversion has focussed on process optimisation at small pilot scale (TRL4), while in Trondheim the construction of a pilot unit (TRL 6) has been started by designing and purchasing of downstream fractionation and purification equipment. In addition, the H2020 project EBIO was funded and had its kick-off in December 2020, focussing on electrochemical stabilisation and co-processing of pyrolysis liquids and black liquor.

The extensive participation in webinars and online workshops in the field of catalytic and thermochemical biomass conversion have laid the basis for various proposal initiatives towards Horizon Europe projects with proposal ideas and consortia for biofuel and chemicals projects already taking on shape.

| SP3: Biochemical Processes |
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| SP Leader: Anikó Várnai |

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| WP3.1 | Pretreatment and Fractionation (Mihaela Tanase-Opedal, RISE PFI) |
| WP3.2 | Enzymatic Saccharification (Anikó Várnai, NMBU) |
| WP3.3 | Fermentation (Alexander Wentzel, SINTEF Industry) |
| WP3.4 | Anaerobic digestion and gas upgrading (Michał Sposób, NIBIO) |

## *Background and approaches*

This value chain focuses on applying biotechnology-based approaches to convert relevant biomass to biofuels and value-added chemicals. Softwood, such as Norway spruce, which constitutes Norway's largest proportion of land-based plant biomass, is known for its resilient structure and complexity and, therefore, has seldom been considered as feedstock for the biochemical production of biofuels. Biochemical conversion of biomass for 2$^{nd}$ generation bioethanol production is currently available commercially for perennial agro-based biomass. Based on these processes, the primary target of this subproject is to establish economically viable conversion of Norway spruce to a variety of biofuels, including ethanol, long-chain alcohols, microbial oil and methane, employing important recent technological improvements in the field. In the first step of the process, i.e. pretreatment, we focus on processing technologies that enable selective separation of lignin, hemicellulose and cellulose, and thereby facilitate efficient downstream use of all main constituents of lignocellulose feedstocks. In the following saccharification step, our target is to improve the currently suboptimal conversion yield and efficiency by identification of enzyme activities that are critical for softwood conversion and of process design that enables efficient use of novel oxidative enzymes. Next, we will assess a large collection of fermenting bacteria and oleaginous fungi for their potential to convert the solubilized sugars to short-chain alcohols, including ethanol, and microbial oil, respectively, in an industrially feasible way. Complementarily to this process, softwood with or without pretreatment will be subjected to anaerobic digestion to produce biogas. Here we will focus on enhancing biological methanation of biogas by optimizing process conditions and consider sorption-enhanced reforming of biogas for the industrially competitive production of hydrogen. In connection with SP5, we will assess the choice of fermentation technology, including the end product, and whether keeping the saccharification and fermentation steps separate or combining them is more feasible for softwood conversion with the selected technologies. Moreover, we will further enhance process efficiency by utilizing residual side streams from the saccharification and fermentation steps for methane production by anaerobic digestion.

**<u>2020 SP3 Biochemical Processes:</u>** Within *Pretreatment* (WP3.1), we have established a pilot-scale reactor at RISE-PFI to carry out organosolv pretreatment with lignin displacement, and the pretreatment technology has been optimized for lignin removal. Within *Enzymatic Saccharification* (WP3.2), we have established a small-scale reaction setup that allows optimization of novel enzyme blends as well as industrial setups that allow more efficient exploitation of the state-of-the-art enzyme cocktails and have already scaled up successfully a novel industrial setup in collaboration with Borregaard to demonstration scale at Borregaard's Demo Unit. With respect to *Fermentation* (WP3.3), we are working with St1 to improve their process efficiency using simultaneous saccharification and fermentation, while we have selected the best oil-producing fungi and optimized growth conditions for biooil production. Activities in *Anaerobic Digestion* (WP3.4), have successfully increased methane productivity during biogas production by supplying hydrogen to biogas reactor.

<u>Achievements</u>

- Successfully implemented a recently developed industrial setup for controlled and improved saccharification of Borregaard's feedstock with Novozymes' enzymes at demonstration scale at Borregaard's Demo Unit.
- Successfully increased methane productivity during biogas production by supplying hydrogen to biogas reactor.
- Success in characterization of the microbial community of a commercial-scale, food-waste biogas reactor using multi-omics approaches, which could enable us to improve the process design for enhanced methane production.

Several publications within prestigious journals, including scientific papers and conference presentations together with Borregaard.

*New Centre for Research-Based Innovation* (SFI) - *Industrial Biotechnology*
Håvard Sletta, Sintef, is the Project Manager of the *Centre for Research-Based Innovation* (SFI) project Industrial Biotechnology, financed by The Research Council of Norway. Industrial biotechnology entails the industrial application of modern biotechnological methods, enzymes and microorganisms for production of a very wide range of commodities, including chemicals, pharmaceuticals, food and feed ingredients, detergents, textiles, energy, materials and polymers. As industrial biotechnology is globally anticipated to become a major driver for establishing a sorely needed sustainable bioeconomy, there is a tremendous international activity concerning the development of new technological capability, new application domains, optimization of production pipelines and product diversification. The interest from the Research organisations and the industry partners in Centre for Industrial Biotechnology reflects the urgent need for establishing a nucleation point for a nationally concerted orchestration of R&D&I that can substantially strengthen Norway's position in this field. The four research organisations in the Centre (SINTEF, NORCE, NMBU and NTNU) possess together the major competence and infrastructure base in industrial biotechnology in Norway, and all 14 industrial partners have industrial biotechnology as a key business area with clearly defined innovation needs for maintaining a competitive edge. These innovation needs are the reason for SFI-IB, and they will be addressed in a potent matrix of a nationally concerted competence base, nationally integrated state-of the-art biotech infrastructures, and nationally coordinated training of future employees with state-of-the-art knowledge in bioprocess technology. In tune with the needs of the industry partners, SFI-IB will focus on four innovation domains (industrial

enzymes, biocatalytic processes, fermentation and gas fermentation/bioprocessing), and thus become a major national instrument for creating real value from the substantial investments in focal infrastructure and competence building made in Norway over the last ten years. Project period: 2020-2028.

## WP3.1 Pretreatment and Fractionation - Mihaela Tanase Opedal

In Bio4Fuels we have been working with developing a novel organosolv pretreatment process for selective fractionation of Norway spruce. Lignin extracted from acetone organosolv pretreatement process of Norway spruce has a high purity and abundance of reactive groups, which make this organosolv lignin suitable for production of high-value products. In this respect, manufacturing of lignin-based biocomposites could be a plausible option for replacing fossil oil-derived thermoplastic materials [1]. Additionally, biocomposites based on various biopolymers and reinforcing wood fibres have major potential for 3D printing operations, as we have recently demonstrated [2].

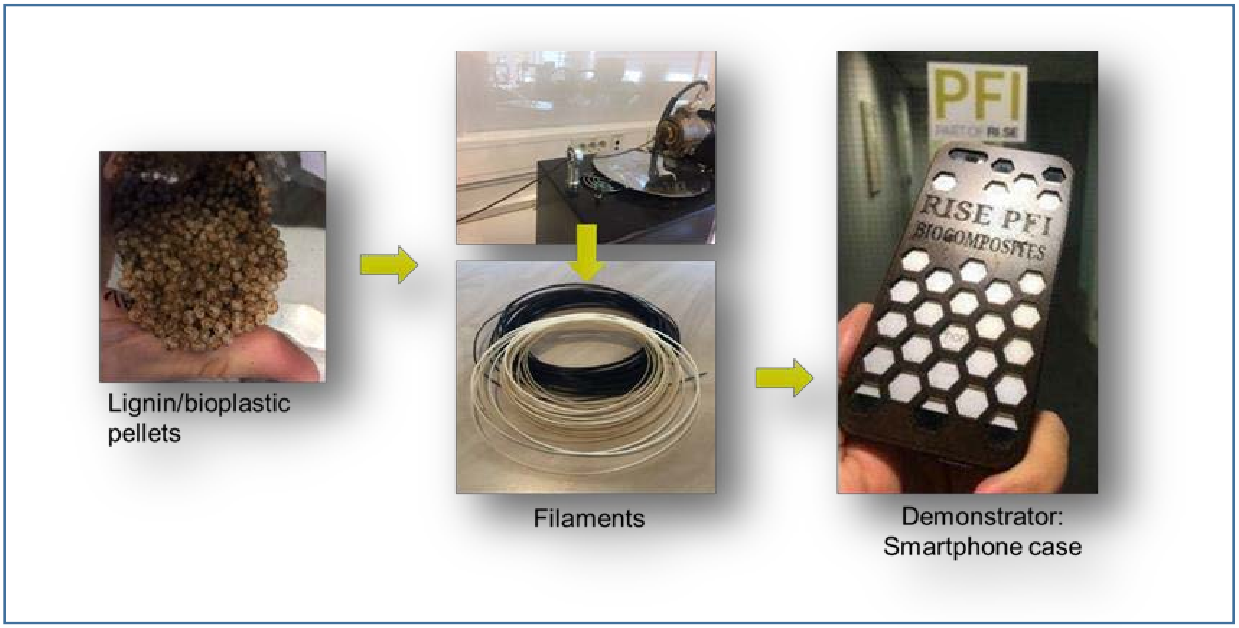



*Figure 1: Left) PLA/lignin pellets. Middle) Extrusion of PLA/lignin filament. Right) 3D printed demonstrator of PLA/lignin biocomposites.*

Reference:
1. Brodin, M.; Vallejos, M.; Opedal, M.T.; Area, M.C.; Chinga-Carrasco, G. Lignocellulosics as sustainable resources for production of bioplastics – a review. Journal of Cleaner Production, **2017**, 162, 646-664
2. Filgueira, D.M.; Holmen, S.; Melbø, J.K.; Moldes, D.; Echtermeyer, A.T.; Chinga-Carrasco, G. Enzymatic-assisted modification of TMP fibres for improving the interfacial adhesion with PLA for 3D printing. ACS Sustainable Chem. Eng., **2017**, 5 (10), 9338–9346.

## WP3.2 Enzymatic Saccharification - Anikó Várnai

Within the Enzymatic saccharification work package (WP3.2), we work in close collaboration with Bio4Fuels partners Novozymes and Borregaard towards improving the efficiency of today's state-of-the-art enzyme blends in depolymerizing softwood-type feedstocks, which are in abundance in Norway. One of the key components of these enzyme blends is lytic polysaccharide monooxygenases (LPMOs). One of our targets is to develop an industrial setup to improve the efficiency of commercial cellulase blends by harnessing the action of oxidative enzymes called LPMOs (lytic polysaccharide monooxygenases), a key component in today's enzyme blends, in a more efficient way than it is done in current industrial processes.

In 2020, scientific publishing has gotten more focus due to limited access to setting up experiments because of the Covid-19 pandemic. In the spring of 2020, the NMBU team and Borregaard published the results of the demonstration-scale saccharification study using $H_2O_2$ supply that was carried out at Borregaard's Demo Unit in a joint publication in the journal of *Biofuels, Bioproducts and Biorefining*. With $H_2O_2$ supply, 15% higher glucose yield was reached within 40% less saccharification time compared to the current state-of-the-art process setup that does not employ $H_2O_2$ supply. Importantly, these experiments were done at 2,000 L working volume, and represent the first ever demonstration of this revolutionary technology at such scale.

In the early summer, NMBU have published a review paper led by Dr. Anikó Várnai, in the prestigious journal of *Biotechnology Advances* on the "Heterologous expression of lytic polysaccharide monooxygenases (LPMOs)". In this extensive review, we presented the current status of LPMO production at bioreactor scale and strategies for scaling up LPMO production successfully, which are a prerequisite of the exploitation of these enzymes for various biotechnological applications at industrial scale. This publication is the result of international collaboration with researchers at Mutah University (Jordan) and at Beni-Suef University (Egypt).

In addition, we have published an invited review in a special issue of Journal of Industrial Microbiology and Biotechnology (JIMB) on "Frontiers in Industrial Microbiology and Biotechnology 2019". This extensive review provides an insight into the state of the art in the field of enzymatic processing of lignocellulosic biomass. This work is the result of a joint effort by two PhD students, Line Degn Hansen from Bio4Fuels and Heidi Østby from Enzymes4Fuels, an NFR-funded project that is associated with Bio4Fuels.

Alongside publishing and slowly resuming experimental work, Bio4Fuels has hired a new PhD student, Camilla Fløien Angeltveit, who started at NMBU in August 2020 and will work on enzymatic saccharification with a focus on the optimization of LPMO activation as well as the identification of limiting enzyme components in Novozymes' state-of-the-art cellulase cocktails. This work will entail close collaboration with Bio4Fuels partners Novozymes and St1.

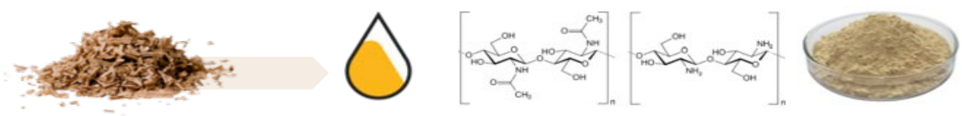
## WP3.3 Fermentation - Alexander Wentzel

**Simultaneous saccharification and fermentation (SSF) using a range of lignocellulosic biomass-derived substrates optimized for lipids and ethanol production.**

The WP3.3 highlights of 2020 have been characterized by the close interaction between partners SINTEF and NMBU. This resulted in two large experimental setups for the production of microbial lipids and ethanol using a variety of lignocellulosic biomass and hydrolysates provided by industrial partners Borregaard and St1 using enzyme mixes supplied by Novozymes.

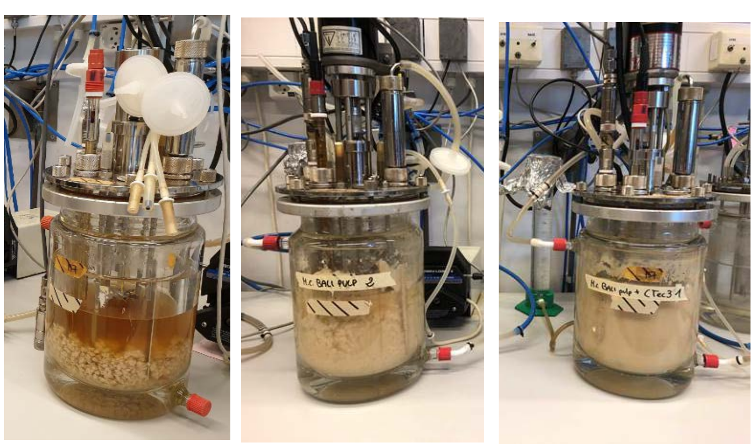
**The strains used for this purpose are:**
*Mucor circinelloides (NMBU) an* oleaginous Mucoromycota fungi have been identified as potential cell factories for the co-production of lipids and chitin/chitosan. (**Fig. 1 A**)

*Saccharomyces cerevisiae (SINTEF)* is the ethanol producing yeast *par excellence* dominating biofuel through industrial biotechnology. (**Fig. 1 B**)



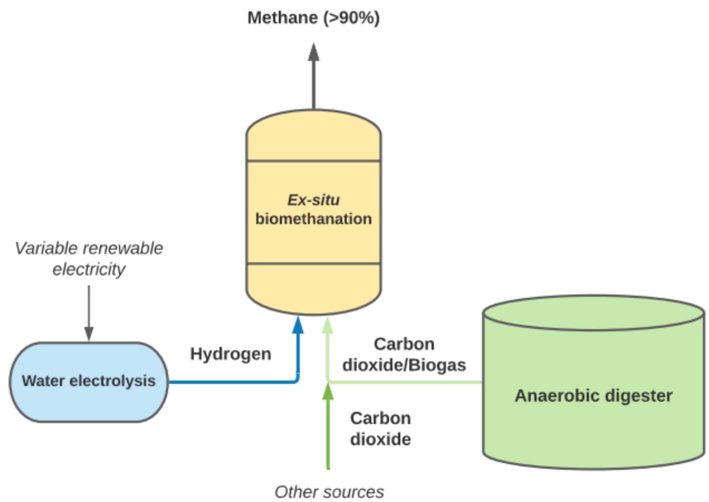
**The substrates used are:**

- Borregaard BALI$^{TM}$ pulp (cellulose pulp from Norway spruce) (**Fig. 2 A**);
- SSF: BALI$^{TM}$ pulp 10% w/w 6% CTec3
- Excello 90 (BALITM pulp hydrolysate) (**Fig. 2 B**);
- St1 substrate, (Pre-treated sawdust)

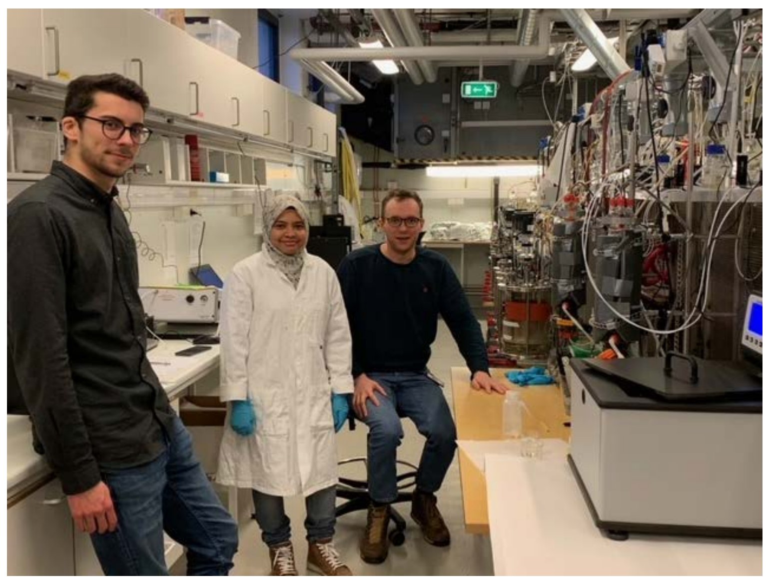



## WP3.4 Anaerobic digestion - Michał Sposób

### Biogas upgrading




In the recent years, methods for carbon dioxide ($CO_2$) reuse in biogas production gained much more research attention since these methods treat the $CO_2$ as a potential resource for e.g., methane ($CH_4$) production. Therefore, in 2020, at biogas lab (NIBIO/NMBU; Vollebekk, Ås) we developed a two new laboratory-scale reactor systems for *ex-situ* biomethantion (BM) studies (c. 1L each). These studies are focused on $CH_4$ production from $CO_2$ and hydrogen ($H_2$) based on the biological activity of hydrogenotrophic methanogens.



The performed tests and studies from continuous operation indicated their capability to produce $CH_4$. In the first experimental trial, the $CH_4$ of purity >95% was produced in the stable manner (at 50 °C and gas loading rate c. 10 $m^3/m^3d$). The internship student at NIBIO - Keno Fischer (Hochschule Bremen, Germany) was also involved in this work from October 2020 until January 2021.

Besides *ex-situ* BM, the other BM strategies such as *in-situ* and hybrid were tested, showing that addition of $H_2$ directly into digester improved $CH_4$ content and yield. For example, hybrid configuration (combined *in-* and *ex-situ*) obtained 60% of extra $CH_4$ compared to control reactor.

The further studies are currently ongoing where the dissemination of obtained results is going to be started in 2021 (e.g., during EUBCE 2021).

In parallel, at IFE's facilities, researchers investigate biogas upgrading for $H_2$ production with integrated $CO_2$ capture. The research looks into reforming glycerol with biogas, and preliminary experiments show that it is possible to produce >95% purity $H_2$ from biogas with 5% of glycerol. This is crucial to fully integrate biogas, biodiesel and gasification/pyrolysis plants to produce green $H_2$ with negative carbon emissions.

| *SP4: Process design and End Use* |
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| SP Leader: Morten Seljeskog |

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| WP4.1 | Gasification (Morten Seljeskog, SINTEF Energy) |
| WP4.2 | Gas Conditioning (Edd Blekkan, NTNU) |
| WP4.3 | Preparing for Piloting and Up-scaling (Klaus Jens, USN) |

## *Background and approaches*

Gasification is a thermochemical process were carbonaceous fuels are converted into combustible gases often referred to as syngas. There are different types of gasification technologies such as fixed- bed, fluidized-bed, and entrained flow. Depending on gasification temperature the ash inside the reactor is either molten or in a dry solid state.
The laboratory-scale reactor available for experimental activities in SP4 WP4.1, can be configured with simple geometric arrangements to operate both in entrained flow and in fixed/fluidized slagging bed mode, and as of such, is a highly flexible instrument to study so-called new “fuels of opportunity”, typically waste streams with high ash content and low marked end-value.
Biomass gasification and subsequent fuel and chemicals synthesis allows for a seamless transition from fossil raw materials to a renewable economy with a limited need to replace existing infrastructure, since the resulting fuels can be designed to fulfil all technical requirements of conventional engines.
A main hurdle in the development of this route is the thermal efficiency of the overall process, where gas cleaning and conditioning is an important factor. There are two relevant gasification routes for fuel synthesis: entrained flow and fluidized bed gasification. Syngas from such processes must be converted to syngas with a high efficiency in order to maximize the thermal efficiency of the process. Hot gas cleaning would be the most economical and efficient route, but in order to achieve a clean syngas many proposed technologies rely on liquid absorption, thus requiring gas cooling and subsequent reheating before further conversion. WP4.2 addresses the gas cleaning challenges in SP4.
Based on existing data from experimental work and simulations, reliable process models will be developed within SP4, for a complete gasification and gas cleaning system, eventually as a refinery integrated system. These models will be used to perform parameter variations to optimize process design. Flow behaviour will be simulated, while process concepts will be analysed using the flow sheeting software. Finally, optimized process combinations will be established, based on both simulation and experimental results from all WP’s and a theoretically optimal solution chosen for pilot plant design.

**2020 SP4 Gasification Processes:** Most goals and targets have been reached according to the annual plans, with no significant delays due to the Covid-19 situation. Several pilot-scale campaigns have been successfully performed on *Gasification* (WP4.1) in SINTEFs Entrained Flow Reactor and in USNs bubbling bed reactor. USN is also building competence on CFD and system simulations related to the scale-up and integration of the final full-scale biofuel plant (WP4.3). NTNU is progressing in their work on the development of catalytic technologies technology for *Gas Conditioning* (WP4.2) and have performed a number of related experimental campaigns. They are also developing numerical models for the same purpose.

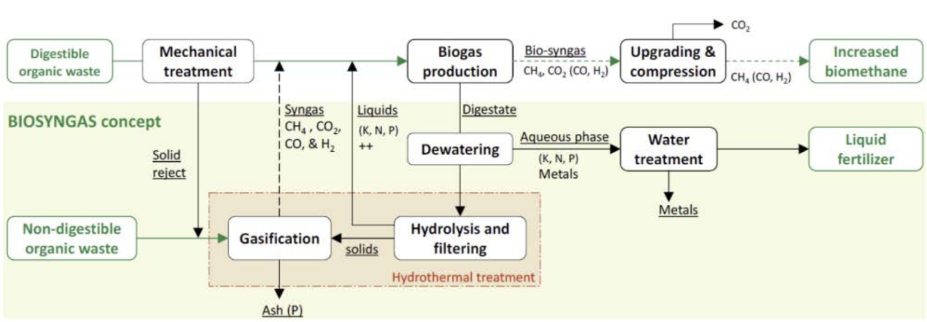
Achievements

- The Entrained Flow Reactor at SINTEF in Trondheim was operative in 2019 and has produced results for woody powder and dried sludge from Ecopro. Additional upgrades with a steam generator and reactor for pressurized experiments (up to 10 bars) have been installed to further enhance the conversion and the quality of the syngas.
- Fundamental research has also been performed to build numeric models to enable the prediction of ash behavior using specialized software tools, combined with experiments and CFD simulations (FLASH and Bio4Fuels projects).
- A kinetics-based simulation model has been developed using Barracuda® software and validated against the experimental results in a pilot-scale
- SINTEF Energy and USN partners in the EnergiX FLASH project, together with University of Natural Resources and Life sciences, Vienna and Aalto University.
- Nine peer reviewed publications.

## WP4.1 Gasification - Morten Seljeskog

The main highlights of WP4.1 during 2020 is the granting of two new associated projects , expanding the Bio4Fuels project portfolio within the gasification value chain, one of which has its focus at demonstration at high TRL scale. Details of the projects are as follows.

**BIOSYNGAS (Next generation Biogas production through the Synergetic Integration of Gasification)** aims at improving many aspects of biogas production plants in Norway. Biogas plants face numerous challenges, most of them related to the so called digestate, a by-product that should be exploited as it contains important nutrients that act as a fertilizer in agriculture. It is a wet/solid fraction that is generated after digesting the organic waste and producing biomethane. This fraction could contain micro-/macro plastics and heavy metals which gives challenges to its utilization. Also, it is available in large quantities making its transport quite costly and contributes negatively to the plant economy. BIOSYNGAS aims at solving these challenges by thermally treating this fraction and producing a range of by-products that will help improving the circular economy of nutrients in wastes. By integrating the thermal treatment with existing biogas plant, we can increase biomethane



production and overall process efficiency. Another benefit from including a thermal treatment step is that it broadens the type of organic waste that could be treated in biogas plants, increasing biogas production furthermore. BIOSYNGAS will investigate the use of by-products from the thermal treatment step as catalyst for enhancing the anaerobic digestion. The effect catalysts such as biochar and syngas (hydrogen) on the anaerobic digestion will be experimentally investigated. The project will also work on the development of the process through process modelling where the integration will be optimized and key parameters such as overall efficiency, environmental impact and profitability will be mapped and compared to existing standalone solutions. The project has a budget of 24 MNOK (2021 – 2025) and is a collaboration between SINTEF Energy Research (project owner) and NIBIO and includes two PhDs linked to NTNU and NMBU. The project will also collaborate with Zhejiang university of technology on hydrothermal gasification. Industry partners involved are, HRA, REG, VEAS, FREVAR, Lindum and Bergen Kommune.

“**Innovative modular energy recovery plant for waste which complies with the EU emissions directive**”, is funded by Innovation Norway for the south-coast based company TeamTec, for the engineering and construction of a small-scale waste-to-energy gasification plant. Gasification technology

being the Bio4Fuels connection. The main goal of the project is to demonstrate a new type of modular small-scale energy recovery plant for environmentally friendly management of municipal waste through successive prototype construction and critical testing for to achieve minimal emissions (EU requirements), optimal efficiency and good mechanical solutions - where the plant will be built on based on TeamTecs existing product portfolio. The project has been budgeted to 12 MNOK (2020 – 2022), with a research budget of about 3.5 MNOK.

## WP4.2 Gas Conditioning - Edd Blekkan

The rig for catalytic hydrocarbon reforming/water gas shift (WGS) has been redesigned and experimental work is underway. The syngas from the gasifier contains hydrocarbons and tar, these components need to be converted in order to maximize the efficiency of the process, to protect downstream units from fouling by tar. The composition of the syngas in terms of hydrogen to carbon monoxide ratio is usually far from ideal for the subsequent fuel synthesis, this also needs to be adjusted. This can be achieved by the WGS reaction. The goal is to establish an efficient and robust combined catalyst system for this purpose. The initial work is being done using a catalyst system developed for other biomass-based systems at NTNU, cobalt-nickel supported on a hydrotalcite-based mixed oxide. This system has previously been demonstrated to be very active and stable, and also appears to be very well suited for the task here. It is very active for methane reforming, and we find that the WGS equilibrium is simultaneously achieved, all at relevant conditions (see figure below).

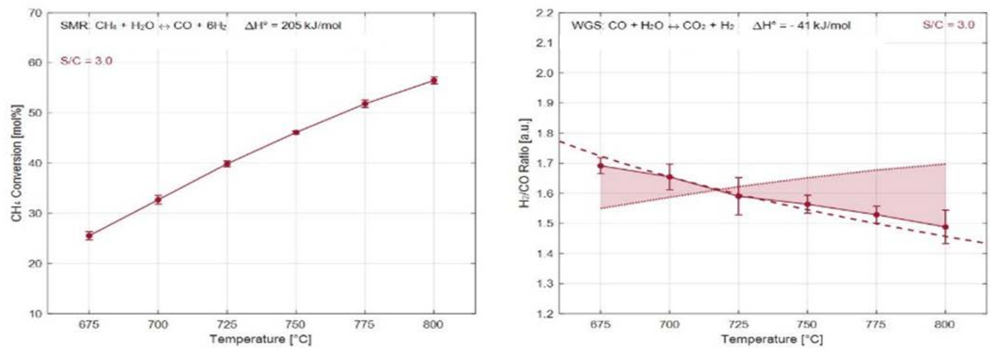



*Figure: Example showing the methane conversion (left graph) and resulting $H_2$:CO ratio (right curve) as a function of the temperature over a supported Co-Ni catalyst (run at high space velocity to investigate the kinetics of the reaction). Dashed line in the right-side graph represents the calculated $H_2$:CO ratio assuming WGS equilibrium. The inlet gas composition is based on a typical exit gas from a gasifier, and the experiment here is run with a steam to carbon ratio of 3.*

A second activity, the hydrocarbon production via the catalytic Fischer-Tropsch synthesis (FTS) was initiated by recruiting PhD student Oscar Luis Ivanez Encinas. The purpose of the work is to adapt the cobalt-based Fischer-Tropsch synthesis to the issues presented by using syngas from biomass gasification. In an initial study we will be using a model system, investigating the effect of one of the typical unwanted elements in biomass-based syngas, phosphorous. Phosphorous is present in most types of biomass and can find its way into the syngas stream if the gas cleaning units in the process are not operating properly. The ultimate goal of the activity is to test our catalyst system with a real syngas from biomass gasification.

## WP4.3 Preparing for piloting and up-scale – Marianne Eikeland (Klaus Jens)

The work package WP4.3 Preparing for piloting and upscale focus in upscale preparations of gasification reactors; Entrained gasifier at SINTEF Energy and Bubbling Fluidized Bed gasifier at USN. The next step is to develop a process simulation model to simulate the conversion of syngas into liquid biofuels or valuable chemicals like methanol.

Gasification is a relatively mature technology, where both SINTEF Energy and USN administer existing pilot systems. Data from these pilot systems form a basis for up-scaling procedures and this work will be utilized to prepare for piloting/up-scaling. Reliable simulation models for fluidized bed gasification and entrained flow gasification are developed in Barracuda VR software based on existing data from experimental work, simulations and litterature. These models will be used to analyse parameter variations to optimize the process design. An example of is given in the figure. The figure shows the change in gas compositions and change in reactor temperature at different heights in an entrained gasifier reactor, the feed is injected at the top of the reactor. The bottom plane of the reactor gives the product gas from the reactor, for further processing.

The process concepts will be analysed using the flow sheeting software Aspen PLUS. The first generation process flowsheets will then be the basis for conceptual design operations from which optimized process combinations will be established. A theoretically optimal solution will be chosen for pilot plant design. At the moment the methanol synthesis is being studied. The Fischer –Tropsch syntesis will also be evaluated.

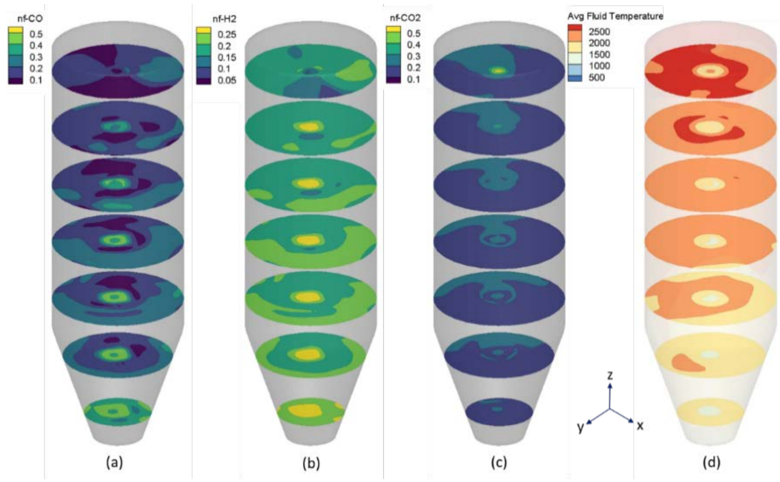



*Figure: Entrained gasifier parameters at different levels in the reactor: Instantaneous mole fraction for gas species: - (a) CO, (b) $H_2$, (c) $CO_2$ and (d) time average fluid temperature*

The cooperation with SINTEF Energy, who is responsible for the gasification, and NTNU, who is responsible for the gas conditioning, is of outmost importance to access relevant data. The cooperation between the institions have been strengten during 2020.

A discussion meeting was held at Herøya Industrial Park on utilization of gasification technology as a tool for the transition to sustainable circular economic production. A webinar is planned for Q1, 2021 to follow up this topic.

The results from 2020 are presented in the papers:

Timsina, Ramesh; Thapa, Rajan Kumar; Moldestad, Britt Margrethe Emilie; Eikeland, Marianne Sørflaten. **Experiments and computational particle fluid dynamics simulations of biomass gasification in an air-blown fluidized bed gasifier**. International Journal of Energy Production and Management 2020; Volum 5.(2) s.102-114

Timsina, Ramesh; Thapa, Rajan Kumar; Moldestad, Britt Margrethe Emilie; Eikeland, Marianne Sørflaten. **Simulation of entrained flow gasification reactor with Multi Phase Particle in Cell (MP-PIC) approach.** Linköping Electronic Conference Proceedings 2020 (176) s. 428-434

***SP5: Process design and End Use***

- Identify most promising process configurations
- Efficient and clean end use

SP Leader: Bernd Wittgens

| | |
|---|---|
| WP5.1 | Modelling Tool for Biorefineries (H. Preisig, NTNU) |
| WP5.2 | Techno-Economic Eval. / Scale of Economy (Bernd Wittgens, SINTEF Industry) |
| WP5.3 | Product quality and End Use (Terese Løvås, NTNU) |

## *Background and approaches*

The viability of processes and the quality of the products will be addressed using high level modelling tools for Biorefineries with an approach that requires biology, process technology, control and material properties to generate the predictive capabilities of the process models required for design and operations. Techno-Economic Evaluation will be applied to the initial crude process design giving an early phase cost estimation followed by in-depth analyses of the best candidate processes. A framework for process design analysis and optimization will be developed and jointly utilized for design and development of business cases for industrial implementation and thus generate insight into the framework needed for a successful commercialization of the most promising technologies.

With the view to the potentials for commercial implementation and piloting, process concepts will be analyzed and optimized using industrial flow sheeting software (e.g. ASPEN-HYSYS, ASPEN PLUS). The first-generation process flowsheets will then be the basis for conceptual design of process instrumentation and control philosophy.

Finally, the activities related to product Quality and End Use will aim to use state-of-the-art simulation and diagnostic tools to develop a framework for optimizing operational cost, energy efficiency and minimizing emissions from biofuel combustion. Focus will include regulated emissions such as NOx, CO, UHC and particulate emissions (soot). Fundamental combustion studies will be performed to map the overall performance of these fuels and ensure safe, clean and durable utilization of biofuels, including studies of new biofuels as well as sn effects of blending into conventional fuels. Approaches will look to coupling state-of-the-art two-phase flow modelling and combustion chemistry with advanced engine and turbine measurements and optical diagnostics tools.

**2020 SP5 Process Design and End Use:** With respect to *Modelling tool for biorefineries* (WP5.1), the two first sections of Ontology-based simulator generator are operating. Detailed modelling is in progress both for the suggested model process, the dual fermentation done in the associated NanoLodge project and selected DBFZ processes.

For the *Techno-Economic Evaluation* / Scale of Economy (WP 5.2), frameworks or implementation of core conversion units have been established, namely bio-chemical (conversion of sugar to butanol and butyric acid) and thermochemical conversion (pyrolysis and electro-chemical degradation of lignin). This includes proper implementation of chemical reactions and kinetics (though simplified). For *Product Quality and End Use* (WP5.3), both optical experimental laboratory and trained engine simulations are operational, and on-going fuel studies are progressing.

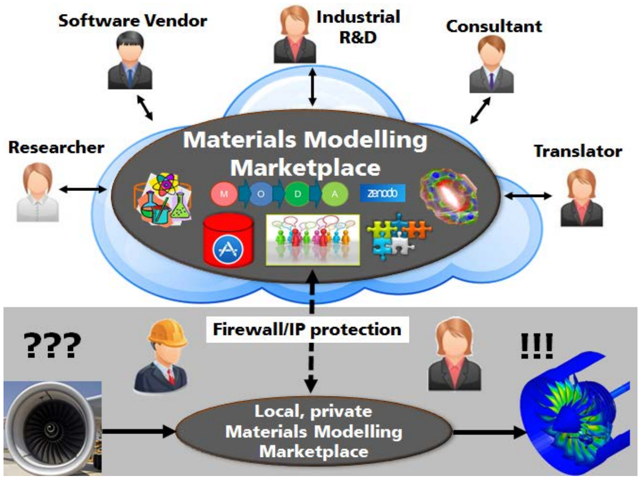
Achievements

- ProMo section associated with generating ontology and equations are operational, and cases for the automatic code generation have been performed.
- The graphical modelling of processes, developed at NTNU's Process Systems Engineering Group is suggested as a new international standard.
- A complete biochemical process has been modelled and costing has been performed, and a similar assessment for thermo-chemical processes particularly biooil up-grading and electro-chemical processing is nearing completion.
- PhD thesis in addition to numerous publications published, submitted and being drafted.

## WP5.1 Modelling Tool for Biorefineries - Heinz Preisig

Horizon2020 - The MarketPlace Project

The MarketPlace consortium aims at utilising state of the art information technologies to build an open web-based integrated Materials Modelling and Collaboration platform. It is to become a one-stop-shop and open Market-Place for providing all-determining components that need to be interwoven for successful and accelerated deployment of materials modelling in industry. MarketPlace links various activities and databases on models, information on simulation tools, communities, expertise exchange, course and training materials, lectures, seminars and tutorials.



The MarketPlace shall be a central-hub for all materials modelling related activities in Europe. It shall provide the tangible tools to connect disparate modelling, discipline experts with translators, and manufacturing communities to yield a vibrant collaboration web-based tool for advancing materials modelling in the European manufacturing industry. The developed platform will include the mechanisms for integrating an interoperable set of advanced materials model workflows that couple and link various discrete (electronic, atomistic, mesoscopic) and continuum models. MarketPlace will achieve interoperability by developing open and standard post and pre-processing methods that allow the complex flow of information from one model to another for both strongly and loosely coupled systems.
The MarketPlace platform will include access to a concerted set of federated databases of materials models, materials data, and access to experimental characterisation. MarketPlace stimulates the development of software interface wrappers and the use of Open Simulation Platforms. The consortium aims to strengthen the competitiveness and lower the European industry's innovation barrier for product development and process design and optimisation using materials modelling.
NTNU's Role:
NTNU's Process Systems Engineering group works on an ontology-based simulation environment, called ProMo, which utilises the MarketPlace facilities. The ProMo produces mathematical equations using ontologies and makes them available as an extension to the European Materials Modelling Council's EMMO, European Material Modelling Ontology (https://emmc.info/ and https://emmc.eu/ ).
ProMo then enables the construction of process models using a graphical tool and generates simulation code. All these facilities are used to model biofuel processes. We generate the basic building blocks for the chemical/biological processes and utilise them in the graphical editor to generate bio-process models. In fact, the ProMo project has its roots in this domain when modelling Life Support systems for NASA's mars-travelling project, which was called Pathfinder.
Web page: https://www.the-marketplace-project.eu/

## WP5.2 Techno-Economic Evaluation and Scale of Economy - Bernd Wittgens

The biochemical production of biofuels has been performed for several years, well known are the production of biodiesel (FAME) from fatty acids and ethanol from starch and sugar rich plants. The technologies for these conventional fuels are developed and optimization of these processes are generally performed. However, recently utilization of other feedstocks requires more advance conversion technologies where optimization in terms of yield and economics are still required.
The process which has been investigated is the conversion of lignocellulos derived sugars towards butyric acid, sub-sequent esterification with butanol to butyl-butyrate. The work is performed in close co-operation to work packages WP3.3 and 5.1. IN the early phase of the work a simple flowsheet was proposed (see Figure 1) which after analysis and verification with experimental data showed several short comings with respect to particularly the efficiency of the esterification route chosen.

Further work considered the optimization of the process flowsheet form the early draft (see Figure 1) to a more energy efficient and realizable process (see Figure 2). In parallel to the development of a new process configuration where energy consumption was the primary driver, the CAPEX costs of the process are evaluated. For evaluation, a unit operation sizing was performed based on experimental data form several associated projects. Scaling of the unit operations involved a combination of numbering-up of critical units (bio-reactors) where a maximum scale was exceeded and scale-up of more conventional systems (distillation columns).

Given the final design of the process, the capital and operational costs of the two systems where analysed. Even though the advanced system has a higher CAPEX cost, a substantial reduction in operation costs was observed.

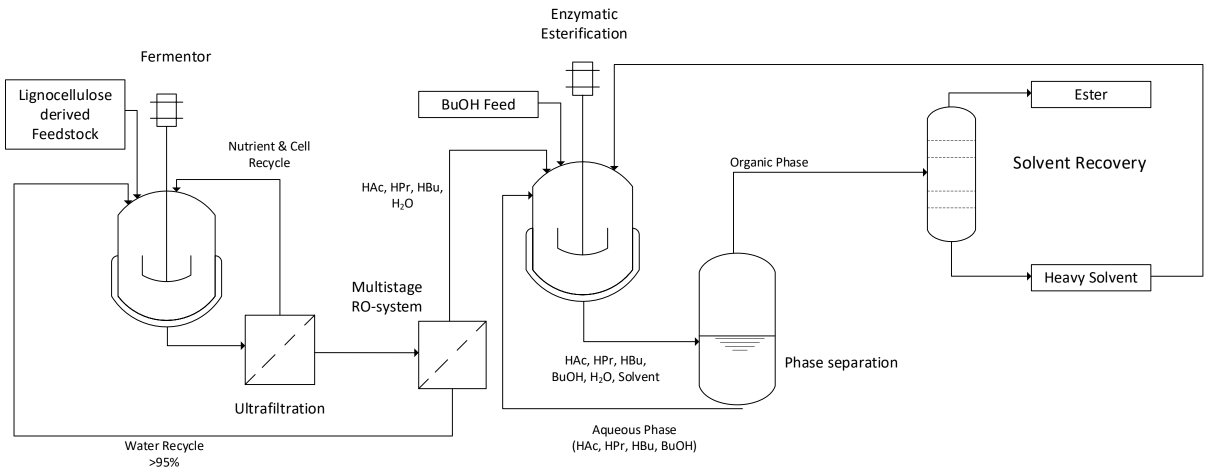
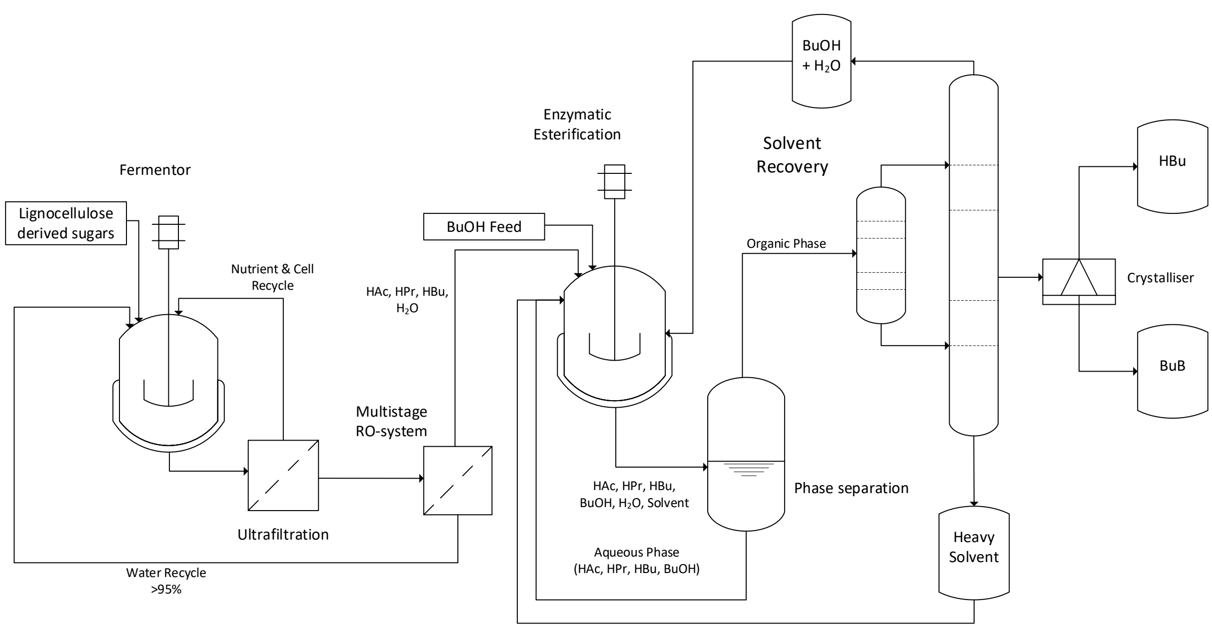


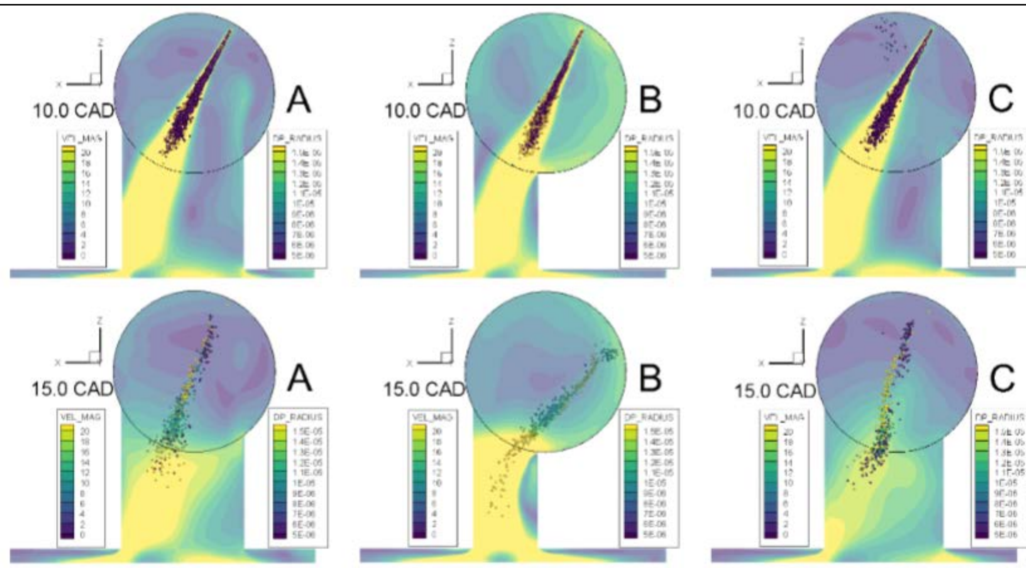

**Figure 1: Initial flowsheet and downstream processing**




**Figur 2: Advanced downstream separation with a multieffect distillation**

## WP5.3 Product quality and End Use - Terese Løvås

The work in this subproject is the study of current and new biofuels under relevant combustion conditions, with the focus on fuel conversion (to power) and emission control, for both regulated and unregulated emission.
The understanding of the in-flame combustion processes of relevant biofuels resulting in formation and oxidation of soot is of great importance since the underlying physical phenomena are not fully understood. Numerical simulations provide further insight into complex processes that are hard to capture in physical experiments, but the models used for running the simulations require validation from experimental results.
In addition to study combustion of relevant biofuels experimentally 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), we have advanced with our numerical modelling using machine learning approaches to optimize the representation of combustion of real fuels. We use trained engine simulation tools of combustion in the OACIC as well as study chemical models of biofuel surrogates. We have conducted a numerical study of the flow in a combustion chamber, which is dedicated and designed to investigate different fuel types under compression ignition conditions. We have furthermore extended the simulations to entire engine maps, in first instance for marine type engines, where varying fuel compositions and engine parameters were targeted for minimizing selected emissions such as soot and nitrogen oxides.

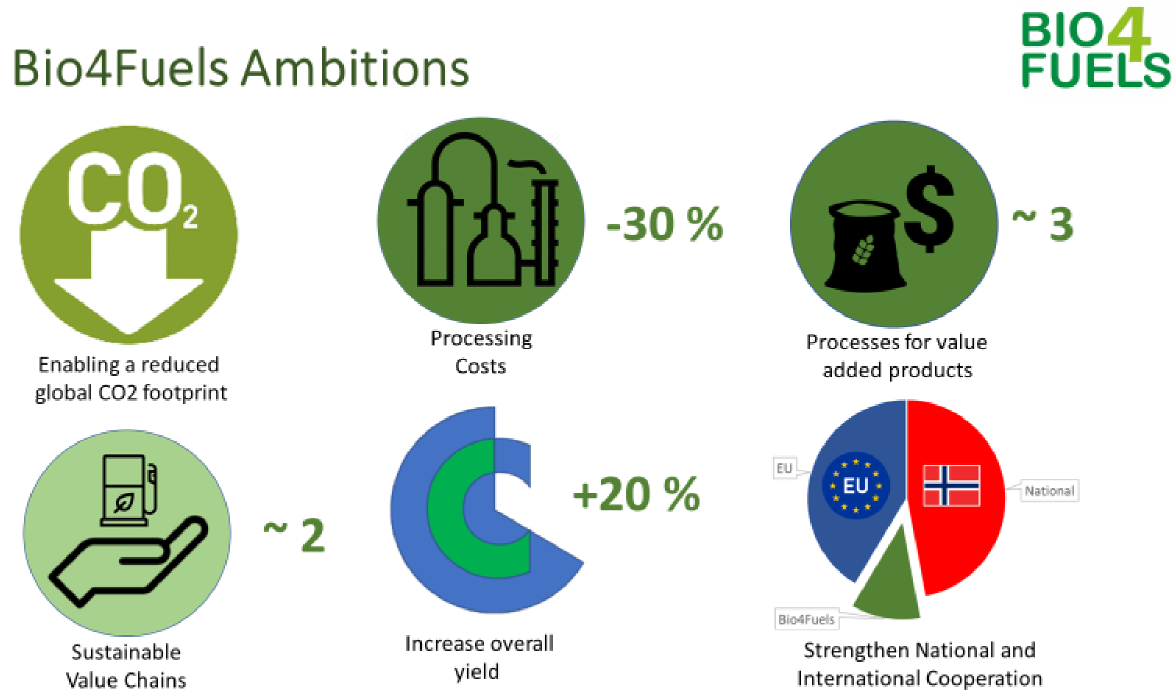


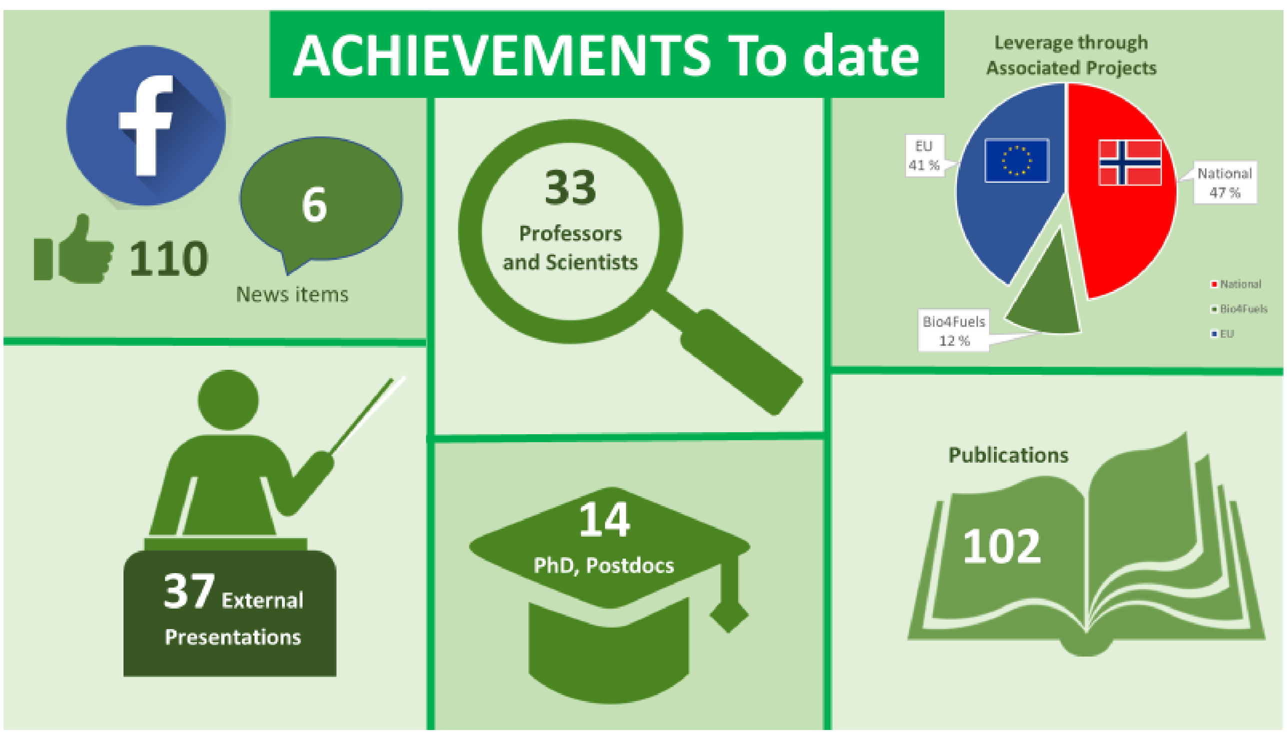

Spray propagation represented by spray parcels on background of velocity magnitude contour at y=0 plane for three studied geometries of the connecting throat between combustion chamber and engine's swept volume at four times 10 and 15 CAD aTDC.

***Publications 2020:***

Lewandowski, Michal; Netzer, Corinna; Emberson, David; Løvås, Terese.
Numerical investigation of optimal flow conditions in an optically accessed compression ignition engine. Transportation Engineering 2020; Volum 2

# Bio4Fuels' Key Performance Indicators



# INTERNATIONAL COOPERATION

Bio4Fuels has from the very start of the operation of the Centre had a significant level of international cooperation at all levels. This presentation presents and overview of the wide range of International engagement though out the Centres.

## INTERNATIONAL AGENCIES AND POLICY FORUMS

**IEA**

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 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.


## 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, given in Table below. This Nordic/European network is expanded through the involvement of associated partners, from the USA. These partners are active in the research activities and 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 Stakeholders | Country | Main interest |
|---|---|---|
| Biomass Technology Group | NL | Biomass to liquid (btl) pyrolysis |
| Johnson Matthey | UK | Chemical and catalytic processing of bio-feedstocks |
| Novozymes | DK | Enzymes for forest based biorefineries |
| Pervatech | NL | Membrane and separation systems for organic substrates |
| Haldor Topsøe | DK | Chemical/catalytic processes for several bio feedstocks |
| Steeper ENERGY | DK | Hydrothermal liquefaction |
| Lund Combustion Engineering ab | SE | Consultancy and software on combustion in motors |
| Preem | SE | Biofuels production and distribution in Sweden/Norway |
| Neste | FI | Upgrading of Biooil |
| Volvo Group Trucks Technology | SE | Truck engines powered by biofuels |

*Bio4Fuels' International Stakeholders*

## 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 in the Centre, most of the research partners have an extensive network of international contacts and collaboration. These include coordinating input to Mission Innovation, representation in EERA, involvement in mobilising input to the revision of the important SET plan for which the Bio4Fuels centre has been proposed as one of the Flagship projects in SET-Plan Action 8 (Renewable fuels and bioenergy) and participating and coordinating national input to the European Technology and Innovation Platform within Bioenergy (ETIP).

For Bio4Fuels, specific links are established with research groups and activities, as listed in the table below. at PNNL, Sandia and RTI in the USA. All partners were involved in the official kick-off of the Bio4Fuels centre and opportunities for collaboration within various international programs are being considered. Within the research topic of final end use of biofuels, Bio4Fuels partners are invited to receive information on the DOE funded project "Co-optima", through participation in the stakeholder Webinars.

Network of Associated Research Partners Outside Norway

| Project | Status | Project owner from Bio4Fuels | Contact Person | Type project | Financed by |
|---|---|---|---|---|---|
| AC2OCEM | Active | Sintef Energy | Mari Voldsund | EU | ACT |
| SiEUGreen | Active | NMBU/NIBIO | Melesse Eshetu Moges /Roar Linjordet | EU | H2020 |
| EHLCATHOL | Active | NTNU | De Chen | EU | EU |
| BL2F | Active | SINTEF Energy | Judit Sandquist | EU | EU - H2020 |
| NextGenRoadFuels | Active | SINTEF Energy | Judit Sandquist | EU | EU - H2020 |
| SET4Bio | Active | SINTEF Energy | Judit Sandquist | EU | EU - H2020 |
| EBIO | Active | SINTEF Industry | Roman Tschentscher | EU | EU |
| 4Refinery | Active | SINTEF Industry | Duncan Akporiaye | EU | EU - H2020 |
| BRISK2 | Active | SINTEF Industry | Bernd Wittgens | EU | EU - H2020 |
| LIBERATE | Active | SINTEF Industry | Bernd Wittgens | EU | EU - H2020 |
| Pulp&Fuels | Active | SINTEF Industry | Bjørn Christian Enger | EU | EU - H2020 |
| SelectiveLi | Active | SINTEF Industry | Bernd Wittgens | EU | EU - H2020 |
| Waste2Road | Active | SINTEF Industry | Duncan Akporiaye | EU | EU - H2020 |
| CONVERGE | Active | | Julien Meyer | EU | EU-H2020 |
| MEMBER | Active | | Julien Meyer | EU | EU-H2020 |
| FunEnzFibres | Active | NMBU | Vincent G.H. Eijsink | EU | ERA-Net – ForestValue program; RCN BIONÆR |
| Oxytrain | Active | NMBU | Morten Sørlie | EU | MC-ITN |
| Baltic Biomass4 Value | Active | NMBU, NIBIO | Erik Trømborg | EU | ERA-NET |
| BESTER | Active | SINTEF Industry | Alexander Wentzel | EU | ERA-CoBioTech Co-Fund; RCN and others |
| MarketPlace | Active | NTNU | Heinz Preisig | EU | Horizon2020 |
| CUBE (ERC Synergy grant) to V.G.H. Eijsink | Active | NMBU | Vincent G.H. Eijsink | EU | ERC |
| EEA-Baltic | Active | Tartu University (No from Bio4Fuels) | Lauri Vares | EEA - Baltic | EEA |
| ACTIVATE | Active | NTNU | Terese Løvås | Internal | RCN |
| CAHEMA | New | NTNU | Terese Løvås | Nordic | NER |
| Nordic Clean Enegy Sdenarios 2020 | Active | NMBU | Torjus Bolkesjø | Nordic | NER |
| FunAccess (NNF Emerging Investigator grant) to A. Varnai | Active | NMBU | Aniko Varnai | Nordic | NNF |
| DAFIA | Completed? | Aimplas (Spain) | Inga M Aasen | EU | EU - H2020 |

| | | | | | |
|---|---|---|---|---|---|
| Prowood | Completed? | INBIOTEC | Alexander Wentzel | EU | ERA-IB; RCN and others |
| ABC4Soil | Completed? | NTNU | | EU | FACE/EEA |
| METAFLUIDICS | Completed? | SINTEF Industry | Alexander Wentzel | EU | EU - H2020 |
| C1Pro | Completed? | NTNU | Trygve Brautaset | EU-ERA | ERA-CoBiotech; RCN and others |
| MicroDE (ERC Starting grant) to P.B. Pope | Completed | NMBU | Phillip B. Pope | EU | ERC |

## EU Research Projects

Many of the research partners involved in the Centre have established a significant portfolio of European projects, both from FP7 and H2020. As of 2020, Bio4Fuels research partners were involved in at least 24 active EU projects. The projects cover different stages of the Bio4Fuels value chain in addition to different ranges of TRL scale, with several projects focussing on pilot scale demonstration of key technologies. The engagement of the Bio4Fuels research partners in so many EU projects is an indication of the level of scientific expertise of the work being carried out in the Centre.

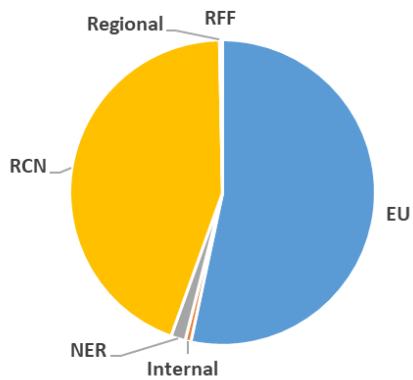



*Figure 3: Overview of the funding level from Projects associated with Bio4Fuels Centre as a proportion of all Bio4Fuels related activities, both internal and external.*

**Selected examples of current running associated EU projects within Horizon 2020** (click on the logos for more information):

4refinery · Liberate · PULP & FUEL pulp and paper industry waste to fuel · WASTE2ROAD · SiEUGreen · SElectiveLI · DAFIA · OXY train · Interreg Baltic Sea Region EUROPEAN UNION EUROPEAN REGIONAL DEVELOPMENT FUND BalticBiomass4Value · NEXTGEN roadfuels · BRISK · ABC Soil · C1Pro · MetaFluidics www.metafluidics.eu

## MOBILITY 2020

None of the Bio4Fuels' researchers have been visiting other Bio4Fuels partners for a longer period in 2020. There were, however, **six master's students** performing their thesis work at NTNU/NMBU this year, and in addition there was **one internship** at NIBIO.

# RECRUITMENTS AND EDUCATION

**PhD student Eirik Ogner Jåstad (WP1.3), 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 must increase with 2-3x from today's level or the producers have 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 are 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.

**Supervisors:** Per Kristian Rørstad and Torjus Folsland Bolkesjø, NMBU.

Eirik Ogner Jåstad defended his PhD degree on 1 December 2020.

**PhD student Junhui Hu (WP1.3), NMBU**

This PhD project will investigate the availability of forest-based biomass for biofuel production in both short term and long-term perspectives. The geographical border is expected to start with Norway and expand to Nordic countries and even Northern Europe.

The current annual harvest of forest is much less than the annual growth in Norway, and the government has set the target for total advanced biofuels used in road to 4% from 1st Jan 2020. This implies the huge potential and necessity for exploring the forest resources for producing the advanced biofuels from forest-based biomass, and this will play a vital role in phasing fossil fuel out in transportation sector and create a low carbon environment. However, the production of forest-based biofuel is far than mature due to various reason like technology immaturity, lacking policy support and raw materials competition.

The raw materials for forest-based biofuels are the biomass from harvest residues and by-products from sawmill, like chips, bark, sawdust, and shavings (as shown in the figure below). However, these materials will not only be used for biofuels, they are also in demand for other industries, like panels, pulp, and paper, as well as electricity and heat. Therefore, the availability and cost of forest-based biomass for biofuels becomes an important topic for discussing the cost and potential of biofuel production in the

future.
**Supervisor**: Per Kristian Rørstad, NMBU
Junhui Hu (June) is a new PhD student in Bio4Fuels; she started in October 2020.

**PhD student Martina Cazzolaro (WP2.4), NTNU**

This project is a part of the work package Catalysis for biomass conversion to chemicals, WP2.4 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 $H_2$ 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 spent 3 weeks in Haldor Topsoe in June 2018 to learn their experiences and I enjoyed a lot the stay there.
**Supervisors**: Jia Yang and De Chen, NTNU.
Martina Cazzolaro will defend her PhD during the summer 2020.

**PhD Student Line Degn Hansen (WP3.2), NMBU**

This PhD project is a part of the work package *Enzymatic saccharification* (WP3.2) 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 $H_2O_2$, 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.
**Supervisor**: Aniko Varnai, NMBU.
Line Degn Hansen will defend her PhD in October 2020.

**PhD student Camilla Fløien Angeltveit (WP3.2), NMBU**

This PhD project is a part of the work package Enzymatic saccharification (WP3.2) and will focus on lytic polysaccharide monooxygenases (LPMOs) role during enzymatic saccharification processes. The use of LPMOs together with the classical hydrolytic enzymes has been shown to greatly increase the depolymerization of lignocellulosic biomass. The ratio between hydrolases and accessory enzymes like LPMOs needs to be tailored for the specific substrates. Most commercial enzyme cocktails are tailored for agricultural waste biomass. In my PhD I will be focusing on creating better and more cost-efficient enzyme cocktails for depolymerization of softwood materials like Norway spruce.

Hydrogen peroxide appears to be the key to the successful depolymerization of polysaccharides by LPMOs. At the same time, the addition or production of hydrogen peroxide must be strictly controlled to hinder inactivation of the LPMOs. I will also investigate the role of LPMOs in simultaneous saccharification and fermentation processes (SSF) and determine the effect of hydrogen peroxide feed compared to in situ generated to improve the overall saccharification efficiency and yield.

**Supervisor**: Svein Jarle Horn, NMBU.

Camilla Fløien Angeltveit is a new PhD student in Bio4Fuels; she started in August 2020.

**PhD student Simona Dzurendova (WP3.3), NMBU**

The PhD project is part of the work package WP3.3, 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. Oleaginous fungi are able to perform concomitant production of lipids and other valuable components as for example chitin/chitosan and polyphosphate. 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.

**Supervisor**: Volha Shapaval, NMBU.

Simona Dzurendova will defend her PhD on 23 April 2021.

**PhD student Cristian Bolaño Losada (WP3.3), NMBU**

**Developing consolidated bioprocessing of lignocellulose materials**

IEA-roadmap reports that 20-30% of global energy demand could be supplied from the conversion of biomass. Lignocellulose biomass, due to its high abundancy and relatively low cost, has been positioned as one of the most important type of biomass for biofuels and biorefineries. Despite of almost a decade of research on the production of biofuels from lignocellulose biomass this process still suffers from the lower economical sustainability in comparison to the fossil-based processes.

In recent years it has been shown that lignocellulose materials can potentially be used to produce single cell oils (SCOs) by microbial fermentation and attention has been taken in microbial consortia or co-cultures with the aim to convert lignocellulose material to sugars directly in one step.

The main aim of the thesis is to develop a consolidated bioprocessing of lignocellulose material by utilizing microbial co-culturing and/or simultaneous saccharification and fermentation.

*The main sub-tasks:*

- Develop submerged fermentation of hydrolysed lignocellulose materials by oleaginous. filamentous Mucoromycota fungi as a reference bioprocessing of lignocellulose to SCOs.
- Investigate a possibility to co-culture cellulolytic fungi and oleaginous Mucoromycota fungi for SCOs production.
- Investigate to what extend simultaneous saccharification and fermentation process can be performed with a reduced amount of enzymes.
- To investigate a possibility to co-culture oleaginous fungi and algae by using hydrolysed lignocellulose materials.
- To utilize and develop application of vibrational spectroscopy for monitoring of CBP.

**Supervisor**: Volha Shapaval, NMBU.

Cristian Losada is a new PhD student in Bio4Fuels; he started in August 2020.

**PhD student Oscar Luis Ivanez Encinas (WP4.2), NTNU**

**Conversion of synthesis gas from fish waste gasification over cobalt catalysts**

The increasing development of the global industry demands further energy production. The main source of energy are the fossil fuels and their use has been increasing every year. In 2016, more than 80 % of primary energy in the world was provided by fossil fuels. The new policies and future scenarios, where the increased prices of the fossil fuels and the demand of cleaner fuels, make necessary alternatives of fuel production.

Within these alternatives, the interest in the Fischer Tropsch Synthesis (FTS) increased in recent years. The FTS converts synthesis gas to hydrocarbons. The selectivity of the FTS can be optimized in order to obtain different products. Among these products, light olefins represent added value compared to fuels, which always will be the main product.

The syngas can be produced from different sources such as natural gas, coal or biomass. One interesting feedstock for the syngas is the biomass. This renewable energy source is abundant and opens the possibility to improve the total yield of different industries by using waste as a feedstock for the FTS. The total aquaculture production in Norway in 2018 was 1.354.941 tons, with 68% of the amount being editable. This represents an opportunity to valorize the fish waste in order to reduce the economic loses and improve the efficiency of the industries.

In this context, cobalt-based catalysts are going to be studied in the FTS with emphasis on olefin selectivity from biomass, BTL. The catalysts are going to be prepared by different synthesis methods, characterized by several standard and advance techniques, and tested in the FTS. The reaction condition choose for the project will favor the light olefin production. Due to the selection of fish waste as feedstock for the syngas, the project will be focused on the effect of several components present on this syngas source, which could affect the performance of the catalytic activity and selectivity. In addition, in order to improve the catalytic activity and selectivity, different metal oxides and noble metals will be studied as catalysts promoters.
**Supervisor**: Edd Blekkan, NTNU.
Oscar Encinas is a new PhD student in Bio4Fuels; he started in August 2020.

**PhD Student Ramesh Timsina (WP4.3), 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.
**Supervisor**: Klaus Jens, USN.
Ramesh Timsina will defend his PhD in September 2021.

**PhD student Ask Lysne (WP4.2), NTNU**
**Catalytic Steam Reforming of Hydrocarbons from Biomass Gasification**

The increasing awareness of the effects of greenhouse gas emissions on the global environment has made the supply of renewable energy sources evident as a major challenge for future sustainable development. The International Energy Agency (IEA) has estimated a 42-50 % increase in the global energy demand by 2035 compared to the 2009 consumption. The transportation sector accounts for around 25 % of the global CO2 emission, where 90 % utilizes petroleum-based fuels. The substitution of currently applied fossil fuels by liquid fuels produced from renewable resources can hereby provide an efficient reduction of the global net CO2 emission. The annual growth of terrestrial plants stores more than 3 times the global energy demand, and biomass is in practice the only viable feedstock regarding production of renewable carbon-based liquid fuels. The successful integration of biomass gasification and Fischer-Tropsch synthesis in biomass-to-liquid fuel (BTL) technology is however limited by the intermediate gas conditioning of the synthesis gas (syngas)

requiring the removal of inorganic, organic and particulate contaminants and adjustment of the composition in order to adapt to the subsequent catalytic fuel synthesis process step. The elimination of tars is one of the most cumbersome challenges to the commercialization of such processes. The PhD project is addressing catalytic steam reforming, converting tars and lighter hydrocarbons to syngas as well as H2/CO/CO2 ratio adjustment by the water-gas shift reaction as part of this key gas conditioning step. The performance of a series of mixed oxide Ni-Co/Mg(Al)O catalysts prepared from hydrotalcite precursors are currently being investigated.
**Supervisor**: Edd A. Blekkan, NTNU. Co-supervisor: Kumar R. Rout.
Ask Lysne started as a PhD student in Bio4Fuels in August 2019.

**PhD student Zhongye Xue (WP5.3), NTNU**

Experimental and Numerical Study of Low-Carbon Biofuels in Internal Combustion Engines. New PhD student September 2020.
This project is focuses on a detailed experimental and numerical investigation of 2nd generation type biofuels in compression ignition engines. Various combustion parameters will be investigated with a focus on emissions of $NO_x$ and soot. Fundamental experimental research on combustion of the biofuels will be carried out in collaboration with the current research team, employing a well-equipped engine laboratory and specially designed combustion rig with optical access for optical measurements. This enables detailed studies of the ignition and flame structure in the combustion chamber as well as particle formation. Matching the experimental data with results from detailed kinetic simulations using a stochastic reactor model will be an important part of the PhD project.
**Supervisor**: Terese Løvås, NTNU.
Zhongye Xue is a new PhD student in Bio4Fuels; he started in September 2020.

## COURSES GIVEN BY BIO4FUELS RESEARCHERS

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

### Courses at 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)
Chemical Engineering, Specialization Project, 15 credits (ECTS)
Industrial Chemistry and Refining, 7,5 credits (ECTS)
Reaction Kinetics and Catalysis, 7,5 credits (ECTS)
Experts in Teamwork - Biofuels - a Solution or a Problem? 7,5 credits (ECTS)
Biofuels and Biorefineries, 7,5 credits (ECTS)

### Courses at NMBU

Biogas Technology, 5 credits (ECTS)
Bioenergy, 10 credits (ECTS)
Applied Biocatalysis and Biorefining, 5 credits (ECTS)
Energy and Process Technology Main Topic, 15 credits (ECTS)

### Courses at USN

Bachelor:
Bærekraftig ressursutnyttelse (Sustainable Resource Management), 10 credits (ECTS)
Organisk kjemi med biopolymere (Organic Chemistry with Biopolymers), 10 credits (ECTS)
Separasjonsteknikk (Separation Technology),10 credits (ECTS)
Energieffektivisering (Energy Efficiency) , 10 credits (ECTS)
Fornybare energisystemer (Renewable Energy Systems), 10 credits (ECTS)
Klima, miljø og LCA (Climate, Environment and LCA), 5 credits (ECTS)

Master:
Gas Purification and Energy Optimization,10 credits (ECTS)
Water Treatment and Environmental Biotechnology, 10 credits (ECTS)
Combustion and Process Safety, 10 credits (ECTS)
Energy Technology, 10 credits (ECTS)
Process Technology and Equipment, 10 credits (ECTS)

# Personnel and Recruitment

## Personnel

| Name leader | Institution | Main research area |
|---|---|---|
| Rasmus Astrup (WP 1.1) | **NIBIO** | Land, Resources and Ecosystem processes |
| Francesco Cherubini (WP 1.2) | **NTNU** | Bio-Resources, Environment, Climate |
| Torjus Bolkesjø (WP1.3) | **NMBU** | Energy, Fuels and Economics |
| Kai Toven (WP 2.1) | **RISE PFI** | Pyrolysis |
| Judit Sandquist (WP 2.2) | **NTNU** | Hydrothermal Liquefaction |
| Roman Tschentscher (WP 2.3) | **SINTEF** | Thermochemical upgrading of bio oils |
| De Chen (WP 2.4) | **NTNU** | Chemo-catalytic conversion |
| Mihaela Opedal (WP 3.1) | **RISE PFI** | Pretreatment and Fractionation |
| Aniko Varnai (WP 3.2) | **NMBU** | Enzymatic Saccharification |
| Alexander Wentzel (WP 3.3) | **SINTEF** | Fermentation |
| Michal Sposob (WP 3.4) | **NIBIO** | Anaerobic digestion and gas upgrading |
| Morten Seljeskog (WP 4.1) | **SINTEF** | Gasification |
| Edd Blekkan (WP 4.2) | **NTNU** | Gas Conditioning |
| Klaus Jens (WP 4.3) | **USN** | Preparing for piloting and up-scale |
| Heinz Preisig (WP 5.1) | **NTNU** | Modelling Tool for Biorefineries |
| Bernd Wittgens (WP 5.2) | **SINTEF** | Techno-Economic Evaluation and Scale of Economy |
| Terese Løvås (WP 5.3) | **NTNU** | Product quality and End Use |
| | | |
| Francesco Cherubini (SP1) | **NTNU** | Bio-resource, Environment and Climate |
| Judit Sandquist (SP2) | **SINTEF** | Liquefaction Processes |
| Aniko Varnai (SP3) | **NMBU** | Biochemical Conversion |
| Morten Seljeskog (SP4) | **SINTEF** | Gasification Processes |
| Bernd Wittgens (SP5) | **SINTEF** | Process design and End Use |
| | | |
| Duncan Akporiaye | **SINTEF** | Centre Leader |
| Svein Jarle Horn | **NMBU** | Vice Centre Leader |
| Odd Jarle Skjelhaugen | **NMBU** | Project Leader |
| Janne Beate Utåker | **NMBU** | Administrator |
| Ann-Solveig Hofseth | **NMBU** | Financial Officer |
| Bente Poulsen | **NMBU** | Communication Officer (Dec) |

## Recruitment

### PhD Students with finance from the Bio4Fuels budget:

| Name | Nationality | Duration | Gen der | Topic |
|---|---|---|---|---|
| Angeltveit, Camilla F. | Norwegian | 17.08.2020 – 16.08.2023 | F | The role of LPMOs during enzymatic saccharification processes |
| Cazzolaro, Martina | Italian | 01.08.2017 – 01.09.2021 | F | Catalytic biomass conversion |
| Dzurendova, Simona | Slovakia | 14.09.2017 – 23.04.2021 | F | Bioconversion of lignocellulose materials into lipid rich fungal biomass. |
| Encinas, Oscar L. I. | Spanish | 24.08.2020 – 24.10.2023 | M | Conversion of synthesis gas from fish waste gasification over cobalt catalysts |
| Hansen, Line Degn | Danish | 01.06.2017 – 31.05.2021 | F | Optimization of enzymatic conversion of biomass to platform chemicals |
| Hu, Junhui | Chinese | 05.10.2020 – 04.10.2023 | F | Analyzing the role of biomass and biofuel in the Nordic energy, forest and transportation sectors towards 2050 |
| Jåstad, Eirik Ogner | Norwegian | 01.02.2017 – 31.12.2020 | M | Models for Economic Assessments of Second-Generation Biofuel Production |
| Losada, Cristian B. | Spanish | 10.04.2020 – 10.04.2023 | M | Fermentation on developing multi-organism system for lipid production |
| Lysne, Ask | Norwegian | 12.08.2019 – 11.08.2022 | M | Catalytic Steam Reforming of Hydrocarbon Impurities from Biomass Gasification |
| Timsina, Ramesh | Nepal | 24.09.2018 – 23.09.2021 | M | Preparing for Piloting and Up-Scale |
| Xue, Zhongye | Chinese | 16.09.2020 – 15.09.2023 | M | Experimental and Numerical Study of Low-Carbon Biofuels in Internal Combustion Engines |

### Postdoctoral Researchers with financial support from Bio4Fuels budget

| Name | Nationa | Duration | Gender | Topic |
|---|---|---|---|---|
| Cavalett, Otávio | Italian | 18.08.2017 – | M | LCA of biofuels in Norway |
| Lewandowski, Michal | Poland | 04.04.2019 – | M | Product quality and End Use |
| Morales, Marjorie | Chile | 01.09.2019 – | F | Bio-resource, Environment |
| Müller, Gerd | Austria | 8 months 2017 | M | Enzymatic Saccharification |
| Wahid, Radziah | Malaysi | 01.03.2017 – | M | Biogas |

## Other researchers

| Name | Institution | Name | Institution |
|---|---|---|---|
| Julien Meyer | IFE | Alex Nelson | IFE |
| Antonio Oliviera | IFE | Saimi Sultana Kasi | IFE |
| | | | |
| Roar Linjordet | NIBIO | Tormod Briseid | NIBIO |
| Hege Bergheim | NIBIO | Roald Aasen | NIBIO |
| Micky Gale | NIBIO | Trine Eggen | NIBIO |
| Thorsten Heidorn | NIBIO | Rikard Pedersen | NIBIO |
| Ove Bergersen | NIBIO | Ksenia Gulyaeva | NIBIO |
| Linn Solli | NIBIO | Carolin Fischer | NIBIO |
| | | | |
| Boris Zimmermann | NMBU | Achim Kohler | NMBU |
| Per Kristian Rørstad | NMBU | Aniko Varnai | NMBU |
| Erik Trømborg | NMBU | Volha Shapaval | NMBU |
| Valeria Tafitseva | NMBU | Vincent Eijsink | NMBU |
| Yi-Kuang Chen | NMBU | | |
| | | | |
| Majorie Morales | NTNU | Otavio Cavalett | NTNU |
| Jia Yang | NTNU | David Emberson | NTNU |
| Christian Frugone | NTNU | | |
| | | | |
| Øyvind Eriksen | RISE Pfi | Jost Ruwoldt | RISE Pfi |
| Gary Chinga | RISE Pfi | Cornelis van der Wijst | RISE Pfi |
| Ingebjørg Leirset | RISE Pfi | Mirjana Filipovic | RISE Pfi |
| Johnny Melbø | RISE Pfi | Kristin Stensønes | RISE Pfi |
| Anne Marie Reitan | RISE Pfi | Romeo Celaya | RISE Pfi |
| Javier C Romeo | RISE Pfi | Mirjana Filipovic | RISE Pfi |
| | | | |
| Liang Wang | SINTEF Energy | Jørn Bakken | SINTEF Energy |
| Michaël Becidan | SINTEF Energy | Annar Bremnes | SINTEF Energy |
| Øyvind Skreiberg | SINTEF Energy | Mathias Vikse | SINTEF Energy |
| Per Carlsson | SINTEF Energy | Helen Langeng | SINTEF Energy |
| Alamo del Gonzalo Serrano | SINTEF Energy | Olaf Lehn Tranås | SINTEF Energy |
| Roger Khalil | SINTEF Energy | Per Egil Gullsvåg | SINTEF Energy |
| Inge Saanum | SINTEF Energy | Jostein Bakken | SINTEF Energy |
| Jorunn Hølto | SINTEF Energy | Einar Jordanger | SINTEF Energy |
| Vegard Hermstad | SINTEF Energy | Cancu Birgen | SINTEF Energy |
| | | | |
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| Håvard Sletta | SINTEF Technology | Olav Trygve Berglihn | SINTEF Technology |
| Sidsel Markussen | SINTEF Technology | Francesca Bartolomeo | SINTEF Technology |
| Bendik Sægrov-Sorte | SINTEF Technology | Anders Brunsvik | SINTEF Technology |
| Merete Wiig | SINTEF Technology | Inga Marie Aase | SINTEF Technology |

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|---|---|---|---|
| Torbjørn Petterssen | SINTEF Technology | Morten Frøseth | SINTEF Technology |
| Kari Hjelen | SINTEF Technology | Tonje Heggeset | SINTEF Technology |
| Snorre sulheim | SINTEF Technology | Martin Fossen | SINTEF Technology |
| Tor Erling Unader | SINTEF Technology | Kolbjørn Zahlsen | SINTEF Technology |
| Torbjørn Pettersen | SINTEF Technology | Bjørn Tore Løvfall | SINTEF Technology |
| Rune Lødeng | SINTEF Technology | Camilla Otterlei | SINTEF Technology |
| Silje Håkonsen | SINTEF Technology | Joanna Pierchala | SINTEF Technology |
| Håkon Bergem | SINTEF Technology | Elisabeth Liland | SINTEF Technology |
| Ana Flavia | SINTEF Technology | Jana Chadek | SINTEF Technology |
| Rune Myrstad | SINTEF Technology | Gunnhild Hageskal | SINTEF Technology |
| Giang-Son Nguyen | SINTEF Technology | Krishnamurthy Shreenath | SINTEF Technology |
| Jayasayee Kaushik | SINTEF Technology | Tonje M Bjerkan Heggeset | SINTEF Technology |
| Malene Jønsson | SINTEF Technology | Heiko Gaerter | SINTEF Technology |
| Marit Dyrendahl | SINTEF Technology | Silje M Olsen | SINTEF Technology |
| Deni Koseto | SINTEF Technology | Ingemar Nærdal | SINTEF Technology |
| Janne Beate Øiaas | SINTEF Technology | Anna Nordborg | SINTEF Technology |
| Birgitte H Di Bartolomeo | SINTEF Technology | Marianne S Kjos | SINTEF Technology |
| | | | |
| Marianne Eikeland | USN | Britt Moldestad | USN |

# Media, Publications and Dissemination

Data from Cristin https://app.cristin.no/

## Communication and Outreach 2020

**Byrtusova, Dana; Shapaval, Volha; Kohler, Achim; Haronikova, Anna; Marova, Ivana.**
Studying the co-production of lipids and -glucans in carotenogenic Basidiomycetes and Ascomycetes yeasts. European Biotechnology Congress; 2020-04-16 - 2020-04-18 NMBU

**Cavalett, Otávio; Cherubini, Francesco.**
Opportunities for climate change mitigation from biofuels in the road transport sector in Norway. Alternative Fuels Group at Equinor; 2020-12-02 - 2020-12-02 NTNU

**Cherubini, Francesco.**
Sustainable aviation fuels and climate change. ICAO Stocktaking seminar; 2020-09-08 - 2020-09-11 NTNU

**Cherubini, Francesco.**
Sustainable biofuels and bioproducts in a defossilized economy. Carbon management policies: global practices in sustainability indicators and assessment; 2020-10-22 NTNU

**Cherubini, Francesco.**
Vi kan ikke løse klimaproblemet først, og naturproblemet etterpå. ABC Nyheter [Internett] 2020-05-02 NTNU

**Costa, Thales; Kadic, Adnan; Chylenski, Piotr; Varnai, Aniko; Bengtsson, Oskar; Lidén, Gunnar; Eijsink, Vincent; Horn, Svein Jarle.**
Enzymatic saccharification of sulfite-pulped spruce at demonstration scale with addition of hydrogen peroxide for LPMO activation. 42nd Symposium on Biomaterials, Fuels and Chemicals; 2020-04-26 - 2020-06-29 NMBU

**Dzurendova, Simona; Zimmermann, Boris; Kohler, Achim; Tafintseva, Valeria; Kòsa, Gergely; Forfang, Kristin; Blomqvist, Johanna Karin Hillevi; Langseter, Anne Marie; Shapaval, Volha.**

Application of Fourier transform infrared spectroscopy for developing, monitoring and control of microbial bioprocesses. European Biotechnology Congress 2020; 2020-09-24 - 2020-09-26 NMBU

**Horn, Svein Jarle.**
Bio4Fuels Autumn Newsletter 2020. NMBU

**Horn, Svein Jarle.**
Bio4Fuels Summer Newsletter 2020. NMBU

**Pujan, Robert; Nitzsche, Roy; Köchermann, Jakob; Preisig, Heinz A..**
Modelling Ontologies for Biorfinery Processes – A Case Study. ESCAPE 30; 2020-08-30 - 2020-09-02 NTNU

**Pujan, Robert; Preisig, Heinz A..**
ProMo - A Tool for the Systematic Modelling of Biorefinery Processes. 3rd Doctoral Colloquium BIOENERGY; 2020-09-17 - 2020-09-18 NTNU

**Pujan, Robert; Preisig, Heinz A..**
Systematic Modelling of Flow and Pressure Distribution in a Complex Tank. ESCAPE 30; 2020-08-30 - 2020-09-02 NTNU

**Rørstad, Per Kristian Kåreson Lobenz.**
Bioenergiens rolle i det fremtidige energisystemet. Bioenergidagene 2020; 2020-11-23 - 2020-11-23
NMBU

**Sandquist, Judit.**
The possibilities for use of biofuels for shipping. What role will biofuel have in the future energy mix?; 2020-06-18 - 2020-06-18 ENERGISINT

**Sandquist, Judit.**
Status biodrivstoff 2020 (i Norge og verden). #SINTEFblogg [Internett] ENERGISINT SINTEF

**Sandquist, Judit.**
Status of biofuels in Norway and worldwide 2020. #SINTEFblog [Internett] ENERGISINT SINTEF

**Varnai, Aniko.**
Autumn newsletter September 2020: Enzymatic Processing of Biomass. NMBU
**Varnai, Aniko.**
Summer newsletter June 2020: Enzymatic Saccharification. NMBU

## SCIENTIFIC TALKS AND PUBLICATIONS 2020

Data from Cristin https://app.cristin.no/

| Publication | CiteScore (2019) |
|---|---|
| **Acha, E; Chen, De; Cambra, J.** Comparison of novel olivine supported catalysts for high purity hydrogen production by CO2 sorption enhanced steam reforming. *Journal of CO2 Utilization* 2020 ;Volum 42. s.101295 NTNU | 8.2 |
| **Bressanin, Jéssica; Klein, Bruno; Chagas, Mateus; Watanabe, Marcos; Sampaio, Isabelle; Bonomi, Antonio; Morais, Edvaldo; Cavalett, Otávio.** Techno-Economic and Environmental Assessment of Biomass Gasification and Fischer–Tropsch Synthesis Integrated to Sugarcane Biorefineries. *Energies* 2020 ;Volum 13.(17) NTNU | 3.8 |
| **Byrtusova, Dana; Shapaval, Volha; Holub, Jiri; Simansky, S; Rapta, M; Szotkowski, M; Kohler, Achim; Marova, Ivana.** Revealing the Potential of Lipid and -Glucans Coproduction in Basidiomycetes Yeast. *Microorganisms* 2020 ;Volum 8.(7) NMBU | 0.5 |
| **Capa, Alma; García, Roberto; Chen, De; Rubiera, Fernando; Pevida, Covadonga; Gil, Mara Victoria.** On the effect of biogas composition on the H2 production by sorption enhanced steam reforming (SESR). *Renewable Energy* 2020 ;Volum 160. s.575-583 NTNU | 11.2 |
| **Capa, Alma; García, Roberto; Chen, De; Rubiera, Fernando; Pevida, Covadonga; Gil, Mara Victoria.** On the effect of biogas composition on the H2 production by sorption enhanced steam reforming (SESR). *Renewable Energy* 2020 ;Volum 160. s.575-583 NTNU | 11.2 |
| **Capa, Alma; García, Roberto; Chen, De; Rubiera, Fernando; Pevida, Covadonga; Gil, Mara Victoria.** On the effect of biogas composition on the H2 production by sorption enhanced steam reforming (SESR). *Renewable Energy* 2020 ;Volum 160. s.575-583 NTNU | 11.2 |
| **Costa, Thales HF; Kadi, Adnan; Chylenski, Piotr; Varnai, Aniko; Bengtsson, Oskar; Lidén, Gunnar; Eijsink, Vincent; Horn, Svein Jarle.** Demonstration-scale enzymatic saccharification of sulfite-pulped spruce with addition of hydrogen peroxide for LPMO activation. *Biofuels, Bioproducts and Biorefining* 2020 NMBU | 6.4 |
| **Dzurendova, Simona; Zimmermann, Boris; Kohler, Achim; Tafintseva, Valeria; Slany, Ondrej; Certik, Milan; Shapaval, Volha.** Microcultivation and FTIR spectroscopy-based screening revealed a nutrient-induced co-production of high-value metabolites in oleaginous Mucoromycota fungi. *PLOS ONE* 2020 NMBU | 5.2 |
| **Dzurendova, Simona; Zimmermann, Boris; Tafintseva, Valeria; Kohler, Achim; Horn, Svein Jarle; Shapaval, Volha.** Metal and Phosphate Ions Show Remarkable Influence on the Biomass Production and Lipid Accumulation in Oleaginous Mucor circinelloides. *Journal of fungi (JoF)* 2020 NMBU | 5.0 |
| **Dzurendova, Simona; Zimmermann, Boris; Tafintseva, Valeria; Kohler, Achim; Ekeberg, Dag; Shapaval, Volha.** The influence of phosphorus source and the nature of nitrogen substrate on the biomass production and lipid accumulation in oleaginous Mucoromycota fungi. *Applied Microbiology and Biotechnology* 2020 NMBU | 6.7 |
| **Gaber, Yasser; Rashad, Boshra; Hussein, Rasha; Abdelgawad, Mai; Ali, Nourhan S.; Dishisha, Tarek; Varnai, Aniko.** Heterologous expression of lytic polysaccharide monooxygenases (LPMOs). *Biotechnology Advances* 2020 ;Volum 43:107583. s.1-15 NMBU | 19.8 |
| **Gavrilovic, Ljubisa; Jørgensen, Erik Andreas; Pandey, Umesh; Putta, Koteswara Rao; Rout, Kumar Ranjan; Rytter, Erling; Hillestad, Magne; Blekkan, Edd Anders.** Fischer-Tropsch synthesis over an alumina-supported cobalt catalyst in a fixed bed reactor – Effect of process parameters. *Catalysis Today* 2020 IFE NTNU SINTEF | 9.5 |
| **Huang, Bo; Hu, Xiangping; Fuglstad, Geir-Arne; Zhou, Xu; Zhao, Wenwu; Cherubini, Francesco.** Predominant regional biophysical cooling from recent land cover changes in Europe. *Nature Communications* 2020 ;Volum 11. s.1-13 NTNU | 18.1 |
| **Jåstad, Eirik Ogner; Bolkesjø, Torjus Folsland; Rørstad, Per Kristian.** Modelling effects of policies for increased production of forest-based liquid biofuel in the Nordic countries. *Forest Policy and Economics* 2020 ;Volum 113. NMBU | 5.7 |
| **Jåstad, Eirik Ogner; Bolkesjø, Torjus Folsland; Trømborg, Erik; Rørstad, Per Kristian.** The role of woody biomass for reduction of fossil GHG emissions in the future North European energy sector. *Applied Energy* 2020 ;Volum 274. NMBU | 16.4 |
| **Kojima, Yuka; Varnai, Aniko; Eijsink, Vincent; Yoshida, Makoto.** The Role of Lytic Polysaccharide Monooxygenases in Wood Rotting Basidiomycetes. *Trends in glycoscience and glycotechnology* 2020 ;Volum 32.(188) s.E135-E143 NMBU | 0.4 |

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|---|---|
| **Mathisen, Georg; Shapaval, Volha.**<br>Bruker muggsopp til å lage sunn mat av tre og fett. Fett, tre og bryggerirester skal gi mennesker sunn mat. Nøkkelen er noe så hverdagslig som muggsopp. *Forskning.no* 2020 NMBU | |
| **Monclaro, Antonielle V.; Petrovic, Dejan; Alves, Gabriel S.C.; Costa, Marcos M.C.; Midorikawa, Glaucia E.O.; Miller, Robert N G; Filho, Edivaldo X F; Eijsink, Vincent; Varnai, Aniko.**<br>Characterization of two family AA9 LPMOs from Aspergillus tamarii with distinct activities on xyloglucan reveals structural differences linked to cleavage specificity. *PLOS ONE* 2020 ;Volum 15:e0235642.(7) s.1-19 NMBU | 5.2 |
| **Pan, M.J.; Wang, J.N.; Fu, W.Z.; Chen, B.X.; Chen,, W.Y.; Duan, Xuezhi; Chen, De; Qian, Gang; Zhou, Xinggui.**<br>Active sites of Pt/CNTs nanocatalysts for aerobic base-free oxidation of glycerol,. *Green Energy & Environment* 2020 ;Volum 5. s.76-82 NTNU | 9.8 |
| **Preisig, Heinz A..**<br>Promo - a Multi-disciplinary Process ModellingSuite. *Computer-aided chemical engineering* 2020 ;Volum 48. s.571-576 NTNU | 0.9 |
| **Pujan, Robert; Nitzsche, Roy; Köchermann, Jakob; Preisig, Heinz A..**<br>Modelling Ontologies for Biorefinery Processes – A Case Study. I: *Proceedings of the 30th European Symposium on Computer Aided Process Engineering*. Elsevier 2020 ISBN 9780128233771. s.1693-1698 NTNU | |
| **Pujan, Robert; Preisig, Heinz A..**<br>Systematic Modelling of Flow and Pressure Distribution in a Complex Tank. I: *Proceedings of the 30th European Symposium on Computer Aided Process Engineering*. Elsevier 2020 ISBN 9780128233771. s.1996-1201 NTNU | |
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| **Smith, Pete; Calvin, Katherine; Nkem, Johnson; Campbell, Donovan; Cherubini, Francesco; Grassi, Giacomo; Korotkov, Vladimir; Le Hoang, Anh; Lwasa, Shuaib; McElwee, Pamela; Nkonya, Ephraim; Saigusa, Nobuko; Soussana, Jean-Francois; Taboada, Miguel Angel; Manning, Frances C.; Nampanzira, Dorothy; Arias-Navarro, Cristina; Vizzarri, Matteo; House, Jo; Roe, Stephanie; Cowie, Annette; Rounsevell, Mark; Arneth, Almut.**<br>Which practices co-deliver food security, climate change mitigation and adaptation, and combat land degradation and desertification?. *Global Change Biology* 2020 ;Volum 26.(3) s.1532-1575 NTNU | 15.2 |
| **Wang, Liang; Seljeskog, Morten; Khalil, Roger Antoine; Bakken, Jørn; Carlsson, Per; Skreiberg, Øyvind.**<br>Characterization of Residues from Entrained Flow Gasification of Wood. *Chemical Engineering Transactions* 2020 ;Volum 80. s.235-240 ENERGISINT | 1.3 |
| **Yeboah, Isaac; Feng, Xiang; Wang, Gang; Rout, Kumar Ranjan; Cai, Z P; Duan, Xuezhi; Zhou, Xinggui; Chen, De.**<br>Jet Fuel Range Hydrocarbon Production from Propanal: Mechanistic Insights into Active Site Requirement of a Dual-Bed Catalyst. *ACS Sustainable Chemistry and Engineering* 2020 ;Volum 8. s.9434-9446 NTNU | 9.7 |
| **Østby, Heidi; Hansen, Line Degn; Horn, Svein Jarle; Eijsink, Vincent; Varnai, Aniko.**<br>Enzymatic processing of lignocellulosic biomass: principles, recent advances and perspectives. *Journal of Industrial Microbiology & Biotechnology* 2020 NMBU | 5.8 |

# Associated Projects

In addition to the research activities financed directly within Bio4Fuels, the partners and stakeholders in the centre aim to stimulate and coordinate additional research and demo activities. These associated projects are focussed towards EU funding as part of the internationalisation strategy, as well as nationally based funding in order to provide a larger platform for addressing the overall challenges within the field. The range of associated EU and Nationally funded projects are listed below.

## EU financed projects

| Project | Total budget [mNOK] | Short Description of Project | Bio4Fuels Stakeholders involved |
|---|---|---|---|
| AC2OCEM | 43 | Accelerating Carbon Capture using Oxyfuel Technology in Cement Production - Biomass used instead of coal in the kiln) | NTNU (Indecol), Sintef Energy |
| SiEUGreen | 70 | Resource-efficient urban agriculture for multiple benefits – contribution to the EU-China Urbanisation Partnership | |
| EHLCATHOL | 40 | Chemical Transformation of Enzymatic Hydrolysis Ligning (EHL) with Catalytic Solvolysis to Fuel Commodities under mild Conditions | |
| BL2F | 50 | Biofuels from black liquor via HTL | SINTEF Energi, SINTEF AS, Neste |
| NextGenRoadFuels | 46 | Biofuels from sludge and organic waste via HTL | SINTEF Energi, Steeper |
| SET4Bio | | Supporting the implementation of the SET Plan Action 8 | SINTEF Energi |
| EBIO | 42 | Electrochemical upgrading o crude bio liquids | SINTEF Industry, BTG |
| 4Refinery | 60 | Conversion of lignocellulosic Biomass via HTL and Pyrolysis to Advance Biofuels | SINTEF Industry |
| BRISK2 | 60 | Transnational access of research infrastructure as well as research on monitoring, process design and costing | SINTEF Industry |
| LIBERATE | 60 | Conversion of Lignin to value added chemicals | SINTEF Industry |
| Pulp&Fuels | 49 | The Pulp & Fuel project, funded by the EU under Horizon 2020, studies how renewable fuel production can be integrated with pulp production to achieve positive synergies for the | SINTEF, RISE |

| | | | |
|---|---|---|---|
| | | production of 2nd generation biofuels at a competitive price. | |
| SelectiveLi | 5 | Conversion of Lignin to value added chemicals | SINTEF Industry |
| Waste2Road | 60 | Conversion of Biogenic Waste via HTL and Pyrolysis to Advance Biofuels | SINTEF Industry, EGE |
| CONVERGE | 49,9 | Production of biomethanol through gasification-sorption enhanced reforming-membrane enhanced methanol synthesis | IFE |
| MEMBER | 77,2 | Production of hydrogen from biogas through membrane-assisted sorption-enhanced reforming | IFE, ZEG Power |
| FunEnzFibres | NMBU: 8,5 | Enzymatic upgrading of cellulosic fibres with LPMOs (redox enzymes) for the production of textiles and nanocellulose | Borregaard, Novozymes |
| Oxytrain | 30 | Research on the mechanism, engineering and application of four different classes of oxygenases | |
| Baltic Biomass4 Value | 30 | | |
| BESTER | 26,9 | Conversion of lignocellulosiic derived sugars to butyrate | SINTEF Industry |
| MarketPlace | 8 | MarketPlace is aiming at an integrated computing hub for simulatoins | |
| CUBE (ERC Synergy grant) to V.G.H. Eijsink | 100 | Unravelling the secrets of synthetic and biological Cu-based catalysts for C-H activation | |
| EEA-Baltic | 8 | Novel high-performance polymers from lignocellulosic feedstock | NTNU (Indecol). |

## NATIONALLY FUNDED PROJECTS

| **Project** | **Total budget [mNOK]** | **Short Description of Project** | **Bio4Fuels Stakeholders involved** |
|---|---|---|---|
| BACS | 24,5 | Extraction of high value chemicals | SINTEF Industry Borregaard |
| BioCirc | 6 | Transnational Access of research Infrastrucutre | |
| Plastic &fuel | 3 | | |
| AORTA | ~1 | Convertering makroalger til produkter | SINTEF Industry, Alginor |

| | | | |
|---|---|---|---|
| Bransjenorm for Biogass | 0,8 | The project aim to develope an industry standard for biogas | |
| SLUDGEFFECT | 10,5 | Life cycle effects from removing hazardous substances in sludge and plastic through thermal treatment | NTNU (Indecol). N.B.: Bio4Fuels explicitly provided a letter of support |
| BarkCure | 10 | | NIBIO, SINTEF Industry |
| Bærekraftig biogass | 22,8 | The project aims increase biogas production in Norway by creating environmental- and resource optimal value chains for biogas, and strengthen the market position for biogas and bio fertilizers. | Oslo EGE / RBA, Lindum |
| FORBIOCHAR | 8 | Evaluating producing biochar from forest biomass. | skogeierforbunnet |
| BYPROVALUE | 10 | Production of lipids, chitin/chitosan, glucans and polyphosphate | Borregaard |
| Enable | 25 | | |
| Enzymes4Fuels | 10 | Developing innovative enzyme technology for sustainable biofuels production with focus on lignin, hemicellulases and CBMs | Borregaard, St1 |
| Foods of Norway | 218 | Centre for Research-based Innovation with focus on developing biorefining techniques to convert Norwegian bioresources to feed ingredients | Borregaard |
| LIGNOLIPP | 12 | Production of high-value lipids and chitin/chitosan | Borregaard |
| LipoFungi | 10 | | |
| NorENS | 11 | | |
| OIL4FEED | 12 | production of high-value lipids | Borregaard |
| OXYMOD | 31,6 | Optimization of oxidative enzyme systems for efficient conversion of lignocellulose to fuels and chemicals | Borregaard |
| Single Cell Oils | 7 | | |
| Rocky | 1 | Upgrading residual fibres from saccharification for value-added products | Borregaard |
| Promac | 35 | | |
| Climat Smart Forestry Norway | 25 | | |
| Bio4Fuels | 236,6 | | |
| PyroGass | 31,5 | Norske Skog Saugbrugs skal utvikle ny teknologi for samproduksjon av | Norske Skog Saugbrugs, Cambi, RISE PFI, USN |

| | | | |
|---|---|---|---|
| | | biogassdrivstoff og biokarbon reduksjonsmiddel til produksjon av manganlegeringer basert på restråstoff fra papirproduksjonen | |
| Advanced Biofuels via Syngas | 8,9 | | |
| B2A | 20 | Conversion fo biomass to aviation fuels | NTNU, SINTEF, St1 |
| BioFT | 12,8 | Optimization of the process for production of fuels via Fischer-Tropsch synthesis | SINTEF Industry |
| CLD | 10,1 | High temperature gas cleaning throgh Chemical looping Desulfurization | SINTEF Industry |
| GasPro | 16,7 | Increase the energy efficiency of the entrained flow biomass gasification technology for bio-fuel production | NTNU, Dr Tian Li, Prof.Terese Løvås, SINTEF Energy |
| H2BioOil | 11,8 | | |
| H2Biooil | 10 | Hydropyrolysis of biomass+catalytic upgarding | NTNU |
| MIRA | 13,3 | | |
| NanoLodge | 5,1 | Development of a new reactor design integrating the biotech production of butanol, butyric acid, and their consecutive enzymatic esterification to butyl butyrate using innovative membrane technology | NTNU, SINTEF Industry |
| Bio4-7Seas | 10,5 | Biofuels for climate change mitigation in of deep-sea shipping | NTNU (Indecol). N.B.: Bio4Fuels explicitly provided a letter of support |
| BioPath | 10 | Advancing the understanding of regional climate implications of bioenergy systems | NTNU (Indecol) |
| Norwegian Seaweed Biorefinery Platform (SBP-N) | 15 | | SINTEF, NTNU, NMBU |
| ReShip | 15 | | |
| PyroGas | 4 | | |
| NanoCat4Fuels | 3,9 | | |
| GAFT | | | |
| BIOGREEN | 6 | | |

| | | | |
|---|---|---|---|
| FLASH | 9,9 | Understand how ash elements physically behave in a gasification or incineration scenario, and specifically how the ash melting temperature and ash viscosity can be determined, modelled and predicated. | USN/ SINTEF Energy |
| TechnoSER | 11,7 | Technical optimization of the sorption-enhanced reforming process for hydrogen production | ZEG Power, IFE |
| CUBE (ERC Synergy grant) to V.G.H. Eijsink | 100 | Unravelling the secrets of synthetic and biological Cu-based catalysts for C-H activation | Unravelling the secrets of synthetic and biological Cu-based catalysts for C-H activation |
| Flex4RES | 24 | | |
| Nordic Clean Enegy Sdenarios 2020 | 9 | | |

# ACCOUNTS 2020

Overview of the accounts for 2020, reported to the Research Council of Norway on 20 January 2021, approved 5 February 2021.

| **Project costs** | | **This Period** | **Budget** |
|---|---|---|---|
| Payroll & Indirect expenses | | 34,943 | 36,931 |
| Procurement of R&D services | | 0 | 0 |
| Equipment | | 1,493 | 1,413 |
| Other operating expenses | | 1,736 | 3,401 |
| | | **38,172** | **41,745** |
| | | | |
| **Financing** | | **This Period** | **Budget** |
| Own financing | | 4,752 | 4,538 |
| Public funding | | 10,243 | 15,828 |
| Private funding | | 5,019 | 3,754 |
| International funding | | 1,612 | 1,625 |
| The Research Council | | 16,546 | 16,000 |
| | | **38,172** | **41,745** |

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## Bio4Fuels Stakeholders