Bio4Fuels Annual Report 2019

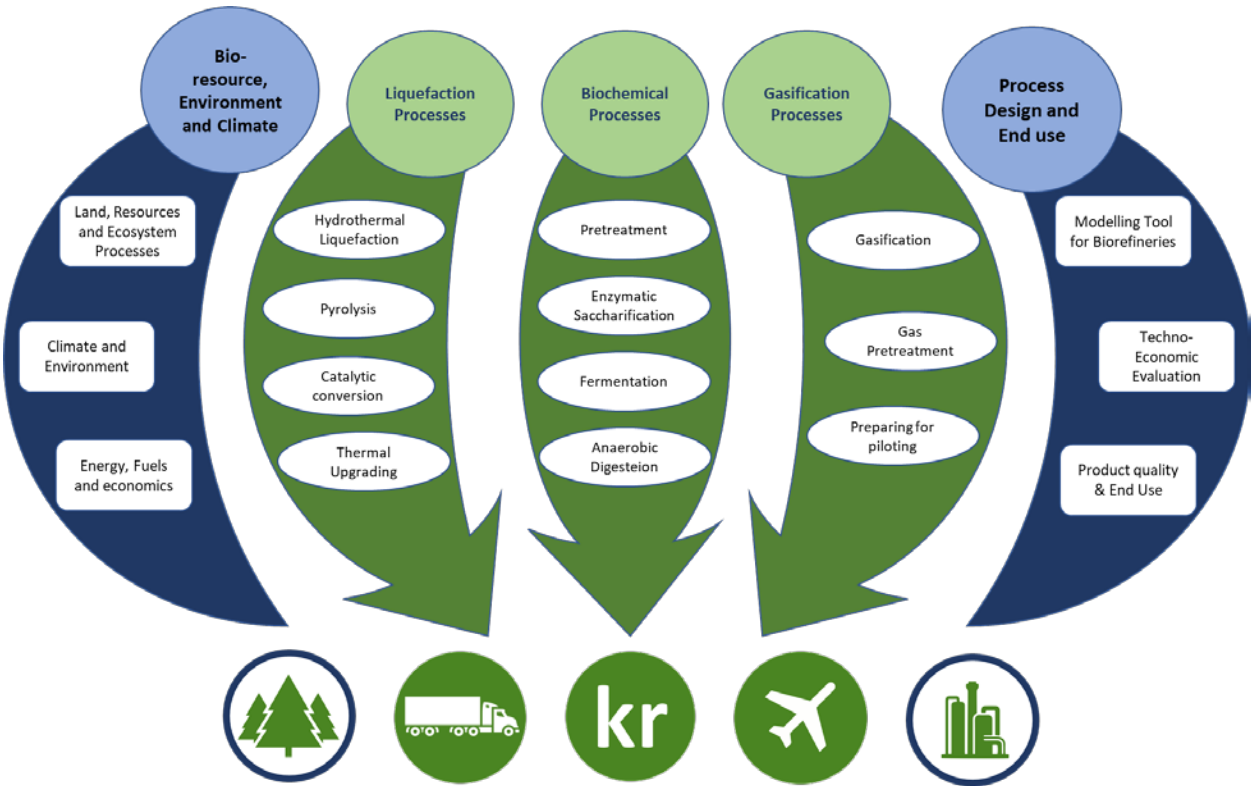
Norwegian Centre for Sustainable Bio-Based Fuels and Energy

Mongstad Refinery Photo: Øyvind Hagen, Equinor

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

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Supplying FPBO as a renewable heating oil to Friesland Campina in the Netherlands (photo: BTG).

FROM THE CHAIR OF THE BOARD AND CENTRE LEADER

During 2019, the Bio4Fuels Centre benefited from having Statkraft as the new Chair of the board. As Europe's largest producer of renewable energy, Statkraft invests into biofuel production and EV charging at the same time, in the belief that different transport segments will require different renewable solutions. Advanced biofuels are scarce in the market due to a lack of commercially available technologies.

In 2019, Bio4Fuels researchers continued to pursue their development efforts on the key technology platforms relevant for Norway, with experimental work on thermochemical conversion routes also gaining momentum. Feedstock sustainability and resource management are a fundamental part of the Centre's research activities, generating valuable insights for the debate on biofuels in Norway.

One of the highlights of 2019 was the annual Bio4Fuels conference held in Gothenburg as a joint event with the Swedish f3 Knowledge Centre for Renewable Transportation Fuels and the UK SuperGen Bioenergy Hub. The international profile of the Centre is also strengthened through coordinating a landmark workshop on HTL technology in Brussels, bringing together the major technology providers worldwide, as well as Bio4Fuels researchers being well linked to several Horizon 2020 projects in addition to contributing to high level policy initiatives, nationally and internationally.

Following a structural reorganization, new communication lines have been established along the major value chains in the Centre to facilitate stronger cooperation between different work areas.

Ingo Machenbach,
Chair of the Board

Duncan Akporiaye
Centre leader

SUMMARY

The ambition of the Bio4Fuels FME Centre is to contribute to reduction of climate gas emissions from the transport sector through enabling sustainable biofuels production in Norway based on low-grade fractions of wood from the forest and waste from agriculture.

There are four main value chains currently being addressed in Bio4Fuels:

- Breaking down the biomass to separate out the sugars in the biomass for use in fermentation to produce "Bioethanol". 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 technologies involved in the value chains, it is also important to convert side streams and biproducts from the processes to products of higher value than fuels. The main issues being addressed for viable commercial production of biofuels from biomass are related to the economics and sustainability of the processes, including:

- 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
- Evaluating and designing the process concepts and testing quality of the biofuels for existing engines.

Since the establishment of the Bio4Fuels, the prospects for production of biofuels in Norway based on the Bio4Fuels main value chains has increased significantly through the activities of key Stakeholders. Currently, technologies are being scaled up in Norway to pilot, demo or commercial scale within nearly all value chains – some of these initiatives are illustrated in the insights from industrial stakeholders. The greatest progress towards commercial production are within liquefaction (Statkraft, Biozin, BTG), fermentation to bioethanol (St1, Borregaard) and biogas production (Biokraft, Cambi and EGE)

An important change in 2019 was the accession of Equinor as a new end user Stakeholder, representing an important refinery in Norway. Changes in the Board has resulted in a new Chair of the board, including the involvement of new members with new perspective and experience.

The annual *Bio4Fuels Days* is proving to be a flagship event for the Centre and in 2019 we realized our ambition of making it more of an international event through organizing it in Sweden together with the Swedish F3 and the UK SuperGen Centres. This was a great success and showed an interesting comparison between the three countries. As a platform for research activities in the field, Bio4Fuels now has an impressive range of associated and spin-off projects, which we aim to capitalize on, on behalf of our stakeholders.

BIO4FUELS ORGANIZATION

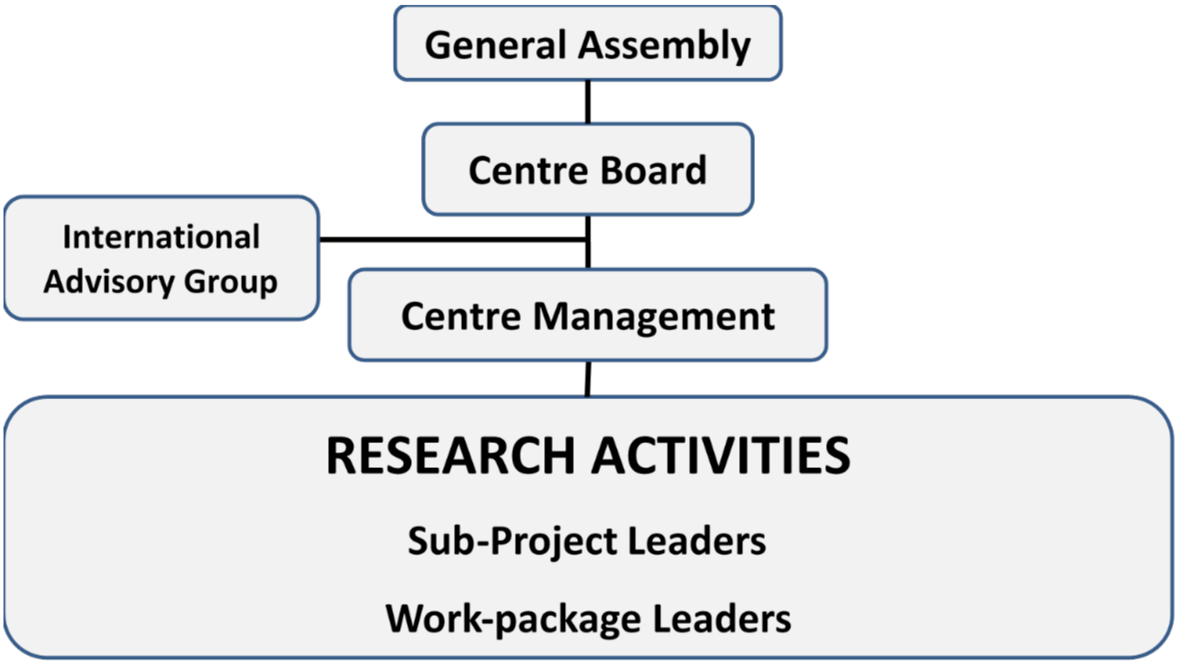


***Figure 1**: Organization of the FME Bio4Fuels Centre.*

Reorganization of the Centre

In 2019 the Bio4Fuels Centre's Research Activities were reorganized. From January 2017 until September 2019 there were 4 Sub-projects (SPs) and 17 Work-packages (WPs) in the Centre. In the self-evaluation process performed during the winter 2018/2019 (see page 13) it was concluded that the number of SPs should be increased to 5 whereas the number of WPs are kept at 17. The reorganization will

- strengthen the cooperation in the Centre and
- ease the data collection performed by the Sub-Project "*Process Design and End Use*"

Table 1: Organization of the Research Activities in the Bio4Fuels Centre after the self-evaluation process. A detailed presentation including responsible persons and work-package descriptions can be found on page 13.

Sub-Project (SP)	SP #	Work-Packages (WPs)
Bio-resource, Environment and Climate	1	1.1, 1.2 and 1.3
Liquefaction Processes	2	2.1, 2.2, 2.3 and 2.4
Biochemical Conversion	3	3.1, 3.2, 3.3 and 3.4
Gasification Processes	4	4.1, 4.2 and 4.3
Process design and End Use	5	5.1, 5.2 and 5.3

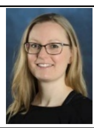
Centre Board and Management

The Bio4Fuels' Board per December 2019:

	**Ingo Machenbach**	**Silva Green Fuel (Statkraft)**	**Chair**
	Tyra Marie Risnes	Østfold County Council	Representing Stakeholders
	Per Skorge	Norges skogeierforbund	Representing Resource partners
	Jens Ulltveit-Moe	UMOE	Representing End Users
	Kine Svensson	CAMBI	Representing Technology partners
	Petter Røkke	SINTEF	Centre Leader Institute
	Ragnhild Solheim	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
	Tonje Lindrup Robertsen	NMBU	Communication Officer (June – Dec)
	Bente Paulsson	NMBU	Communication Officer (Dec -)

THE INTERNATIONAL ADVISORY GROUP (IAG)

	Advisor	Affiliation	Area of expertise
	Prof. Patricia Thornley	Supergen Bioenergy Hub, Aston University, Birmingham (UK)	Sustainability
	Prof. 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

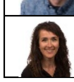
Bioresource owners	**Main interest**
The Norwegian Farmers Union	Biogas production from agricultural feedstocks
The Norwegian Forest Owners' Federation	Value from forest biomass
The City of Oslo, The energy recovery unit	Biogas production from food waste
Tech./knowledge providers, Norwegian	**Main interest**
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
Østfold Fylkeskommune	Sustainability, Resource Use, Transport policy, Techn Econ
Hedmark Fylkeskommune	Sustainability, Resource Use, Transport policy, Techn Econ
Akershus Fylkeskommune	Sustainability, Resource Use, Transport policy, Techn Econ
Oppland 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
NVE	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

Adesso Bioproducts, Fredrikstad (photo: Adesso).

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)	NTNU	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
	Linn Solli (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 2019

BIO4FUELS SELF-EVALUATION

All "*Forskningssentre for miljøvennlig energi*" (FMEs) received the framework for the performance of a self-evaluation process from the Norwegian Research Council (NRC) in October 2018. After agreement with the Board, the evaluation process was divided into four parts:

- Questionnaire sent to all Stakeholders (Nov 2018 – Jan 2019)
- Self-Assessment workshop involving representatives of all interested parties of the Centre (Stakeholders, PhD Students, Board members, Scientists, Management group) (Feb 2019)
- Interviews with key Stakeholders in the Centre (Jan – March 2019)
- Input from the Board (Feb 2019)
- Review of the results by the Board and recommended actions (Mar 2019)

Conclusions
The main conclusions from the Self-evaluation process are outlined below. These specific aspects have been raised throughout the different channels that were set up for the evaluation process (survey, workshop, interviews, input from the Board), thus indicating that these need to be addressed by specific actions.
Strengthening the involvement of the User partners
There is generally agreed that significant efforts and changes need to be made to increase the engagement of the User partners and the potential for innovation. It is clear that there are intrinsic aspects with respect to the Centre which have so far limited the strong engagement of partners from certain sectors and these need to be addressed.

Greater focus on communication – internally and externally
There is a clear desire for a higher level of communication internally and externally with respect to the Centre. With respect to external communication, it is quite clear that the field of biomass conversion to advanced biofuels is a topic that needs additional resources in order that the Centre can fulfill its role as a knowledge provider.

More effective operation of the Centre
There has been a general feedback both from the management and the evaluation process, that the operation of the Centre has not been optimal, in a major part due to the organizational structure and, to some extent, the level of commitment of selected leaders of activities. This has consequences in fulfilling the obligations of the Centre.

Recommended Actions
Change to the structure of the Centre
As was discussed during the Self-evaluation workshop, the initial premise for the organizational structure of Bio4Fuels were quite ambitious, but in practice has been shown to be too complex to implement in practice, as well as being a barrier against optimal involvement of Use partners at different levels of the Centre. Based on this, the management group, with the support of the Board, has decided to realign the organizational structure to fit with the main value chains being addressed in the Centre, as shown below in Figure 2.

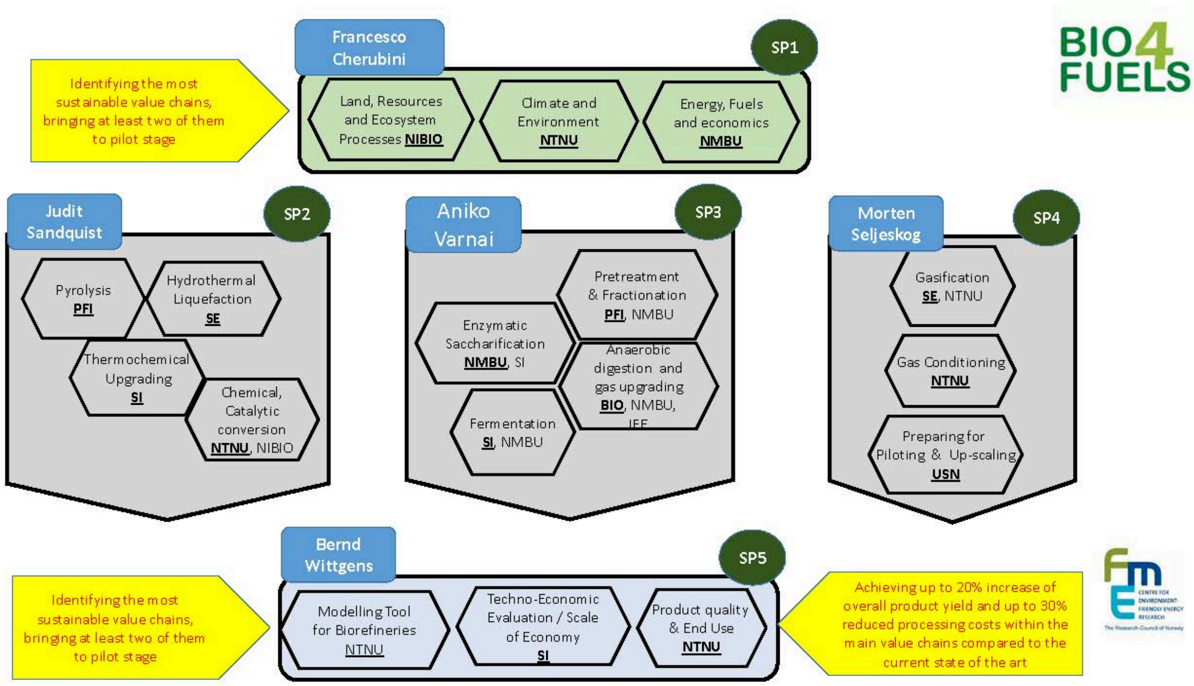


Figure 2: New Centre structure obtained through the self-evaluation process. This structure fit with the main value chains being addressed in Bio4Fuels.

BIO4FUELS' EXTERNAL WORKSHOPS, SEMINARS, WEBINARS

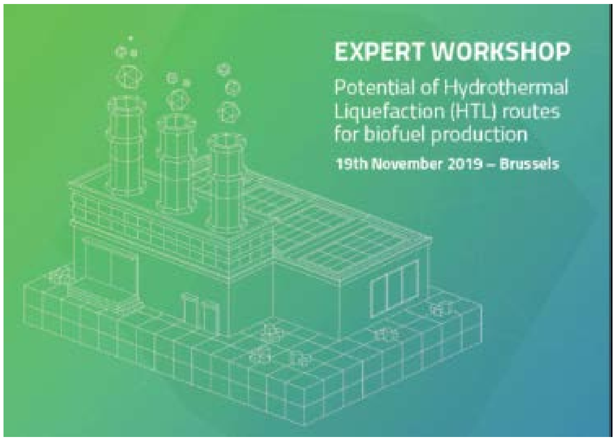
One important ambition for the Bio4Fuels is external engagement and dissemination within the field of advanced biofuels. This has been achieved in during 2019 through several national and European events, an overview which is presented below.

Webinar on H2020 Bioenergy & Biofuels Proposals, 26 November 2019

- EU in the context of Bio4Fuels, by Duncan Akporiaye - Bio4Fuels centre leader and research director for Process Technology at SINTEF
- About NorEUnergy II (Strategic national project for the mobilization and engagement of Norwegian actors within bioenergy/biofuels towards H2020), by Berta Matas Güell, senior research scientist in thermal energy at SINTEF
- Relevant H2020-calls
- Interest from participants on the H2020-calls (round the table)

A detailed information of the three relevant calls can be found here.
Presentations from the webinar, as well as recordings of the whole webinar can be found here.

Bio4Fuels workshops



European Expert Workshop on the potential of HTL for Biofuel production. This was based on a cooperation between Bio4Fuels and 5 running EU projects for which HTL technology was being developed.
Attendance of the workshop was from US, India, Australia and Europe.

National Breakfast meeting on "*Sustainable biomass in the Nordic region – how should we farm the ocean?*" This was formally organized by the NGO Bellona and Nordic Energy Research, with input from Bio4Fuels partner SINTEF and presentation from SINTEF on the potential of producing Fuels from marine biomass.

Introduction Nordic Energy Research (Julia Hansson or Kenneth Karlsson)

Biofuels strategy for the coming decade - The Nordic region at the forefront of technology and sustainability!

Time to discuss the way forward
Discussion in small groups for all participants and panel debate.

Panellists:
a) **Patrick Pitkänen, St1 Oy**, biofuel producing industry perspective
b) **Anne Sophie Vinther Hansen, A.P. Møller - Mærsk A/S**: transport industry perspective
c) **Mirjam Röder, European Bioenergy Research Institute**: sustainable biomass research perspective
d) **Julia Hansson, IVL or Kenneth Karlsson, Shift**: transport research perspective

Moderator: Jakob Lagercrantz, the 2030 secretariat

Biofuels Strategy for the coming decade – The Nordic region at the forefront of technology and sustainability! This was a workshop organized between Bio4Fuels and Nordic Energy Research to provide input to policy document being develop for the Nordic Minister Council. The workshop was arranged as a "back-to-back" event to the main conference organized in Sweden.

Summer School MoZEES/Bio4Fuels (17-21 June 2019)

The 2019 Norwegian Research School in Renewable Energy (NorRen) took place in June. The summer school was organized by *UiO:Energy* in collaboration with the two Norweigan centres for environment-friendly energy research (FME Centres) MoZEES and Bio4Fuels.

The school gathered PhD students from UiO, NTNU, NMBU and USN. The school covered lectures on biofuels, hydrogen and batteries - for road, rail and sea. Also, political, social and economic aspects of the transitions in the transport sector. These scientific topics where presented by a mix of lecturers from UiO, NTNU, NMBU, Technical University of Munich, IFE, TØI and SINTEF.

Involvement of Stakeholders

Both private companies and the government sector shared their views on sustainable transport - possibilities and challenges. Wilhelmsen/Massterly, Acando, IKEA and the Norwegian Railway Directorate gave lectures ranging from transport of goods to Mobility as a Service, and from autonomous solutions to new fuel alternatives for sustainable shipping.

Unibuss, a public transport operator in Oslo, organized a site visit to their new infrastructure facilities at Alnabru, Mortensrud and Klemetsrud. They presented key learnings from the electrification of their bus fleet.

Students' Involvement

The students presented their PhD research with a poster and a short pitch. During the week they worked in groups on an interdisciplinary assignment, the result of which was presented on the last day of the school.

For a detailed program of the summer school see the NorRen webpage. In 2020 the NorRen summer school will most likely once again focus on sustainable energy systems.

Bio4Fuels Days, 4-6 November, 2019

The 2019 Bio4Fuels Days gathered key actors to address the main objective of sustainable biofuel implementation prospects in Norway, Sweden and the UK. The intergovernmental organization Nordic Energy Research offered a back-to-back workshop to all participants.

The conference brought together researchers, industry specialists and policy-makers to review the status of bioenergy deployment, analyse the future of sustainable biofuel production and use in Europe, and connected sectorial expertise with a view to supporting sustainable biofuel production and greenhouse gas mitigation.

The conference cooperated with the international Elsevier journal Biomass & Bioenergy, and authors of scientific oral and poster presentations were invited to submit papers. These papers are currently going through a review process and selected papers will be published in a special issue of this journal in 2020.

This year's Bio4Fuels Days was a joint conference organized by three research centres:

- f3 Swedish Knowledge Centre for Renewable Transportation Fuels, SE
- Supergen Bioenergy Hub, UK
- Bio4Fuels, NO

Program 4 November (41 participants)

- ***Early Career Researchers Forum***, Chalmers University of Technology
  Networking activities, research pitches and presentations, and Q&A session with guest speakers from conference program on careers in the bioenergy/biofuels field.
- ***Site visit at Volvo Tuve Plant***
  Guided tour with the Tuve train and presentation on demands for meeting future sustainable transports.

Gothia Towers, Göteborg (photo: Gothia Towers Hotel).

Program 5 November (202 participants)

WELCOME AND INTRODUCTIONS

Ingrid Nohlgren, director ***f3 Swedish Knowledge Centre for Renewable Transportation Fuels***
Duncan Akporiaye, director ***Bio4Fuels***
Patricia Thornley, director ***Supergen Bioenergy Hub***

Opening speaker
Robert Andrén, Director General of the Swedish Energy Agency

FOCUS: POLICY

UK transport policy and the Renewable Transport Fuel Obligation
Aysha Ahmed, Head of Advanced Biofuels Programme, Department for Transport

Biofuel Policy in Norway
Mats Nordrum, Senior Advisor, Climate Department, Norwegian Environment Agency

FOCUS: INDUSTRY

Sustainable Advanced Biofuels and more – St1 Biorefinery
Patrick Pitkänen, Director Advanced fuels, St1 Oy

Biogas futures in transport
Keith Simons, Principal Scientist, SHV Energy

Brazil – The country of competitive and sustainable biofuel
Jens Ulltveit-Moe, Founder and CEO, Umoe

The quest for green profitability
Håvard Wollan, CEO, Biokraft AS

FOCUS: SUSTAINABILITY

Biofuels in the future fossil-free energy system: The Nordic perspective
Torjus Bolkesjø, Professor, Faculty of Environmental Sciences and Natural Resource Management, Norwegian University of Life Sciences

Sustainability challenges for biofuels from an UK perspective
Patricia Thornley, Professor, School of Engineering and Applied Science, Aston University

Land, climate and global development pathways: implications for biofuels and the bioeconomy
Francis X. Johnson, Senior Research Fellow, Stockholm Environment Institute

PARALLEL SESSIONS

SUSTAINABLE BIOMASS RESOURCES

Session chair
Pål Börjesson, Professor, Environmental and Energy Systems Studies, Lund university

Industry presentation

Forest-based biofuels - potentials for a new business to grow
Henrik Brodin, Business Development Manager, SÖDRA

Research presentations:

Drop-in fuels from black liquor – combining increased pulp capacity with production of sustainable biofuels
Elisabeth Wetterlund, Associate Professor, Dept. of Engineering Sciences and Mathematics, Luleå University of Technology

The impact of bioenergy systems on soil carbon
Rebecca Rowe, Ecologist, The Centre for Ecology & Hydrology

Potential for HVO production from Swedish raw materials
Hanna Karlsson, Postdoctor, Dept. of Energy and Technology, Swedish University of Agricultural Sciences

CONVERSION TECHNOLOGIES FROM BIOMASS TO SUSTAINABLE BIOFUELS

Session Chair
Judit Sandquist, Research Scientist, SINTEF Energy Research

Industry presentation

Roll-out of pyrolysis technology in Europe
Gerhard Muggen, Managing Director, BTG Bioliquids

Research presentations:

Well-to-wheel cost for forest-based biofuels
Karin Pettersson, Researcher, RISE Research Institutes of Sweden

Hybrid process of distillation and gas permeation for production of dehydrated ethanol
Olaf Trygve Berghlin, Research Scientist, Process Technology Dept., SINTEF

Model-based fast screening of electrochemical reaction pathways for the integrated biofuels synthesis and CO_2 reduction
Jin Xuan, Professor, Chemical Engineering, Loughborough University

Fast pyrolysis lignin with catalytic vapor upgrading for the production of alkyl-phenols and aromatics
Dumitrita Spinu, PhD candidate, Dept. of Chemical Engineering, Norwegian University of Science and Technology (NTNU)

POSTER SESSION: 56 posters were presented

Program 6 November (202 participants)

FOCUS: INDUSTRY AND END USE

High blend biofuel adoption by bus and truck operators in the UK
Gloria Esposito, Head of projects, Low Carbon Vehicle Partnership

Fossil free domestic aviation in Sweden
Anna Soltorp, Sustainability & Political Affairs, BRA Flyg

Net zero emissions by 2050 - a maritime approach to renewable energy transition
Anne Sophie Vinther Hansen, Senior Innovation Project Manager, A.P. Møller - Mærsk A/S

Driving the shift to a sustainable transport system – here and now!
Henrik Dahlsson, Senior Advisor Sustainable Transports, Scania

PARALLEL SESSIONS

POTENTIAL FOR BIOCHEMICAL AND BIOMATERIAL BYPRODUCTS/ALTERNATIVES

Industry presentation:

Potentials for biochemical and biomaterial products in a sugar platform biorefinery setting
Gudbrand Rødsrud, Technology Director, Business Development, Borregaard

Research presentations:

How can alcohols contribute to a fossil-independent non-road machinery fleet?
Gunnar Larsson, Researcher, Swedish University of Agricultural Sciences

Co-production of Lipids and Biopolymers in a single fermentation process – a way to improve sustainability of Microbial Lipid-based Biofuels
Volha Shapaval, Associate Professor, Faculty of Science and Technology, Norwegian University of Life Sciences (NMBU)

Understanding sustainability within a net zero emission target. Synergies between environment, economy and society
Mirjam Roeder, Senior Research Fellow, Energy and Bioproducts Research Institute, Aston University

ENVIRONMENTAL AND SOCIAL IMPACTS OF EUROPEAN BIOFUEL DEPLOYMENT

Industry presentation:

The role of the European Technology and Innovation Platform for Bioenergy
Patrik Klintbom, Senior Researcher, RISE Research Institutes of Sweden, Chair ETIP Bioenergy

Research presentations:

Biogas development – public procurement, networks, and policy instruments
Julia Hansson, Senior Scientist, IVL Swedish Environmental Research Institute

Forecasting Impact: A case study of bioenergy systems
Samuel Cooper, Research Associate, University of Bath

Can the Nordics become CO2 negative by 2040? The role of biomass
Kenneth Karlsson, Senior Project Manager, IVL Swedish Environmental Research Institute

Back-to-back Conference by Nordic Energy Research 6 November (≈50 participants)

ADDITIONAL WORKSHOP: BIOFUELS STRATEGY FOR THE COMING DECADE - THE NORDIC REGION AT THE FOREFRONT OF TECHNOLOGY AND SUSTAINABILITY!

The workshop is arranged in cooperation with NER, Nordic Energy Research, an intergovernmental organization within the framework of the Nordic Council of Ministers.

Come join us in a strategic discussion spanning over the coming decade. We identify some hot spots and discuss solutions.

Nordic Energy Research

INTRODUCTION: Nordic Energy Research

GROUP DISCUSSION: The way forward

PANEL DEBATE

Moderator Jakob Lagercrantz, founder of the 2030 Secretariat

Panelists:

- Patrick Pitkänen, St1 Oy, biofuel producing industry perspective
- Anne Sophie Vinther Hansen, A.P. Møller - Mærsk A/S, transport industry perspective
- Mirjam Roeder, European Bioenergy Research Institute, sustainable biomass research perspective
- Julia Hansson or Kenneth Karlsson, IVL: transport research perspective

Bio4Fuels Lunch Meetings 2019

Vitenparken at campus Ås. Photo: Janne Beate Utåker

Campus Ås

Bio4Fuels people situated in the Oslo area were invited to three lunch meetings at Vitenparken, located at campus Ås, the Norwegian University of Life Sciences (NMBU). During the lunch, there are scientific presentations and information from the Bio4Fuels management. The aim of the lunch meetings is to get people to know each other and to feel as part of a Centre.

Date (2019)	***Theme***
1 February	Scientific talk by Eirik Ogner Jåstad (PhD student SP1)
24 May	PhD disputation, Oda Kjørlaug Svennevik (Industrial PhD, NMBU/Cambi)
11 October	About Bio jet fuel by Arvid Løken, AVINOR

BIO4FUELS INDUSTRIAL STAKEHOLDERS INSIGHTS

EQUINOR

Equinor is an energy company committed to long term value creation in a low carbon future. Our strong technology base and ability to apply new technologies, constitute a competitive advantage. Going forward we will prioritize a portfolio towards renewables and low carbon activities. Sustainable carbon neutral liquid fuels are not widely available today, hence we work on advanced biofuels solutions to provide viable alternatives to conventional fuels, particularly for the sectors of transportation not easily electrified.

In 2019 successful test-runs of co-processing bio-oil feedstocks in the existing units of the Mongstad and Kalundborg refineries were completed. There are several benefits from co-processing at a refinery as reduced capital costs by leveraging existing refinery process units and ability to effectively increase the renewable share above blending wall limits. Our objectives are to replace the tested bio feedstock with even more sustainable feedstocks with lower supply chain CO_2 footprint compared with first generation biofuels, and at the same time find solutions enabling a higher share of co-processed based on lignocellulosic feedstocks, utilizing available refinery hydrogen. Our goal is to make our refineries at Mongstad and Kalundborg relevant for the energy transition by reducing the CO_2 footprint of our production and products.

New conversion technology is needed to enable using other biomass resources than today for producing advanced biofuels at scale. Thus, we are open for dialogue with feedstock providers and conversion technology developers. Bio4Fuels membership is regarded as an important meeting arena for making contacts and as an enabler for relevant research cooperation.

BTG BIOLIQUIDS BV

As BTG Bioliquids we replace fossil fuels by Fast Pyrolysis Bio-Oil (FPBO). FPBO is an advanced biofuel that can be used directly as a renewable heating fuel, to replace heating oil or natural gas, and that can also be converted into a drop-in fuel for transportation. The associated greenhouse gas savings are very high (up to 93 %). FPBO is produced by fast pyrolysis of lignocellulosic biomass (residues from forestry, agriculture and related industries). As a technology provider and product leader we are committed to the commercial deployment of our fast pyrolysis technology. We built the first commercial pyrolysis plant in the Netherlands (Empyro) and are currently constructing two more plants in Scandinavia; one in Finland for Green Fuel Nordic and one in Sweden for Pyrocell.

The Empyro plant in Hengelo (NL) (photo: BTG).

The Empyro plant started up in 2015 and produces 20 million litres/year of pyrolysis oil using the pyrolysis process developed by BTG. It is the first fast pyrolysis bio-oil production plant worldwide that operates 24/7. The plant is self-sustaining and produces an excess of renewable electricity and steam as by-products. The steam is supplied to the neighbouring salt factory of Nouryon. The pyrolysis oil is supplied to the dairy company Royal FrieslandCampina location in Borculo in the Netherlands. They use the pyrolysis oil to produce steam in their boilers. This replaces an amount of natural gas that is equivalent to the annual use of 8,000 households.

Green Fuel Nordic Oy, will also produce 20 million litres of pyrolysis oil per year that will be used as a renewable heating oil. The pyrolysis plant will be located next to a sawmill in Lieksa, approximately 500 km north-east of Helsinki. The waste sawdust from the sawmill serves as raw material for the pyrolysis oil production. The pyrolysis plant is planned to start up in Q4 of 2020.

For Pyrocell, being a joint venture between wood products company Setra and oil company Preem, we are building a pyrolysis plant next to Setra's Kastet sawmill in Gävle. Sawdust from the sawmill will be converted into pyrolysis oil, which will then be used as a renewable feedstock for the production of advanced biofuels for transportation by Preem's refinery in Lysekil. The annual consumption of fresh sawdust will be approximately 80,000 tonnes. Annual production of pyrolysis oil will total around 25,000 tonnes and result in a GHG reduction versus fossil oil of 80-90%. An equivalent of 15,000 family cars can be powered per year with this and Preem Refinery will comply with this to both Swedish legislation as well as the European RED II directive. The project started in autumn 2019, and the pyrolysis plant will become operational in 2021.

These developments show that our fast pyrolysis is proven at commercial scale and worldwide capacity is expanding. The applications of Fast Pyrolysis Bio-Oil are currently as a renewable heating oil and soon as a renewable refinery feedstock for producing advanced biofuels. Further applications are under development together with BTG Biomass Technology group and other European partners, for example in R&D projects such as Waste2Road, that aim to broaden both the potential feedstock base as well as the potential application range of pyrolysis oil, thereby working towards a complete bioliquids refinery.

The Kastet site in Gävle (SE) where the Pyrocell plant will be located (photo: BTG).

ADESSO BIOPRODUCTS – THE ONLY BIOFUEL PRODUCER IN NORWAY PER 2019

Adesso biodiesel plant in Fredrikstad (photo: Adesso)

Adesso Bioproducts is the only full operating biofuel producer in Norway, in operation since 2016. The company operates two factories, located in Fredrikstad in Norway and Stenungsund near Gothenburg in Sweden. It is a subsidiary from the Swedish company Adesso Holding AB. It was until November 2018 owned by Perstorp AB, a major specialty chemical company

The biofuel production in 2019 was 260 million liters, corresponding to 52 % of the Norwegian consumption in 2018. The biodiesel and bioethanol is sold to the Scandinavian market. They are used for mandatory blend-in with fossil fuels, as 100% biofuels for trucks, buses and ferries and as a replacement for heating oil. Adesso fuels are documented to have good cold weather performance.

Adesso Bioproducts is ISCC-certified, an EU-approved voluntary system for realizing the European Renewable Energy Directive (RED). Every step in the production line, from growing rapeseed via processing to biofuels and distribution to end user, forwards sustainability and CO_2 load to the next step, see figure below. In this way the real total climate impact is documented for the total value chain. It is 51-71% compared to fossil fuels, depending on the feedstock.

The feedstocks are mainly rapeseed from unused farmland in Europe, where the level of unsaturation is favorable for the Scandinavian climate. In order to meet the demand for “advanced” biofuels, some cooking oil and fish oil has been evaluated and included in the process. Adesso is not involved in feedstocks from rainforests or deforestation, and thus fully avoid both palmoil and soya oil. One of

Adesso´s main objective is to maximize usage of non-crop raw materials without jeopardizing the product quality and winter properties.

Technology: Adesso applies two different methods for the tranesterification, which both yield high quality products. In Stenungsund, a heterogeneous process employs a fixed bed of zeolit catalyst for the reaction while in Fredrikstad potasium hydroxide together with methanol creates at methylate that serves as catalyst in a homogeneous liquid process. The heterogeneous process requires high pressue and temperature, it is dry and yields less byproducts. In the homogeneous process the reactor is more simple, but the purification more complicatred.

Beside the vegatable oil, methanol is used for the process. Here Adesso closely follow the various processes for non-fossil methanol which are under developmenmt; e.g. gasification of biomass and electrochemical conversion of CO_2 in order to form methanol.

NORWEGIAN FARMERS UNION "BONDELAGET"

Strong CO2-cut from* Norwegian *agriculture

June 2019 the signed an agreement with the Norwegian Government on reducing climate gas emission from the agriculture by 5 million tons CO_2-eqv. annually within 2030. Replacing fossil diesel with biodiesel and biogas is a prioritized action. In the long-term perspective use of electric machines and self-operating robots also will be an important part of Norwegian farming. Status on Climate actions will be a central issue in the annual negotiations between The Farmers Union and the Ministry of agriculture and food.

January 2020, the Norwegian Environment Agency released their large 'Climate cure' showing several climate actions to be taken to meet the 2030 target. Agricultural actions with highest climate impact are: change from red beef production to plant production and reduce the large losses in the food chain from producer to consumer. Also, replacing fossil fuel with biofuel and biogas is important.

Fossil fueled tractors release 0.29 million tons CO_2-eqv. annually. 155.000 tractors consume 135 million liters fossil diesel. The farmers union prioritize to replace this fuel with advanced biodiesel and biogas.

Biodiesel-tests performed by Inland Norway University of Applied Sciences in collaboration with The Norwegian Farmers Union in 2018-2019 conclude that the existing tractor park operates well when fueled with the biodiesel on the market (advanced HVO). This counts also in cold weather. The biodiesel also reduces particle emission and keeps the vital parts of the motor cleaner. However, biodiesel is more expensive than fossil fuel.

Checking tractor-motor wear during the biodiesel test by analyzing the oil quality (photo: Bondelaget).

Also, biogas is a relevant tractor fuel. Livestock manure makes a large feedstock for producing biogas. This is confirmed in a large survey made by the Farmers Union, NIBIO and NMBU. However, the energy content is moderate, and adding energy rich biomass, e.g. food waste, will boost the microbial process. Some few farm-plants have been tested in 2018-2019. Experiences show that technical and economic challenges still exist.

The first ZEG Power hydrogen production plant with carbon capture

Zeg Power (Zero Emission Gas) is a spin-off company since 2008 from IFE (Institute for energy technology). The company develops technology for clean and high-efficient hydrogen production with integrated carbon capture. The technology is based on sorbent enhanced reforming, producing streams of high purity carbon dioxide ready for utilization or storage.

Based on methane from fossil feedstocks, the Zeg Power technology opens up for separating carbon dioxide and producing clean hydrogen, a climate neutral energy source that can be used for transportation and industry. The carbon dioxide produced is clean and will be stored or used in industrial processes. Globally, hydrogen is being produced from fossil gas with no carbon capture.

After 11 years research and developing the process technology, the time has come to build the first ZEG-H2 plant. Seven investors agree, and they have signed for a 130 MNOK investment. The investors are: AP Ventures (UK), Sparx Group (multinational), Nysnø (NO), CCB (NO), Danske Invest (DK), Stratel (NO) and IFE Invest (NO).

The plant will be built in CCB Energy Parke at Kollsnes near Bergen, adjacent to the planned Northern Lights large scale CO2-storage facility. Production of clean hydrogen will start 2022. Until the Northern Lights plan is established, ZEG Power will use renewable biogas as input gas in order to enable clean hydrogen production.

Hydrogen production from the first ZEG-plant and future site expansions shall provide zero-emission fuels to Norwegian and international transport and industry users. The production capacity from start will be 250 tons hydrogen annually, later expanding to 5000 tons.

ZERO – SUSTAINABLE BIOFUEL CONTINUES TO BE POLICY DRIVEN

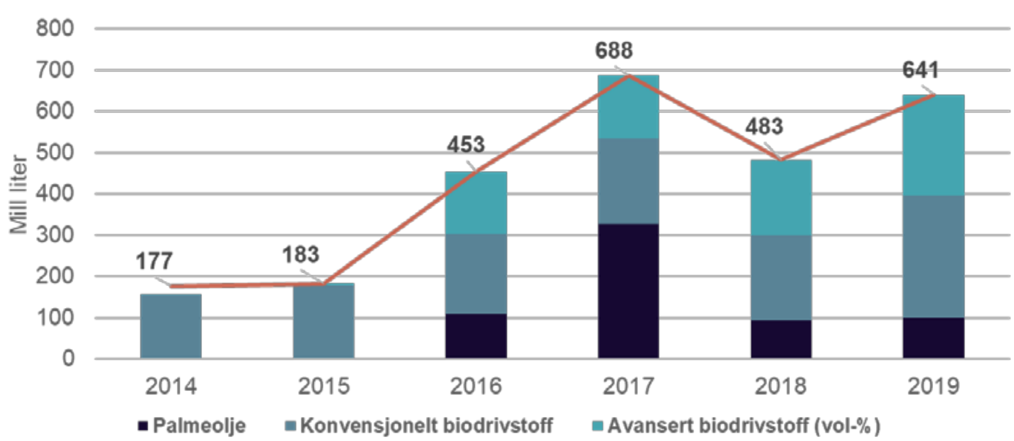
There is a policy push for biofuels in Europe and forward leaning US states. Leading the way with high biofuels share are the Nordic countries. In 2019 the Norwegian biofuels market reached 640 million litres, while the Swedish market reached 1,7 billion litres[1]. Both countries have high shares of advanced biofuels with high greenhouse gas savings.

Sustainable biofuels is key for rapid and deep decarbonisation of transport, especially heavy duty transport and aviation. Current biofuels consumption is a mix of conventional biodiesel, bioethanol, HVO and small volumes of naphtha. Political goals are reduced transport emissions and increased domestic production of advanced biofuels.

There are two main barriers for sustainable biofuels today: 1) availability of advanced biofuels and 2) biofuels reputation. The most important task ahead is getting new production volumes of advanced biofuels in operation. New biofuels production is good climate policy, and it is a possible new green industry in Norway. To succeed with this there is a need for predictable policy for sustainable biofuels. The sales mandate for advanced biofuels in aviation from 2020 is a good example, with stated ambitions of 30 % in 2030.

The production capacity for advanced biofuels is limited but growing internationally. New investments are policy driven, by high ambitions in the EU and selected US states. The Norwegian sales mandate, with a sub mandate for advanced biofuels, is investment friendly as it gives predictable demand volumes.

Whether biofuels is considered a climate solution is depending on political and public perception. In recent years palm oil has contributed quite considerably to increased sales volumes, peaking in 2017. For continued political support for biofuels it is crucial to phase out these volumes, unwanted by both politics, environmental organisations and consumers.



Biofuel development in Norway 2014-2019 (source: Miljødirektoratet and Skattedirektoratet).

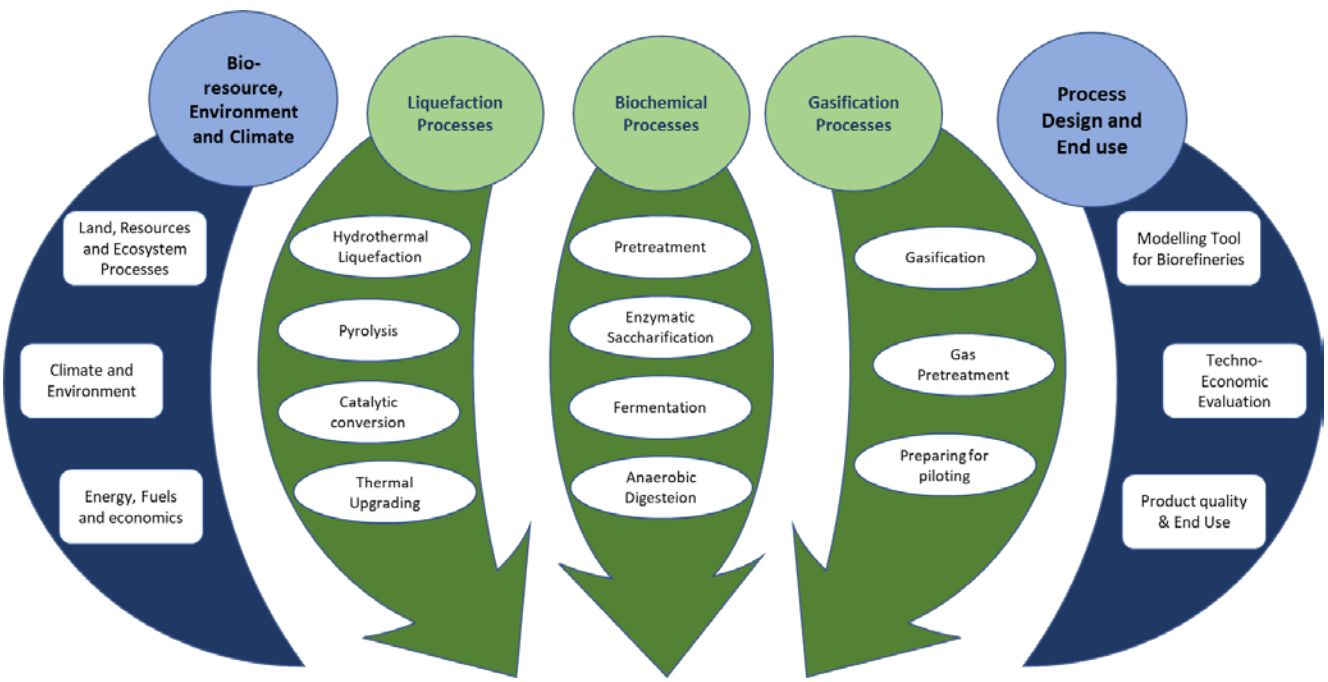
[1] Source: Skattedirektoratet and SCB

HIGHLIGHTS FROM BIO4FUELS' WORK PACKAGES

The organisation of the scientific activities in Bio4Fuels were restructured in 2019. The previous organisation of the activities had a reporting structure across the value chain with the goal of stimulating new synergies and innovation through interaction between the "thermochemical" and "biochemical" approaches. Based on a through review of alternative options, the reporting structure has been organised to be aligned along the three main technology value chains.

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

Within this new organisational structure, Bio4Fuels has greater focus and coordination of the activities along the value chains, looking at 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 2019

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

WP1.1	Land, Resources and Ecosystem Processes (Rasmus Aastrup, 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.

WP1.1 Land, Resources and Ecosystem Processes Rasmus Astrup

Norwegian biofuel production is dependent on feedstock at a competitive price but the marked for forest biomass is showing signs of increased prices and competion for biomass. In WP1.1 we investigate different options for increasing acess to biomass from sustaniablely managed forests. One option is increasing thinning and investigations of long-term thinning experiments have given new insight into the effects of thinning in Norway spruce forests. From analyses of tree and stand growth, it was determined that thinning can reduce biomass losses to mortality and potentially lead to greater volume/biomass stocks as compared with no thinning. Economic analysis has indicated that thinning can increase net present value of a forest when the initial stand density is high and when thinning is performed relatively early in stand development. These results imply that we through forest management thinning can lead to an increase in the availability of biomass while providing a greater return on investments to forest owners.

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

Professor Francesco Cherubini (NTNU) was one of the lead authors of the **IPCC's new special report**, released in August 2019, on **Climate Change and Land**, and was the only author from a Norwegian-based institution. He handed the report to the Norwegian Minister of Climate and the Environment during a launching event at the Norwegian Environmental Agency.

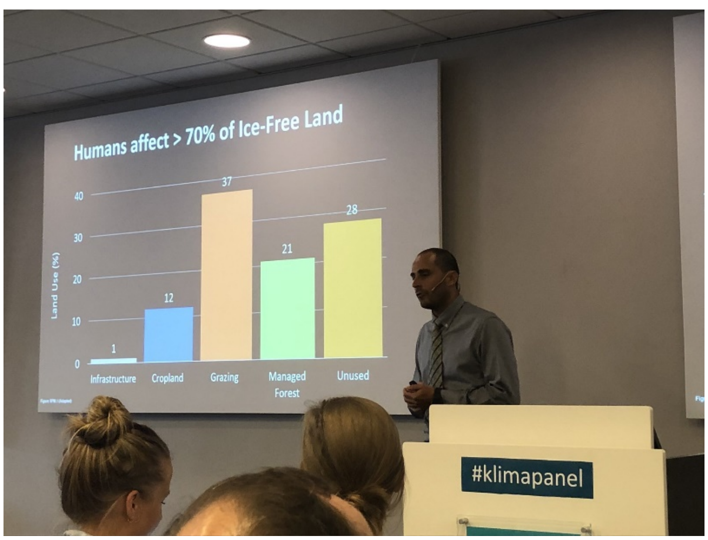
The IPCC report addresses the interlinkages between climate change and land, including the role played by land-based climate change mitigation options like bioenergy.

The IPCC describes the report as an "assessment of the latest scientific knowledge about climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems." The report is an analysis of more than 7000 publications and looks at possible future scenarios to suggest the kinds of changes that need to happen under different socioeconomic situations, assuming society tries to limit warming to 1.5 C.

A lot of land is needed for climate change mitigation. Even in the most sustainable future scenario that will allow us to meet the 1.5-degree goal, the amount of forest land needed to soak up CO2 and to produce bioenergy (either with or without carbon capture and storage) by the end of this century will top out at about 7.5 million km2, or roughly the size of Australia. Bioenergy needs to be put in place with all the other climate change mitigation options to achieve the 1.5 C goal. This is not a competition for land between forest and energy crops. We need both.

Although these changes will cost money, the IPCC report emphasizes that the costs of inaction will exceed the costs of immediate action in many areas. That means that money spent now can be seen as a sound investment to prevent future larger costs from social and environmental damages and adaptation needs.

Reference: IPCC Special Report on Climate Change and Land at: https://www.ipcc.ch/srccl/



WP1.3 Energy, Fuels and Economics Torjus Bolkesjø

Forest biomass plays an important role in heat production in Norway and the other Nordic countries, as well as rest of the world, and the use of forest biomass for heating may increase further in the future as a result of reduced use of fossil fuels. At the same time, the transportation sector may also demand more wood for biofuels production. Since biomass availability is limited, it is important to assess the advantages and disadvantages of using woody biomass for power and heating purposes versus using it for biofuels in transportation.

For these reasons, we have analysed the optimal use, i.e. cost minimizing of woody biomass for power and heat in northern Europe towards 2040 using an energy system model (Balmorel). Furthermore, we have quantified the reduction in fossil carbon emissions when using woody biomass for power and heat generation. According to our preliminary results, woody biomass can reduce the direct emissions in 2030 from the northern European power and heat sector by 4–27% compared to a when woody biomass is not available for power and heat generation. One major driver in the model is the carbon price which was varied in the range of 5–103 €/tonne CO_2eq. When assuming a low carbon price, the use of natural gas, wind, and coal power generation increases when biomass is not available for power and heat generation. At higher carbon prices, solar power, wind power, power-to-heat, and natural gas become increasingly competitive, and therefore the use of biomass has a lower impact on emission reduction. Using the same biomass volumes for liquid transport fuel, a higher impact on fossil carbon emission reductions was found. At the same time, the cost per tonne fossil carbon reduction are substantially higher.

Production of liquid biofuel produced from forest biomass has higher production cost than conventional fossil fuel. Subsidies or other policy measures are therefore necessary to induce production of liquid biofuel. In a second study conducted in 2019, we assessed six different policy schemes that may increase the attractiveness of investing in forest-based liquid biofuel production facilities. In the study we simulated the likely effects of the policy schemes using a partial equilibrium forest sector model. The study analysed investment support, feed-in premiums, quota obligations, increased fossil fuel taxes, biofuel tax exemptions, and support for using harvest residues. We found that a feed-in premium gives the lowest total subsidy needed when the Nordic production level is below 6 billion litres (25% market share) of forest-based biofuel, while quota obligation is the cheapest option for production levels above 6 billion litres. According to these model results, the necessary subsidy level is in the range of 0.60–0.85 €/L (82–116% of the fossil fuel cost in 2030) for realistic amounts of biofuel production. The pulpwood prices increase up to 24% from the base scenario due to increasing biomass demand.

References:

Jåstad, E. O., Bolkesjø, T. F. & Rørstad, P. K. (2020). Modelling effects of policies for increased production of forest-based liquid biofuel in the Nordic countries. Forest Policy and Economics, 113: 102091. doi: https://doi.org/10.1016/j.forpol.2020.102091.

Jåstad, E. O., Bolkesjø, T. F., Trømborg, E. & Rørstad, P. K. (2020). The role of woody biomass for emission reductions in the heat and transport sectors. Energy (under review).

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

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.

WP2.1 Pyrolysis Kai Toven

Pyrolysis processes are of particular interest for direct conversion of biomass and residue feedstocks into liquid fuels and biocarbon materials. However, novel technology concepts are needed to obtain high carbon yield of preferred products from the pyrolysis process and obtain a biocrude fuel quality suitable for further upgrading into transportation fuels. In 2019, the Bio4Fuels' research team at RISE PFI demonstrated that favorable product yields can be obtained by combining pyrolysis technology with anaerobic digestion in cooperation with the key stakeholders Norske Skog Saugbrugs and Cambi. By combining pyrolysis and anaerobic digestion both biocrude fuel oil, biocarbon and biogas fuel can be produced simultaneously and thereby obtain higher carbon product yields as compared to a stand-alone pyrolysis process. The Bio4Fuels' research team at RISE PFI is also addressing novel two step catalytic pyrolysis processes for direct production of biocrude fuel oils in diesel and jet fuel molecular weight range. Now, a unique two-step pyrolysis reactor system has been established at RISE PFI suitable for screening effects of feedstock composition, process conditions and catalysts combined with quantitative analysis of preferred chemical products. Some results from testing two-step catalytic pyrolysis conversion of various feedstocks was presented at the tcbiomassplus2019 conference in Chicago in October. 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.

Photo: The Bio4Fuel research team at RISE PFI are working with novel pyrolysis technology routes for producing transportation fuels from lignocellulose feedstocks. The research activities related to pyrolysis in Bio4Fuels are led by Dr. Kai Toven, Lead Scientist in Biorefining and Bioenergy at RISE PFI.

WP2.2 Hydrothermal Liquefaction Judit Sandquist

Modelling

During the HTL process, inorganic compounds originating from the feedstock may cause operational issues as well as they can deteriorate the product quality. The combined use of two thermodynamic equilibrium models were applied to model the speciation and phase distribution of the inorganic compounds in HTL products through several approaches. All the approaches were validated against both the quality of the modelling results (convergence and accuracy) and the similarity between the modelled products and the product distribution from the experimental data. Through this process, it was discovered that there are still some challenges connected to the combined models. The main challenge is that the MATLAB-based model assumes thermodynamic equilibrium, which is not the case for a real HTL system. Constraints were therefore applied to the MATLAB model in an attempt to predict the product distribution in a non-equilibrium process, however, excessive use of constraints does not seem to be effective to improve the modelling results.

Reactor

A continuous HTL mini pilot was designed and constructed in 2019. During the first half of 2019, the P&ID was developed in collaboration with the manufacturer, Top Industrie in France. The reactor has two tanks, one stirred tank for slurry and one water/solvent tank for start-up and cleaning. Double piston pumps ensure continuous operation at a maximum rate of 2 L/H. The reactor itself is a stirred 1 L CSTR tank which can be heated to 500 °C with a maximum operating pressure of 350 bar. The reason of the CSTR design is to minimize clogging during small-scale operations as well as it gives the possibility to incorporate corrosion samples to study corrosion of spent materials in real HTL environment. Downstream the reactor, the HTL mini pilot exhibits a two-stage pressure release system with liquid and gas separation. Successful function tests were carried out in France in December 2019. During the tests, the flow, heating, controls and separation were tested with water and biomass feedstock.

Expert HTL workshop

The Expert workshop *Potential of Hydrothermal Liquefaction (HTL) routes for biofuel production* was co-organized by Bio4Fuels and five European H2020 projects. Almost 100 participants attended from industry, SMEs, EC, research organizations, universities, and other organizations. The workshop brought together different stakeholders working on the commercialization of HTL in addition to research and academia while keeping the focus industrial.

The workshop started with the presentations of the six organizing projects, followed by a presentation about the European research and innovation policy. Thereafter we learnt about a Canadian ATM project and about the activities are going on in the United States. During the workshop, five industrial stakeholders from around the globe (Steeper Energy, Eni Rewind, Armstrong, Reliance and Southern Oil Refining) presented their commercial status. It became clear that there are many different HTL processes and approaches to commercialize those. The stakeholders expect the first commercial plant to be operational between 2022-2025. Compared to other technologies such as pyrolysis and gasification, HTL appears to be a more robust technology as it can handle broader feedstock quality ranges. In addition, it can easily be replicated at several locations close to the feedstock, which is an advantage compared to technologies that require scale.

Photos: From the workshop.

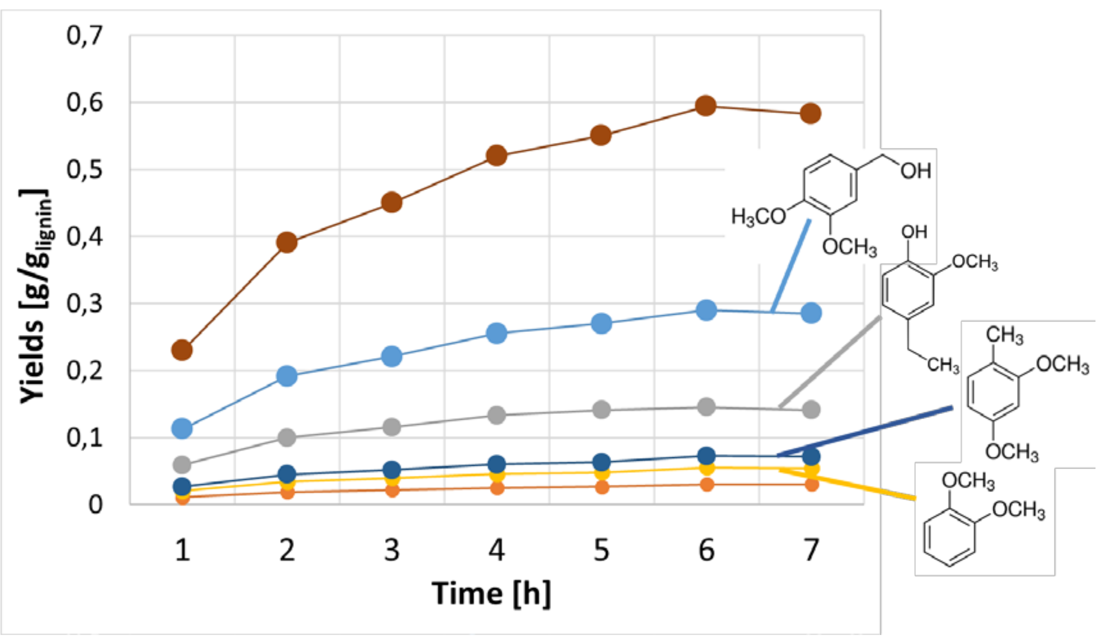
WP2.3 Thermochemical upgrading of bio oils Roman Tschentscher

The aim of this work package has been to catalytically convert intermediates into higher value products. In particular the conversion of oxygen-containing components into energy-dense and stable products is essential. Those target products can further be co-processed with refinery streams. Alternatively, they can be locally stored and be used as fuel.

With respect to bio oil upgrading the experimental work has focused on the hydrotreatment of crude oil from hydrothermal liquefaction. The spruce-based oils were obtained from the HTL pilot rig at Aarhus University. At SINTEF they were converted into hydrocarbons using batch processes. A temperature test program was conducted. The results showed that the crude oils could be nearly completely deoxygenized without the use of additional catalysts.

At reaction temperatures below 300 °C instable acids, ketones and aldehydes were hydrogenated to alcohols. At temperatures above 300 °C those alcohols were deoxygenated into hydrocarbons. At the most severe conditions the yield of liquid hydrocarbon products was above 75 wt%. The hydrocarbon products can easily be blended with refinery streams. Future work includes a further screening of the parameter space including hydrogen pressure, and the use of low-cost catalytic materials. The aim is thereby to shift the operational regime towards milder conditions resulting in reduced investment and operational costs.

As a side project the conversion of lignin into higher value compounds was studied. As catalysts hydrotalcite-based materials are synthesized. They are characterized by a high surface area and high basicity, which is required for an effective depolymerization. The Figure below shows the example of organosolv lignin depolymerization at mild conditions. Compounds of type dimethoxy aromats could be produced with high selectivity. Those monomers can be applied as precursors for polymer and resin production.



Yields of monomeric products from mild catalytic depolymerization of lignin.

WP2.4 Chemo-catalytic conversion De Chen (Jia Yang)

This WP 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; in addition, it can be used as simple model-compound to study carbonyl selective hydrogenation of oxygenates. The main challenge of the work is the catalyst stability towards deactivation. In order to improve stability, Cu supported on carbon nanofibers are investigated. Platelet carbon nanofibers (PCNF) were prepared via carbon vapor deposition of CO and H_2 at 600°C over iron powdered nanoparticles. 9 catalysts were prepared using PCNF as support, varying Cu precursors (nitrate, acetate, and basic carbonate) and impregnation solvents (water, ethanol, isopropanol). Additional 9 catalysts were prepared using silica as support (with the same Cu precursors and impregnation solvents as for the PCNF) to be used as non-carbonaceous references. These catalysts were tested in the reaction of hydrogenation of hydroxyacetone at standardized conditions (3 hours reaction at 240°C and 6 bar and with an hourly space velocity of 8 $g_{acetol}/h/g_{cat}$) and are being characterized in order to get insights on the properties controlling the catalysts performances. Surface treatments of PCNF will be explored, in order to tune the surface properties of the carbon nanofibers, and thus of the catalysts. Lastly, the most promising catalysts will be tested for long-term stability.

Photo: Catalyst testing setup (left) , copper based catalyst materials (upper right) and the fixed bed reactor (lower right) for testing catalysts activity.

SP3: Biochemical Processes
SP Leader: Anikó Várnai

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 (Linn Solli, NIBIO)

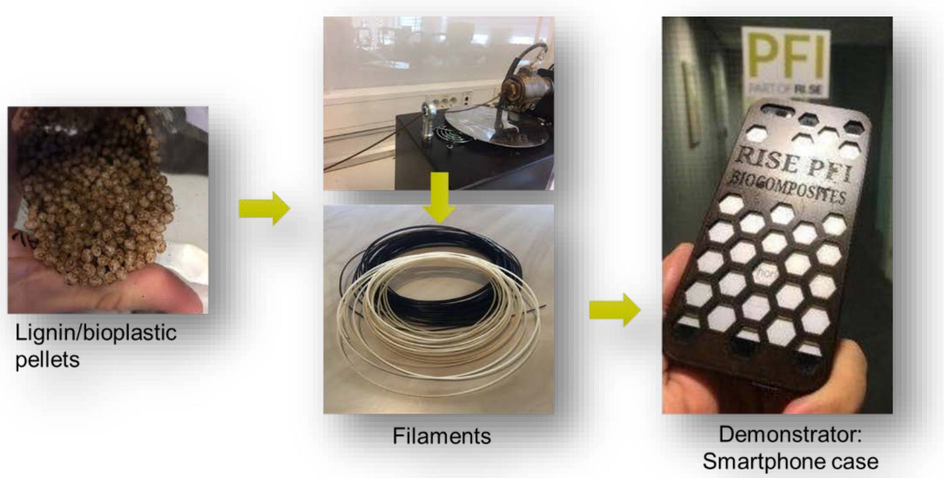
Background and approaches

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 2nd 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.

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. To do that, a series of organosolv pre-treatments were performed on Norway spruce to generate pulps with different lignin content. The results showed that increasing cellulose accessibility is a more important pre-treatment objective than delignification for effectively releasing sugars from recalcitrant lignocellulose at high yield. More than 90% of the cellulose in low lignin pulps (≤ 18% residual lignin) was hydrolysed to glucose in 24h using an enzyme loading of 67 FPU/ g cellulose. By decreasing the enzyme loading to 8 FPU/g cellulose, about 70% of cellulose was hydrolysed to glucose in 24h, but complete conversion was achieved in 72h. The increased cellulose accessibility is largely due to the reactor characteristics which facilitate efficient separation of components and overcome lignin reprecipitation problems by displacing the pre-treatment liquor at high temperature and pressure levels. Moreover, chemical analysis of lignin extracted during acetone organosolv pretreatement process of Norway spruce showed 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. Additionally, biocomposites based on various biopolymers and reinforcing wood fibres have major potential for 3D printing operations.



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

WP3.2 Enzymatic Saccharification Aniko Varnai

Successful application of novel enzymatic mechanism for biomass saccharification at demonstration scale

A team led by Profs. Svein Horn and Vincent Eijsink at NMBU has worked in close collaboration with Bio4Fuels partners Novozymes and Borregaard to develop an industrial setup to harness the action of oxidative enzymes called LPMOs (lytic polysaccharide monooxygenases) in commercial cellulase cocktails in a more efficient way than it is done in current industrial processes. The novel process is based on the recent scientific breakthrough at NMBU showing that LPMOs can utilize hydrogen peroxide much more efficiently than oxygen to break down cellulose.

In 2019, the team successfully implemented this recently developed industrial setup at demonstration scale at Borregaard's Demo Unit (see photo below). Using H_2O_2 supply for the controlled activation of LPMOs in Cellic CTec3 enabled faster and more complete saccharification of Borregaard's BALI-pretreated spruce feedstock. With the new setup, 15% higher glucose yield was reached within 40% less saccharification time than using the current state of the art process setup at 2000 L scale.

In parallel with the scale-up, the team at NMBU has also developed a small-scale reactor system at 50-mL scale, which enables optimization of saccharification of feedstocks, including those from Bio4Fuels partners St1 and RISE-PFI (WP3.1), in a higher throughput manner.

The NMBU team has been disseminating information about the recent developments at the most relevant conferences in the field worldwide, including the GRC (Gordon Research Conferences) on Metals in Biology (by Vincent Eijsink, Jan 2019) and the SIMB (Society for Industrial Microbiology and Biotechnology) Annual Meeting and Exhibit (by Anikó Várnai, Jul 2019). The leading role of the NMBU team in this field has been also recognized through a number of recent invited review papers for prestigious journals, namely *Biotechnology for Biofuels, ACS Catalysis, Current Opinion in Structural Biology.*

Photo showing Borregaard's Demo Unit in Sarpsborg, which were used to showcase faster and more complete saccharification of Borregaard's BALI-pretreated spruce feedstock at demonstration scale.

WP3.3 Fermentation Alexander Wentzel

Lipid production

At NMBU, several oleaginous Mucoromycota fungi have been identified as potential cell factories for the co-production of lipids and chitin/chitosan. Lipids are stored in intracellular organelles called Lipid Bodies, while chitin/chitosan is located in the Cell Wall (Fig. 1). Our results indicate that targeted nutrient enrichment of lignocellulose hydrolysates could lead to controlled co-production of two different high-value products in a single cultivation. Further research on the optimization of total yields of products is ongoing.

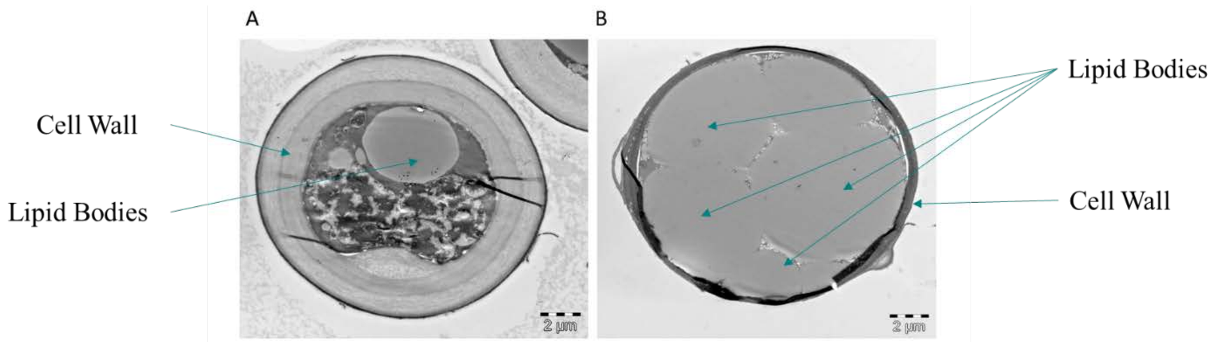


Figure: Co-production of lipids and cell wall biopolymers (chitin/chitosan) in a single cultivation of the oleaginous fungus *Mucor circinelloides*.

Ethanol production

The yeast *Saccharomyces cerevisiae* plays a fundamental role in the production of advanced biofuels and other bio-based building blocks, and the currently dominating biofuel ethanol is produced via yeast fermentation. During 2019, SINTEF has started work in collaboration with Bio4Fuels industry partners St1 (providing lignocellulosic feedstock) and Novozymes (providing commercial enzyme mixtures) towards more efficient production of bioethanol using the approach of Simultaneous Saccharification and Fermentation (SSF). In SSF, enzymatic breakdown of cellulose occurs integrated in the fermentation of the resulting sugars to ethanol by *S. cerevisiae*. Plans for systematic experiments have been made in close interaction with NMBU on both optimized enzyme mixes and online monitoring of fermentations. These plans will be implemented jointly in the first half of 2020.

Additionally, SINTEF has made further progress on establishing three moderate thermophilic microorganisms producing relevant biofuel compounds like ethanol at elevated temperature as new anaerobic biorefinery platforms for further development in Bio4Fuels.

WP3.4 Anaerobic digestion Linn Solli

AD and gas upgrading

Biological methane upgrading by addition of H_2 to methanogenic communities have been investigated in batch and continuous systems, and an increase from 67 to 94 % CH_4 in the biogas was obtained when adding H_2 to a batch mode AD process. The reactor microbial communities shifted in composition over time, which corresponded to changes in the reactor variables. Numerous taxa responded to the H_2 inputs, and in particular, the hydrogenotrophic methanogen *Methanobacterium* increased in abundance with addition of H_2.

In continuous mode, the influence of mixing speed and gas recirculation on biological methanation (BM) using two- stage CSTRs (se figure below) was investigated.

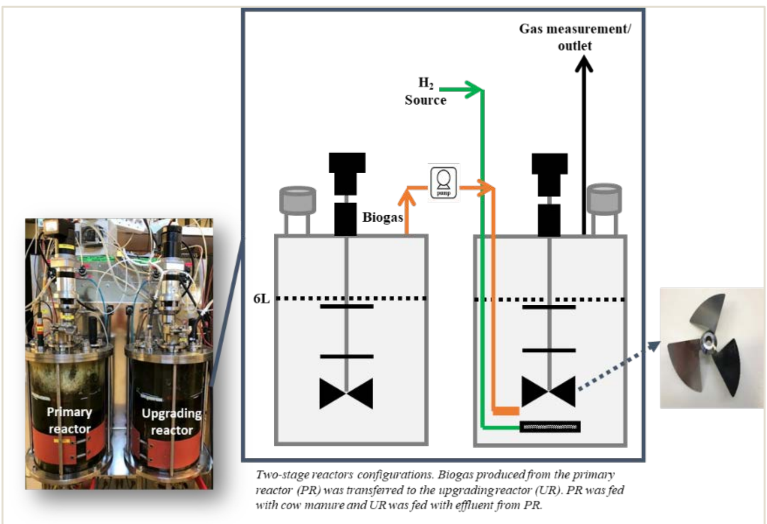


Figure: Reactor configurations.

The experiments showed that the mixing speed and gas recirculation had a significant effect on BM in CSTRs. Above 140 rpm, mixing becomes counter-productive and the total CH_4 production rate falls. However, BM was improved at 170 rpm, but it was not energy efficient as the total CH_4 production rate did not increase. The CH_4 production rate from CO_2 and H_2 conversion was further enhanced as the output gas was recirculated at 12.20 mL min^{-1}. Further gas recirculation above 12.20 mL min^{-1} did not improve BM.

Sorption-Enhanced Reforming (SER) for H2 production

The sorption-enhanced reforming (SER) technology including CO2 capture has the potential to introduce renewable hydrogen to the marked and at the same time provide bio-CO2 that can be used to produce biomethane through the Sabatier process. Additionally, the bio-CO2 produced can be used, after purification, in the food and beverage industry, greenhouses, biopolymer synthesis, as well as algae production. For instance, 1000Nm3/h of Biogas with 40% CO2 it is possible to produce 2000Nm3/h of H2 via SER process.

SER Conversion Efficiency

Figures 1 to 4 present the results of the SER experimental campaigns. In total, we performed 14 experiments to test 4 SER process parameters: 1) CH_4/CO_2 ratio, 2) solid inventory, 3) steam to CH_4 ratio, and 4) fluidization velocity.

As a result, H_2 yields of over 95% have been obtained for SER operated in a fluidized bed reactor for CH_4/CO_2 ratios varying between 1 and 2.33, steam/CH_4 ratios of 3 and 4, and gas velocity up to 0.1 m/s. The CO2 sorption was also high, not being above 2% in any of the cases.

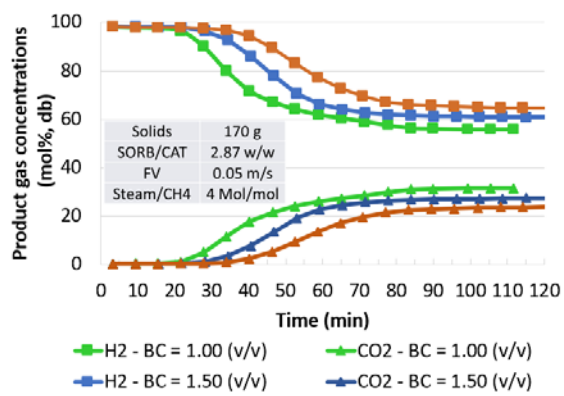


Figure 1: Biogas Composition – CH4/CO2 ratio

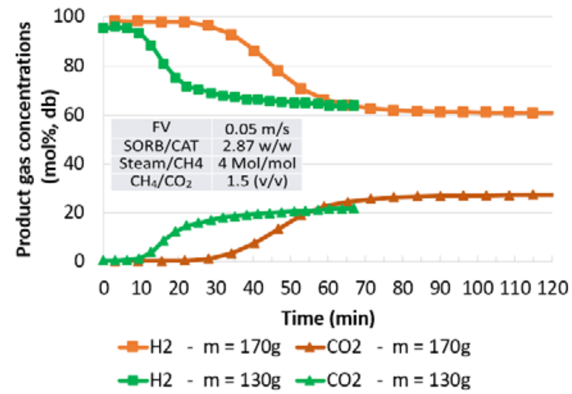


Figure 2: Solids inventory (m)

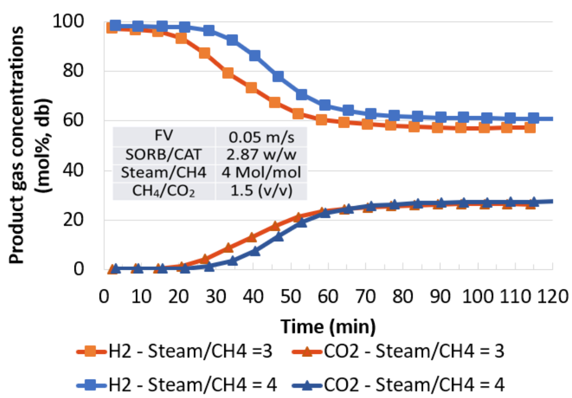


Figure 3: Steam to CH4 ratio

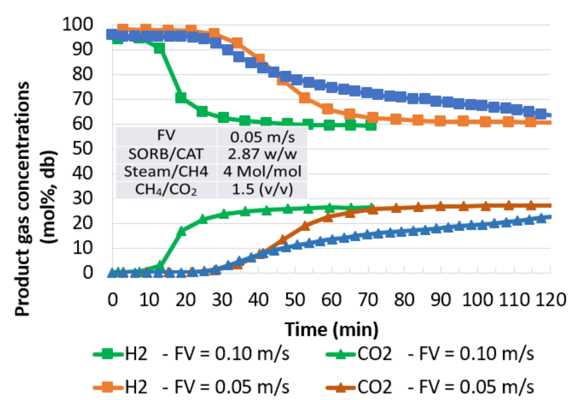


Figure 4: Fluidization Velocity (FV)

Figure: SER allows avoiding both water-gas shift and upgrading steps, resulting in potentially lower H_2 production cost from biogas than conventional technology. Therefore, SER proved to be a suited technology for reforming of biogas and allows producing additional valuable bio-CO_2.

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

WP4.1	Gasification (Morten Seljeskog, SINTEF Energy)
WP4.2	Gas Conditioning (Edd Blekken, 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 to 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.

WP4.1 Gasification Morten Seljeskog

In 2019 several experimental campaigns were effectively accomplished. All-in-all, ten campaigns using both generic biomass sawdust (7 campaigns) as well as dried and milled sludge (3 campaigns). The Entrained flow reactor is now able to deliver useful scientific results. We are currently preparing several scientific publications. SINTEF published a blog in 2019 to inform the "World" about the good news of having an operational gasification reactor (see links below). Late in 2019 an additional steam generator was acquired and is now installed. The purpose is to further enhance conversion and the quality of the syngas. Several more campaigns are planned for 2020, using e.g. sludge (Ecopro) and lignin (ST1).

Links:

https://blogg.sintef.no/sintefenergy-nb/nordbiolabs-gassifiseringsreaktor-klar-for-bruk-sintef-energy-lab/

https://www.facebook.com/sintefhq/videos/entrained-flow-reactor-gassifiseringsreaktoren-p%C3%A5-sintef-energy-lab/1874894889276741/

WP4.2 Gas Conditioning Edd Blekkan

- A new PhD-student has been recruited: Ask Lysne
  The thesis project preliminary title is “Biomass for fuel - Syngas conditioning”

Photo: Ask Lysne

- Catalysis rig to be used has been redesigned and the rebuilding has started
- Several presentations have been given at international conferences, for example:
  - Jianyu Ma et al.; Investigations of molybdenum-promoted manganese-based solid sorbents for H2S capture, 5th International Congress on Catalysis for Biorefineries (CATBIOR 2019). Åbo, Finland , September 2019.
  - Koteswara Rao Putta et al.; Modeling, optimization and validation of entrained flow biomass gasifier for syngas production for FT-synthesis. 27th European Biomass Conference & Exhibition, EUBCE2019, Lisboa, May 2019.
  - Mehdi Mahmoodinia et al., Performance of Manganese-based Solid Sorbents for H2S Removal: Particle Size and Promoter Effects on Sorbent Capacity, Geet19-Green Energy and Environmental Technology, Paris, France, July 2019.

WP4.3 Preparing for piloting and up-scale **Marianne Eikeland**

University of South-Eastern Norway (USN) is working on piloting and up scaling of conversion processes for biomass to biofuel. Modeling and simulations is a major part of this research. The main focus is to develop simulation models to study the conversion of biomass into biofuels. The first step is to develop a CPFD model to simulate the conversion of biomass into syngas. The second step is to develop a process simulation model to simulate the conversion of syngas into liquid biofuels. It is desired to have a validated model to study the different process parameters.

Experiments were performed in both a cold flow model of bubbling fluidized bed gasification reactor (Figure 1), and in a pilot-scale fluidized bed gasification reactor (Figure 2). Analysis of the fluidization characteristics such as mixing, segregation was performed in the cold flow model. A simulation model was developed using the commercial software called Barracuda®, based on MultiPhase Particle-In-Cell (MP-PIC). The effects of different particle sizes on fluidization behaviour were investigated and the results are documented in the paper "Effect of particle size on flow behavior in fluidized beds" published in International Journal of Energy Production and Management, (vol 4) 2019.

A kinetics-based simulation model was developed using Barracuda® software and validated against the experimental results in a pilot-scale fluidized bed gasification reactor, with air as a fluidizing agent and birch wood chips as biomass feed. The paper "Simulation of air-biomass gasification in a bubbling fluidized bed using CPFD model" published in Linköping Electronic Conference Proceedings 2019, represents the validation of the developed Barracuda model and gives the basic results from the simulation. The validated model from this paper was used to study the effects of different biomass feed and the Air to Biomass Ratio (ABR). The results from the simulation model as well as experimental results are documented in the paper "Experiments and CPFD simulations of biomass gasification in an air-blown fluidized bed gasifier" is submitted to International Conference on Energy Production and Management 2020. The results were also presented at the poster presentation in Bio4Fuls days Conference in Gothenburg, Sweden, 2019.

The paper "Aspen Plus simulation of biomass gasification for different types of biomass" published in Linköping Electronic Conference Proceedings 2019, presents the biomass gasification phenomena using a thermodynamic equilibrium model in Aspen Plus. Reaction kinetics is unknown and the products of gasification are estimated based on the minimization of Gibbs free energy. The model was used to study the product gas composition for different feedstocks, at different temperature and biomass feed loadings.

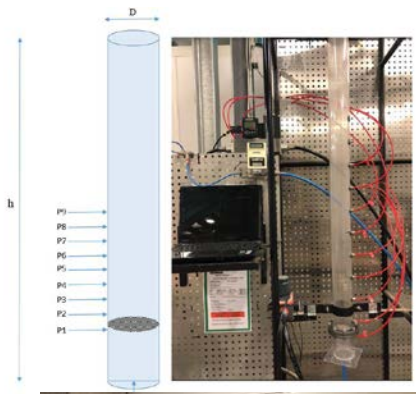


Figure 1. Cold flow model of bubbling fluidized bed at USN Porsgrunn

Figure 2: Fluidized bed gasification reactor at USN Porsgrunn

Other acivities WP 4.3

- During 2019 the cooperation with SINTEF Energy, has strengthen through meeting and discussions related to gasification.
- The PhD student at USN (Ramesh Timsinave) has made contact with the PhD students at NTNU working within the group of gas conditioning.
- USN and RISE PFI have meet to discuss cooperation within the Bio4Fuel. The discusion will continue in 2020. RISE PFI and USN cooperate in other relevant projects like PYROGAS.
- SINTEF Energy and USN are partners in the EnergiX FLASH project (predicting the flow behaviour of ash mixtures for production of transport biofuels in the circular economy), togheter with University of Natural Resources and Life sciences, Vienna, Aalto University Helsingfors, duration: 2018-2021. USN is project leader of the FLASH-project.

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.

WP5.1 Modelling Tool for Biorefineries **Heinz Preisig**

EcoLodge Fermentation Process

EcoLodge explores an innovative process aiming at the production of the biofuel butyl butyrate from sugars. The process consists of a butanol fermentation, a butyric acid fermentation, two separating process, an in-situ gas stripping and an electro-dialysis, and an enzymatic transesterification of the alcohol and the carboxylic acid to butyl butyrate. The lab-scale rig is located in the laboratory of the NTNU's Process Systems Engineering group constructed jointly with SINTEF. Initial experiments have been conducted. The experimental results will be utilised to validate and verify a model of the EcoLodge process. NTNU's graphical modelling method is employed to generate an abstraction representing the topology of the process. The ProMo software suite, currently in development at the NTNU, links the topology to the physical/chemical fundamental principles collectively describing the plant's behaviour. This systematic approach minimises modeller-caused errors and enables rapid model design. *ProMo i*mplements the introduced methodology, compiles the model equations into several target languages, and generates with the aid of a graph-based reasoner executable program code based on the expert-defined ontology and the modeller-defined topology.

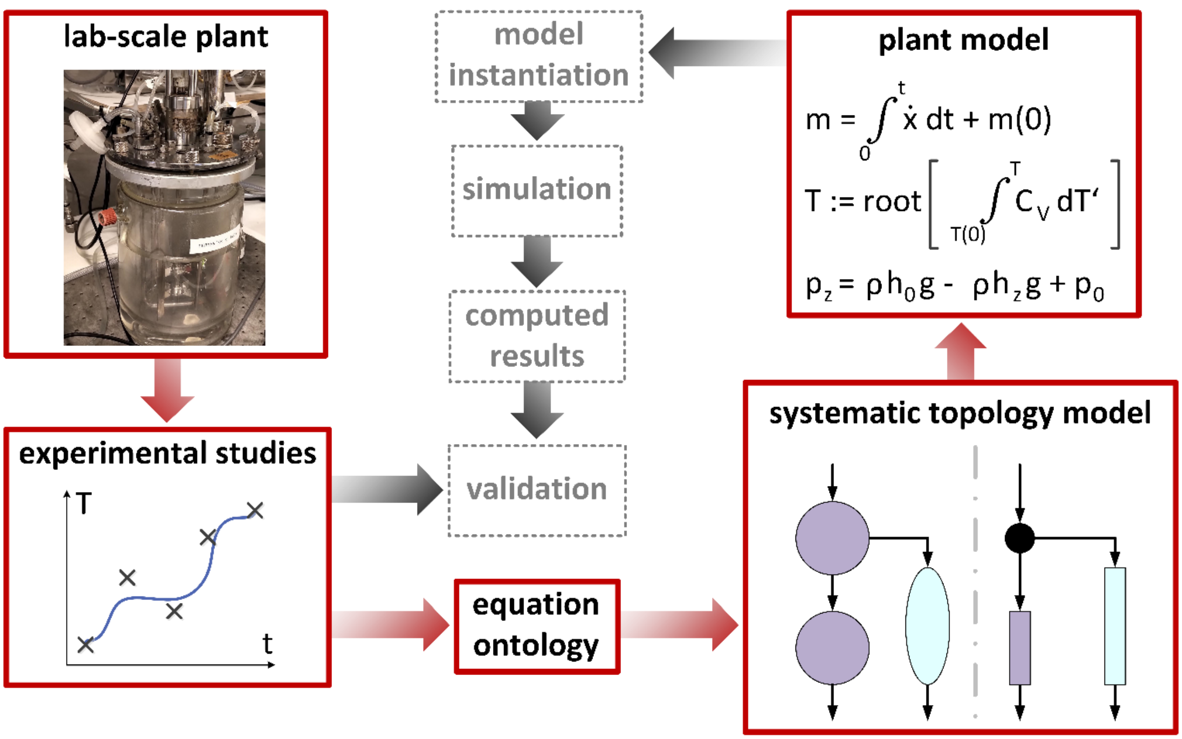


Figure: Graphical depiction of the EcoLodge investigations – red markers indicate the work currently in progress, grey marks future work.

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

Production of biofuels can be performed by either biochemical of thermochemical conversion. Biochemical conversion pathways are characterized by diluted aqueous solutions in which microbe's lignocellulose derived sugars are converted into fuel compounds. The energy efficient separation of these aqueous mixtures is necessary to improve the economic viability of the production.

Within Bio4Fuels work has been performed to see for alternative methods to reduce energy consumption through development of hybrid processes which integrated the strength of individual unit operations. For production of ethanol, generally a sequence of two distillation columns and a molecular sieve for final de-hydration are used.

We have developed a system which combines a classical distillation with a pervaporation process where the distillation column is utilized in its highest efficiency range. Sub-sequent a pervaporation process is applied. Pervaporation processes are generally operated with liquid systems on the retentate side and vacuum on the permeate side. This is an energy intensive process. However, here we choose to feed the pervaporation system with the vapor from the distillation column, which reduced energy consumption in this step considerably.

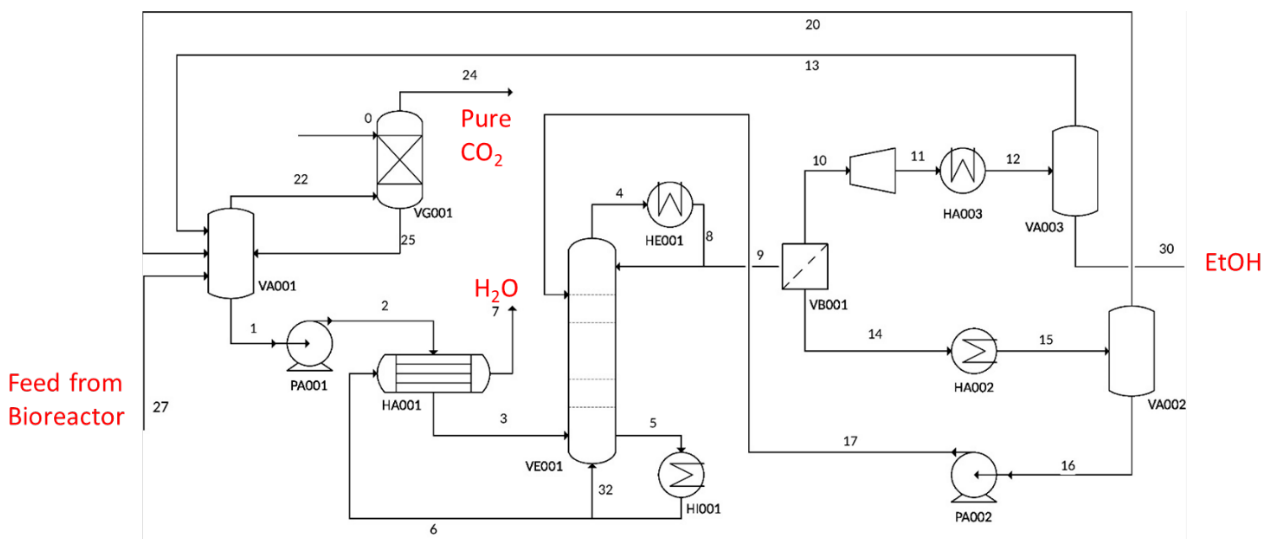


Figure: The developed process has an estimated 15% lower capital costs and approximately 18% lower energy consumption.

WP5.3 Product quality and End Use

Terese Løvås

In this WP, we 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.

Temporally and spatially resolved in-flame soot measurements in engines are hard to perform since the process occurs over a few milliseconds, optical access is usually limited, and the environment in the combustion chamber is harsh, i.e. large density gradients, high temperature and high concentrations of soot.

This year we have conducted several campaigns both to establish our measurement technique in the scientific community, as well as employ this to study biofuels as well as a biobased emulsion as soot reducing agent to diesel. All experiments were performed using the Optical Accessible Compression Ignited Chamber (OACIC) at the Norwegian University of Science and Technology (NTNU). The OACIC is a reciprocating rapid compression machine equipped with windows, enabling line-of-sight optical measurements of the reacting spray under CI engine conditions. In order to access the errors associated with the estimated flame luminosity distribution (If) after applying the mean, the optical flow or the two camera method, a sequence of flame only images was collected.

Also studies of the fuels and their sooting characteristics have been performed, both experimentally and numerically. Here we have used TEM images to understand the soot structures resulting from fossil diesel fuels compared to that of biofuels. Some clear morphological differences between these two are found and discussed in subsequent publications. We are now working on the implementation of a soot model in our numerical tools to reveal in more detail how this can be explained kinetically.

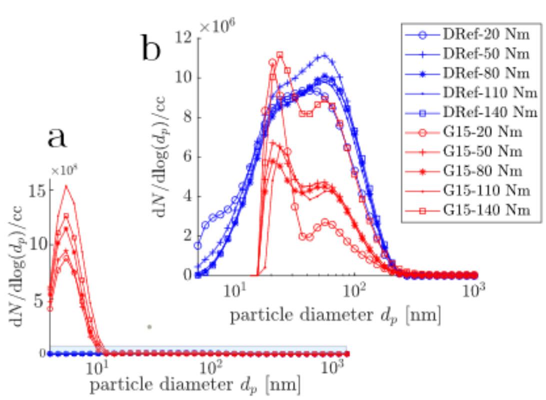


Figure: Predicted particle size distribution of soot from studies of bio-based glycerol emulsion compared to reference diesel, using stochastic reactor modelling. The study shows increase of the smallest particles from glycerol emulsion, although total particle mass emissions are lower. This is verified also experimentally using dynamic soot sampling.

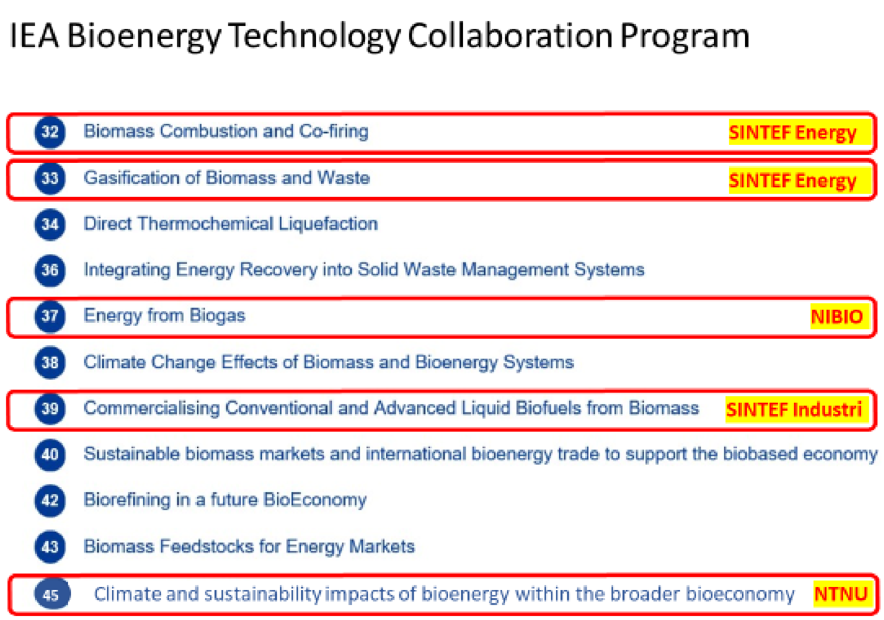
INTERNATIONAL COOPERATION

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 also had a significant role in the Bio4fuels kick-off, providing an international perspective with respect to the state of the art. These partners will in the future operation of the Centre, will also be active as hosts for short mobility tours of students and researchers from the centre to obtain experience in specific areas in an industry context.

International 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 (new in 2019)	FI	Upgrading of Biooil
Volvo Group Trucks Technology	SE	Truck engines powered by biofuels

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

- Sandia National Laboratories (USA)
- Pacific Norwest National La – PNNL (USA)
- f3 fossil free fuels (SE)
- Supergen (UK)
- VTT (FI)
- Aalto Univ (FI)
- DTU Chemical Engineering (DK)
- Johannes Gutenberg Universität (DE)
- DBFZ (GER)
- Chalmers University (SE)
- Vilnius University (LT)
- Tartu University (EE)
- Institute of Environmental Assessment and Water Research (IDAEA) (ES)
- Johannes Gutenberg Universität (DE)

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 2019, 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 a number of 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.

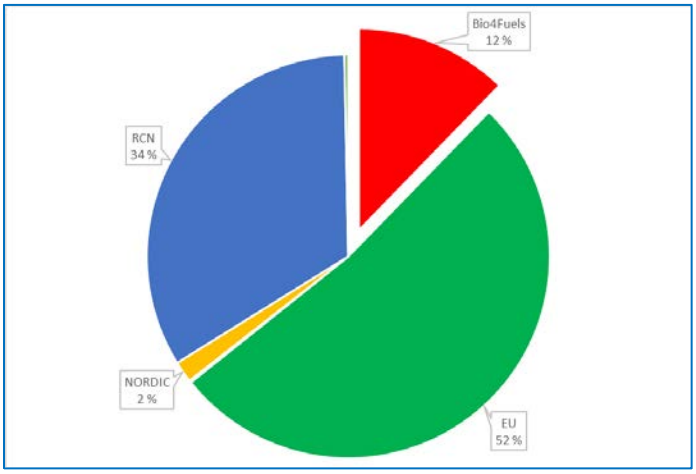


Figure 3: Overview of the funding level from Projects associated with Bio4Fuels Centre as a proportion of all Bio4Fuels related activities, both internal and external

Selected examples of current running associated EU projects within Horizon 2020.

Mobility

Martina Cazzolaro, PhD Student, NTNU (WP2.4) - Visit to Haldor-Topsøe

Period: 3rd - 14th of June 2018
Scope: learn the experimental methodology used by the researchers at Haldor-Topsøe to test catalysts' activity
Techniques:

- set-up for catalyst testing with liquid feeding and collection system
- GC analysis of the liquid products

Results:
Testing of Haldor-Topsøe catalysts and catalysts prepared at NTNU for activity comparison. All the catalysts were active and selective to propylene glycol.

#	Catalyst	WHSV [gace/gcat/h]	Carbon Balance [%]	Conversion [%]	PG Yield [%]
1	10%Cu/SiO2	7.8	91	91	70
2	10%Cu/SiO2	32.3	93	64	59
3	5%Cu/SiO2	8.5	80	82	62
4	5%Cu/SiO2	16.6	94	57	51

This series of experiments was used as references for the following tests performed at NTNU.

Recruitments and Education

PhD Student Line Degn Hansen (WP2.5), NMBU

This PhD project is a part of the work package *Enzymatic saccharification* (WP2.5) and will focus on enzymatic saccharification of Norway spruce, with special attention on process optimization and integration. Biochemical biomass-to-liquid processes and the currently available commercial enzyme cocktails have been developed for grasses and hardwood materials and are not optimized for Norwegian biomass. In this project, we are going to identify enzyme components, such as redox and hemicellulolytic accessory enzymes, that are critical for efficient saccharification of softwood. Moreover, the recent discovery of the novel catalytic mechanism of lytic polysaccharide monooxygenases (LPMOs) creates an opportunity to considerably improve saccharification yields by optimizing process parameters including different feed strategies of 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.

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.

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 has to increase with 2-3x from today's level or the producers has to get an equivalent level of subsidy for making biofuel production competitive at today's raw material costs. Large investments of biofuel will give some structural changes in the traditional forest sector, the main findings 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.

PhD student Simona Dzurendova (WP3.4), NMBU

The PhD project is part of the work package WP3.4, Fermentation, where one of the objectives is to develop utilization of lignocellulose hydrolysates as a source of carbon for production of microbial lipids by oleaginous fungi fermentation. Oleaginous fungi are able to produce lipids with fatty acids profile similar to vegetable or fish oils. 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.

PhD student Heidi Østby (WP2.5), NMBU

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

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

Student profile Martina Cazzolaro (WP3.3), NTNU

This project is a part of the work package Catalysis for biomass conversion to chemicals, WP 3.3 and aims to develop a stable copper-based catalyst for selective hydrogenation of hydroxyacetone to 1,2-propanediol, a major commodity chemical. Hydroxyacetone is a by-product of various biomass-based processes: biomass pyrolysis, sugar hydrogenolysis, glycerol dehydration. The main challenge of the project is the catalyst stability towards deactivation. In order to achieve this goal, carbon supports are tested. Platelet carbon nanofibers (PCNF) were prepared via carbon vapor deposition of CO and H2 at 600°C over iron powdered nanoparticles. Various catalysts were prepared using PCNF and varying Cu precursors (nitrate, acetate and basic carbonate) and impregnation solvents (water, ethanol, isopropanol). Characterization of the catalysts and catalyst activity tests will follow.

Moreover, surface treatment of PCNF will be explored, as surface oxidation, foreign-ion doping or confinement effect can be used to tune the surface properties of the carbon nanofibers. She also spend 3 weeks in Haldor Topsoe in June 2018 to learn their experiences and I enjoyed a lot the stay there.

COURSES GIVEN BY BIO4FUELS RESEARCHERS

The researchers connected to the Bio4Fuels Centre are involved in 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
Linn Solli (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
Frode Bjerkås	**NMBU**	Communication Officer (Jan – Mar)
Tonje Robertsen	**NMBU**	Communication Officer (May – Nov)
Bente Poulsen	**NMBU**	Communication Officer (Dec)

Recruitment

PhD Students with finance from the Bio4Fuels budget:

Name	Nationality	Duration	Gender	Topic
Line Degn Hansen	Danish	01.06.2017 – 31.05.2021	F	Optimization of enzymatic conversion of biomass to platform chemicals (WP3.2).
Eirik Ogner Jåstad	Norwegian	01.02.2017 – 31.12.2020	M	Models for Economic Assessments of Second Generation Biofuel Production (WP1.3).
Martina Cazzolaro	Italian	01.08.2017 – 31.07.2020	F	Catalytic biomass conversion (WP2.4).
Simona Dzurendova	Slovakia	14.09.2017 – 13.09.2020	F	Bioconversion of lignocellulose materials into lipid rich fungal biomass (WP3.3).
Ramesh Timsina	Nepal	24.09.2018 – 24.09.2021	M	*Preparing for Piloting and Up-scale* (WP4.3)

Postdoctoral Researchers with financial support from Bio4Fuels budget

Name	Nationality	Duration	Gender	Topic
Radziah Wahid	Malaysia	01.01.2017 - 28.02.2021	F	Enzymatic Saccharification
Otávio Cavalett	Italian	18.08.2017 - 17.08.2019	M	LCA of biofuels in Norway
Michal T. Lewandowski	Polish	04.04.2019 - 03.04.2022	M	Product quality and End Use

Other researchers

Name	Institution	Name	Institution
Julien Meyer	IFE	Alex Nelson	IFE
Antonio Oliviera	IFE	Jean-P. Pinheiro	IFE
Roar Linjordet	NIBIO	Tormod Briseid	NIBIO
Hege Bergheim	NIBIO	Roald Aasen	NIBIO
Micky Gale	NIBIO	Uno Andersen	NIBIO
Thorsten Heidorn	NIBIO	Ove Bergersen	NIBIO
Roar Linjordet	NIBIO	Ksenia Gulyaeva	NIBIO
Ove Bergersen	NIBIO		
Boris Zimmermann	NMBU	Achim Kohler	NMBU
Per Kristian Rørstad	NMBU	Aniko Varnai	NMBU
Erik Trømborg	NMBU	Volha Shapaval	NMBU
Daniel Mulat	NMBU		

Name	Institution	Name	Institution
Majorie Morales	NTNU	Robert Pujan	NTNU
Jia Yang	NTNU	David Emberson	NTNU
Ask Lysne	NTNU	Erlend Strendo	NTNU
Øyvind Eriksen	RISE Pfi	Marianne Dalheim	RISE Pfi
Kenneth Aaserød	RISE Pfi	Cornelis Wiisj	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
Jonathan Torstensen	RISE Pfi	Kristin Syverud	RISE Pfi
Liang Wang	SINTEF Energy	Jørn Bakken	SINTEF Energy
Michaël Becidan	SINTEF Energy	Annar Bremnes	SINTEF Energy
Øyvind Skreiberg	SINTEF Energy	Erik Bjerrehorn	SINTEF Energy
Per Carlsson	SINTEF Energy	John Eidsmo	SINTEF Energy
Berta Guell	SINTEF Energy	Fanziska Kausch	SINTEF Energy
Roger Khalil	SINTEF Energy	Helen Langeng	SINTEF Energy
Marie Olsen	SINTEF Energy	Line Rydså	SINTEF Energy
Inge Saanum	SINTEF Energy	Krister Vikedal	SINTEF Energy
Sarina Bao	SINTEF Energy	Jonas Kruger	SINTEF Energy
Olaf Tranås	SINTEF Energy		
Håvard Sletta	SINTEF Technology	Olav Berglihn	SINTEF Technology
Sidsel Markussen	SINTEF Technology	Randi Aune	SINTEF Technology
Kristin Degnes	SINTEF Technology	Francesca Bartolomeo	SINTEF Technology
Le Truong	SINTEF Technology	Jody Veenendaal	SINTEF Technology
Bendik Sægrov-Sorte	SINTEF Technology	Anders Brunsvik	SINTEF Technology
Torunn Holten	SINTEF Technology	Simone Balzer	SINTEF Technology
Tina Andersen	SINTEF Technology	Miguel Munoz	SINTEF Technology
Kirsten Wiebe	SINTEF Technology	Inga Aasen	SINTEF Technology
Torbjørn Petterssen	SINTEF Technology	Morten Frøseth	SINTEF Technology
Kari Hjelen	SINTEF Technology		
Marianne Eikeland	USN	Britt Moldestad	USN

PhD students with financial support from other sources

Name	Funding	Nationality	Duration	Gender	Topic
Kine Svensson	NIBIO	Norwegian	01.02.2015-31.01.2018	F	Pre-, post-treatment and recirculation as strategy for improved biogas-yield in anaerobic digestion of food waste
Oda Kjørlaug Svennevik	NMBU / Cambi	Norwegian	29.01.2016 - 24.05.2019	F	Dewatering of digested biomass (Industrial PhD)
Jianyu Ma	NRC	Chinese	28.09.2017-27.09.2020	M	Hot gas cleaning using sorbent development, reactor development, kinetics and modelling.

MEDIA, PUBLICATIONS AND DISSEMINATION

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

COMMUNICATION AND OUTREACH 2019

Cherubini, Francesco.
Avfall, skog og bioøkonomi – hvordan bruker vi landarealer bærekraftig?. ZERO Conference; 2019-11-07 NTNU

Cherubini, Francesco.
Bridging the gap between international status of knowledge and local implementation. Knowledge about climate and nature in change: - interaction between research and management; 2019-11-20 NTNU

Cherubini, Francesco.
Skogens rolle i FNs nye rapport om klimaendringer og landarealer. Norskog Forum - Hvordan sikre en klimaoptimal skognæring?; 2019-09-25 NTNU

Cherubini, Francesco.
The IPCC Special Report on Climate Change and Land in the Norwegian context. Internal meeting at the Landbruks- og matdepartementet seksjon næringsutvikling og miljøtiltak; 2019-11-06 NTNU

Eijsink, Vincent.
Bioteknologiens rolle i en delvis biomasse basert sirkulær økonomi. Bioeconomy in Norway (BioN); 2019-10-30 NMBU

Eijsink, Vincent; Horn, Svein Jarle.
Foods of Norway og Bio4Fuel. Møte med Norske Skog; 2019-10-07 NMBU

Wittgens, Bernd.
Biofuel Production – Potential for Marine Biomass; presented at Bellona Seminar. Sustainable biomass in the Nordics – How should we farm the Ocean. Bellona Seminar; 2019-12-14 - 2019-12-14 SINTEF

Sandquist, Judit.
Status biodrivstoff 2019 (i Norge og verden). #SINTEFblogg [Internett]
ENERGISINT SINTEF

Sandquist, Judit.
Status of biofuels in Norway and worldwide 2019. #SINTEFblog [Internett]
ENERGISINT SINTEF

Scientific Talks and Publications 2019

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

Bartocci, Pietro; Tschentscher, Roman; Stensrød, Ruth Elisabeth; Barbanera, Marco; Fantozzi, Francesco.
Kinetic Analysis of Digestate Slow Pyrolysis with the Application of the Master-Plots Method and Independent Parallel Reactions Scheme. *Molecules* 2019; Volume 24. (9) SINTEF

Bjørgen, Karl Oskar Pires; Emberson, David; Løvås, Terese.
Diffuse Back-Illuminated Extinction Imaging of Soot: Effects of Beam Steering and Flame Luminosity. *SAE technical paper series* 2019; Volume 2019-January. (January) NTNU

Bjørgen, Karl Oskar Pires; Emberson, David; Løvås, Terese.
Optical Measurements of In-Flame Soot in Compression-Ignited Methyl Ester Flames. *Energy & Fuels* 2019; Volume 33. s.7886-7900 NTNU

Cai, Zhenping; Feng, Xiang; Chen, De.
Co-pyrolysis of biomass and polyethylene into C2-C4 olefins over zeolite catalyst. The 11th International Conference on Applied Energy (ICAE2019); 2019-08-12 - 2019-08-15 NTNU

Cazzolaro, Martina; Yang, Jia; Svendby, Jørgen; De Clercq, Rik; Beier, Matthias Josef; Taarning, Esben; Chen, De.
Stable Cu/C catalysts for selective hydrogenation of hydroxyacetone to 1,2-propanediol. 14th European Congress on Catalysis, EuropaCat 2019; 2019-08-18 - 2019-08-23 NTNU

Chylenski, Piotr; Bissaro, Bastien; Sørlie, Morten; Kjendseth, Åsmund Røhr; Varnai, Aniko; Horn, Svein Jarle; Eijsink, Vincent. Lytic polysaccharide monooxygenases in enzymatic processing of lignocellulosic biomass. *ACS Catalysis* 2019 ;Volume 9. s.4970-4991 NMBU

de_Freitas_Costa, Thales; Eijsink, Vincent; Horn, Svein Jarle.
The use of lytic polysaccharide monooxygenases in anaerobic digestion of lignocellulosic materials. *Biotechnology for Biofuels* 2019 ;Volume 12.(1) NMBU

Dubava, Darya; Kohler, Achim; Deniset-Besseau, Ariane; Dzurendova, Simona; Shapaval, Volha.
Strategies for preprocessing nanospectroscopic infrared data for visualizing chemistry of lipid bodies in oleaginous filamentous fungi. A Workshop on Machine Learning and Chemometrics in Biospectroscopy; 2019-08-19 - 2019-08-21 NMBU

Dzurendova, Simona; Zimmermann, Boris; Kohler, Achim; Hansen, Line Degn; Varnai, Aniko; Horn, Svein Jarle; Eijsink, Vincent; Shapaval, Volha.
Optimization of lignocellulose-based substrates for sustainable production of lipids by oleaginous filamentous fungi. Bio4Fuels Days 2019: Building a Sustainable European Biofuel Industry; 2019-11-04 - 2019-11-06 NMBU

Dzurendova, Simona; Zimmermann, Boris; Kohler, Achim; Kòsa, Gergely; Langseter, Anne Marie; Blomqvist, Johanna Karin Hillevi; Tafintseva, Valeria; Shapaval, Volha.
Co-production of Lipids and Biopolymers in a single fermentation process – a way to improve sustainability of Microbial lipids – based Biofuels. Bio4Fuels Days 2019: Building a Sustainable European Biofuel Industry; 2019-11-04 - 2019-11-06 NMBU

Dzurendova, Simona; Zimmermann, Boris; Kohler, Achim; Shapaval, Volha.
The effect of phosphorus source on the lipid accumulation in oleaginous fungi grown under nitrogen limitation. European Biotechnology Congress; 2019-04-11 - 2019-04-13 NMBU

Dzurendova, Simona; Zimmermann, Boris; Kohler, Achim; Shapaval, Volha.
The role of phosphorus in the lipid accumulation of oleaginous fungi. Copenhagen School of Chemometrics; 2019-05-06 - 2019-06-07 NMBU

Dzurendova, Simona; Zimmermann, Boris; Tafintseva, Valeria; Kohler, Achim; Shapaval, Volha.
Monitoring the lipid accumulation in oleaginous fungi grown under nitrogen limitation and different phosphorus levels by FTIR spectroscopy combined with multivariate calibration. Workshop on Machine Learning and Chemometrics in Biospectroscopy; 2019-08-18 - 2019-08-21 NMBU

Eijsink, Vincent.
Lytic Polysaccharide Monooxygenases (LPMOs) and other redox enzymes in polysaccharide degradation – fundamental and applied aspects. Foredrag, Chalmers Universitet; 2019-10-29 NMBU

Eijsink, Vincent; Petrovic, Dejan; Forsberg, Zarah; Mekasha, Sophanit; Kjendseth, Åsmund Røhr; Varnai, Aniko; Bissaro, Bastien; Vaaje-Kolstad, Gustav.
On the functional characterization of lytic polysaccharide monooxygenases (LPMOs). *Biotechnology for Biofuels* 2019 ;Volume 12.58. s.1-16 NMBU

Emberson, David; Bjørgen, Karl Oskar Pires; Løvås, Terese.
Detailed In-flame Soot Characteristics of Diesel, HVO and FAME using Extinction Imaging. Bio4Fuels Days; 2019-11-04 - 2019-11-06 NTNU

Emberson, David; Rohani, Behzad; Wang, Liang; Sæterli, Ragnhild; Løvås, Terese.
On soot sampling: Considerations when sampling for TEM imaging and differential mobility spectrometer. *SAE technical paper series* 2019; Volume 2019:2019-24-0159.(September) ENERGISINT NTNU

Forsberg, Zarah; Sørlie, Morten; Petrovic, Dejan; Courtade, Gaston; Aachmann, Finn Lillelund; Vaaje-Kolstad, Gustav; Bissaro, Bastien; Kjendseth, Åsmund Røhr; Eijsink, Vincent.
Polysaccharide degradation by lytic polysaccharide monooxygenases. *Current Opinion in Structural Biology* 2019 ; Volume 59. s.54-64 NTNU NMBU

Gavrilovic, Ljubisa; Save, Jonas; Blekkan, Edd Anders.
The Effect of Potassium on Cobalt-Based Fischer– Tropsch Catalysts with Different Cobalt Particle Sizes. *Catalysts* 2019 ; Volume 9.(4) NTNU

Gavrilovic, Ljubisa; Save, Jonas; Blekkan, Edd Anders.
The Effect of Potassium on Cobalt-Based Fischer– Tropsch Catalysts with Different Cobalt Particle Sizes. *Catalysts* 2019; Volume 9.(4) NTNU

Hansen, Line Degn; Eijsink, Vincent; Varnai, Aniko; Horn, Svein Jarle.
Enhancing saccharification of Norway spruce by optimizing LPMO activity in enzyme cocktails. Bio4Fuels Days 2019; 2019-11-04 - 2019-11-06 NMBU

Hansen, Line Degn; Varnai, Aniko; Eijsink, Vincent; Horn, Svein Jarle.
Optimization of enzyme cocktails and process conditions for efficient saccharification of Norway spruce. Bio4Fuels Days 2019; 2019-11-04 - 2019-11-06 NMBU

Hansen, Line Degn; Varnai, Aniko; Eijsink, Vincent; Horn, Svein Jarle.
Optimization of enzyme cocktails and process conditions for efficient saccharification of Norway spruce. 41st Symposium on Biotechnology for Fuels and Chemicals; 2019-04-28 - 2019-05-01 NMBU

Hillestad, Magne; Runningen, Anders; Rout, Kumar Ranjan; Pandey, Umesh; Putta, Koteswara Rao; Gavrilovic, Ljubisa; Jørgensen, Erik A.; Rytter, Erling; Blekkan, Edd Anders.
Modeling Fischer-Tropsch Kinetics for Optimized BTL Plant Design. 5th International Congress on Catalysis for Biorefineries (CATBIOR 2019); 2019-09-23 - 2019-09-27 NTNU

Huang, Bo; Hu, Xiangping; Næss, Jan Sandstad; Cherubini, Francesco.
Quantifying the evolution of agriculture impact on climate in Europe by observation and regional climate model simulations. International Conference on Regional Climate-CORDEX 2019; 2019-10-14 - 2019-10-18 NTNU

Hüttner, S; Varnai, Aniko; Petrovic, Dejan; Bach, CX; Kim Anh, DT; Thanh, VN; Eijsink, Vincent; Larsbrink, Johan; Olsson, L. Specific Xylan Activity Revealed for AA9 Lytic Polysaccharide Monooxygenases of the Thermophilic Fungus Malbranchea cinnamomea by Functional Characterization. *Applied and Environmental Microbiology* 2019 ;Volume 85.(23) NMBU

Joseph, Prajin; Ottesen, Vegard; Tanase-Opedal, Mihaela; Moe, Størker.
Evaluation of H-factor on the delignification of Norway Spruce by organosolv pre-treatment. Building a Sustainable European Biofuel Industry; 2019-11-04 - 2019-11-06 NTNU

Jåstad, Eirik Ogner; Bolkesjø, Torjus Folsland; Trømborg, Erik; Rørstad, Per Kr..
Large-scale forest-based biofuel production in the Nordic forest sector: Effects on the economics of forestry and forest industries. *Energy Conversion and Management* 2019; Volume 184. s.374-388 NMBU

Krivopolianskii, Vladimir; Bjørgen, Karl Oskar Pires; Emberson, David; Ushakov, Sergey; Æsøy, Vilmar; Løvås, Terese.
Experimental Study of Ignition Delay, Combustion, and NO Emission Characteristics of Hydrogenated Vegetable Oil. *SAE International Journal of Fuels and Lubricants* 2019 ; Volume 12.(1) s.29-42 NTNU

Langseter, Anne Marie; Zimmermann, Boris; Kohler, Achim; Blomqvist, Johanna Karin Hillevi; Sandgren, Mats; Passoth, Volkmar; Marova, Ivana; Shapaval, Volha.
Green solvent extraction of microbial lipids. European Biotechnology Congress 2019; 2019-04-11 - 2019-04-13 NMBU

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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
DAFIA	58	New conversion routes of municipal solid waste (MSW) and marine rest raw materials (MRRM) to obtain high value products	SINTEF Industry
Prowood	17,5	Understanding microbial lignocellulose breakdown for new wood-protectants	SINTEF Industry
Oxytrain	30	Research on the mechanism, engineering and application of four different classes of oxygenases	
ABC4Soil	4,8	Advanced Biochar Fertilizers for Multiple Ecological Benefits in Soil Conditioning	NTNU, Dr. Kathrin Weber, Prof. Terese Løvås, SINTEF Energy
C1Pro	17,1	Microbial conversion of methanol to value-added products	NTNU, SINTEF Industry
NextGenRoadFuels	46	Biofuels from sludge and organic waste via HTL	SINTEF Energi, Steeper
METAFLUIDICS	83,2	New enzymes for biomass processing	SINTEF Industry, NTNU, Novozymes
4Refinery	60	Conversion of lignocellulosic Biomass via HTL and Pyrolysis to Advance Biofuels	SINTEF Industry
LIBERATE	60	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
Pulp&Fuels	49		
SelectiveLi	5	Conversion of Lignin to value added chemicals	SINTEF Industry
BESTER	26,9	Conversion of lignocellulosiic derived sugars to butyrate	SINTEF Industry
BRSIK2	60	Transnational access of research infrastructure as well as research on monitoring, process design and costing	SINTEF Industry
FunEnzFibres	48	Enzymatic upgrading of cellulosic fibres with LPMOs (redox enzymes) for the production of textiles and nanocellulose	Borregaard, Novozymes
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
AC2OCEM	43	Accelerating Carbon Capture using Oxyfuel Technology in Cement Production - Biomass used instead of coal in the kiln)	NTNU (Indecol), Sintef Energy
EEA-Baltic	8	Novel high-performance polymers from lignocellulosic feedstock	NTNU (Indecol).
Baltic Biomass4 Value	30		
CUBE	100	Unravelling the secrets of synthetic and biological Cu-based catalysts for C-H activation	NMBU
SiEUGreen	70	Resource-efficient urban agriculture for multiple benefits – contribution to the EU-China Urbanisation Partnership	
Flex4RES	24		
Nordic Clean Enegy Scenarios 2020	9		

NATIONALLY FUNDED PROJECTS

Project	Total budget [mNOK]	Short Description of Project	Bio4Fuels Stakeholders involved
BarkCure	10		NIBIO, SINTEF Industry
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
LipoFungi	10		
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		
MIRA	13,3		
Advanced Biofuels via Syngas	8,9		
GasPro	16,7	Increase the energy efficiency of the entrained flow biomass gasification technology for bio-fuel production	NTNU, SINTEF Energy
H2BioOil	11,8		
ReShip	15		
PyroGas	4		
NanoCat4Fuels	3,9		
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
GAFT			
BIOGREEN	6		
AORTA	1	Convertering makroalger til produkter	SINTEF Industry, Alginor
Norwegian Seaweed Biorefinery Platform	15		SINTEF, NTNU, NMBU
TechnoSER	11,7	Technical optimization of the sorption-enhanced reforming process for hydrogen production	ZEG Power, IFE
BioPath	10	Advancing the understanding of regional climate implications of bioenergy systems	NTNU (Indecol)
SLUDGEFFECT	10,5	Life cycle effects from removing hazardous substances in sludge and plastic through thermal treatment	NTNU
Bio4-7Seas	10,5	Biofuels for climate change mitigation in of deep-sea shipping	NTNU
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
BioNEXT	11		
NorENS	11		
Enable	25		
Climat Smart Forestry Norway	25		

CLD	10,1	High temperature gas cleaning through Chemical looping Desulfurization	SINTEF Industry
BioFT	12,8	Optimization of the process for production of fuels via Fischer-Tropsch synthesis	SINTEF Industry
B2A	20	Conversion fo biomass to aviation fuels	NTNU, SINTEF, St1
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, Lindum
LIGNOLIPP	12	Production of high-value lipids and chitin/chitosan	Borregaard
BYPROVALUE	10	Production of lipids, chitin/chitosan, glucans and polyphosphate	Borregaard
OIL4FEED	12	production of high-value lipids	Borregaard
BioCirc	6	Transnational Access of research Infrastructure	

ACCOUNTS 2019

An overview of the accounts for 2019 is given in the tables below. This provides a summarized overview of the costs and finance related to the research and support activities at the research partners and Stakeholders.

Reported Accounts for 2019

Cost category	Actual	Budget
Payroll and indirect expenses	32 231 518	10 500 000
Procurement of R&D services	0	27 097 000
Equipment	1 234 476	1 500 000
Other operating expenses	2 967 918	6 273 000
Total amount	**36 433 912**	**45 370 000**
Funding plan	**Actual**	**Budget**
Own financing	4 539 036	5 000 000
Public financing	15 591 811	11 000 000
Private funding	3 723 518	6 000 000
International funding	1 138 560	2 000 000
The Research Council	11 440 987	21 370 000
Total amount	**36 433 912**	**45 370 000**

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BIO4FUELS STAKEHOLDERS